PDHonline Course C810 (12 PDH)

Whole Lotta Shakin' Goin' On: A History of Seismicity

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Whole Lotta Shakin' Goin' On

A History of Seismicity

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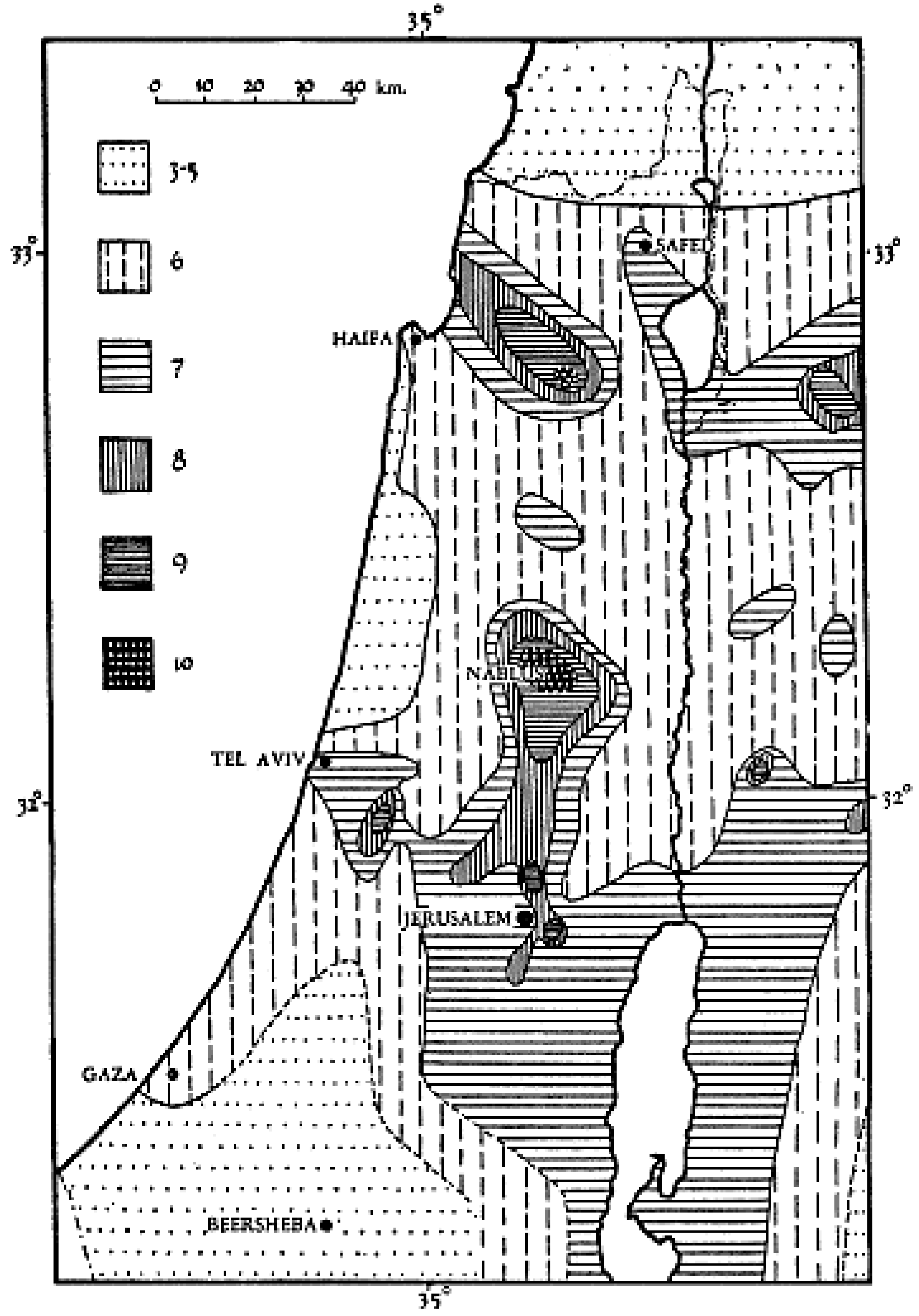
Part 1

Know Your Enemy

Since Ancient Times

“…Since ancient times man has wondered at earthquakes. According to one primitive belief, the earth was disk-shaped and rested on the horns of an enormous bull. In turn, the bull balanced precariously on a large egg which lay on the back of a giant fish. When the bull was pestered by cosmological insects, he shook his head or wiggled an ear – thus causing earthquakes…”

***Popular Mechanics,* October 1939**



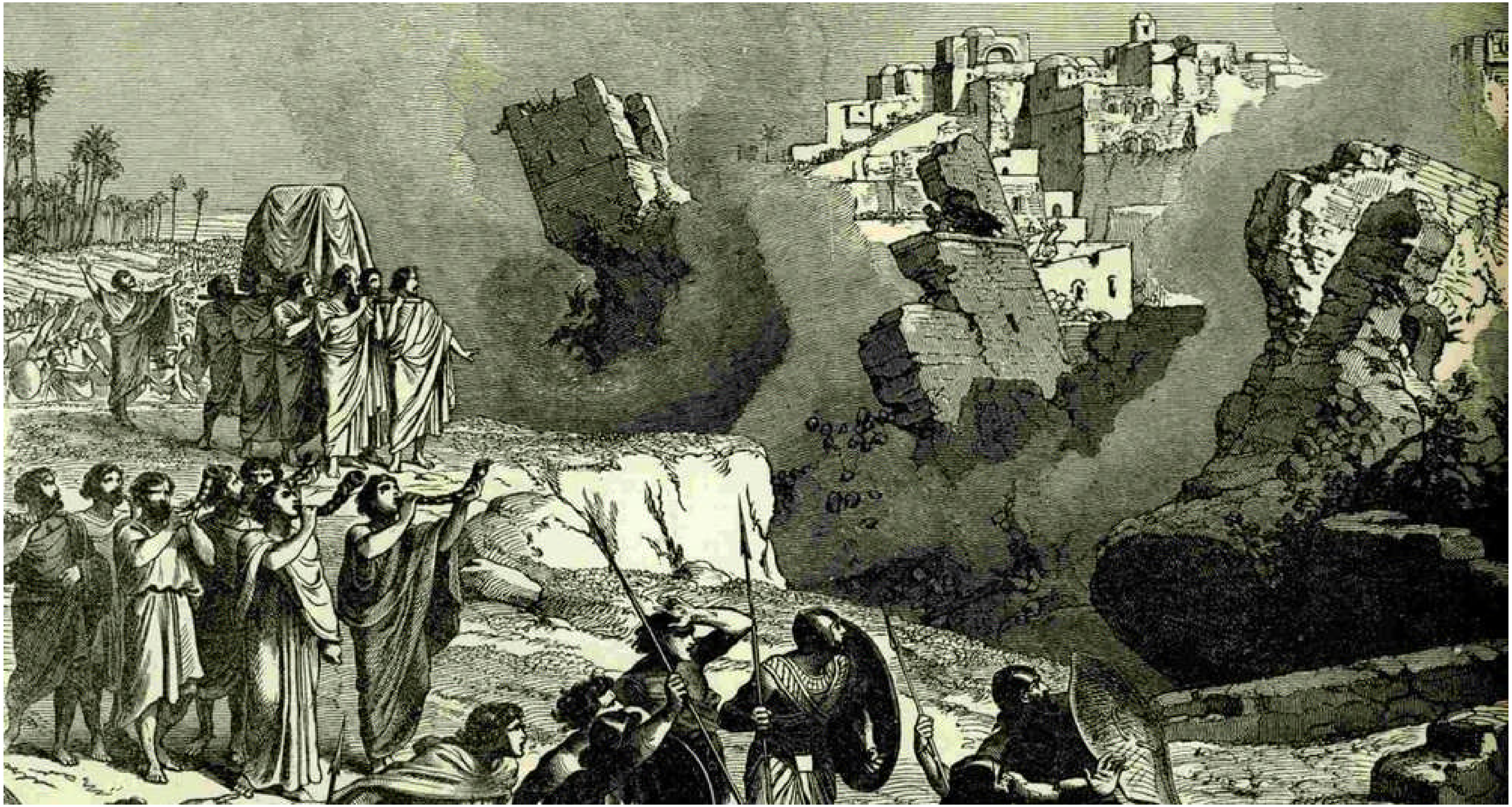
"…Several cataclysmic events reported in the Old Testament may have been connected with earthquakes, according to two scientists who have found tentative evidence of a fault line in the Holy Land. Geophysics Prof. Amos Nur of Stanford and geologist Ze'ev Reches of Israel's Weizmann Institute said frequent earthquakes may have occurred along the north-south ground fracture over the past several thousand years, including major events every two centuries or so. The last such quake shook the area July 11, 1927, measuring 6.5 on the Richter scale…"

***Popular Mechanics,* September 1979**

<u>Left</u>: caption: "The Jericho Earthquake of 11 July 1927 (Isoseismic Map in Sieberg Mercalli Scale)"

<u>Above</u>: caption: “The earthquake of July 11, 1927. Shattered remains of St. John’s Convent at the Jordan. A complete ruin.”

<u>Left</u>: caption: “A house in Nablus reduced to a mere shell by the earthquake of July 11, 1927”



"…'It is very likely that the collapse of the walls of Jericho, under Joshua's siege, was caused by an earthquake similar to the 1927 event,' the investigators reported. The fault, they said, passes about five miles east of Jericho. 'Aside from proximity of the fault, there is a remarkable similarity between the (biblical) description of the river-flow cutoff, and the damming of the Jordan River by earthquake-induced mud-slides observed during the past millenium'…"

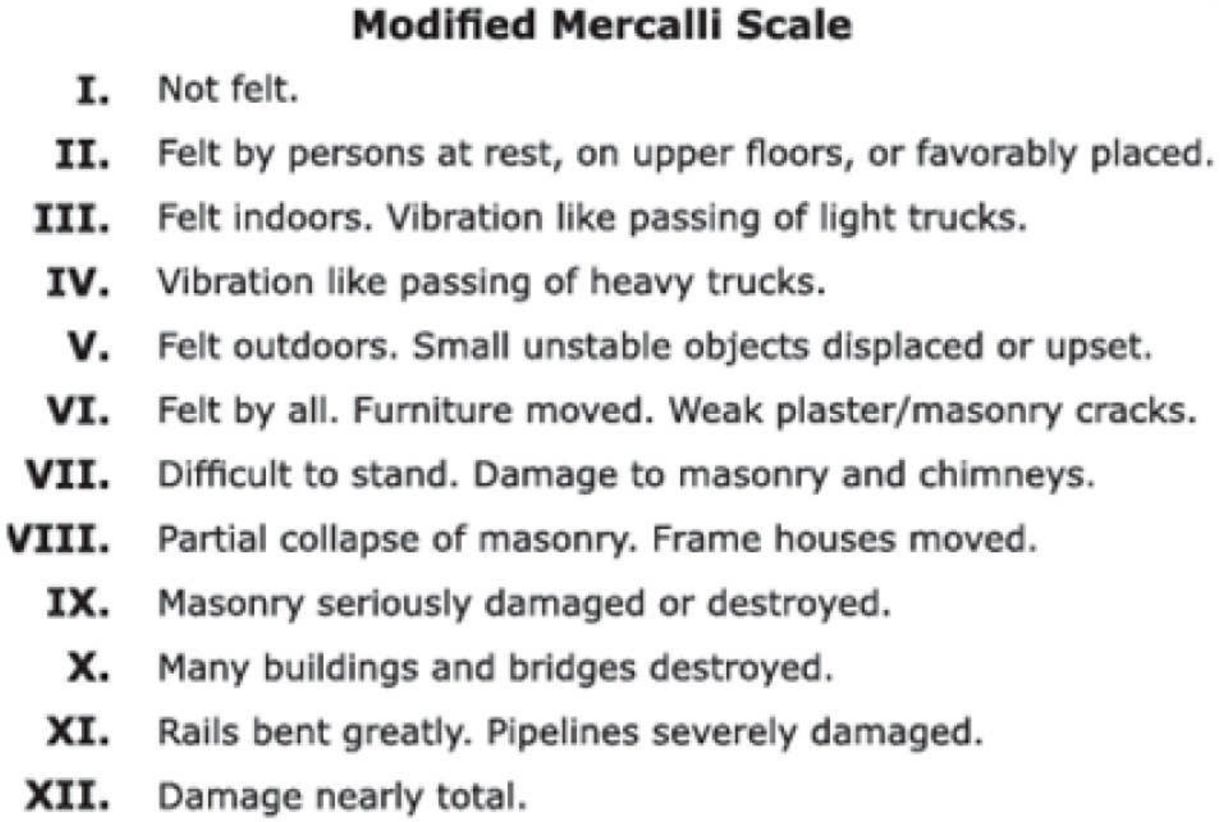
Popular Mechanics, **September 1979**

"…Nur and Reches also said it was likely that Sodom and Gomorrah, east of Jericho, fell into ruin during another earthquake some 4,000 years ago…"

***Popular Mechanics,* September 1979**

The *Beirut Earthquake* of 551 occurred on July 9th 551 A.D. It had an estimated magnitude of about 7.6 on the *Moment Magnitude Scale* and a maximum felt intensity of X (Intense) on the *Mercalli Intensity Scale* (MIS). It triggered a devastating tsunami which affected the coastal towns of Byzantine Phoenicia, causing great destruction; sinking many ships and killing large numbers of people. One estimate by *Antoninus of Piacenza* for Beirut alone was 30K dead as a result of the temblor and ensuing tsunami.

The *Crete Earthquake* of 1303 occurred at dawn on August 8th 1303. It had an estimated magnitude of about 8, a maximum intensity of IX (Violent) on the MIS and triggered a major tsunami that caused severe damage and loss of life on the island of Crete and in Alexandria, Egypt. The MIS is a seismic scale used for measuring the intensity of an earthquake. It measures the *effects* of an earthquake and is distinct from the *Moment Magnitude Scale* usually reported for an earthquake (sometimes mis-reported as the "Richter Magnitude"), which is a measure of the *energy* released. The intensity of an earthquake is not totally determined by its magnitude; it is not based on first physical principles but is, instead, empirically based on observed effects. The MIS quantifies the effects of an earthquake on the Earth's surface, human beings, objects of nature and man-made structures on a scale from I (not felt) to XII (total destruction). Values depend upon the distance to the earthquake (with the highest intensities being around the epicentral area). Data gathered from people who have experienced the quake are used to determine an intensity value for their location. Between 1884 and 1906, the Italian volcanologist *Giuseppe Mercalli* revised the widely used, simple ten-degree *Rossi–Forel Scale,* creating the MIS, which is still in use today.



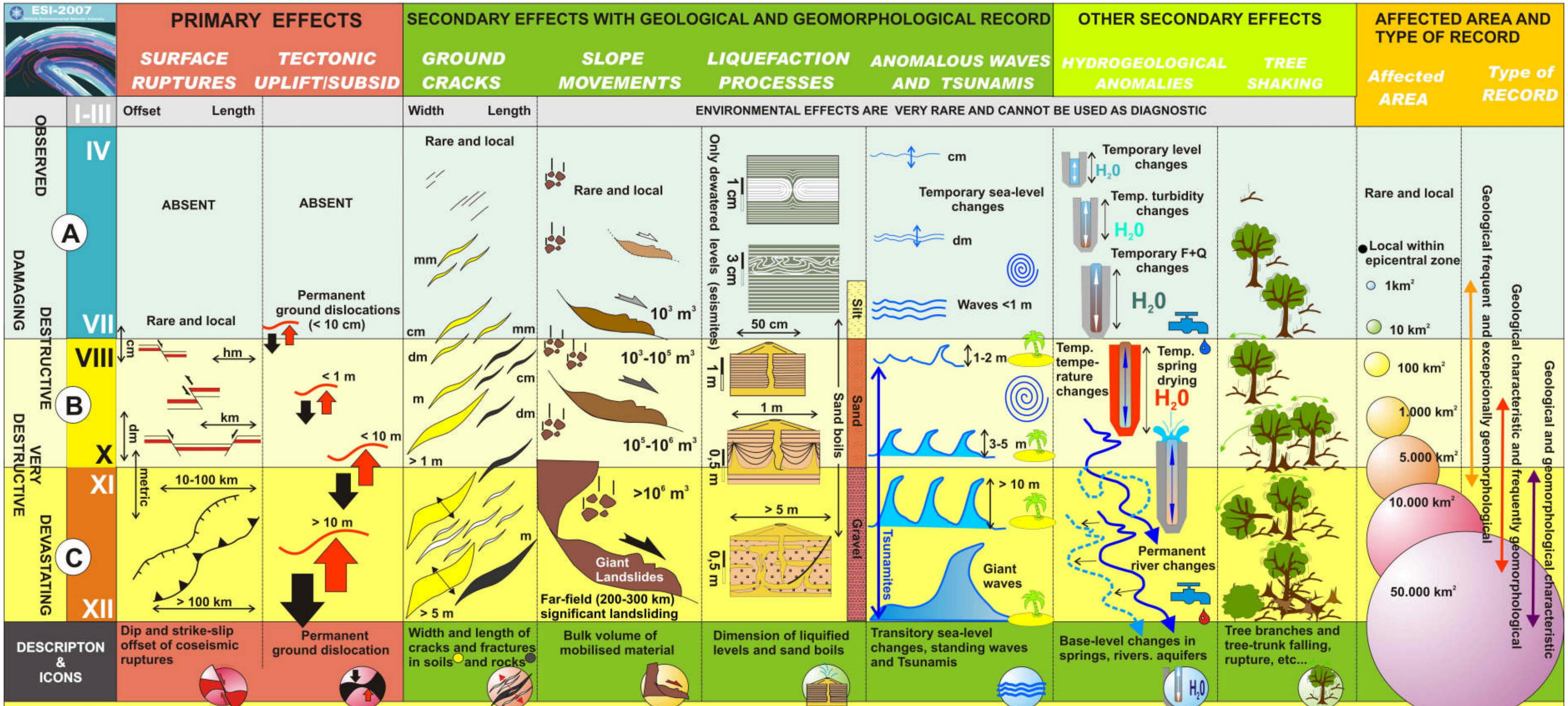
Modified Mercalli Scale

I.	Not felt.
II.	Felt by persons at rest, on upper floors, or favorably placed.
III.	Felt indoors. Vibration like passing of light trucks.
IV.	Vibration like passing of heavy trucks.
V.	Felt outdoors. Small unstable objects displaced or upset.
VI.	Felt by all. Furniture moved. Weak plaster/masonry cracks.
VII.	Difficult to stand. Damage to masonry and chimneys.
VIII.	Partial collapse of masonry. Frame houses moved.
IX.	Masonry seriously damaged or destroyed.
X.	Many buildings and bridges destroyed.
XI.	Rails bent greatly. Pipelines severely damaged.
XII.	Damage nearly total.

In 1902, the ten-degree MIS was expanded to twelve degrees by Italian physicist *Adolfo Cancani*. It was later completely re-written by the German geophysicist *August Heinrich Sieberg* and became known as the *Mercalli–Cancani–Sieberg* (MCS) scale. The MCS scale was later modified and published in English by *Harry O. Wood* and *Frank Neumann* in 1931 as the *Mercalli–Wood–Neumann* (MWN) scale. It was later improved by *Charles Richter*, the father of the *Richter Magnitude Scale* (RMS). The scale is known today as the *Modified Mercalli* (MM) scale (above) or *Modified Mercalli Intensity* scale (MMI).

The *Environmental Seismic Intensity* scale (ESI) is a seismic scale used for measuring the intensity of an earthquake on the basis of the effects of the earthquake on the natural environment (*Earthquake Environmental Effects* or EEE). The international effort to develop a new scale of macroseismic intensity that would focus exclusively on environmental effects of earthquakes began in the early 1990s and was sponsored by the *International Union for Quaternary Research* (INQUA). After the final draft of the scale was approved by INQUA at its *XVII Congress* in Cairns, Australia (in 2007), the scale became officially known as "ESI 2007." Like many other intensity scales, ESI 2007 uses the basic structure of twelve degrees of seismic intensity and is designed for application during field surveys immediately after the seismic event. However, the definitions of intensity degrees in ESI 2007 are based on the observation of distribution and size of environmental effects produced by an earthquake. This approach makes ESI 2007 a unique diagnostic tool for the assessment of seismic intensity levels X to XII in sparsely populated and uninhibited areas where earthquake effects on people and built environment may not be easily observed. For intensity level IX and lower, the ESI 2007 scale is intended to be used as a supplement to other intensity scales.

CHART OF THE INQUA ENVIRONMENTAL SEISMIC INTENSITY SCALE 2007 - ESI 07 *(Modified from Silva et al., 2008 and Reicherter et al, 2009)*



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Silva et al., 2008. Catalogue of the geological and environmental effects of earthquakes in Spain in the ESI-2007 Macroseismic scale. Cong. Geol. Esp. Gran Canaria, Spain

Reicherter, K., Michetti, A.M., Silva, P.G., 2009. Paleoseismology: Historical and Prehistorical Record of Earthquake Ground Effects. Geol. Soc. London Spec. Publ. 316. 324 pp. GSL Publishing Hous, London, UK.

This chart is a contribution of the INQUA Focus Area on Paleoseismology and Active Tectonics (TERPRO), developed by the Spanish Working Group of AEQUA, 2008-2010

The *Earthquake of 1343* struck the *Tyrrhenian Sea* and *Bay of Naples* on November 25th 1343. Underground shocks were felt in Naples and caused significant damage and loss of life. Of major note was a tsunami created by the earthquake which destroyed many ships in Naples and destroyed many ports along the *Amalfi Coast*, including Amalfi itself. The effects of the tsunami were observed by the poet *Petrarch*, whose ship was forced to return to port and recorded in the fifth book of his *Epistolae familiares*.

“It was in this country impossible to keep upon our legs, or in one place on the dancing Earth; nay, those that lay along on the ground, were tossed from side-to-side, as if on a rolling billow.”

Vincentius Bonajutus

RE: contemporary account of the *Sicily Earthquake* of 1693 which struck parts of southern Italy near Sicily, Calabria and Malta on January 11th 1693 at 9:00 p.m. This earthquake was preceded by a damaging foreshock on January 9th. It had an estimated magnitude of 7.4 on the *Moment Magnitude Scale* (the most powerful in Italian history) and a maximum intensity of XI (Extreme) on the MIS, destroying at least seventy towns and cities, seriously affecting an area of 2,200 square miles and causing the death of about 60K people. The earthquake was followed by tsunamis that devastated the coastal villages on the *Ionian Sea* and in the *Straits of Messina*. Almost two thirds of the entire population of Catania were killed. The epicenter of the disaster was probably close to the coast, possibly offshore, although the exact position remains unknown. The extent and degree of destruction caused by the earthquake resulted in extensive rebuilding of the towns and cities of southeastern Sicily.

A Better Understanding

“…Probably the most important work that has been done in the observation of the causes and nature of earthquakes has been accomplished since the beginning of the twentieth century. Previously all earthquakes were regarded as being of volcanic origin. Scientists now believe that most earthquakes are caused by wrinkling and slipping of part of the earth’s crust caused by strain resulting from shrinkage of the more plastic interior of the earth, contortion of the earth’s strata, or changes in pressure in the crust itself. However, in some cases, subterranean volcanic action is believed to have been the cause of certain quakes…”

***Popular Science*, December 1923**

Lines of Weakness

“…The crust of the earth may be considered as a relatively thin skin or rind of rock, about five miles in thickness. As stone broken in a quarry splits along certain definite lines, so this outer covering of the earth tends to split along lines of weakness which geologists know as ‘faults.’ Variations in pressure – which may be caused by the weight of mountains or of the water in the ocean – cause movements or dislodgements between the sections of crust, which, of course, are constantly seeking to remain in equilibrium…”

***Popular Science,* December 1923**

“…The situation may be compared with a row of building blocks, laid side-by-side and subjected to pressure from both ends. When the pressure becomes too great to be released by the friction between the blocks, something will give. They will buckle, and the buckling will correspond in a way to the movement of the earth’s crust that causes an earthquake…”

***Popular Science*, December 1923**

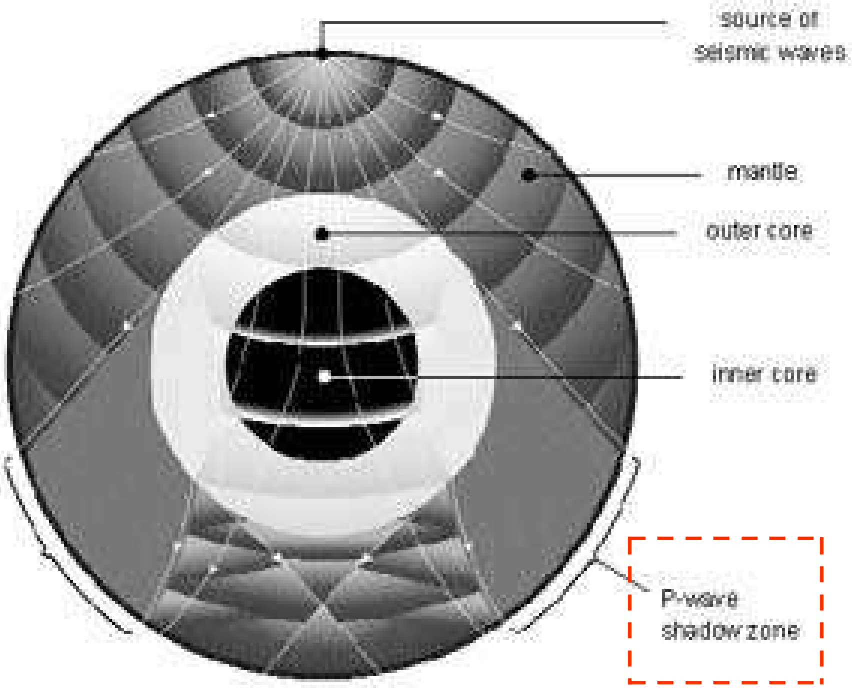
The Zones

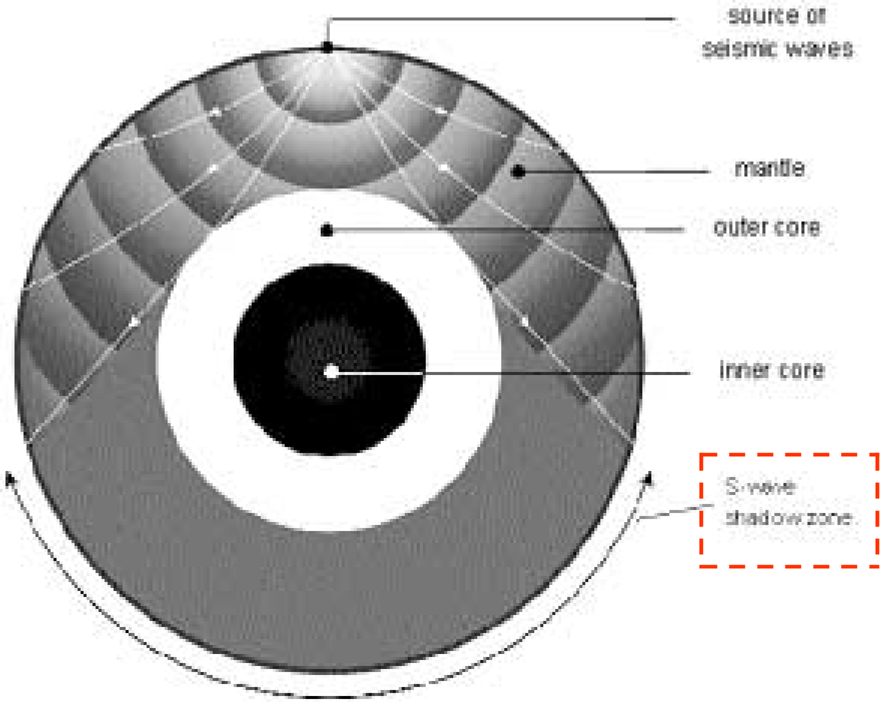
"…Recent study of earthquake waves has led to new scientific discoveries indicating that the earth's interior may be divided into three definite zones – a rigid, elastic outer shell; a semi-metallic intermediate zone, and the central non-rigid core. This theory is deduced from seismographic records showing that the course of earthquake waves through the earth is curved toward the surface; therefore that the earth is denser and less rigid at its center."

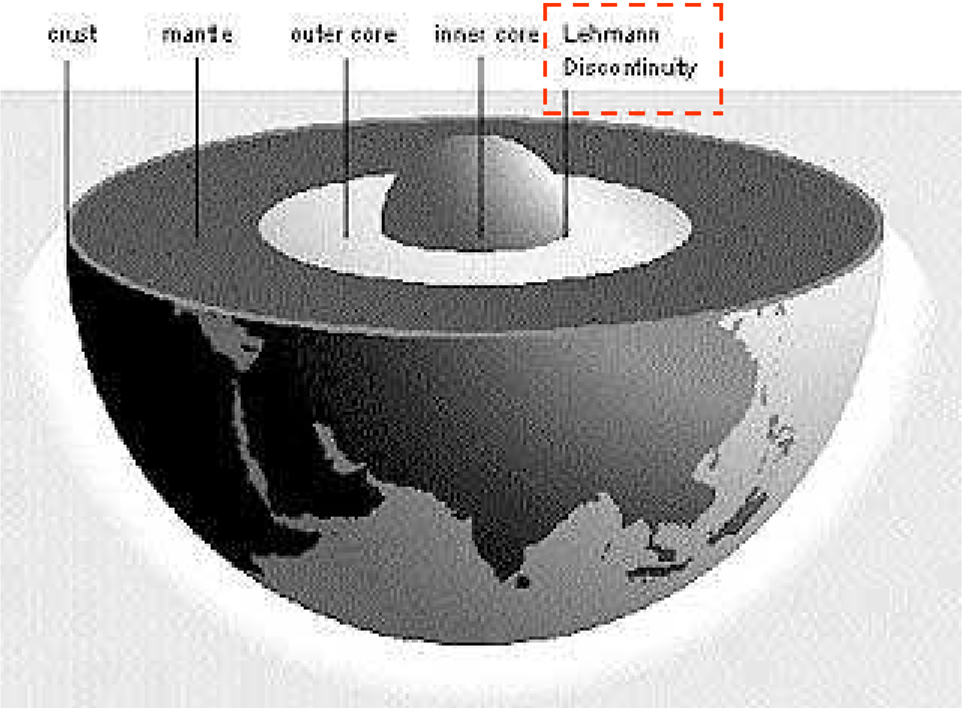
***Popular Science,* December 1923**

RE: thousands of earthquakes occur annually, each one providing a fleeting glimpse of the Earth's interior. Temperatures deep inside the Earth are too hot, pressures too extreme and distances too vast to be explored by conventional probes. Thus, scientists rely on seismic waves; shock waves generated by earthquakes and/or explosions that travel through the Earth and across its surface, to reveal the structure of the interior of the planet. Seismic signals consist of several kinds of waves. Those most important for understanding the Earth's interior are *P-waves*, (primary, or compression waves) and *S-waves* (secondary, or shear waves), which travel through solid and liquid material in different ways.

The seismograph, which detects and records the movement of seismic waves, was invented in 1880. By the end of that decade, seismic stations were in place all over the world. At the time, geophysicists believed the Earth to be made up of a liquid core surrounded by a solid mantle, itself surrounded by a crust, all separated by abrupt density changes in the Earth called “discontinuities.” In 1929, a large earthquake occurred near New Zealand. Danish seismologist *Inge Lehmann* (left) studied the shock waves and was puzzled by what she saw. A few *P-waves* (which should have been deflected by the core) were in fact recorded at seismic stations. Lehmann theorized that these waves had traveled some distance into the core and then bounced off some kind of boundary. Her interpretation of this data was the foundation of a 1936 paper in which she theorized that Earth’s center consisted of two parts: a solid inner core surrounded by a liquid outer core, separated by what has come to be called the “Lehmann Discontinuity.” Lehmann’s hypothesis was confirmed in 1970 when more sensitive seismographs detected waves deflecting off this solid core.



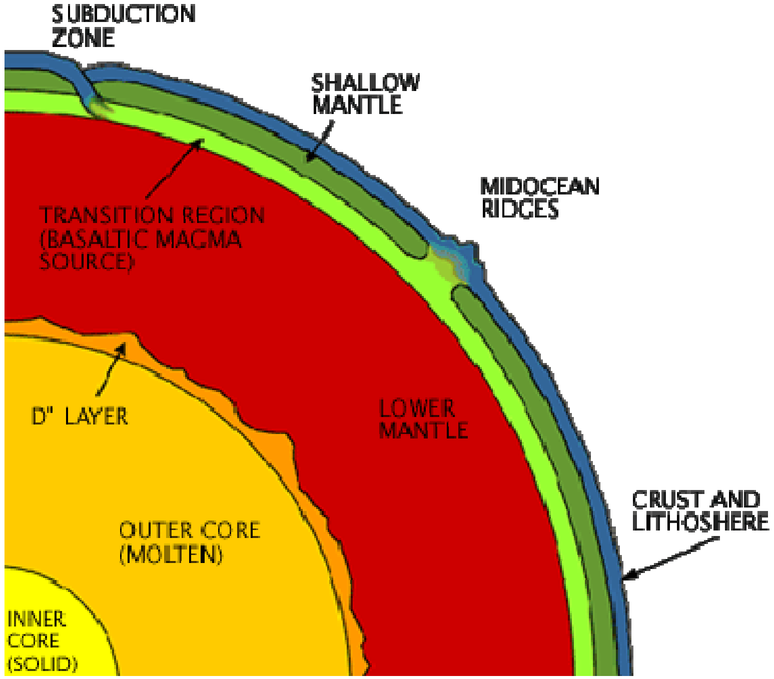


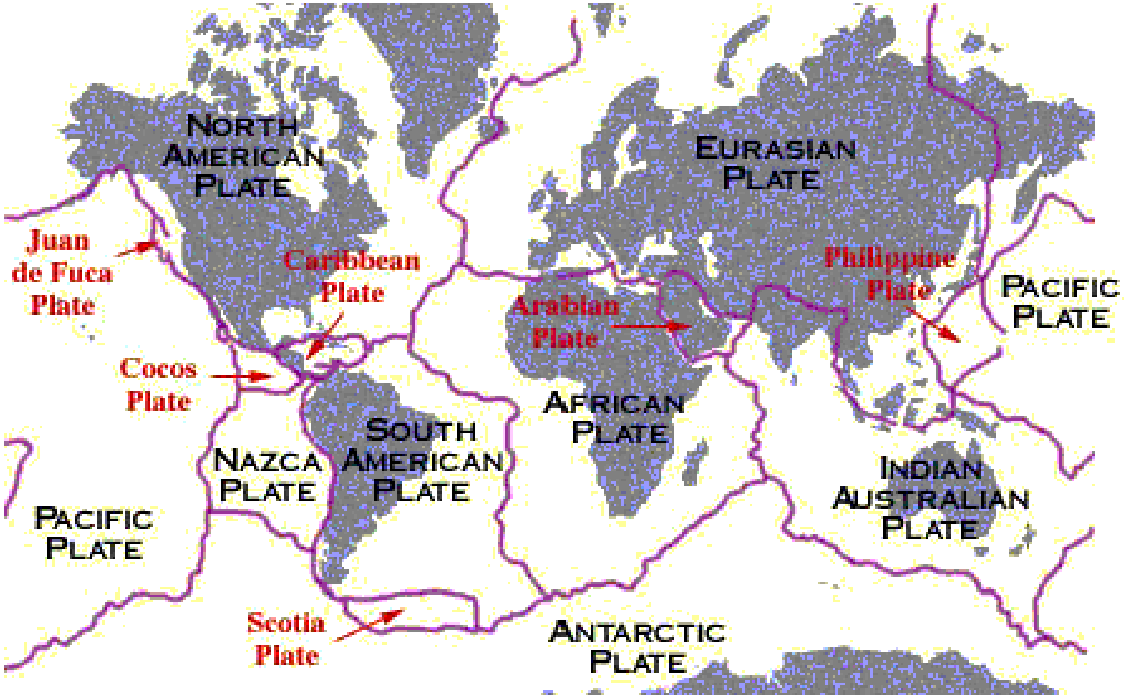


Top Left: caption: "The seismic waves called P-waves pass through the core and are detected on the far side of the Earth. Indirect signals received in the P-wave shadow zone suggest there is a solid inner core deflecting some waves."

Top Right: caption: "The seismic waves called S-waves do not travel through liquid. We know that the outer core is liquid because of the shadow it casts in S-waves."

Left: caption: "Cut-away showing the four main layers of Earth: solid inner core, liquid outer core, mantle, and crust"

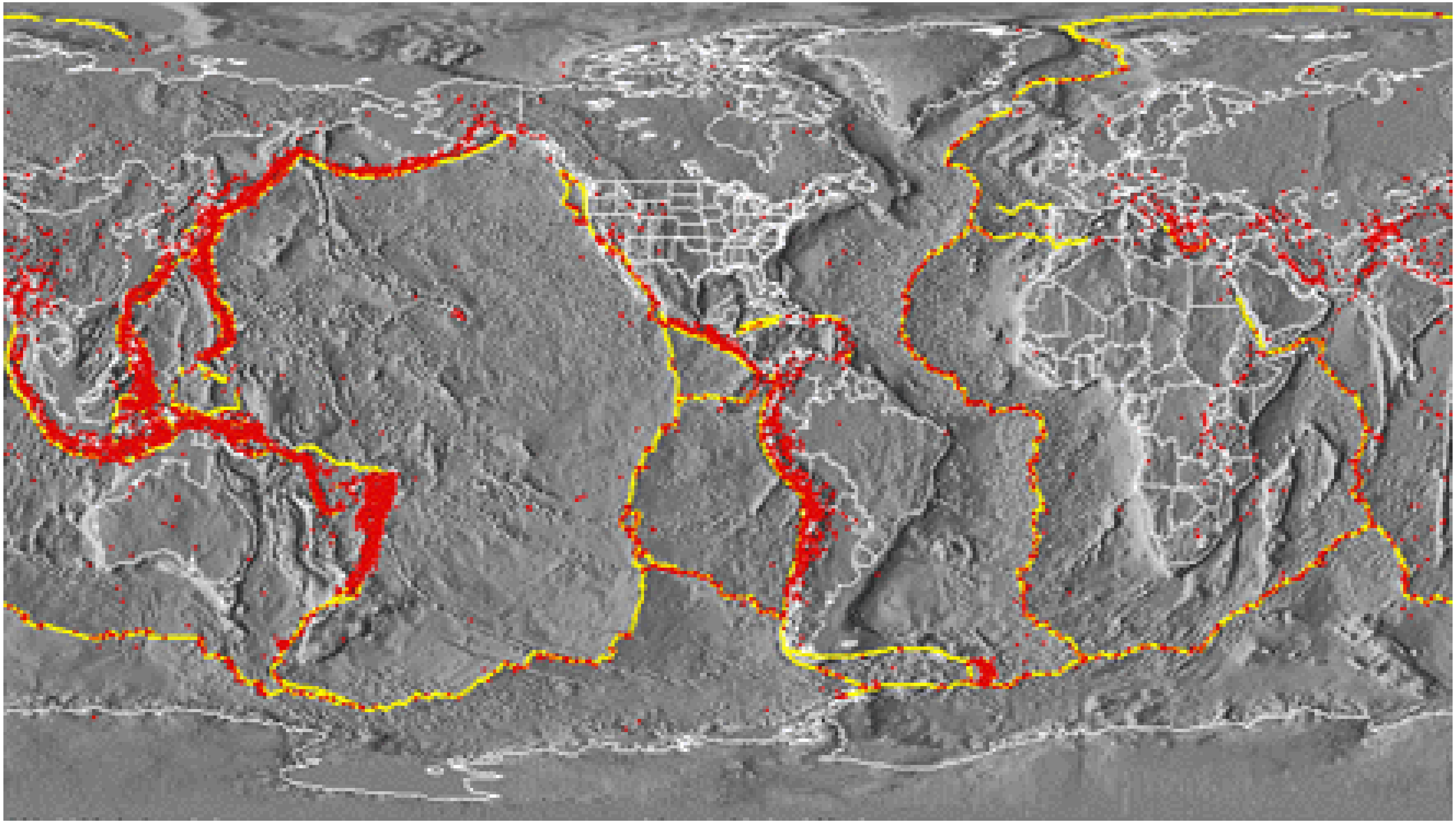




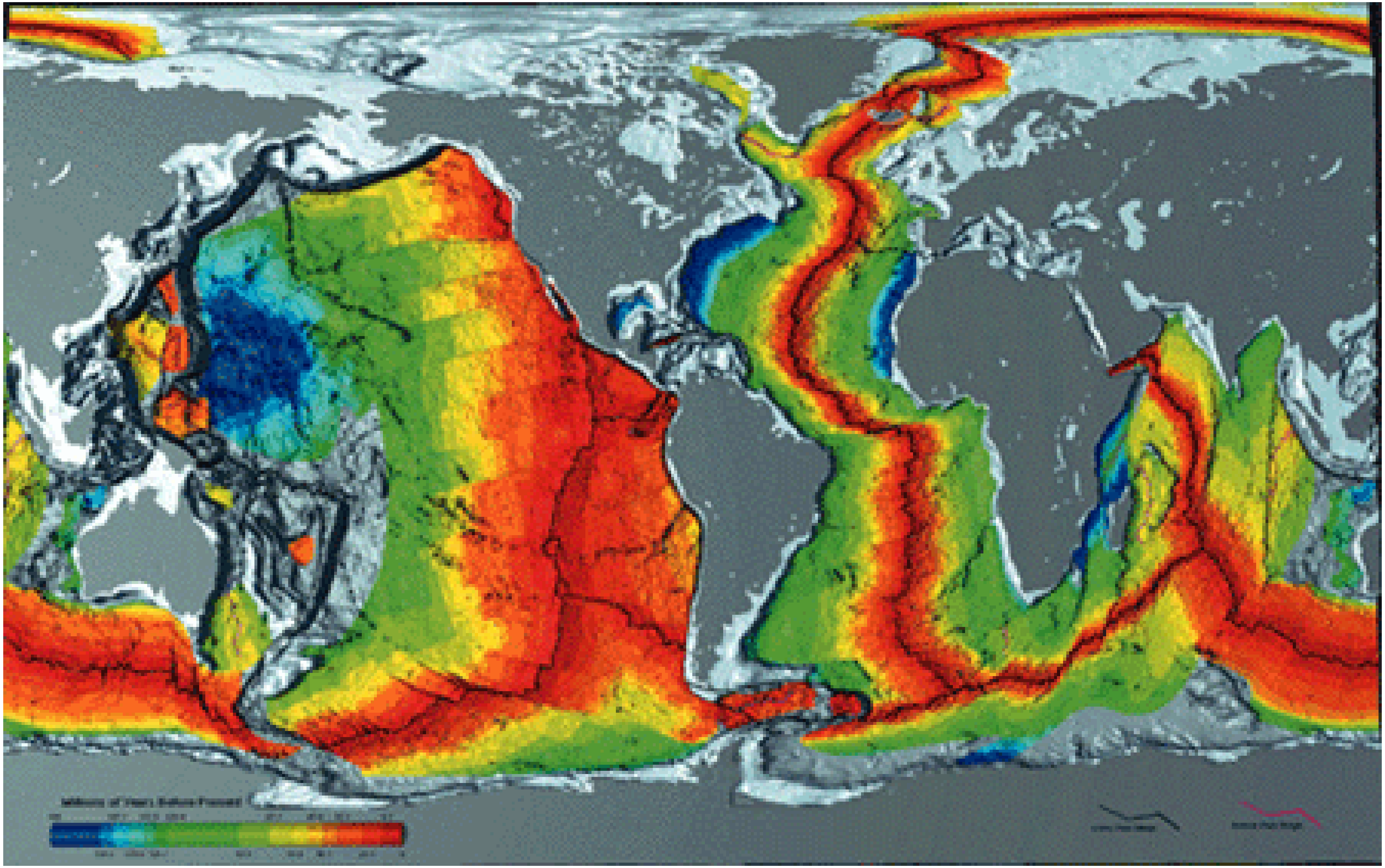
Left: caption: "Geologists have determined that the Earth is actually comprised of four distinct layers:

- **The inner core;**
- **The outer core;**
- **The lower mantle, and;**
- **The transition region (which includes the lithosphere and crust).**

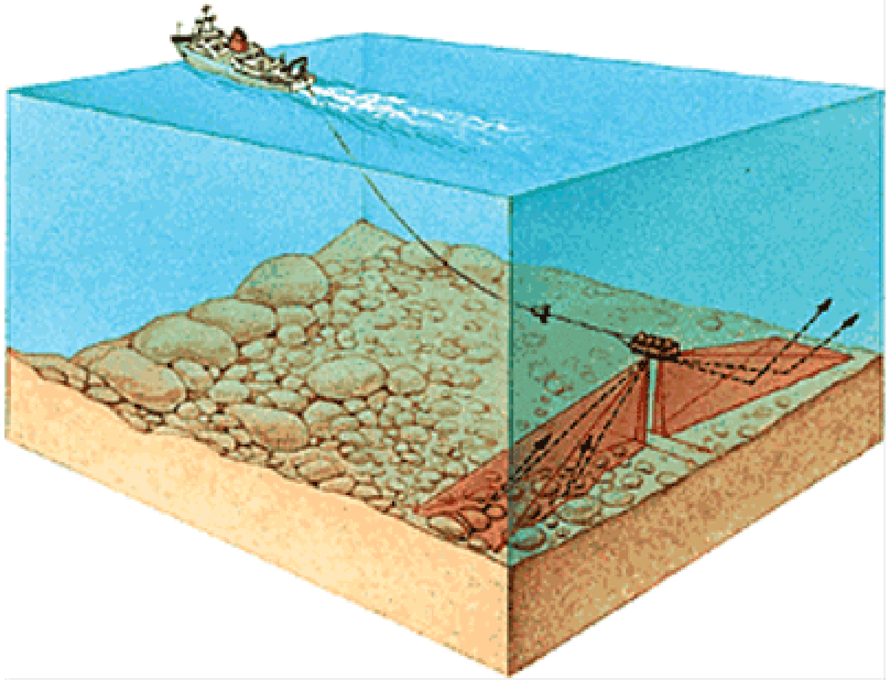
Right: caption: "The crust is broken into plates that fit together much like the pieces of a puzzle. These puzzle pieces are comprised of eight large plates and about two-dozen smaller ones. As this map illustrates, the plates encompass both continental crust as well as sea floor. Most of the plate boundaries are found underwater on the ocean floor."

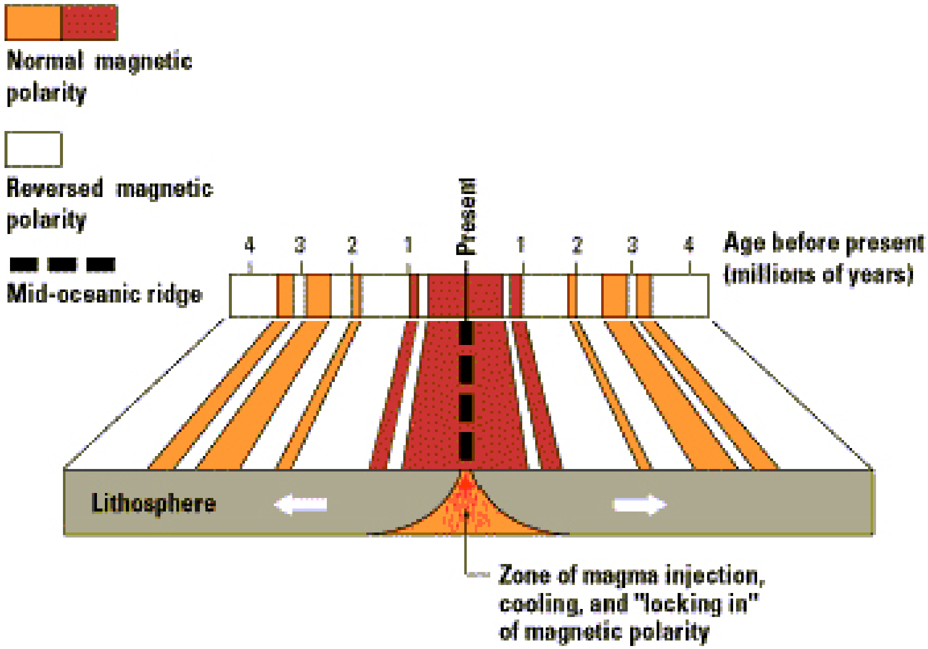


<u>**Above**</u>**: caption: “Each plate moves independently; pulling apart from, sliding past or colliding with adjacent plates, all the while carrying the landmasses along in a process called ‘continental drift.’ The red dots on this map indicate earthquakes and volcanic eruptions - geologic events known as ‘tectonic activity.’ Note that these centers of tectonic activity correlate closely with the plate boundaries. Earthquakes and volcanic eruptions are the result of plate interactions.”**

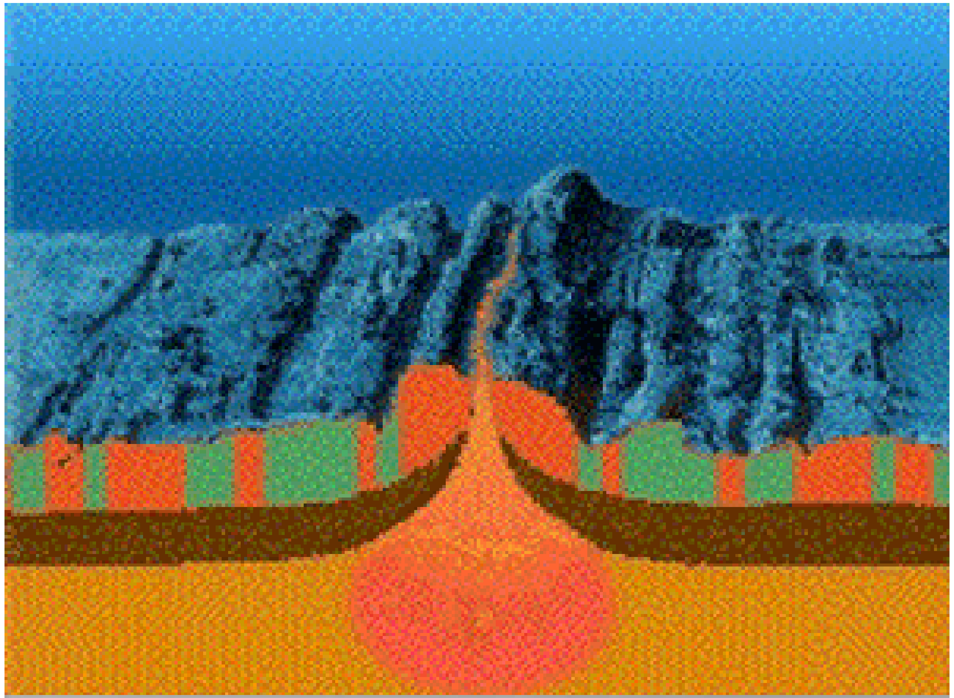


<u>Above</u>: caption: “Plates that pull apart are called ‘divergent boundaries.’ These boundaries act like a conveyor belt, churning up lava from the Earth’s core and literally creating new crust. The colors on this map indicate the age of the sea floor around the world. Red represents the newest (0-9.6 million years old) crust, and blue represents the oldest (156-180 million years old). As the map reveals, the youngest crust is found along the spreading plate boundaries of the Mid-Ocean Ridges.





Left: caption: “This understanding of the spreading sea floor first came about in the 1950s, while researchers were using magnetic instruments (magnetometers) to detect submarines. These scientists began to note odd magnetic variations across the ocean floor. The magnetic variations turned out not to be random or isolated occurrences, but instead recognizable patterns.”
Right: caption: “Further study revealed that these patterns corresponded directly to the magnetic polarity of the Earth over time. Throughout its history, the planet’s magnetic field has reversed direction many thousands of times. Along the Mid-Ocean Ridges, magma emerges from the Earth rich with iron. As it solidifies into rock and new sea floor is created, the iron assumes the same polarity as the Earth’s current magnetic field. This history of magnetic reversals is thus imprinted on the sea floor.”



<u>Top</u>: caption: “Scientists found that when these magnetic patterns were mapped over a wide area, the ocean floor showed a series of stripes. Alternating stripes of magnetically different rock are laid out in matching rows on either side of the Mid-Ocean Ridges: one stripe with one polarity and the next stripe with reversed polarity. This overall pattern is known as ‘magnetic striping.’”

<u>Bottom</u>: caption: “To better understand magnetic striping, a research vessel named the *Glomar Challenger* embarked on a year-long scientific expedition in 1968. Criss-crossing the Mid-Ocean Ridge between South America and Africa, scientists used the ship’s enormous drill to take core samples of the ocean floor.”

Left: caption: “The core samples were studied to determine the age and magnetic orientation of the sea floor at the various drill sites. This data provided a global picture of the Earth’s formation, and strengthened the evidence of the spreading sea floor along the Mid-Ocean Ridges.”

Master of a Black Art

“I remember Inge one Sunday in her beloved garden…with a big table filled with cardboard oatmeal boxes. In the boxes were cardboard cards with information on earthquakes…all over the world. This was before computer processing was available, but the system was the same. With her cardboard cards and her oatmeal boxes, Inge registered the velocity of propagation of the earthquakes to all parts of the globe. By means of this information, she deduced new theories of the inner parts of the Earth.”

Niles Groes

RE: born in Denmark in 1888, *Inge Lehmann* was a pioneer among women and scientists. Her early education was at a progressive school where boys and girls were treated exactly alike. This was a sharp contrast to the mathematical and scientific community she later encountered, about which she once protested to her nephew, Niles Groes, *“You should know how many incompetent men I had to compete with - in vain.”* A critical and independent thinker, Lehmann subsequently established herself as an authority on the structure of the upper mantle. She conducted extensive research in other countries, benefiting from an increased global interest in seismology for the surveillance of clandestine nuclear explosions. When Lehmann received the *William Bowie Medal* in 1971; the highest honor of the *American Geophysical Union*, she was described as: “The Master of a Black Art for which no amount of computerizing is likely to be a complete substitute.” Inge Lehmann died in 1993 at the age of 105.

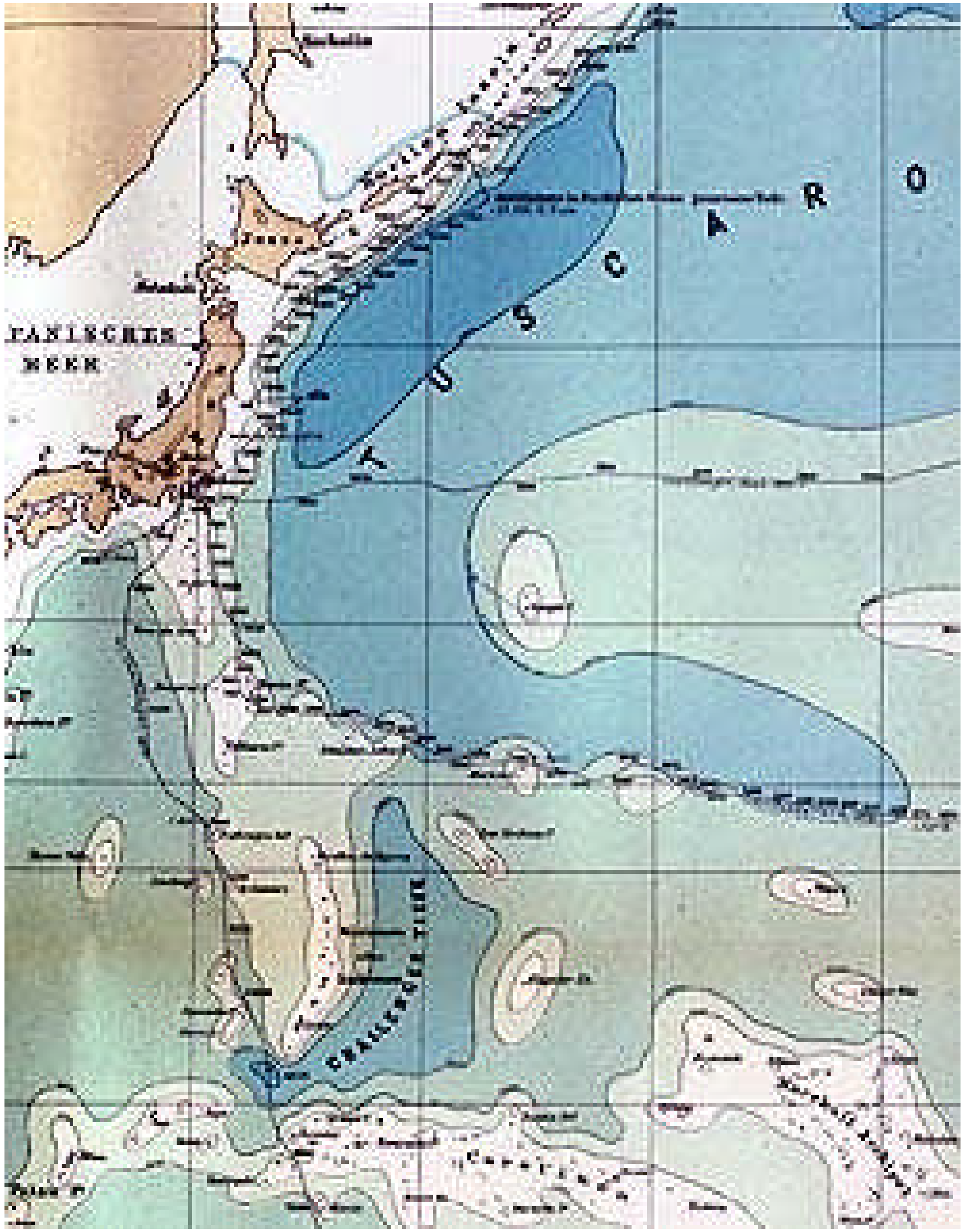
The Deeps

"…The basic cause of the earthquake which devastated Japan, as well as of other tremendously destructive earthquakes of history, is gradual leakage of waters of the ocean through the earth's crust, bringing terrific upheavals when the water meets the hot lava in the interior…"

***Popular Mechanics*, November 1923**

“…Places of greatest strain lie between mountains along the coast and deep valleys under the ocean. If the outer crust of the earth were molten, it would tend to flow to these deeps under the sea, the lowest points on the globe. Being hard, it resists the tendency. This adds to the strain…”

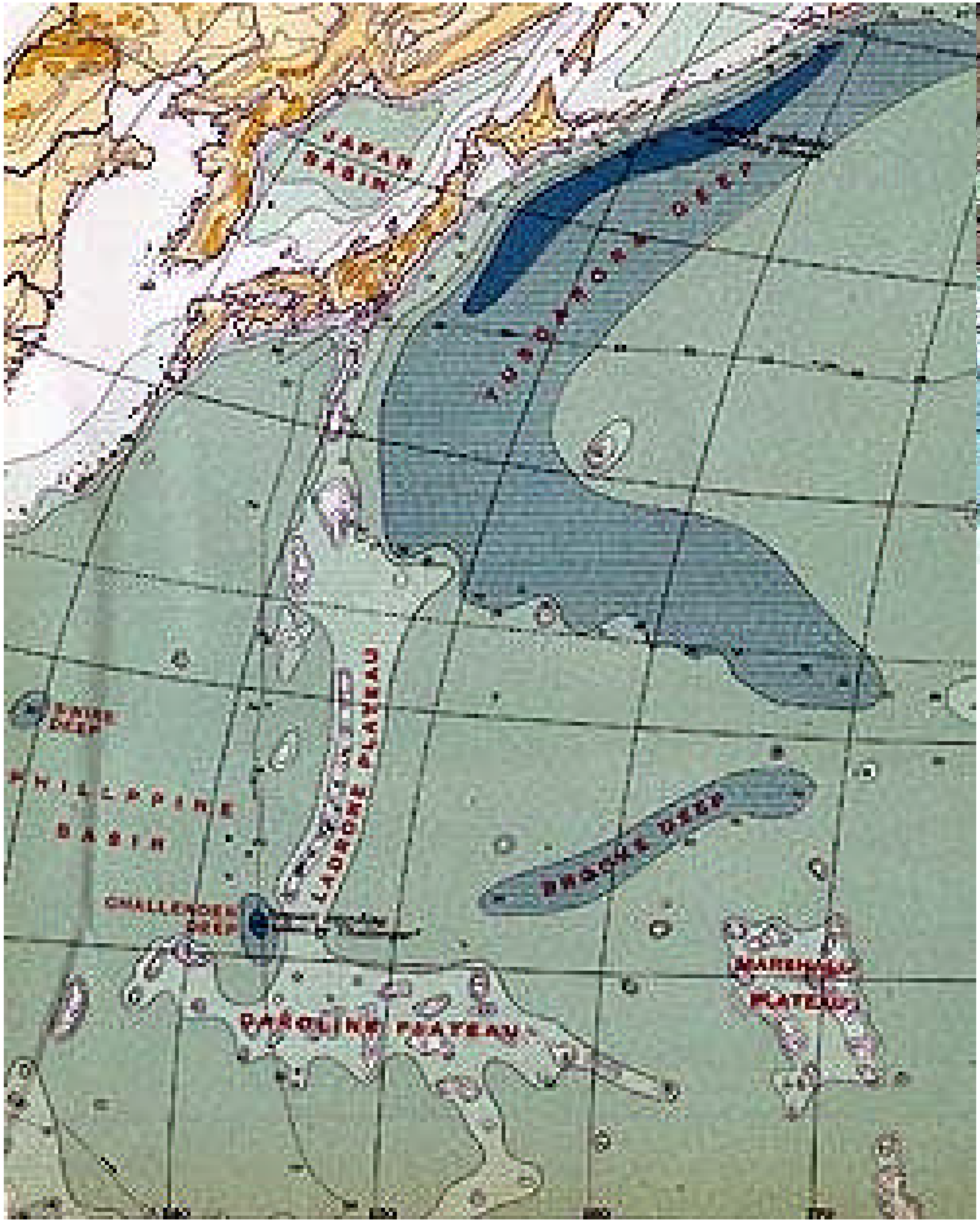
***Popular Science*, May 1933**

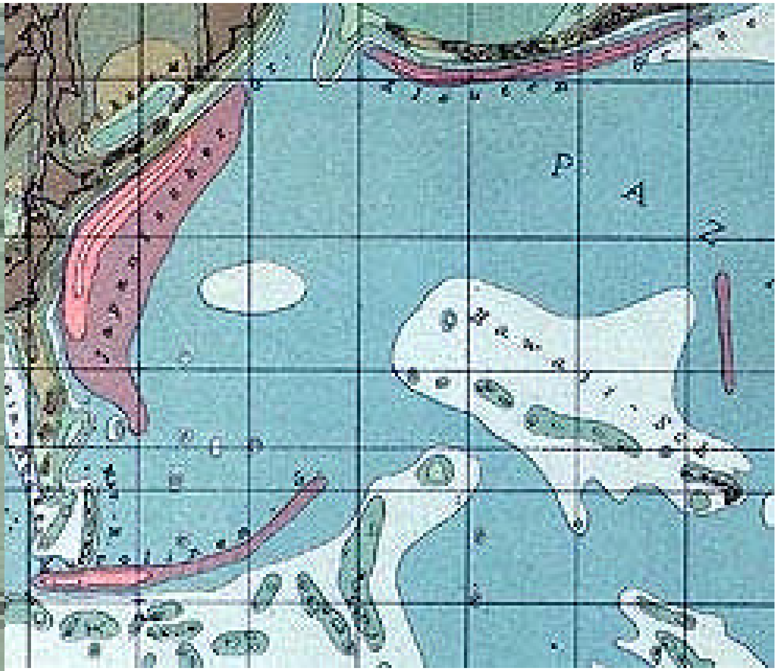


“…Lying to the east of Japan is the ‘Tuscarora Deep,’ a pit in the Pacific (27,600 feet deep), the source of the greatest seismic disturbances which history records. Leakage from this abyss into the depths of the earth is greater than it is anywhere else because of the tremendous pressure of the water. It is reported that this latest Japanese earthquake occupied six minutes of time, rather long duration for a heavy earthquake, and proving the lava beneath the crust of the earth was adjusting itself from the sea toward the land…”

***Popular Mechanics*, November 1923**

Left: 1877 map by geographer *Augustus Petermann*. It was the first bathymetric chart of the *Pacific Ocean.*

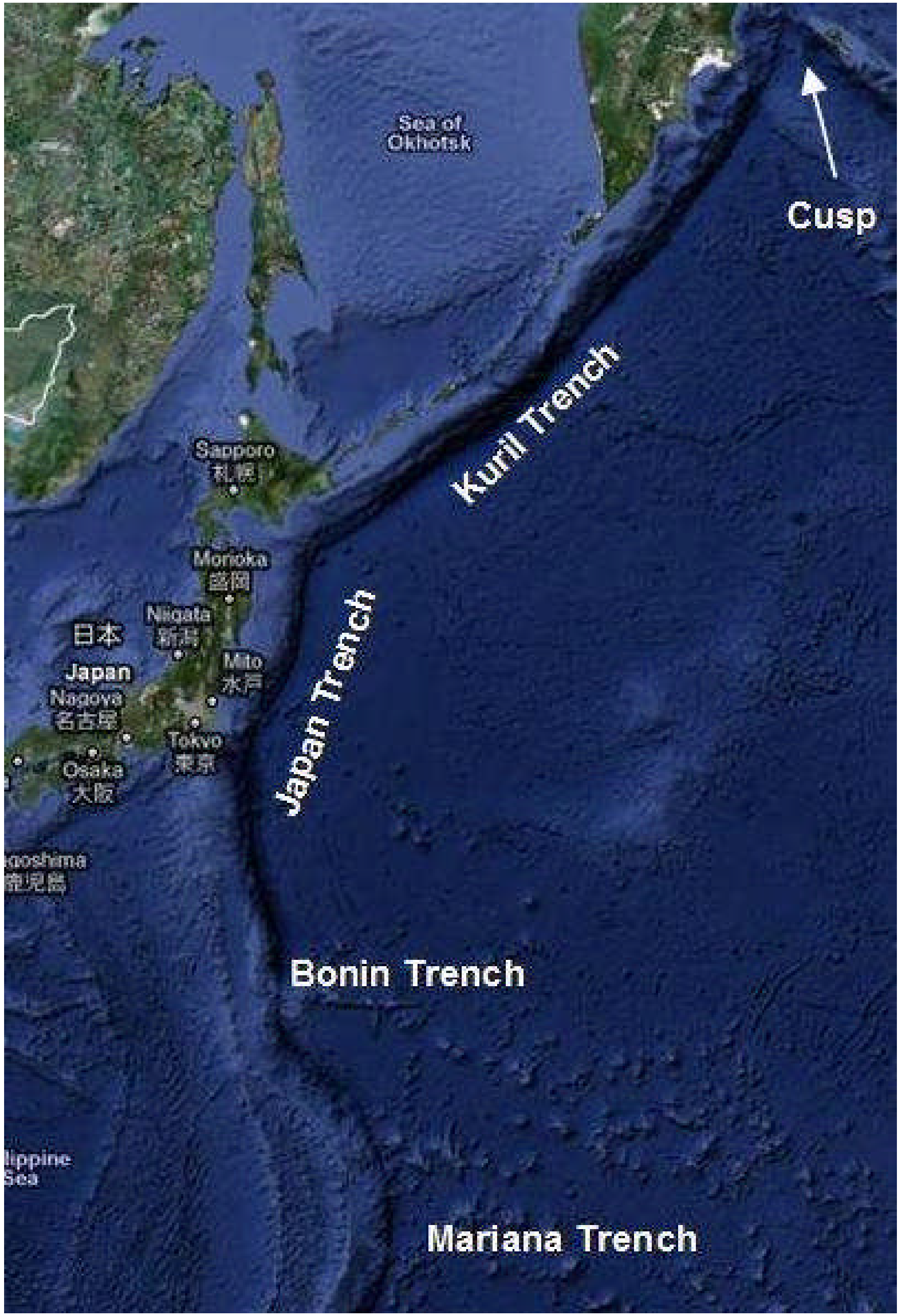




The next two maps were produced by *John Murray*, the first in 1895 (left) and the second in 1899 (above). In the *Tuscarora Deep* (today's *Kuril Trench*), Murray acknowledged it as "Deepest authentic sounding known." Murray's 1899 map was published in *The Scottish Geographical Magazine* and accompanied the article:
The Deep Sea.

“…The most unsettled part of the earth’s surface is the western shore of the Pacific Ocean. Here the crust is being thrust upward, giving rise to steep slopes. It was such a buckling of the earth’s crust along the cracks believed to exist in the bottom of the Tuscarora Deep, off the coast of Japan, that caused the recent disaster, according to theories so far advanced. The proximity of the Japanese coast to this great trough-like ‘deep,’ which goes down more than five miles, and the numerous earthquakes experienced by Japan, lend weight to the theory that pressure exerted by this tremendous volume of water is the cause of such disturbances…”

***Popular Science*, December 1923**



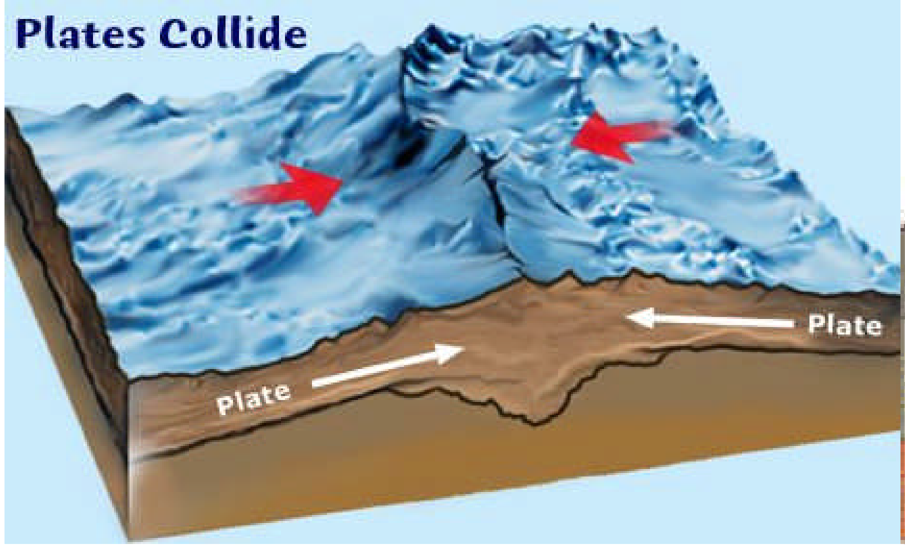
"…Further proof that the sea bottom was disturbed is found in the great tidal wave which followed the earthquake, and the broken cables lying on the bed of the sea…"

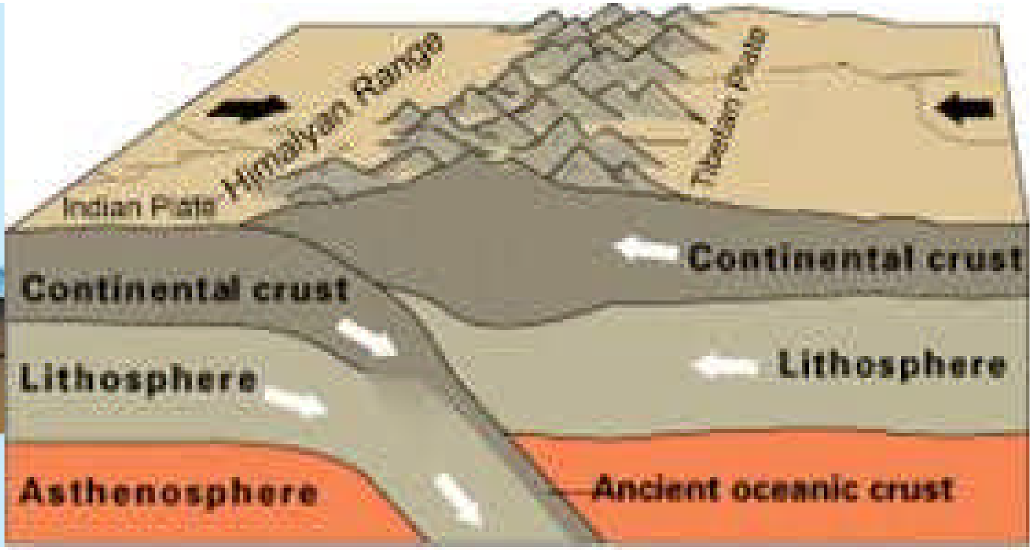
***Popular Mechanics*, Nov. 1923**

Left: the *Japan Trench* is a deep submarine trench lying east of the Japanese islands, in the floor of the western *North Pacific Ocean*. It is one of a series of depressions stretching south from the *Kuril Trench* and the *Bonin Trench* to the *Mariana Trench*. The 27,929-foot *Tuscarora Deep* was once considered the deepest point in the world (subsequently found to be in the Mariana Trench).

“…The great 34,210-foot deep off the coast of Japan has much to do with the frequent tremors which rock that island. Until a few weeks ago it was thought to be the lowest point on earth. Then American oceanographers a sounding of 44,000 feet, or eight and three-tenths miles, north of Puerto Rico, in the Caribbean Sea…”

Popular Science, **May 1933**





"…The earthquake is nature's method of building mountains, and, if there were no earthquakes, all our globe would be dead level…"

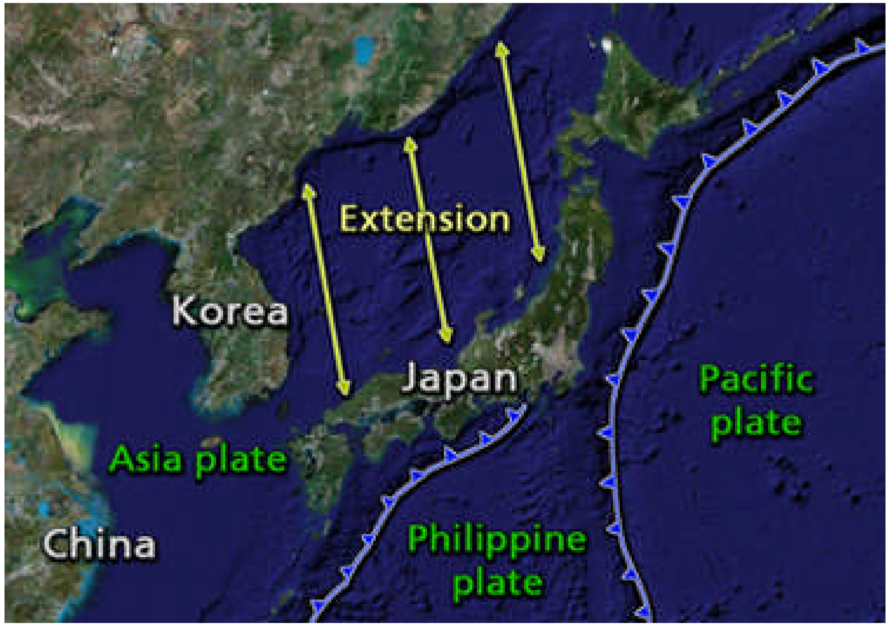
***Popular Mechanics*, November 1923**

<u>Left</u>: caption: "Mountain ranges are created when two tectonic plates collide. Since the rock has nowhere to go but up, a mountain is created."

<u>Right</u>: caption: "Collision of Indian plate with Tibetan plate and formation of Himalayas Range." An active plate boundary which separates India from Asia is a convergent plate boundary where India is trying to subduct or sink beneath Asia, causing earthquakes. There is also a major fault separating the two continents. Eventually the stress builds-up and the fault ruptures, causing an earthquake.

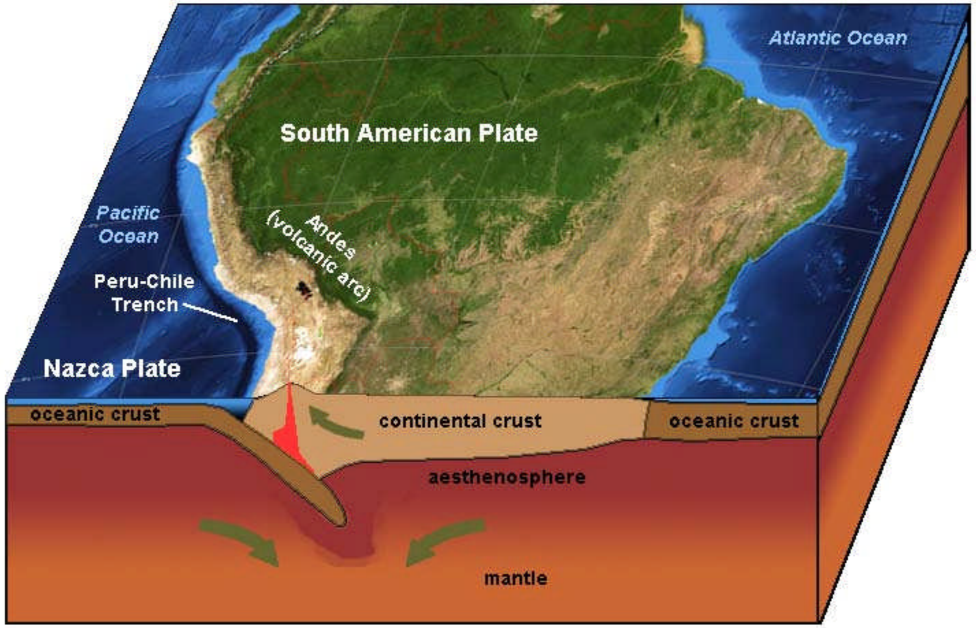
“…It is a well established fact that the pressure at any point on the sea’s bottom is great enough to throw a column of water as high as the sea is deep at that point. It is easy from this to see that the pressure at the bottom of the ‘Tuscarora Deep’ – five miles below the surface of the ocean – would throw such a column of water up to the highest clouds of our sky. Pressure of this strength would force the water through the granite of the earth’s crust, and thus the creation of untold forces of steam when the water hits the superheated lava of the earth’s interior. Not only the main island of Hondo but the other bits of Japanese land have been so lifted…”

***Popular Mechanics*, November 1923**



The formation of the Japanese archipelago was primarily the result of several large oceanic movements occurring over hundreds of millions of years as a result of the subduction of the *Philippine Sea Plate* beneath the continental *Amurian Plate* and *Okinawa Plate* (to the south) and subduction of the *Pacific Plate* under the *Okhotsk Plate* (to the north). Japan was originally attached to the eastern coast of the Eurasian continent. The subducting plates (being deeper than the Eurasian plate) pulled Japan eastward, opening the *Sea of Japan* about fifteen million years ago (the *Strait of Tartary* and the *Korea Strait* opened much later). Japan is situated in a volcanic zone on the Pacific Ocean's "Ring of Fire." Frequent low intensity earth tremors and occasional volcanic activity are felt throughout the islands. Destructive earthquakes, often resulting in tsunamis (tidal waves), occur several times each century.

Above: caption: "The island of Japan was separated from mainland Asia by back-arc spreading"



"…The Cordillera, or Andes Mountains, was similarly lifted up, and very deep water is still to be found along the Pacific coasts of both North and South America…"

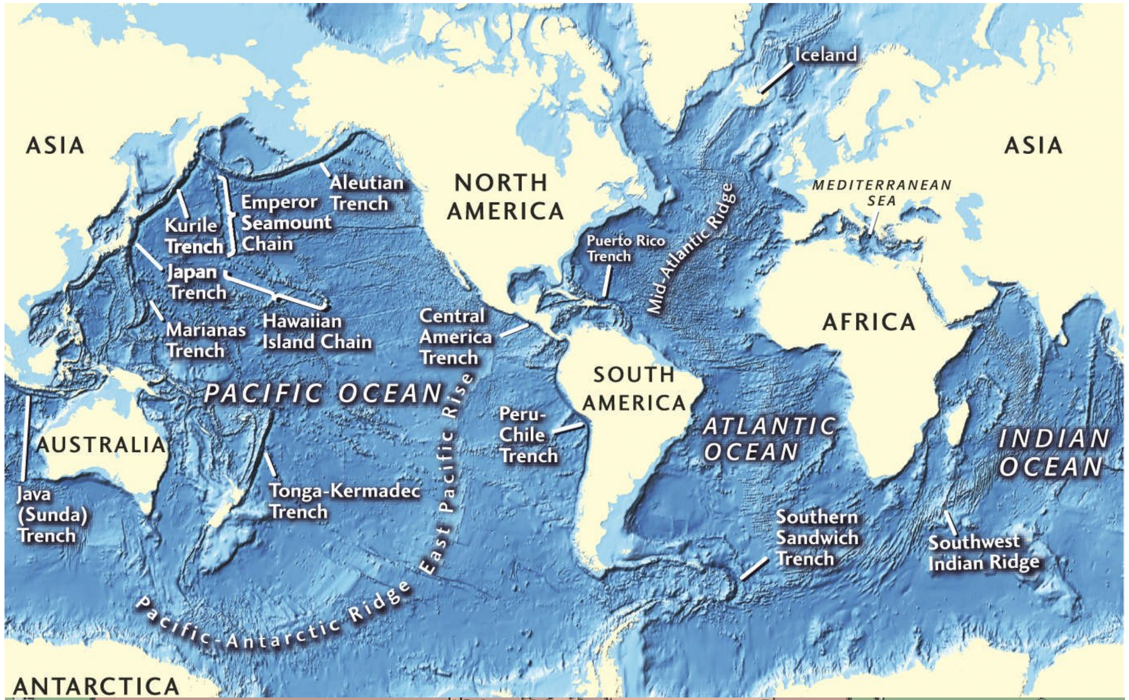
***Popular Mechanics*, November 1923**

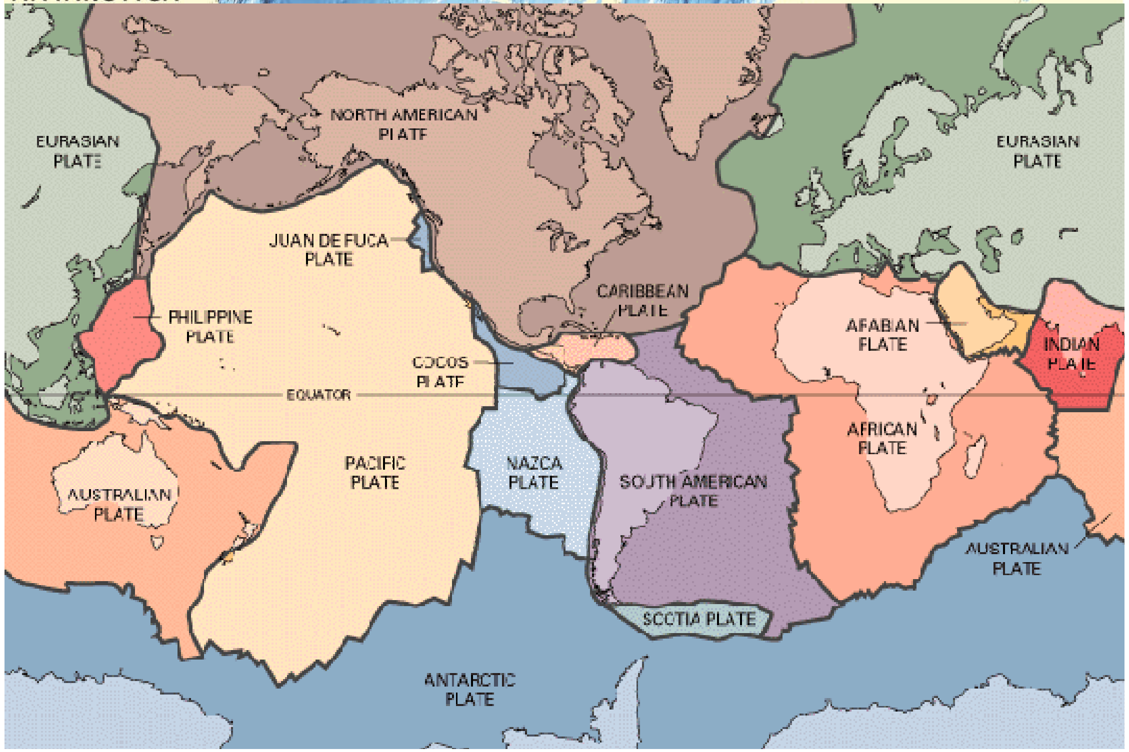
<u>Top</u>: caption: "Convergent boundary along the west coast of South America." A *Convergent Boundary* occurs when continents collide, forming mountains ranges. Examples include the *Himalayas*, *Alps* and *Appalachian Mountain Range/s*. Likewise, when continental plates collide with ocean crust, subduction zones with deep ocean trenches and volcanic arcs form. Examples include the *Andes* (bottom), *Sierra Nevada* and *Cascade Mountain Range/s*, Aleutian Islands, Japan, Philippines and Indonesia,

“…Late last fall, representatives of twenty-nine nations, meeting at Praha, Czechoslovakia, proposed a plan whereby the mysterious ocean canyons, or ‘deeps,’ are to be probed soon in order to trace their possible connection with earthquakes. Far-reaching and deep-set are the canyons. The Aleutian deep, largest in the Pacific, extends for 1,500 miles and is five miles deep. The Nares deep, largest in the Atlantic, falls more than five miles. Other great depths are off the coasts of Mexico, Java and Sumatra. Since three-fourths of the world’s earthquakes have their cradle in the sea and particularly in the Pacific, the probe should be of great importance. New seismograph stations will be established and those on hand improved, so that, when a quake occurs, its location may be determined…”

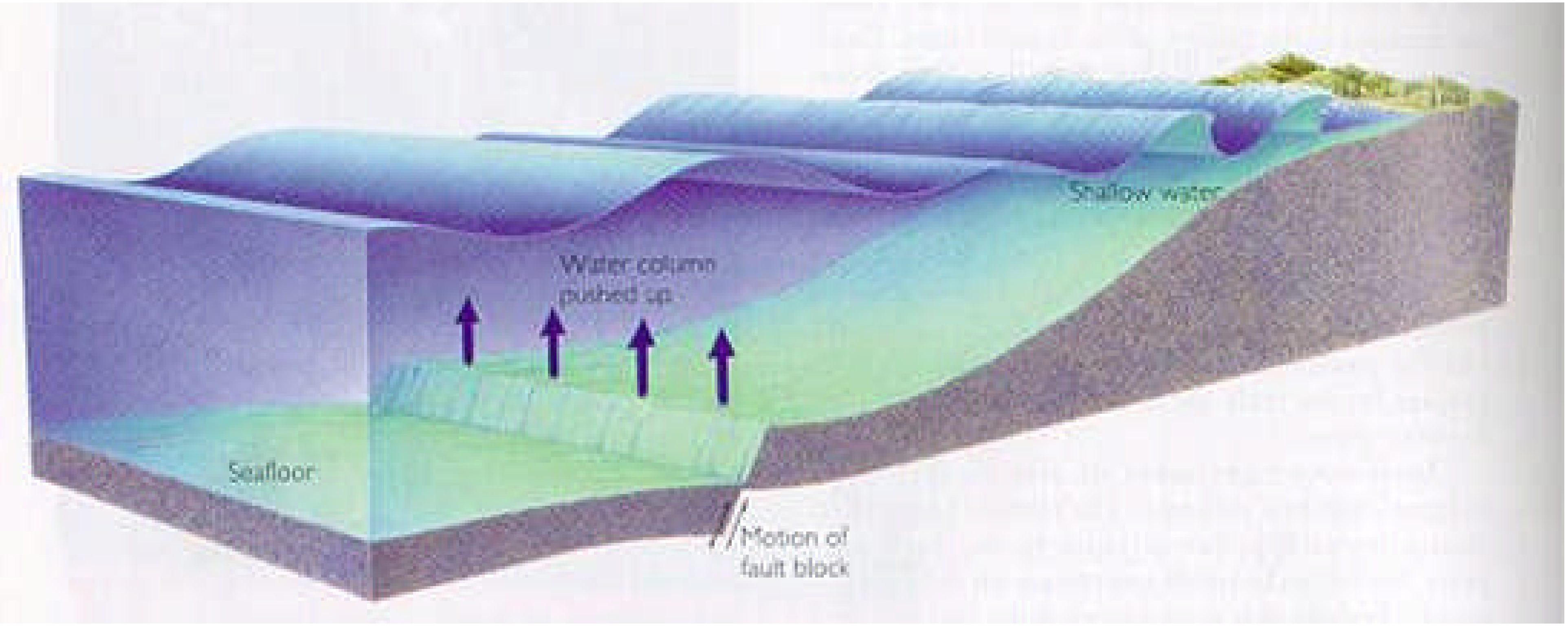
***Popular Mechanics,* June 1928**

RE: it is now a well established fact that the Earth’s crust is broken into about twelve rigid slabs (a/k/a “tectonic plates”) that move relative to one another


ASIA
Iceland
ASIA
Aleutian Trench
NORTH AMERICA
Emperor Seamount Chain
Kurile Trench
MEDITERRANEAN SEA
Puerto Rico Trench
Mid-Atlantic Ridge
Japan Trench
AFRICA
Central America Trench
Hawaiian Island Chain
Marianas Trench
SOUTH AMERICA
PACIFIC OCEAN
East Pacific Rise
Peru-Chile Trench
ATLANTIC OCEAN
INDIAN OCEAN
AUSTRALIA
Java (Sunda) Trench
Tonga-Kermadec Trench
Southern Sandwich Trench
Southwest Indian Ridge
Pacific-Antarctic Ridge
ANTARCTICA


NORTH AMERICAN PLATE
EURASIAN PLATE
EURASIAN PLATE
JUAN DE FUCA PLATE
CARIBBEAN PLATE
PHILIPPINE PLATE
ARABIAN PLATE
INDIAN PLATE
COCOS PLATE
EQUATOR
AFRICAN PLATE
PACIFIC PLATE
NAZCA PLATE
SOUTH AMERICAN PLATE
AUSTRALIAN PLATE
AUSTRALIAN PLATE
SCOTIA PLATE
ANTARCTIC PLATE

Seaquakes

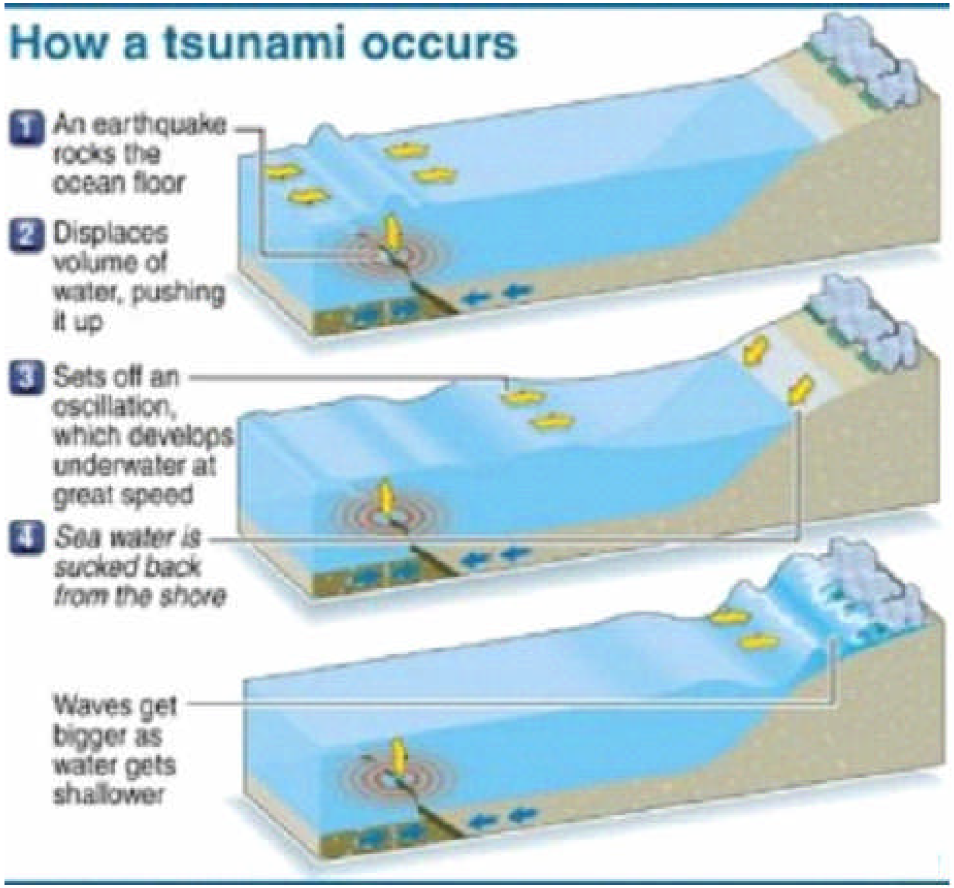


"…Earthquakes under the sea are called seaquakes. So tremendous are the waves that they can travel at a rate of four or five hundred miles an hour, and still be detected after a journey of more than 10,000 miles…"

***Popular Science,* December 1923**

<u>Above</u>: caption: "When there is a strong undersea earthquake (a/k/a 'seaquake') a part of the seabed rises abruptly with a vertical displacement. The mass of water above loses its balance and is set in motion, so that the surface will form one or more waves that, even if only a few tens of centimeters high, have a large wavelength (distance between one wave and the next)."

The seaquake ("tsunami," in Japanese) is a series of ocean waves generated by the rapid movement of a large mass of water. In the open sea the waves propagate very quickly over large distances, with almost imperceptible heights (less than one-meter) but the wavelength (distance between one wave and the next) can reach many kilometers. Approaching the coast, the wave speed decreases while its height increases rapidly. The tsunami waves can be distinguished from ordinary ocean waves by certain characteristics. The common sea wave produced by the wind moves only the most superficial part of the water, not causing any movement in depth. The tsunami wave, instead, moves the entire water column; from the bottom to the surface. For this reason, unlike other waves, they have a strong energy capable of pushing them at high speed for several hundred meters inland and their impact on the coast, therefore, is much stronger. The tsunami wave may look like a wall of water that hits the coast causing a flood, or as a rapid rise in sea-level (similar to a tide that is growing rapidly). Sometimes, the wave may be preceded by an unusual and temporary withdrawal of water (several meters), which leaves dry ports and coastlines. The first wave may not be the biggest and between the arrival of a wave and the next it can take several minutes. A tsunami wave in open water less than a meter high turns, when it arrives on the coast, into a wall of water that can exceed 30-meters. The propagation speed of a tsunami wave depends on the depth of the bottom (i.e. the greater the depth, the greater the speed of the waves). In very deep water (over 4K-meters) waves can exceed 700 km/h. Arriving near the coast, the wave encounters shallower depths therefore its speed decreases dramatically. This is due to the fact that the energy flow of the tidal wave (which depends both on the speed that the height of the wave) remains constant. Consequently, when the speed of the tidal wave decreases, its height increases. This is why tsunami waves are not noticeable off the coast but become devastating when reaching several meters in height. The *Great Kanto Earthquake* (with a magnitude of 7.9) devastated the Tokyo-Yokohama areas in September 1923, leaving 140K people dead. The tsunami that followed ruined 155 houses and caused sixty deaths.


How a tsunami occurs
1 An earthquake rocks the ocean floor
2 Displaces volume of water, pushing it up
3 Sets off an oscillation, which develops underwater at great speed
4 *Sea water is sucked back from the shore*
Waves get bigger as water gets shallower

A tsunami is born from the sudden displacement of a large mass of water, caused by strong earthquakes with epicenter in the sea or near the coast, from coastal or submarine landslides, volcanic activity in the sea or near the coast and, much more rarely, from meteorites falling into the sea. Its energy (and thus its hazard) depend on the size of the phenomenon that caused it. A tsunami can be generated by an undersea earthquake if it:

- **Is very strong, generally with magnitudes greater than 6.5;**
- **Has a hypocenter (depth in areas where there is the breaking of rocks giving rise to the earthquake) not too deep, and;**
- **Produces a vertical displacement of the seafloor.**

Tsunamis generated by landslides (both undersea and above the sea-level with material falling into the sea) have less energy than those generated by earthquakes. Their strength is exhausted more quickly and the waves can't get very far. However, these tsunamis can produce very high waves and be destructive in areas close to where the landslide was/is generated. The tsunamis generated by volcanic activity, at sea or near the coast, are less frequent than those produced by underwater earthquakes, but can still be very strong. Violent submarine eruptions can cause the movement of large volumes of water and generate dangerous tsunamis. Tsunamis of volcanic origin are mainly caused by explosive eruptions. This happens when the vent of the submarine volcano is located near the surface of the water. Sub-aerial eruptions of volcanoes located near the coast (i.e. *Stromboli*) can produce dense clouds of gas and lava fragments which, gliding at high speed along the slopes of the volcano and falling into the sea, move large volumes of water generating tsunami waves. In the case of particularly violent eruptions, the volcano may collapse completely or partially form a *Caldera* (what remains of a volcano following the collapse of the magma chamber). If this happens on a volcanic island, a tidal wave may occur.

TWS

A *Tsunami Warning System* (TWS) is used to detect tsunamis in advance and issue warnings to prevent loss of life and damage. It is made up of two equally important components:

- **A network of sensors to detect tsunamis;**
- **A communications infrastructure to issue timely alarms to permit evacuation of coastal areas.**

There are two distinct types of tsunami warning systems:

- **International**
- **Regional**

When operating, seismic alerts are used to instigate the watches and warnings then, data from observed sea-level height (either shore-based tide gauges or buoys) are used to verify the existence of a tsunami. Other systems have been proposed to augment the warning procedures.

Predicting the Weather

“Prediction of earthquakes, with the same accuracy with which conditions of the weather are now foretold, has become possible, according to a discovery just made by Dr. Andrew C. Lawson, professor of geology at the University of California. However, the theory will necessarily have to be checked against the actual occurrences over a period of years before the scientists would dare to make public their forecasts in advance of disturbances…”

***Popular Mechanics,* April 1922**

“…In the opinion of leading scientists the day is not far distant when people may live in larger security in places like Japan where earthquakes are of frequent occurrence. The tremendous importance of this task has been made evident when we consider that 160,000 earthquakes actually have been catalogued and that about 4,000 earthquakes are felt each year in different parts of the world…”

***Popular Science,* December 1923**

“…the displacement within the earth that results in rock slips that science now regards as the cause of earthquakes is developing below the surface for months before the quake occurs. This displacement usually does not actually reach the surface, but produces vibrations or waves that can be recorded by special instruments as a means of obtaining forewarning of the coming quake. The vibrations travel great distances at high velocity before they die out…”

Popular Science**, December 1923**

"…The instruments will have to be set up in many places and the records kept for years before the science of predicting earthquakes is set on a firm basis. It is not at all unlikely that in the future earthquakes can be predicted much as the weather is predicted now. Warnings can be sent to threatened districts and measures taken by the populations to save themselves."

Popular Science, **December 1923**

The Creep of the Crust

“…The discovery of the method of forecasting the time and place of earthquakes follows, and is based upon, another recent discovery, also made by Professor Lawson, that movements of the earth’s surface, technically known as ‘the creep of the earth’s crust,’ are antecedent to, as well as consequences of, earthquakes. That is to say, the crust of the globe, to a depth varying from a few feet to scores of miles, is constantly on the move, in a generally northward direction, though during and following earthquakes, such movement may be in two or more directions…”

Popular Mechanics, **April 1922**

“…This latter discovery is of far greater interest to scientists than the forecasting of earthquakes, or the discovery of the method of forecasting. Thus, Doctor Lawson, by his two discoveries, has added tremendously, not only to the available knowledge of the globe on which we live and its movements within itself, but to the safety of millions of persons who live in zones in which earthquakes have occurred and may occur again…”

Popular Mechanics**, April 1922**

<u>Left</u>: caption: “Dr. Andrew C. Lawson, Professor of Geology ”

“…The creep of the earth’s crust, to explain it briefly and in non-technical language, is due indirectly to the fact that the poles of the earth do not run true. The North Pole describes a circle about 60-ft. diameter every time the earth revolves on its axis. It is as if the earth were a globe revolving on a shaft which oscillated around its center. While this deviation of a 60-ft. circle is so small, in view of the size of the earth, as to be almost infinitesimal, it is sufficient to set the soil and the rocks, even the mountains and valleys, in a slow but steady motion, usually to the northward…”

***Popular Mechanics,* April 1922**

Andrew Cowper Lawson (1861–1952) was a Scottish-born professor of geology at the _University of California_, _Berkeley_. He moved to Hamilton, Canada with his parents at the age of six. In 1883, he received his B.A. degree in natural science from the _University of Toronto_. While pursuing his graduate degrees, he worked for the _Geological Survey of Canada_. He received his M.A. from the University of Toronto in 1885 and his Ph.D. from _Johns Hopkins University_ in 1888. In 1890, he left the Geological Survey to work as a consulting geologist in Vancouver. In October 1890, he accepted a position as Assistant Professor of Mineralogy and Geology at the UC Berkeley. He became a full professor in 1892 and a Professor Emeritus from 1928 until his death in June 1952. He was the editor and co-author of the 1908 report on the 1906 _San Francisco Earthquake_ which became known as the "Lawson Report." He was also the first person to identify and name the _San Andreas Fault_ (in 1895) and, after the 1906 quake, he was first to delineate the entire length of the fault (which previously had been noted only in the SF Bay Area). He named the _Franciscan Complex_ and served as a consulting geologist for the construction of the _Golden Gate Bridge_ (1937). His home in Berkeley, CA (a/k/a "Lawson House") was specially designed by noted architect _Bernard Maybeck_ to withstand earthquakes. The mineral _Lawsonite_ was named in his honor as is the _Lawson Adit_. Originally a mining construction research tunnel on UC Berkeley's campus, during the _Cold War_ it was used to house special equipment to monitor Soviet nuclear tests. Currently, it houses seismological instruments.

“Many people think that earthquakes are peculiar to some particular sections of the globe, but they are not. They are common the world over, and there probably is no fraction of the earth’s surface that has not suffered from them. Now it has been found that certain points on the earth’s surface move in a rather mysterious manner…”

Dr. A.C. Lawson, **Professor of Geology at the** ***University of California*** **(November 1923)**

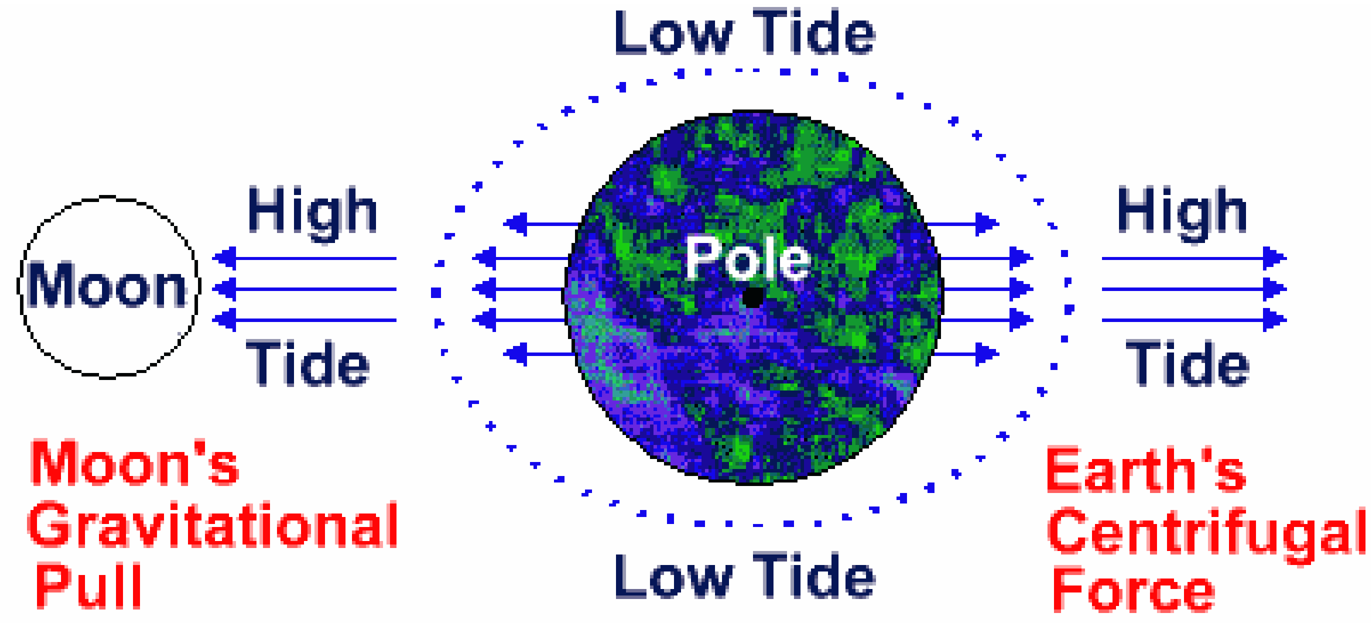
“…These movements of the earth are not confined to sudden and violent disturbance experienced at the time of an earthquake shock. The energy that was let loose in Japan, or that was released in San Francisco in 1906, had been stirred up in the earth’s crust as an elastic compression. It seems probable that this energy was being stored by a slow accumulation of strain due to the application of some force, and that, when the strain reached the limit, things broke. It was the snapping at the time of the maximum possible strain that gave rise to the sudden shifting of the ground, an gave us the vibration that we recognized as an earthquake shock…”

Dr. A.C. Lawson, **Professor of Geology at UC Berkeley (November 1923)**

Humpty Dumpty in Outer Space

"…Our planet has been compared to a soft-boiled egg hurtling through space. More accurately, perhaps, it is like an egg that is still boiling on the inside, while the shell trembles almost constantly from tremendous internal and external pressures…"

***Popular Mechanics,* December 1967**



"…The apparently solid surface of the earth rises and falls about 14 inches a day because of the tidal effects of the moon. Lava and gases forced toward the surface near volcanoes make the surrounding are swell upward like the chest of a breathing giant. But the best known of the earth's vibrations are the destructive earthquakes that have been changing the face of our planet for thousands of years…"

***Popular Mechanics,* December 1967**

<u>Above</u>: caption: "The length of time that it takes for the earth to rotate around so that the moon is in the same position is 24 hours and 50 minutes or a 'tidal day.' This is why the tidal cycle starts approximately 50 minutes later each day. As the earth rotates, the moon's gravitational force continually mounds the water and that fluid mound moves around the earth. The actual height of the tide is influenced by the shape of the coastline and depth of the water."

Disturbing the Balance

"…If the crust of the earth in any region is moving slowly to the north, as figures and measurements indicate, certainly the force causing this movement is not applied at the surface. The indications are that portions of the earth are in balance which sets up a disturbance, or undertow, of the deeper portions of the earth's crust toward the lighter portions. The process of erosion, the wearing down of mountains, is removing a load in an area where the mountains are and transferring it to a neighboring region…"

***Dr. A.C. Lawson,* Professor of Geology at UC Berkeley (November 1923)**

“…We are thereby disturbing what we call the ‘balance,’ and, if that disturbance be significantly great, then we must inevitably have a return flow from the region that is being loaded to the region that is being unloaded, and that return flow is very probably sufficient to bring about a drag effect on the brittle crust above it, and to apply it to a strain which can only be relieved by rupture, or slipping, give rise to earthquakes.”

***Dr. A.C. Lawson*, Professor of Geology at UC Berkeley (November 1923)**

Somethin’s Gotta Give

"…Like a liquid tide setting ever in one direction, this current of earth creates a tremendous strain in its own mass. The pull is so great that a distinctly measurable tension ensues in all the layers of the earth's crust which is creeping. When this tension reaches a certain point, something has to give way. The result is a tearing open of the earth's crust, and a backward or sideways motion – which Doctor Lawson calls 'the elastic rebound' – and the visible, tangible phenomenon known as an earthquake occurs…"

Popular Mechanics, **April 1922**

“…As soon as Doctor Lawson had definitely established the creep of the earth’s surface, and the rebound under the strain of its own tremendous weight, he said: ‘If we find the weight of creep and the length of time necessary to produce the limit of tension in the earth’s crust, we shall know when and where there is to be the next earthquake, merely by watching closely the increase in tension’…”

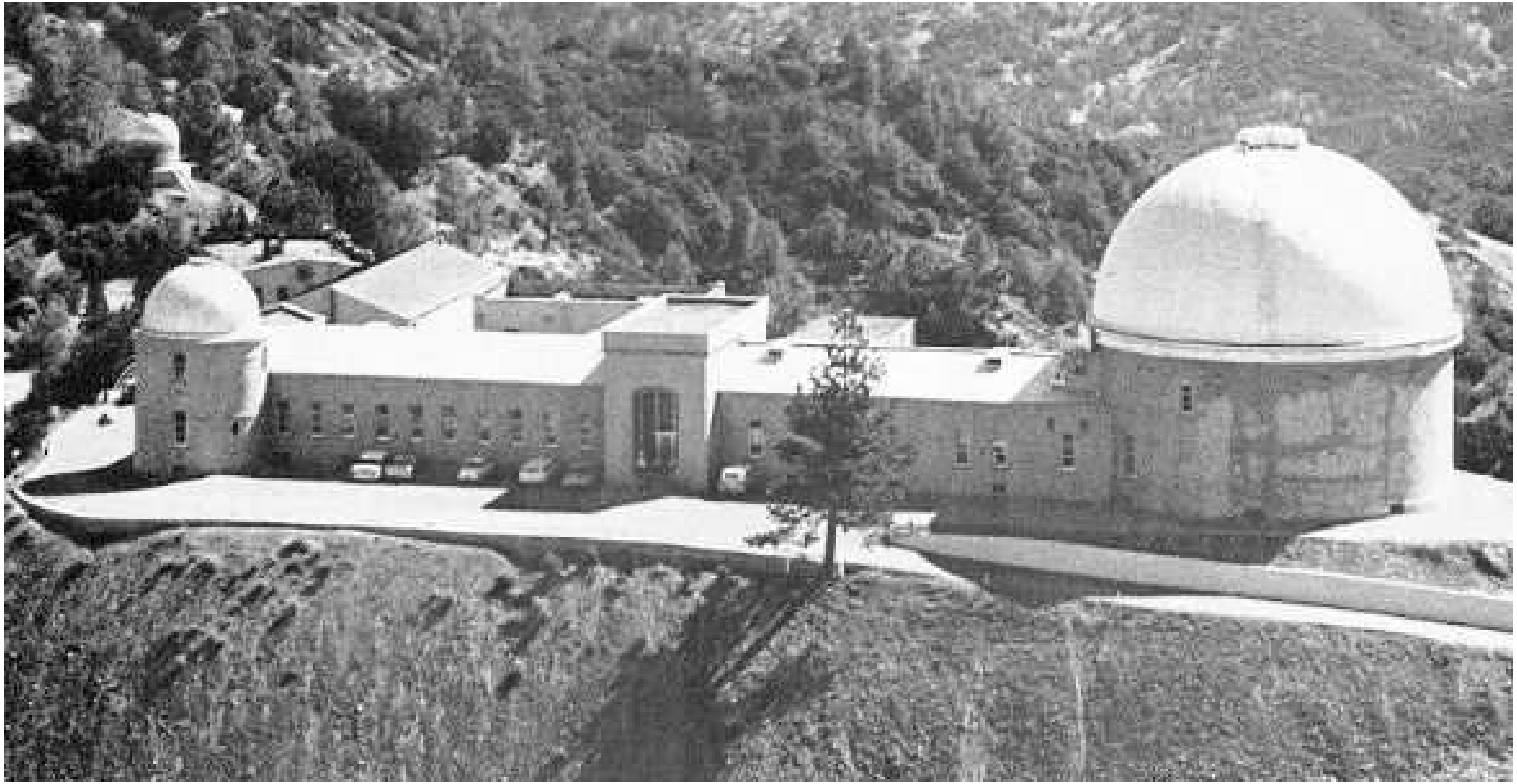
***Popular Mechanics,* April 1922**

The Rate of Creep

“…It is necessary, however, that constant, consistent, accurate observations of the rate of the creep of the earth’s crust be made at frequent intervals. With the known factors of time and rate of creep necessary to create the limit of tension in the earth’s crust, the observer knows all the time whether or not there is to be an earthquake in his section of the world, and, by the rate of creep, the time the elastic rebound will take place, within a few hours. ‘This gives to the forecasting of earthquakes,’ says the University of California, in its bulletin announcing Doctor Lawson’s double discovery, ‘the same precision as that which weather forecasts are made’…”

***Popular Mechanics,* April 1922**

Fixing the Limit of Tension



"…With the object of establishing the exact rate of creep of the earth's crust along the Pacific slope, and of fixing the limit of tension which that crust will endure, the University of California has appropriated $4,000 for the purchase of a photographic latitude telescope, to be installed and used in the observatory on Mt. Hamilton, California, permanently…"

***Popular Mechanics,* April 1922**

<u>Above</u>: caption: "Lick Observatory (Mt. Hamilton) with 12" and 36" Refractor"

<u>P</u>hotographic <u>Z</u>enith <u>T</u>ube **(PZT) is a zenith telescope where part of the optical system is a pool of Mercury that reflects the light from a star through a lens system whose node is filled with a glass photographic plate that moves on a track at the sidereal rate. After making four exposures the plate is read in an X-Y measuring machine and from that the sidereal time of the exposure could be determined to better than one millisecond. In 1972, it was replaced by atomic time (an atomic clock keeps much more accurate/uniform time than does the rotation of the Earth). The telescope was made specifically for measuring the angle between straight up and a star near the zenith or, more accurately, to measure the difference in declination of a star-pair where both stars have about the same declination but are on opposite sides of the zenith. This is done using an eyepiece micrometer. Thus, the scale factor depends on the actual focal length of the telescope. When the scope is rotated so that the horizontal axis is East-West, the scope moves in the meridian plane (there were stops on the lower azimuth circle that can be set to 180-degrees). If the scope is pointing 10-degrees** ***<u>East</u>*** **of the meridian and the scope is rotated about the vertical axis to the other stop 180-degrees away, then it will be pointing 10-degrees** ***<u>West</u>*** **of the meridian, allowing the difference between the zenith angles to be measured using the eyepiece micrometer.**

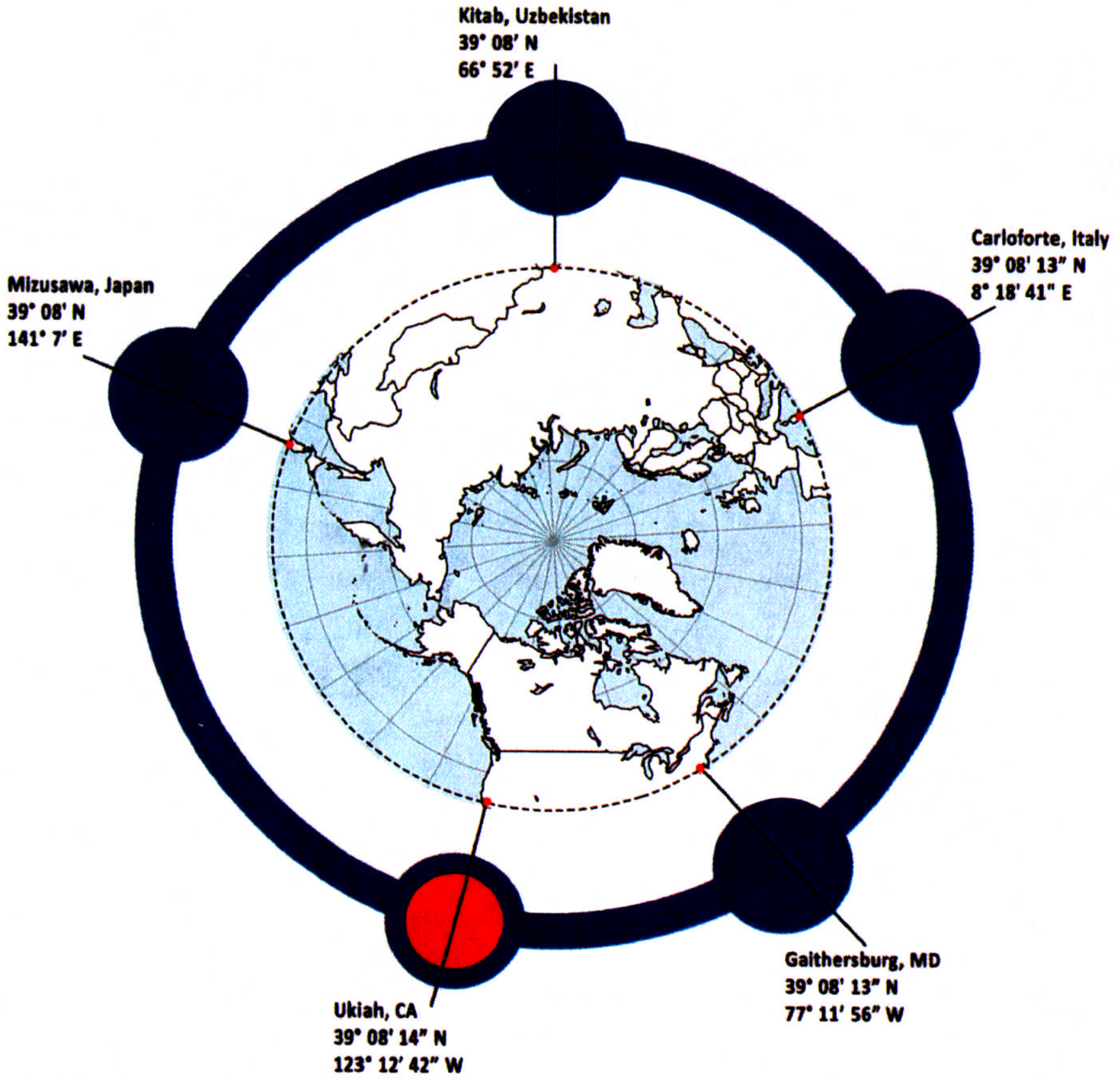
<u>Left</u>: caption: “Ukiah Latitude Observatory Zenith Telescope”

At a Moment’s Glance

"…Arrangements have also been made for Doctor Lawson, W.W. Campbell, director of the Lick Observatory on Mt. Hamilton, and R.H. Tucker, astronomer, to make continuous studies of this earth movement, all along the Pacific slope, tabulating the results, and thereby establishing records and tables from which all necessary data regarding the creep, tension, and rebound may be obtained at a moment's glance…"

***Popular Mechanics,* April 1922**

Left: caption: "Lick Observatory - Mount Hamilton, California. Exterior View of the Crossley 36-inch Reflector Building."



Starting in 1899, observations were made to determine the location of the Earth's rotational axis. To do this, several observatories (spread equidistant around the globe) at the same Latitude (39-degrees 08-minutes North Latitude) sequentially observed the same set of about sixty star-pairs each night, measuring the zenith distance and time of meridian crossing using a *Vertical Zenith Telescope* (VZT). *Ukiah Obsevatory* was the location of one of the small number of "Latitude Observatories" which measured their latitude (and longitude) nightly in order to help define the wobble of the Earth's poles. Many astronomical observations cannot be made without prior knowledge of where exactly the *North Pole* is located (i.e. where the spin-axis of the Earth is pointing to in outer space). Decommissioned in 1982, the Latitude Observatories operated for almost a century.

Moving Mountains

"…During past seismic disturbances entire mountains have been moved 5 or 6 ft.; other areas have been moved even farther; buildings, fences, monuments, trees, and similar ordinary fixed objects, have been carried 10 or 12 ft., without being damaged, by a movement of the entire crust of the earth for a considerable distance around the object moved…"

***Popular Mechanics,* April 1922**

“…The segment of the earth’s crust which moved prior to the Pacific coast earthquake of April, 1906, is estimated to have been approximately 15,000 square miles in area, and about 65 miles in depth – that is to say, 975,000 cubic miles of earth shifted distances varying from 1 ft. to 10 or 12 ft., depending on its distance from the main center of disturbance, the so-called ‘San Andreas fault,’ running, roughly, southeast to northwest, and disappearing in the Pacific Ocean…”

Popular Mechanics, **April 1922**

Left: caption: “Distortion of trolley tracks, San Francisco 1906”

Right: caption: “San Francisco street fissure, April 1906”

“…With these conditions, it is obvious that the only manner in which the position of any point on the earth’s surface can be fixed, is by accurate astronomical observations at regular intervals. Even by this method, a certain amount of error creeps in, but much of this error will be eliminated by the use of the Ross photographic latitude telescope, which surpasses the international latitude instrument (visual) in accuracy. It records on the photographic plate, automatically, and so removes the human element in recording its own observations…”

Popular Mechanics, **April 1922**

"…Some of the figures obtained by Doctor Lawson in his investigations of the creep of the earth's crust are of surprising interest, as denoting the movements which supposedly immovable mountains and hills have made prior to, during, and after earthquakes. From 1854 to 1906, for example, Mt. Tamalpais, a peak rather more than 2,000 ft. in height on the Marin Peninsula, north of the Golden Gate entrance to San Francisco Bay, moved, by strain creep, 9.97 ft. in a north-northwesterly direction. In 1906 it moved, by elastic rebound, 6.46 ft. in a south-southeasterly direction, but not along the line of the previous movement…"

***Popular Mechanics*, April 1922**

<u>Above</u>: caption: "Mount Tamalpais from San Rafael"

“…Interesting comparisons between the movement due to strain creep and the backward, or sideways-backward, movement due to rebound, of several points, are made by Doctor Lawson. For instance, Chaparal moved 8.56 ft., almost due north, by strain creep, from 1856 to 1906, and in a few seconds in 1906 moved backward, by elastic rebound, in a southeasterly direction, 6.76 ft.; almost as much as it had moved in the previous 50 years. Farallon Lighthouse, located on an island off the Golden Gate, moved 6.76 ft., in a northwesterly direction, by strain creep, in the 46 years between 1860 and 1906, and in the short duration of the earthquake of 1906, moved by rebound 4.23 ft., almost due west…”

***Popular Mechanics,* April 1922**

“…Other places and groups of places moved similarly, but in varying directions. Yet, out of all these movements, closely recorded, studied, compared, and tabulated, order can be worked, and the rate of creep, as well as of rebound, ascertained. Difference of soil characteristics, and of sub-soil structure, have to be taken into consideration, since some forms of soil and rock will endure more strain than others before reaching the breaking point…”

***Popular Mechanics,* April 1922**

“…One interesting feature of these studies is that no general change of elevation of any of the points has been found ‘of sufficient magnitude to be detected with certainty’…”

***Popular Mechanics,* April 1922**

“It is well known that, on the occasion of the April, 1906, earthquake, there was a relative displacement of the earth’s surface stratum on the two sides of the San Andreas fault line. This amounted, in the Bolinas region, to as much as 24 ft., and at many points, to about 17 ft. That this relative displacement included areas lying several miles away from the fault line was shown conclusively for several critical observing stations by the work of the United States Coast and Geodetic Survey conducted shortly after the date of the earthquake. Inter-comparisons of the results for the positions of these observing stations made at different epochs left no doubt that the earth movements, on a general scale, were intimately connected with the earthquake phenomena of 1868 and 1906…”

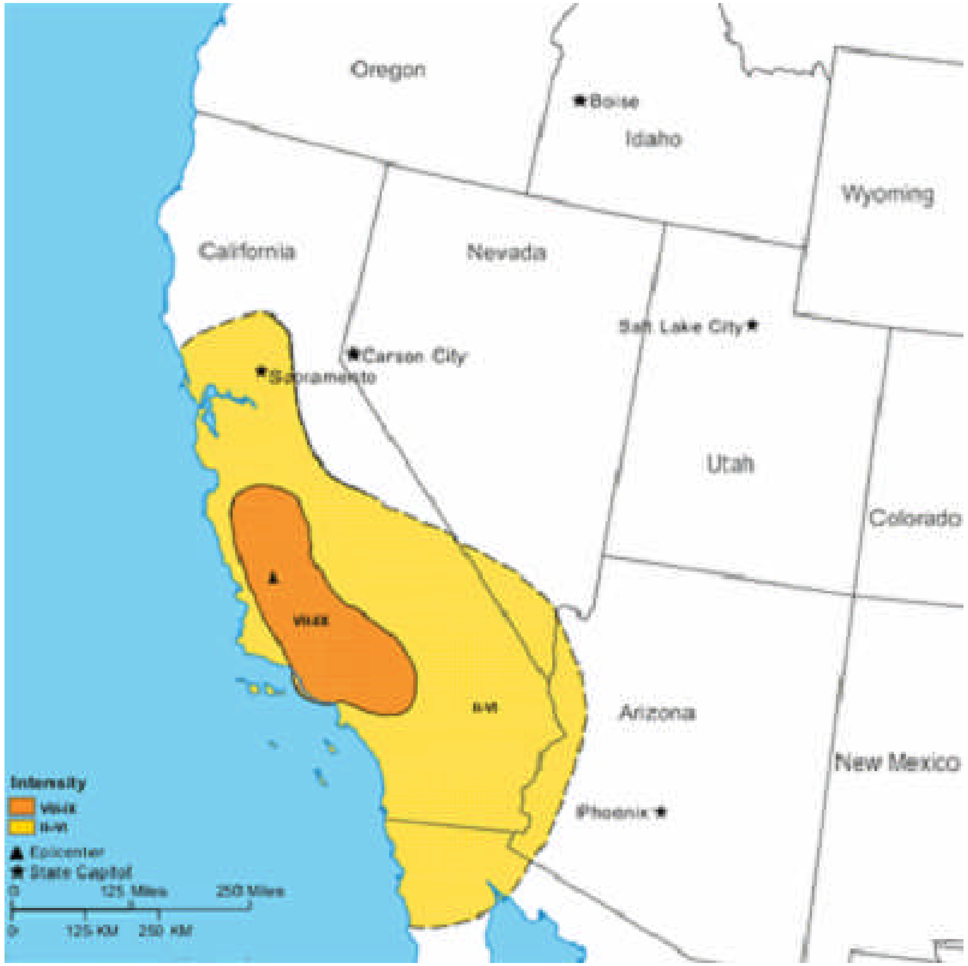
Office of President *David P. Burrows*, University of California (1922)

Result of Earthquake on Mission Street, opposite Postoffice.

"…The last great adjustment in the northern part of the fault produced the San Francisco earthquake of 1906. Farther south, the last big adjustment was in 1857, with its epicenter near a corner of Los Angeles County. The earth was ruptured for a distance of 200 miles. The ground was displaced 20 feet or more along the fault. A circular corral on the fault line was changed to the shape of an S. Buildings and large trees were thrown down and the shock was felt as far as 500 miles away…"

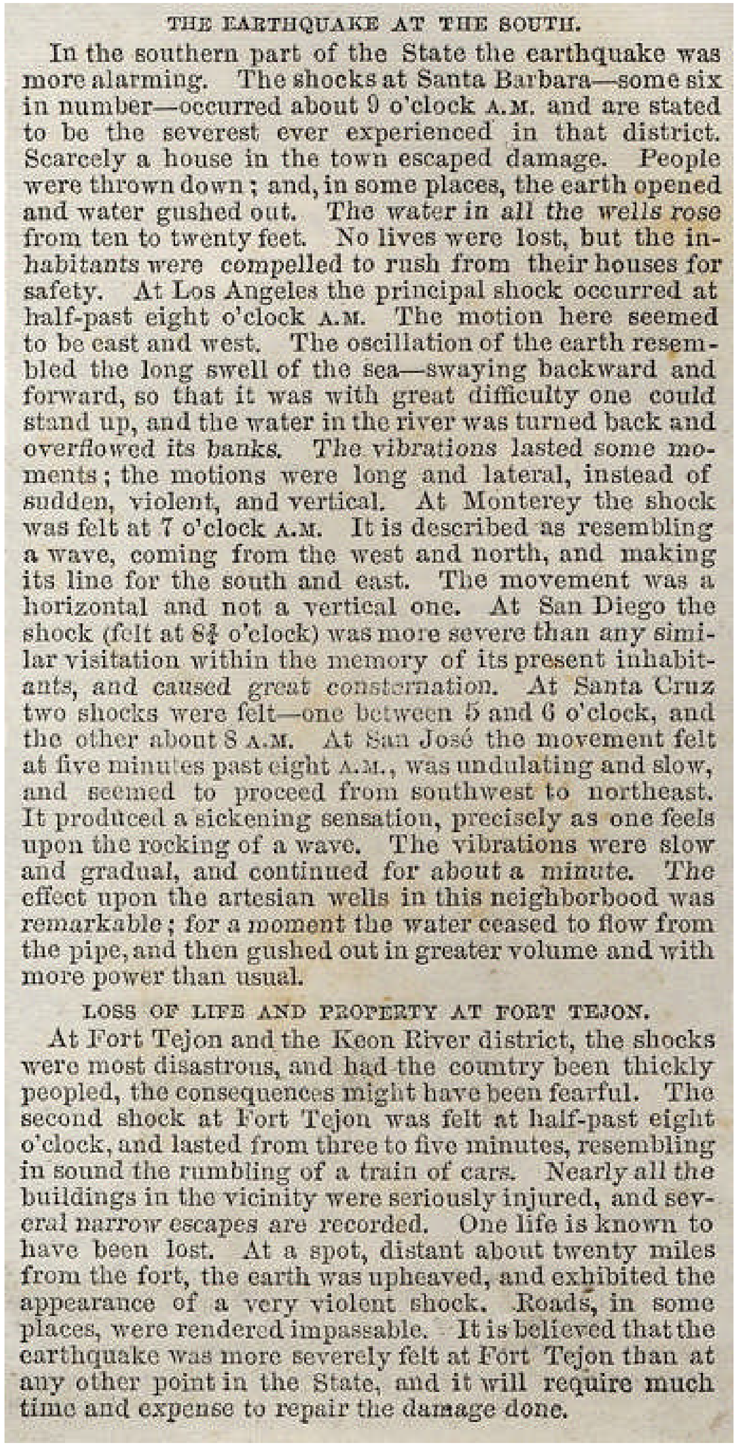
***Popular Mechanics,* May 1958**

RE: on January 9th 1857, at about 8:20 a.m., the *Fort Tejon Earthquake* struck Southern California. It was one of the largest earthquakes ever recorded in the continental U.S., lasting from one to three minutes. The magnitude of the quake was about 7.9. The surface of the earth was ruptured along the *San Andreas Fault* for about 225 miles and offset 30-feet by the powerful quake. Even though this was one of the largest historical earthquakes, only two people were recorded killed. The Fort Tejon Earthquake had such severe shaking, it caused major flooding of many lakes and rivers.



Left: caption: “Fort Tejon Earthquake - 7.9 - January 9, 1857.” Instances of seiching, fissuring, sandblows and hydrologic changes were reported from Sacramento to the *Colorado River* delta. Ground fissures were observed in the beds of the *Los Angeles, Santa Ana, and Santa Clara River/s* and at Santa Barbara. Sandblows occurred at Santa Barbara and in the flood plain of the Santa Clara River. Sunken trees (liquefaction) were reported in the area between Stockton and Sacramento. Changes in the flow of streams were observed in the areas of San Diego, Santa Barbara, Isabella and at the south-end of the *San Joaquin Valley*.

***Liquefaction* is a term used in materials sciences to refer to any process which either generates a liquid from a solid or a gas, or generates a non-liquid phase which behaves in accordance with fluid dynamics. Liquefaction occurs both as part of natural processes (i.e. sinkholes, left) and in man-made processes used in science and commerce (i.e. conversion of solid coal into a liquid form usable as a substitute for liquid fuels).**



THE EARTHQUAKE AT THE SOUTH.

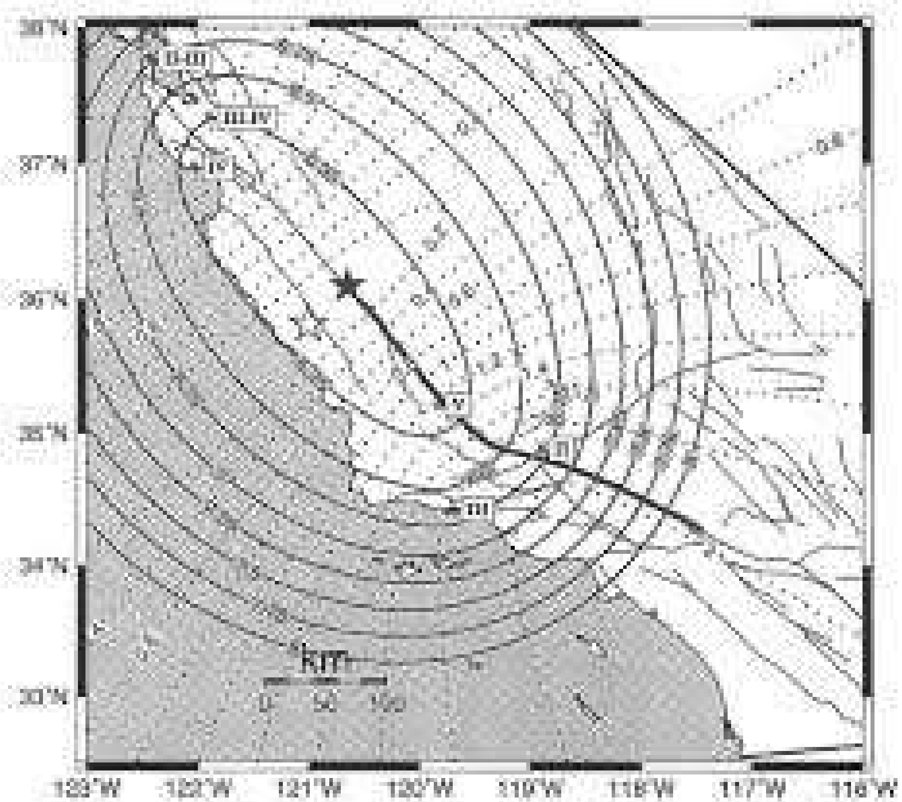
In the southern part of the State the earthquake was more alarming. The shocks at Santa Barbara—some six in number—occurred about 9 o'clock A.M. and are stated to be the severest ever experienced in that district. Scarcely a house in the town escaped damage. People were thrown down; and, in some places, the earth opened and water gushed out. The water in all the wells rose from ten to twenty feet. No lives were lost, but the inhabitants were compelled to rush from their houses for safety. At Los Angeles the principal shock occurred at half-past eight o'clock A.M. The motion here seemed to be east and west. The oscillation of the earth resembled the long swell of the sea—swaying backward and forward, so that it was with great difficulty one could stand up, and the water in the river was turned back and overflowed its banks. The vibrations lasted some moments; the motions were long and lateral, instead of sudden, violent, and vertical. At Monterey the shock was felt at 7 o'clock A.M. It is described as resembling a wave, coming from the west and north, and making its line for the south and east. The movement was a horizontal and not a vertical one. At San Diego the shock (felt at 8¾ o'clock) was more severe than any similar visitation within the memory of its present inhabitants, and caused great consternation. At Santa Cruz two shocks were felt—one between 5 and 6 o'clock, and the other about 8 A.M. At San José the movement felt at five minutes past eight A.M., was undulating and slow, and seemed to proceed from southwest to northeast. It produced a sickening sensation, precisely as one feels upon the rocking of a wave. The vibrations were slow and gradual, and continued for about a minute. The effect upon the artesian wells in this neighborbood was remarkable; for a moment the water ceased to flow from the pipe, and then gushed out in greater volume and with more power than usual.

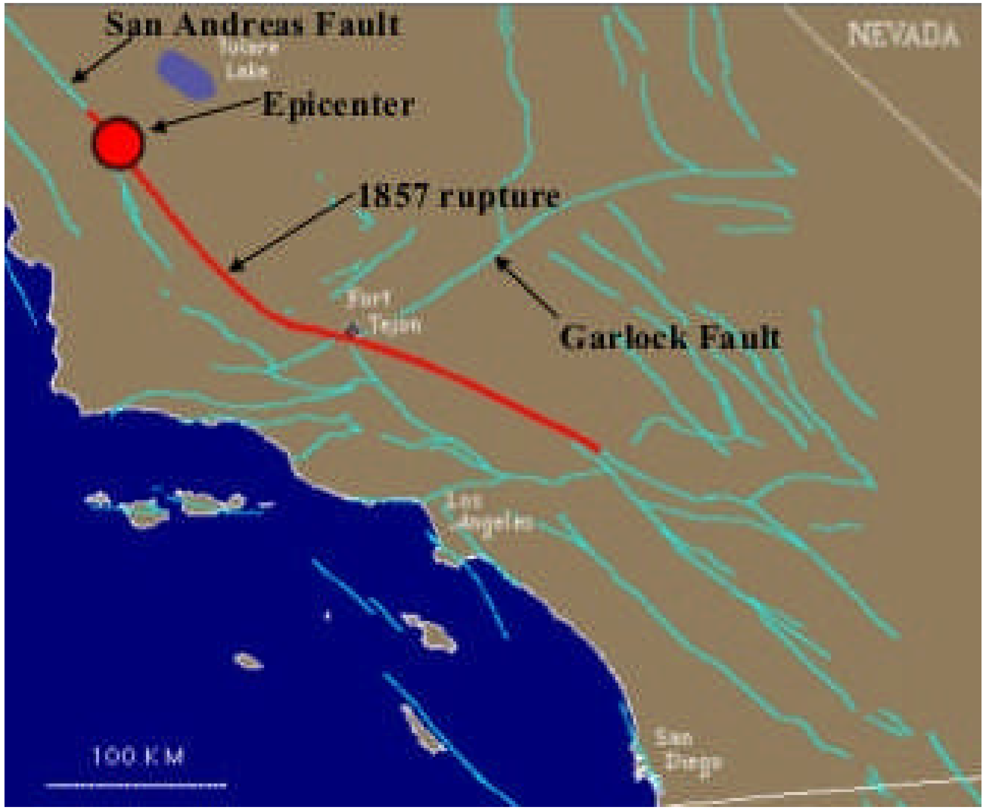
LOSS OF LIFE AND PROPERTY AT FORT TEJON.

At Fort Tejon and the Keon River district, the shocks were most disastrous, and had the country been thickly peopled, the consequences might have been fearful. The second shock at Fort Tejon was felt at half-past eight o'clock, and lasted from three to five minutes, resembling in sound the rumbling of a train of cars. Nearly all the buildings in the vicinity were seriously injured, and several narrow escapes are recorded. One life is known to have been lost. At a spot, distant about twenty miles from the fort, the earth was upheaved, and exhibited the appearance of a very violent shock. Roads, in some places, were rendered impassable. It is believed that the earthquake was more severely felt at Fort Tejon than at any other point in the State, and it will require much time and expense to repair the damage done.

THE EARTHQUAKE AT THE SOUTH.

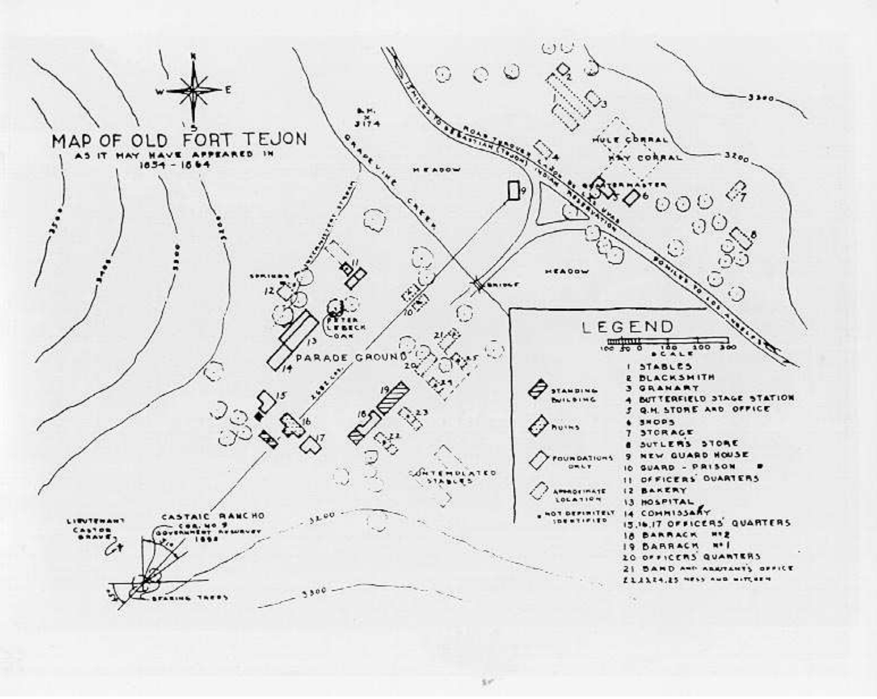
In the southern part of the State the earthquake was more alarming. The shocks at Santa Barbara - some six in number - occurred about 9 o'clock A.M. and are stated to be the severest ever experienced in that district. Scarcely a house in the town escaped damage. People were thrown down; and, in some places, the earth opened and water gushed out. The water in all the wells rose from ten to twenty feet. No lives were lost, but the inhabitants were compelled to rush from their houses for safety. At Los Angeles the principal shock occurred at half-past eight o'clock A.M. The motion here seemed to be east and west. The oscillation of the earth resembled the long swell of the sea - swaying backward and forward, so that it was with great difficulty one could stand up, and the water in the river was turned back and overflowed its banks. The vibrations lasted some moments; the motions were long and lateral, instead of sudden, violent, and vertical. At Monterey the shock was felt at 7 o'clock A.M. It is described as resembling a wave, coming from the west and north, and making its line for the south and east. The movement was a horizontal and not a vertical one. At San Diego the shock (felt at 8¾ o'clock) was more severe than any similar visitation within the memory of its present inhabitants, and caused great consternation. At Santa Cruz two shocks were felt - one between 5 and 6 o'clock, and the other about 8 A.M. At San Jose the movement felt at five minutes past eight A.M., was undulating and slow, and seemed to proceed from southwest to northeast. It produced a sickening sensation, precisely as one feels upon the rocking of a wave. The vibrations were slow and gradual, and continued for about a minute. The effect upon the artesian wells in this neighborhood was remarkable; for a moment the water ceased to flow from the pipe, and then gushed out in greater volume and with more power than usual. (*Harper's Weekly*, February 21st 1857)





<u>Left</u>: caption: “Map of rms contours and magnitude contours for the dawn foreshock. Thin lines are faults; the thick line is the extent of the 1857 rupture; Mangles are stations with intensity data (possible MMI values are indicated in roman numerals); dotted contours are rms contours; the clear star is the location corresponding to the intensity center; the filled star is the location of the least rms value among points on the SAF; and the solid contours are magnitude contours.”

<u>Right</u>: caption: “On January 9, 1857, an enormous earthquake ruptured the San Andreas Fault from Parkfield through the Big Bend segment and southeast at least to Wrightwood, a total of at least 360 km. Fort Tejon, a military outpost at the southernmost end of the Carrizo Plain was one of a few population centers near the epicenter. There the ground shook for 1 to 3 minutes. The earthquake produced as much as 9 meters of offset in the Carrizo Plain and 3 to 4 meters in the Mojave Desert.”



Property loss was heavy at *Fort Tejon*, an Army post about 7 km from the *San Andreas Fault*. Two buildings were declared unsafe, three others were damaged extensively but were habitable and others sustained moderate damage. About 20 km west of Fort Tejon, trees were uprooted and buildings were destroyed (between Fort Tejon and *Elizabeth Lake*). One person was killed in the collapse of an adobe house at Gorman. A comparison of this shock to the 1906 *San Francisco Earthquake* shows that the fault break in 1906 was longer, but the maximum and average displacements in 1857 were larger.

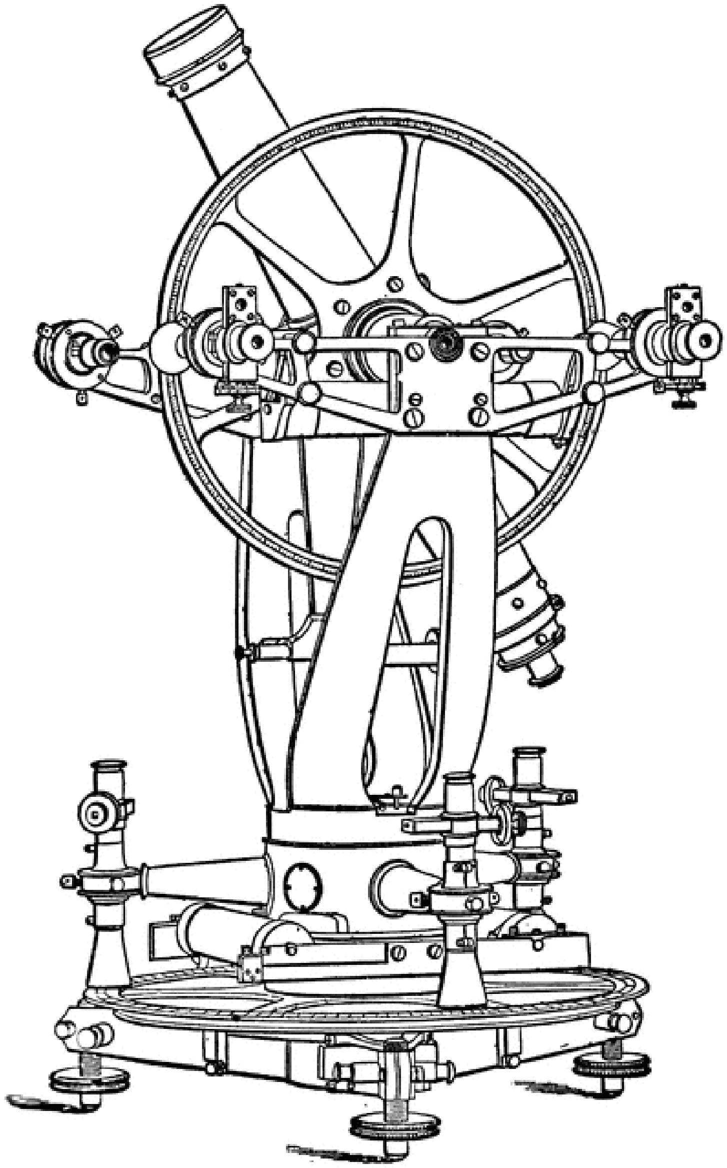
<u>Left</u>: caption: “Map of Old Fort Tejon”

<u>Right</u>: caption: “Fort Tejon ca. 1854”

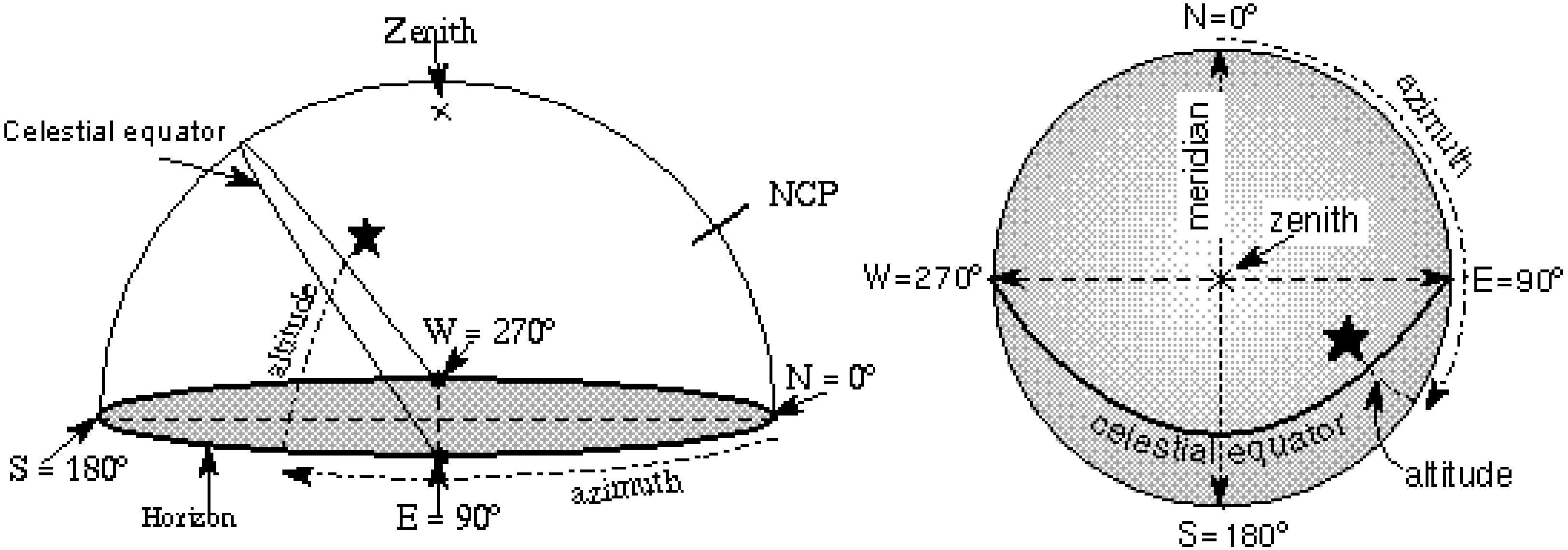
Go Set a Watchman

"…The practical study of the possible movements of the crust of the earth, due to strain creep, is now going on by means of monuments established at Olema, Marin County, and Crystal Springs Lake, San Mateo County, California. These points are about 40 miles apart on the rift. Each monument consists of four concrete piers, two on each side of the fault trace of the 1906 disturbance. These piers are sunk about 6 ft. and founded on the rock 'backbone' of the country. The piers rise 2 or 3 ft. above the surface, those at Olema being 13 in. square, and those at Crystal Springs 18 in. square. A bronze plate is set firmly on the top of each pier, with appliances for holding the 10-in. altazimuth instruments always in identically the same position with respect to the pier itself…"

***Popular Mechanics,* April 1922**



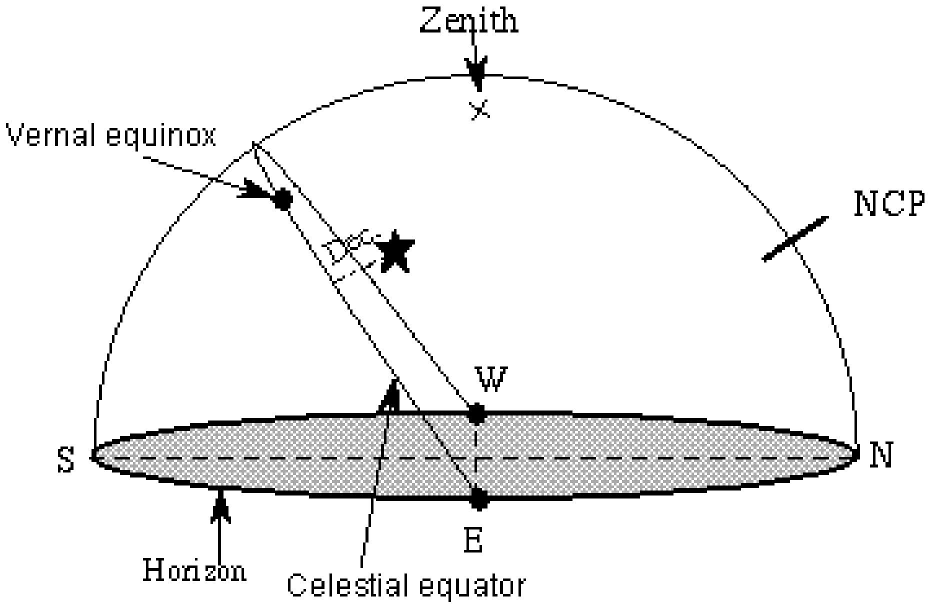
An *Altazimuth Theodolite* (a/k/a *Astronomical Theodolite*, *Universal Instrument*) is a portable instrument used to measure angles in the vertical and horizontal planes. Observations of stars and the sun by means of an Altazimuth Theodolite are used to determine clock corrections and the geographic coordinates of locations and to carry out azimuth determinations with maximum precision. Altazimiths are also used to solve practical problems in geodesy. An Altazimuth Theodolite differs from an ordinary Theodolite in the higher precision with which angles (especially vertical angles) are measured.



side view top view

There are several ways of determining the location of a celestial object. With the ***Altitude-Azimuth System***, the altitude of a star is defined by how many degrees above the horizon it is (from 0 to 90-degrees) while the azimuth of a star is how many degrees along the horizon it is (corresponds to compass direction). Azimuth starts from 0-degrees (exactly north) and increases clockwise; exactly east = 90-degrees, exactly south = 180-degrees, exactly west = 270-degress and exactly north = 360-degrees = 0-degrees.

Above L&R: caption: "A star's position in the Altitude-Azimuth Coordinate System. The azimuth = 120-degrees and the altitude = 50-degrees. The azimuth is measured in degrees clockwise along the horizon from due north. The azimuths for the compass directions are shown in the figure. The altitude is measured in degrees above the horizon. The star's altitude and azimuth changes throughout the night and depends on the observer's position (in the figure/s, at the intersection of the north-south and east-west line/s). The star's position does not depend on the location of the NCP or celestial equator in this system."



The *Equatorial Coordinate System* is very similar to the *Longitude-Latitude System* used to specify positions on the Earth's surface. This system is fixed with respect to the stars thus, unlike the *Altitude-Azimuth System*, a star's position does not depend on the observer's location or time.

<u>Above</u>: caption: "The lines on a map of the Earth that run east-west parallel to the equator are lines of latitude and when projected onto the sky, they become lines of declination. Like the latitude lines on Earth, declination (dec) is measured in degrees away from the celestial equator (positive degrees for objects north of the celestial equator and negative degrees for objects south of the celestial equator). Objects on the celestial equator are at 0-degrees dec, objects half-way to the NCP are +45-degrees, objects at the NCP are +90-degrees and objects at the SCP are -90-degrees."

“…The record of observations will be tabulated and from this data deductions will be drawn which in turn will be checked against the actual disturbances. This procedure will be carried forward until such time as there is no reasonable chance of error, when it will be possible to forecast the location and probable intensity of coming earthquake shocks, in time, at least, to prevent serious loss of life.”

***Popular Mechanics,* April 1922**

Part 2

Predicting the Future

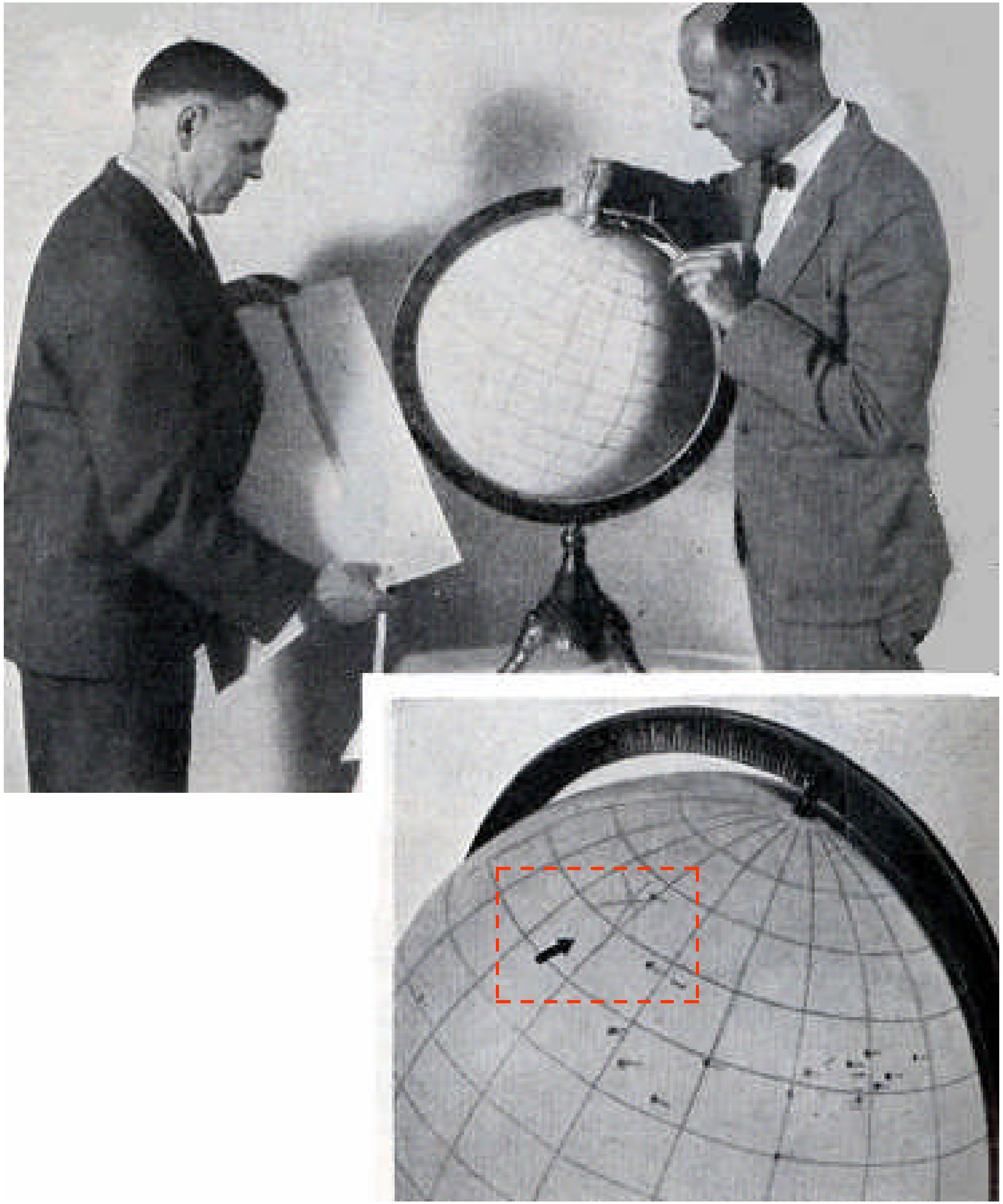
The Learned Men of Science

“Will the learned men of science, with all their vaunted weapons, ever be able to do anything about the earthquake, the world’s most mysterious and devastating convulsion of nature? Of course, one might as well try to stop a quake as to control the arrival of hurricanes, typhoons and tornadoes. But there is hope for the world in the fact that the newest scientific methods follow the sensible plan of studying the natural phenomenon with greatest care before attempting to solve its problems. These methods are now being followed by the seismology division of the U.S. Coast & Geodetic Survey…”

Modern Mechanics and Inventions, **December 1930**

“…In the first place, as a basis for future studies, a catalogue has been prepared of all past earthquakes in the United States, of which records are available, and provision has been made for collecting full information regarding future felt quakes as they occur, with the assistance of a great number of voluntary cooperators scattered all over the country. In the second place, excellent progress is now being made in providing better instruments and better time control in existing seismological stations and in securing the establishment of new stations, so that the country will be more adequately covered by instrumental records…”

Modern Mechanics and Inventions, **December 1930**

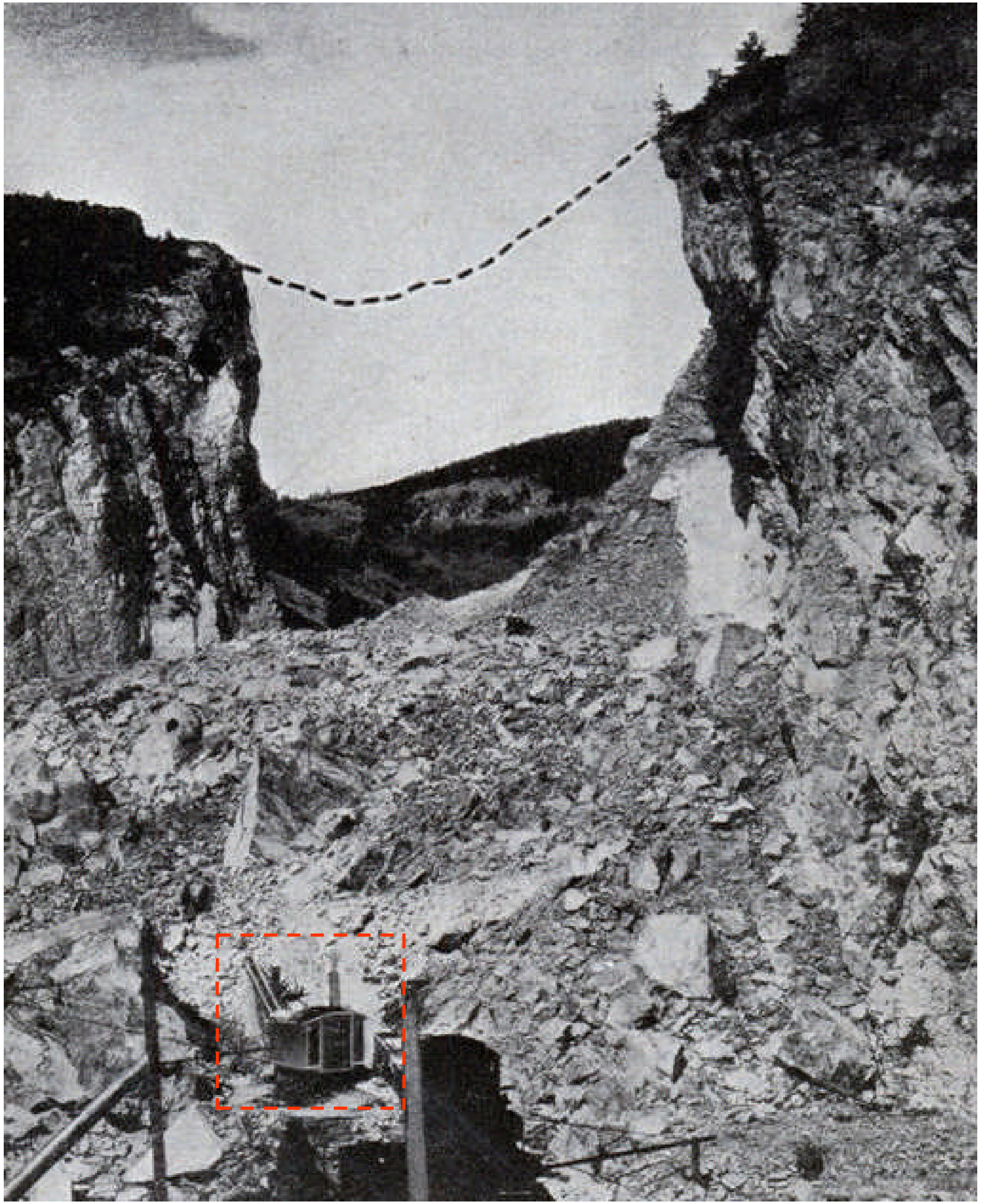


Top: caption: “Locating an earthquake. A traveling time chart, held by the scientist at the left, enables him to determine distance of a quake from a seismograph station. This distance is marked on the globe, and when three stations have reported, the exact spot of the earthquake is determined.”

Bottom: caption: “Arrow points to intersecting arcs which mark earthquake location”

“…That there is a relation between widely scattered disturbances seems certain. The best explanation of their cause is readjustment of the earth to relieve the strains and stresses of internal pressure. The crust slips and slides, sometimes in a limited locality, and again over a wide area…”

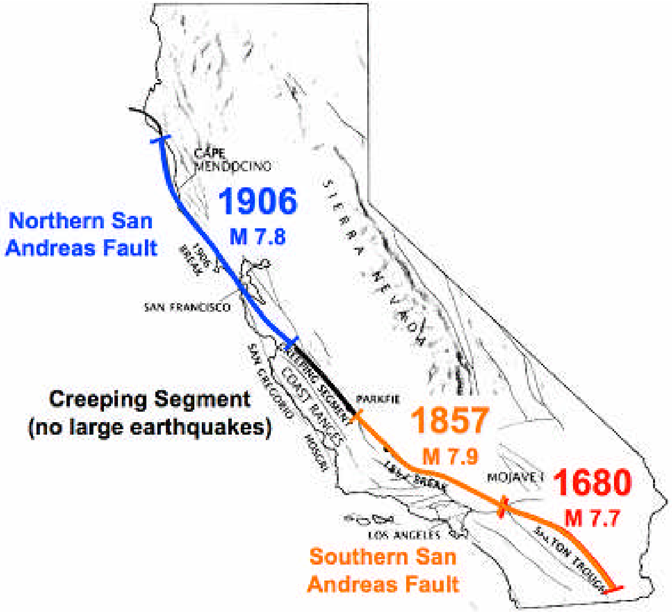
***Popular Mechanics,* June 1928**



“…The Montana quake of June 27, 1925, while severe, did not cause any vast damage, aside from loss of the railroads whose canyon tracks and tunnels were damaged to a serious extent…”

Popular Mechanics, **June 1928**

<u>Left</u>: caption: “Mountains tumbled in the 1925 Montana earthquake. Note seemingly tiny steam-shovel in foreground.”

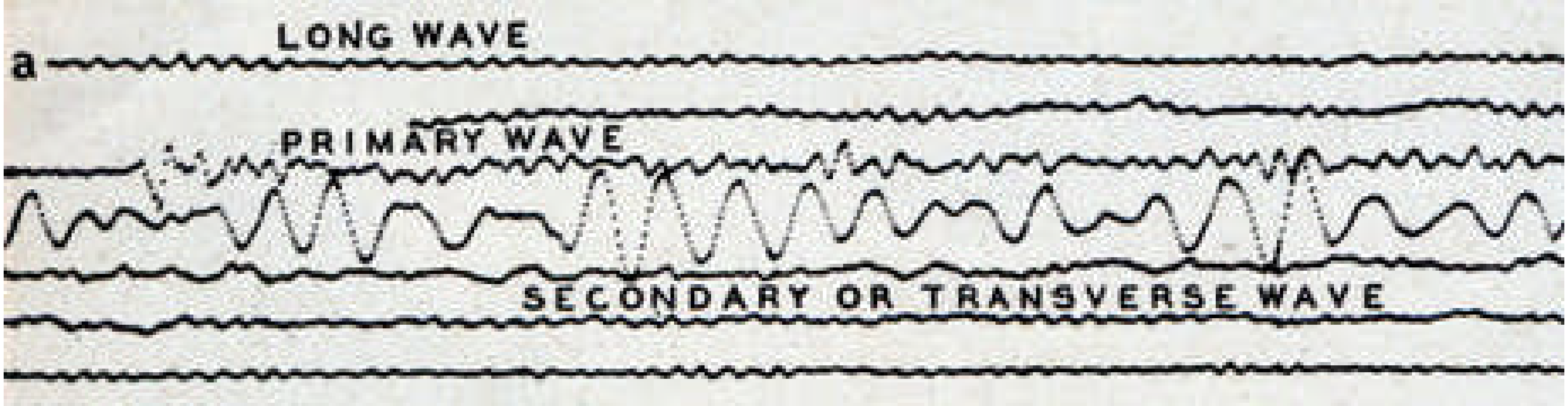


"…Two days later, and hundreds of miles away to the southwest, Santa Barbara, Calif., was visited by a destructive temblor, with further shocks the following day. Santa Barbara is located on the great San Andreas fault, stretching for 600 miles through the Coastal range, passing just west of San Francisco, east of Los Angeles, and, finally, an indeterminate distance into the Gulf of Mexico. The great quake of 1906 occurred along the San Andreas rift, taking in a stretch of some 150 miles with San Francisco near the center…"

Popular Mechanics, **June 1928**

Above: caption: "On average, large earthquakes recur on the San Andreas fault about every 150 years"

Left: caption: "The San Andreas Fault"



"…It is now pretty generally agreed that the great majority of earthquakes are caused by adjustment of stresses in the earth's crust. Any transfer of material, as by erosion, from one place to another, decreases the load on the crust at one place, and increases it at the other. No doubt other forces are at work all the time, causing changes in the relative positions of different parts of the crust. As a result of these movements there is a gradual accumulation of stress in the material. When the elastic limit is reached, then a break occurs, one part suddenly slips by another, and elastic vibrations are set up, which are propagated in every direction in various forms of wave motion…"

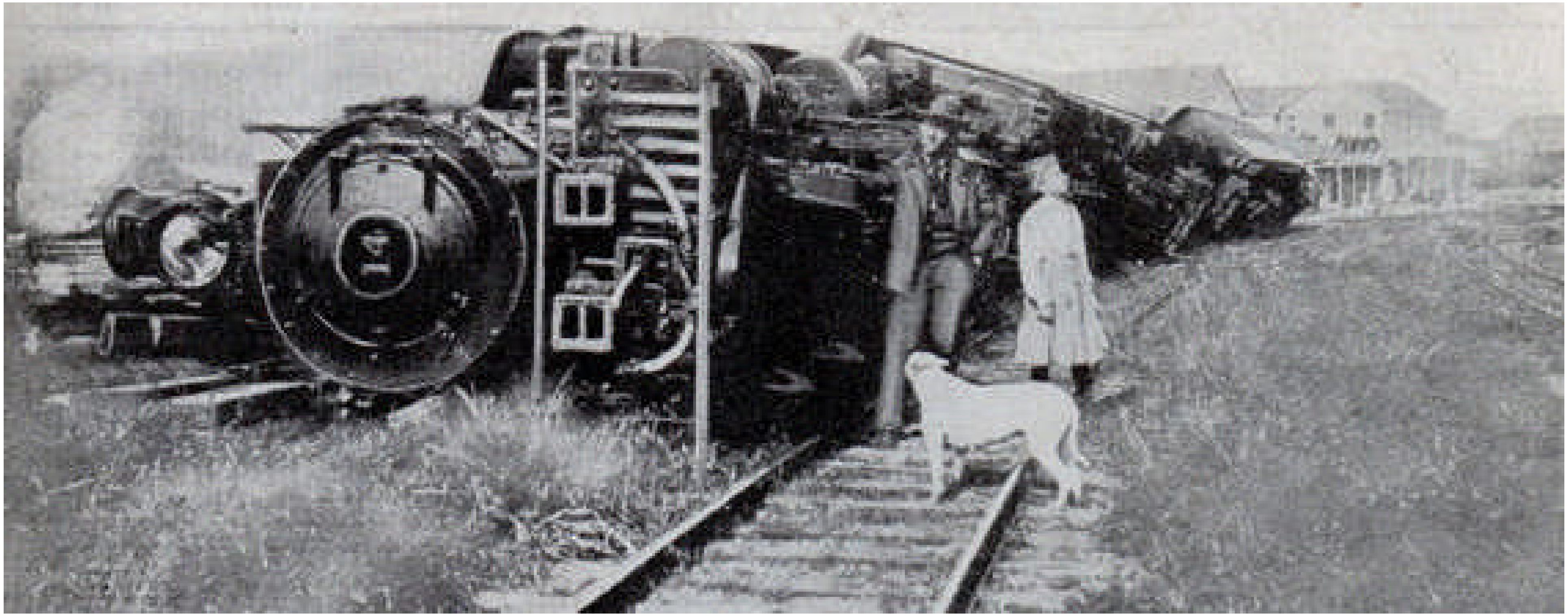
***Modern Mechanics and Inventions*, December 1930**

Above: caption: "Signature of an earthquake. Three types of wave are registered by every quake, each varying in speed and time of arrival on the seismograph."

“…To obtain accurate observations, records must be made near the center of disturbance. A hundred miles away, the vibrations are not the same as at the point of greatest violence. As the earthquake waves race through the rock, they pass from one type to another. In changing from, say, granite to limestone, the shift in pace is so sudden that the waves are sometimes reflected back to the point of origin…”

***Popular Science*, May 1933**

With the Utmost Ease



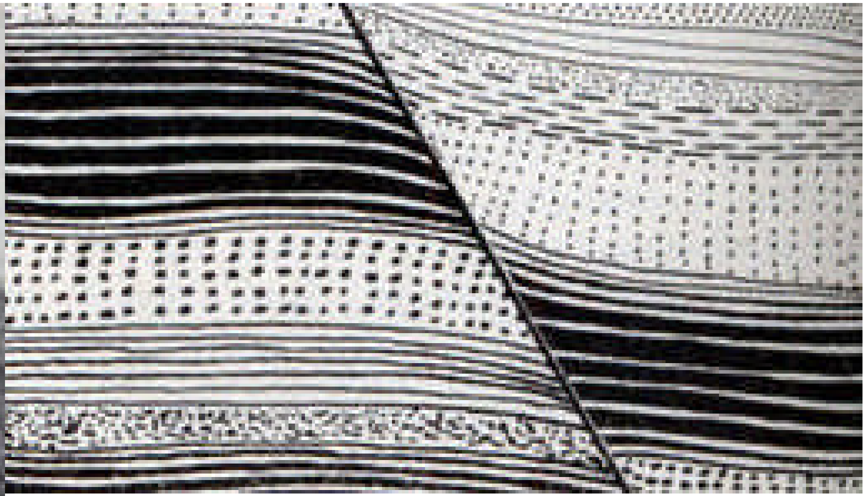
"…In some cases, as in the California quake of 1906, the break occurs at the surface. Advantage is being taken of this fact to determine, if possible, to what extent stress is accumulating along the famous San Andreas fault, where the major movement occurred in 1906. Suitable movements on opposite sides of the fault have been connected by triangulation and leveling, and this work will be repeated at regular intervals in the future. In this way any change in the relative position of points on opposite sides of the fault either in direction or elevation can be determined…"

***Modern Mechanics and Inventions,* December 1930**

<u>Above</u>: caption: "The California earthquake of 1906 tossed this train off the tracks with the utmost ease. Earthquakes, floods, and volcanic outbursts are natural phenomena of destruction which man is unable to control."

"…Japan, scene of such terrific cataclysms of the past, is doing her share in investigation of earth convulsions. Particularly interesting is the work being done in that country in providing for the erection of buildings which may be expected to withstand earthquake shocks. In order that the structural engineer may work effectively in designing buildings to be erected in a region where quakes may be expected, he must have some idea of the movements and forces actually encountered in the central region of the earthquake, the amount of ground movement, vertical, horizontal and rotational, the velocity of motion, the period of vibration, and how these factors are related to the nature of the sub-soil…"

***Modern Mechanics and Inventions,* December 1930**



Above: caption: “Diagram of a fault. The diagonal line indicates the plane along which rock masses slip past each other.”
Left: caption: “This is what an earthquake ‘fault’ looks like. Many experts believe that slippage along a fault, in which portions of the earth’s crust slide past each other to compensate some strain, is the cause of earthquakes.”

Tools of the Trade

"…Some information on these points can be obtained from the damage done to different types of buildings by an earthquake, but so far no instrumental records of these quantities have been made. Mr. John R. Freeman, a competent observer of earth convulsions, who visited Japan recently, has urged very strongly an investigation along two lines; in the first place, to develop suitable earthquake-recording instruments and install them in a region where a severe earthquake may be expected within a reasonable time, the instruments to be so constructed that they will be put in operation by the earthquake itself; and in the second place, the study of the problem in the laboratory by the use of model structures mounted on a platform to which motions simulating an earthquake may be given…"

***Modern Mechanics and Inventions,* December 1930**

RE: according to the USGS, there are as many as 1.3 million earthquakes annually that people can actually feel. While there are many reasons for earthquakes (ranging from meteor impacts and volcanic eruptions to man-made events like mine collapses and underground nuclear tests), the most common reason for earthquakes are the shifting of the Earth's tectonic plates. However, rather than what causes the earthquakes, of more importance is:

- **How strong the earthquake is;**
- **How much damage can it cause, and;**
- **How to best plan for it.**

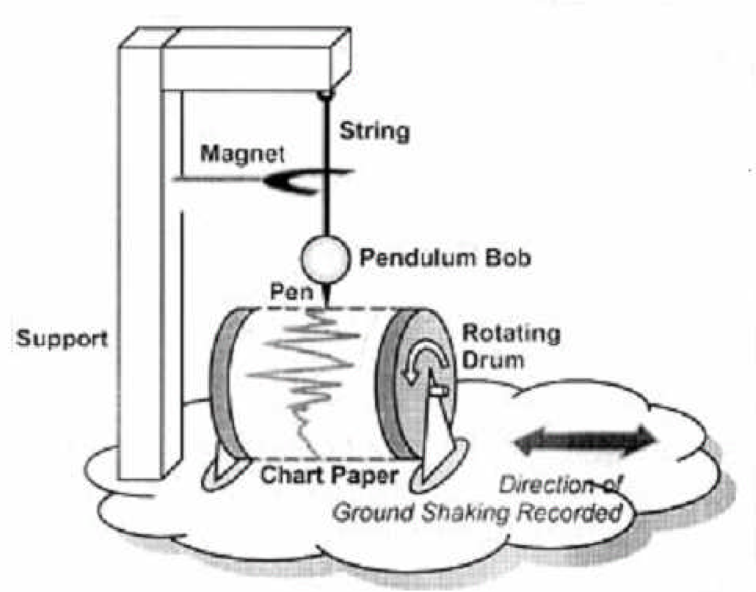
"…Another line of investigation to which much attention is being given is the makeup of Mother Earth, her interior, as well as her crust. This study is based on the travel-times of the various types of waves which are set up by an earthquake. But more of this later. Suffice it to say that with more and better instruments the available data is improving rapidly both in quantity and quality…"

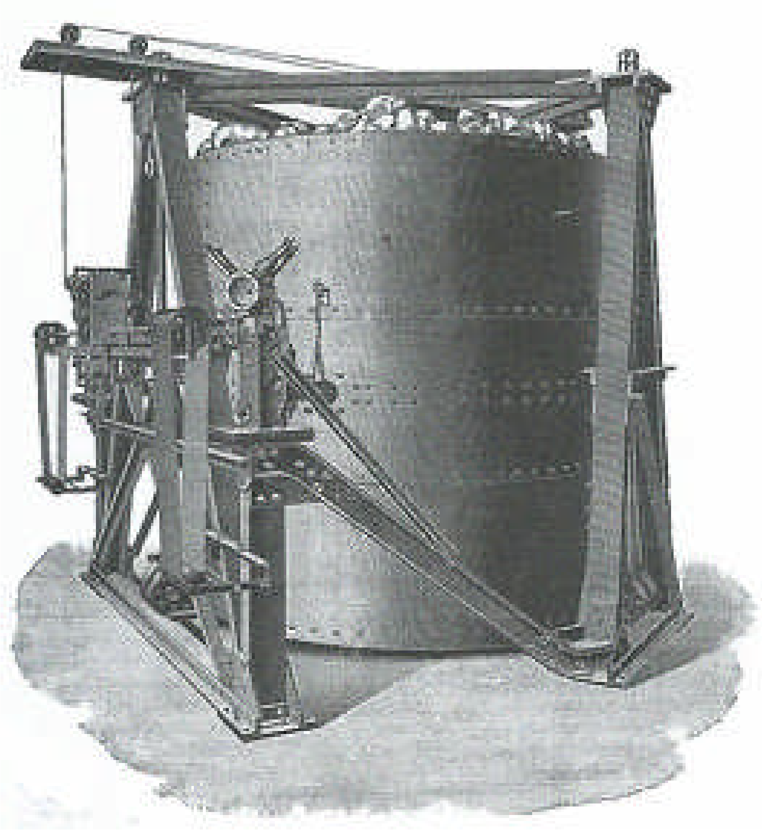
Modern Mechanics and Inventions, **December 1930**

"…It is by means of the seismograph that most of our knowledge of earthquake movements is determined. Now the seismograph is rather a mystery. Its ability to detect many earthquakes which cannot be felt, to tell where they occurred, how much the ground moved even if the amount is so small as to be scarcely measurable, is positively uncanny. As a matter of fact, however, the fundamental principle is simple, being based on certain modifications of the ordinary pendulum. A swinging gate can be considered as a special form of pendulum. Suppose that such a gate swings from two supports and that we have neither friction nor any force acting on the gate except through its supports…"

***Modern Mechanics and Inventions,* December 1930**

RE: the seismograph (a/k/a "seismometer") is an instrument that measures the motions of the ground, including those of seismic waves generated by earthquakes, volcanic eruptions and other seismic sources. The records of the seismic waves helps seismologists to map the interior of the Earth and to locate and measure the different sources of earthquakes.



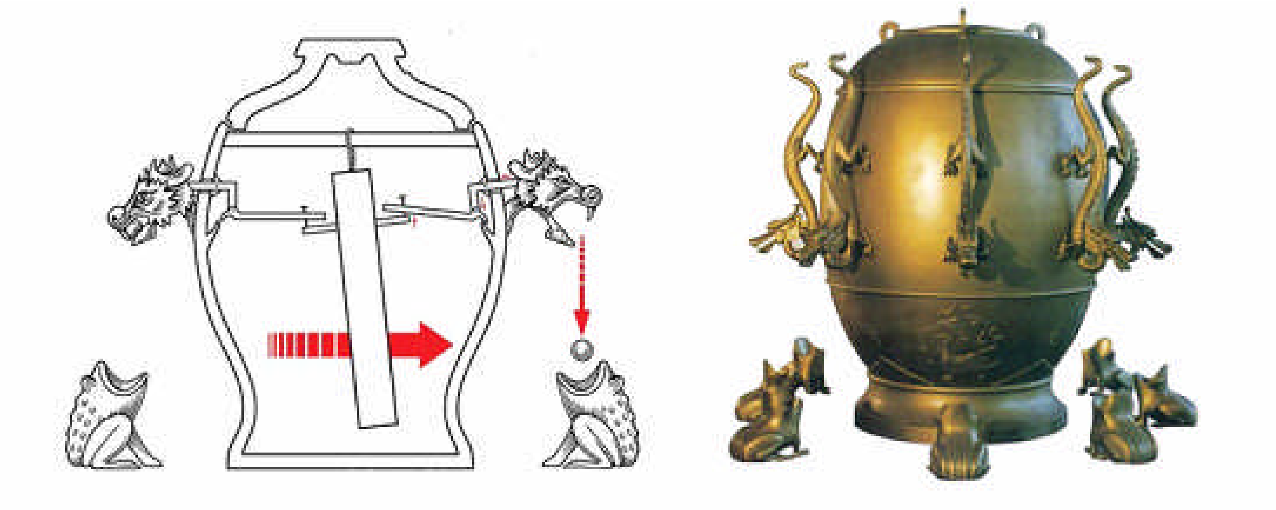


"…In the standard seismograph, the pendulum is the so-called steady mass and since, like all pendulums it has an independent movement, it is steadied by a damping device. Now strike the side of the table horizontally with a hammer or mallet to simulate an earthquake. The stationary structure will vibrate but the pendulum will not, especially if it is damped. An arm extending from the structure to the pendulum without touching it will magnify the vibrations. This is the basic principle of the intricate seismograph…"

***Popular Mechanics,* August 1946**

Top: caption: "Schematic of Early Seismograph"

Bottom: caption: "Drawing of 17 t horizontal pendulum built by Wiechert in 1904"

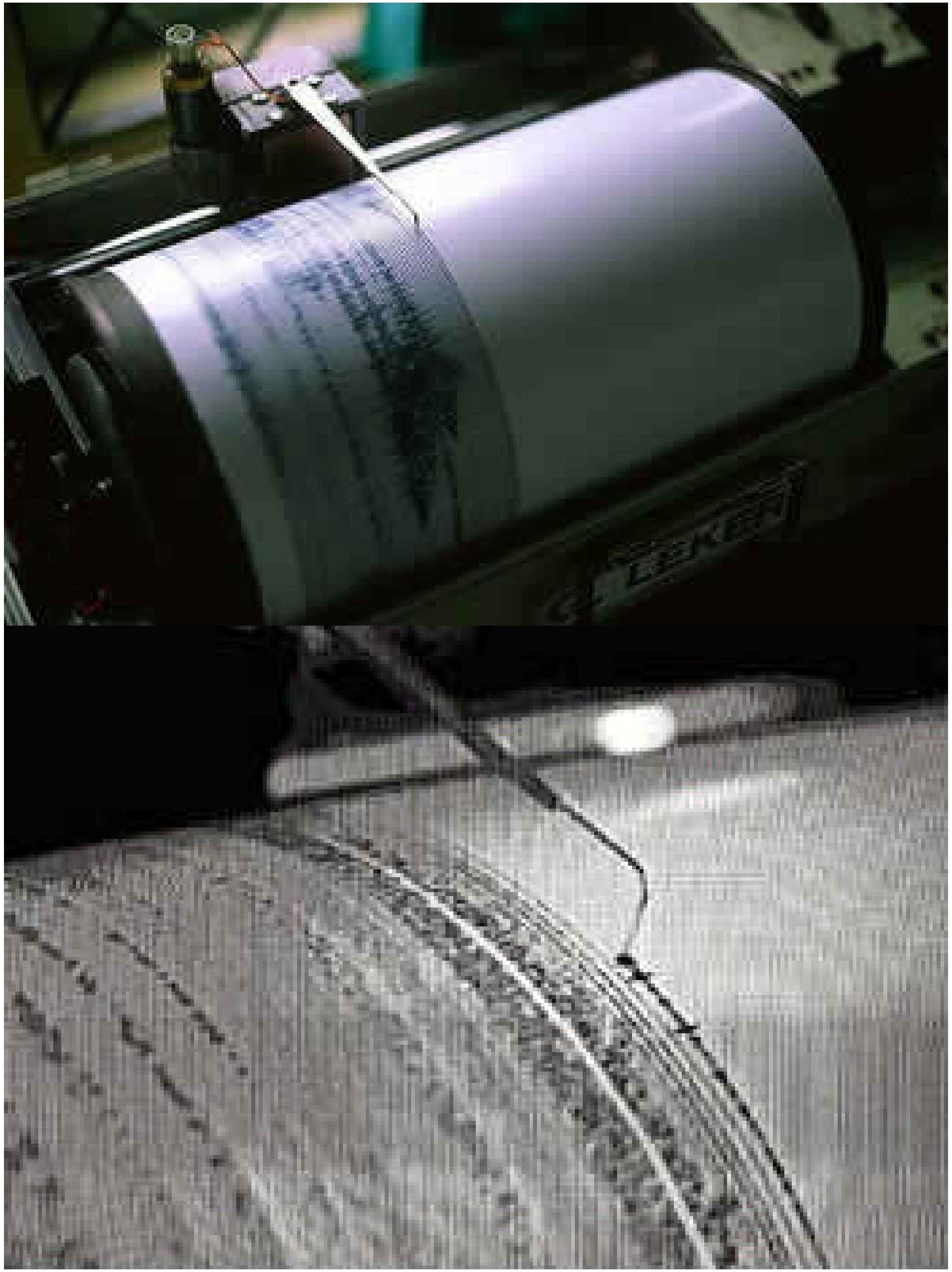


The first seismograph was designed by *Zhang Heng* of China's *Han Dynasty* in the year 132 AD. It was called "Houfeng Didong Yi" (instrument for measuring the seasonal winds and the movements of the Earth). While, the device worked on the presumption that earthquakes were caused by the direction, force and timing of the winds, it still could predict the direction of an earthquake that occurred over three-hundred miles away. The plans of the original Zhang Heng's seismometer were lost over time, however, historians and scientists have been able to recover enough information to be able to create a working model. Nonetheless, after 1880 most seismometers were descended from those developed by the team of *John Milne, James Alfred Ewing* and *Thomas Gray*, who worked in Japan from 1880 to 1895. After WWII, these were adapted into the widely used Press-Ewing seismometer.

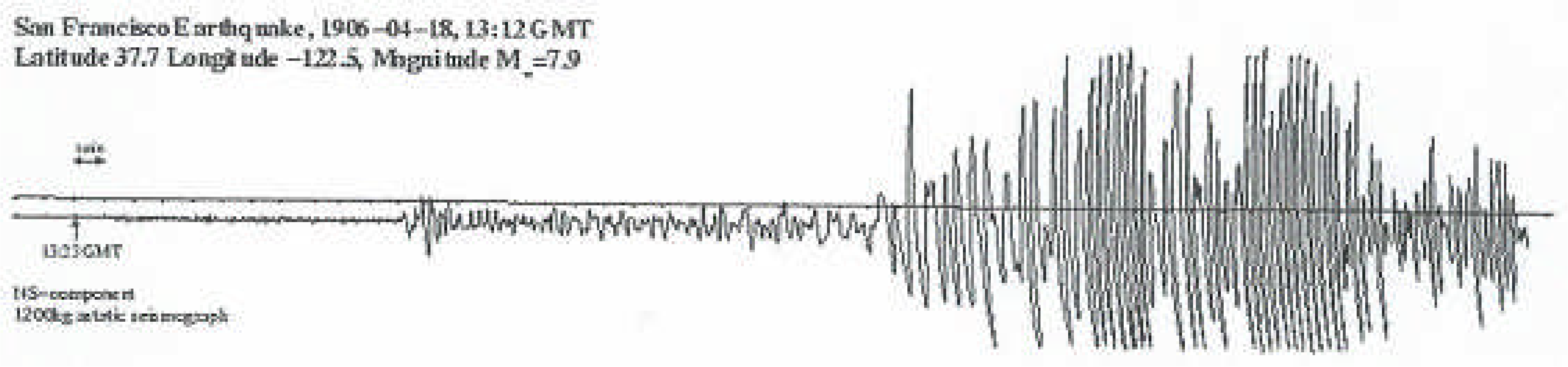
Above: caption: "The Houfeng Didong Yi was a large vessel about two-meters in diameter. At eight points around the top were dragon's heads holding bronze balls. When there was an earthquake, one of the mouths would open and drop its ball into a bronze toad at the base, making a sound and, in effect, indicating the direction of the earthquake."

“…Now, if one support is directly over the other, then the gate swings freely, but has no definite place for coming to rest. If the upper support is moved a little toward the gate so that it is not directly above the other, the gate will swing just as freely, but it will have a definite position of rest. If we substitute for the gate a weight attached to a rod, or boom, we have one type of seismograph. The weight, like the gate, is balanced at a point of rest. The earthquake moves its supports, but owing to inertia, the weight for a time remains in the same position. Actually after a time it starts to move, and this complicates the record and introduces the necessity for damping the motion…”

Modern Mechanics and Inventions, **December 1930**



A seismometer has a weight hanging on a spring. Hence, it is sensitive to up-down motions of the earth. The spring and weight are suspended from a frame that moves along with the Earth’s surface. As the earth moves, the relative motion between the weight and the earth can be recorded to create the history of the Earth’s motion. Changes in motion can be used to indicate the chances and/or intensity of an earthquake.



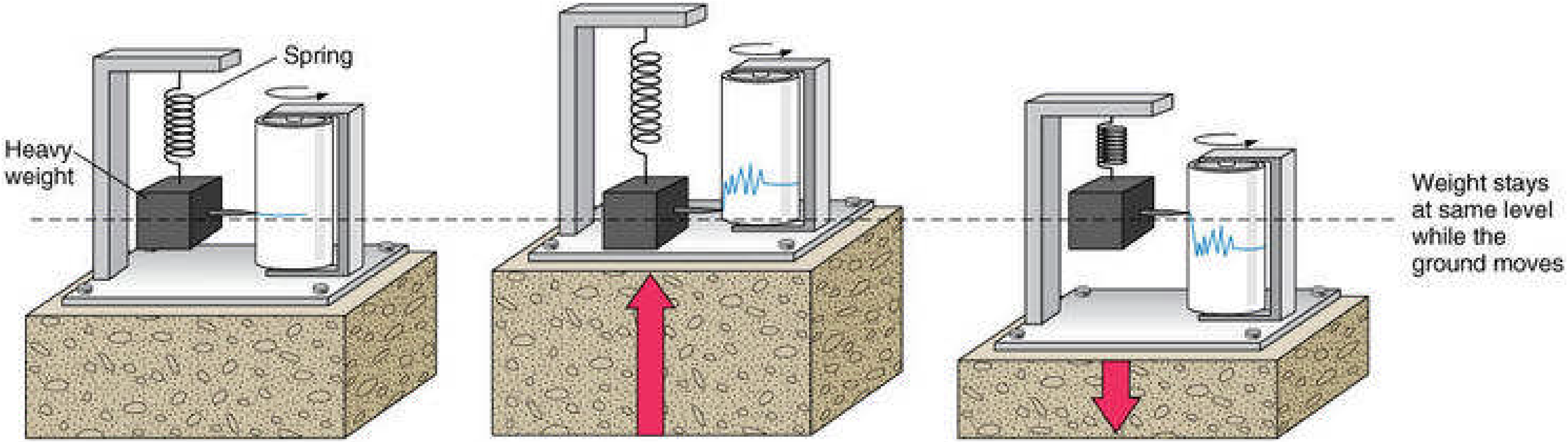
"…The recording apparatus is essentially a drum revolved by clockwork or by electrical means at a constant speed. Paper is placed on the drum, either smoked paper for visible recording, in which case the record is made by a stylus, or else photographic paper, in which case the record is made by a suitably directed beam of light. The latter method is more accurate since there is no friction in the recording. The former method is more convenient in some respects since the record can be used without development as soon as it is known that an earthquake has occurred. In any case, the seismograph is in continuous operation…"

Modern Mechanics and Inventions, **December 1930**

Above: caption: "Recording of the 1906 San Francisco Earthquake"

“…A complete installation consists of two horizontal component seismometers which are set at right angles to each other, and a vertical seismometer. There are no installations of the latter instrument at the stations, scattered throughout the country, of the U.S. Coast & Geodetic Survey, since there is at present no apparatus available for the purpose. However, the Bureau of Standards is now at work on the development of a suitable instrument…”

Modern Mechanics and Inventions, **December 1930**



A At rest

B Ground moves up

C Ground moves down

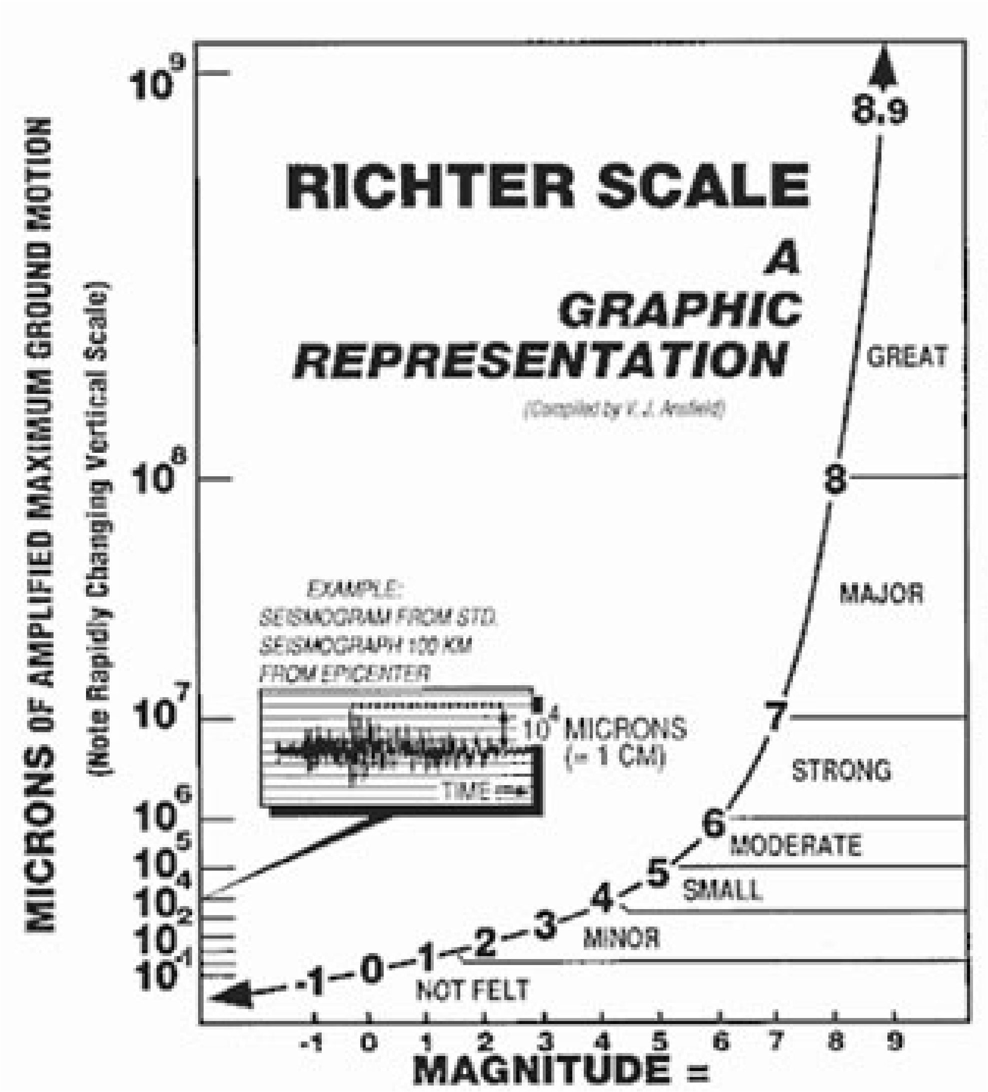
"…At first sight the seismograph, or smoked paper record of an earthquake, seems to be merely a confused series of waves which have little meaning. It has required many years of study by competent investigators to learn their full significance, and there are still many unsolved problems, but the fundamental ideas are not at all difficult to grasp…"

Modern Mechanics and Inventions, **December 1930**

Above: caption: "In the diagram above, as the ground moves, the seismograph is designed such that the position of the mass (heavy weight) is relatively constant. The pen records the relative displacement between the spring and the paper."

Seismic Scale

A *Seismic Scale* is used to calculate and compare the severity of earthquakes. Two fundamentally different but equally important types of scales are commonly used by seismologists to describe earthquakes. The original force or energy of an earthquake is measured on a *Magnitude Scale*, while the intensity of shaking occurring at any given point on the Earth's surface is measured on an *Intensity Scale*. To adequately describe the intensity of an earthquake, a scale was developed to assign a number depending on the intensity of the earthquake. This scale became known as the *Richter Magnitude Scale*. It assigns the earthquake a number from 1 to 10 in order of increasing intensity. The scale was developed in 1935 by *Charles Francis Richter* in partnership with *Beno Gutenberg*, both of the Seismological Laboratory at the *California Institute of Technology*. Initially, the scale was only to be use in a particular study area in California (on seismograms recorded on only the *Wood-Anderson Torsion Seismograph*). However, eventually the scale was developed into a worldwide accepted standard.



The *Richter Scale* assigns a number based on how much energy is released during the earthquake. The scale is a "Base-10" logarithmic scale (i.e. an earthquake that measures 5.0 has a shaking amplitude 10x larger than one that measures 4.0, corresponding to a 31.6x larger release of energy). While the scale is from 1 to 10 (0 being the basis to which the energy is being compared), in reality the scale does not have a lower limit. Many sensitive modern seismographs now routinely record quakes with negative magnitudes.

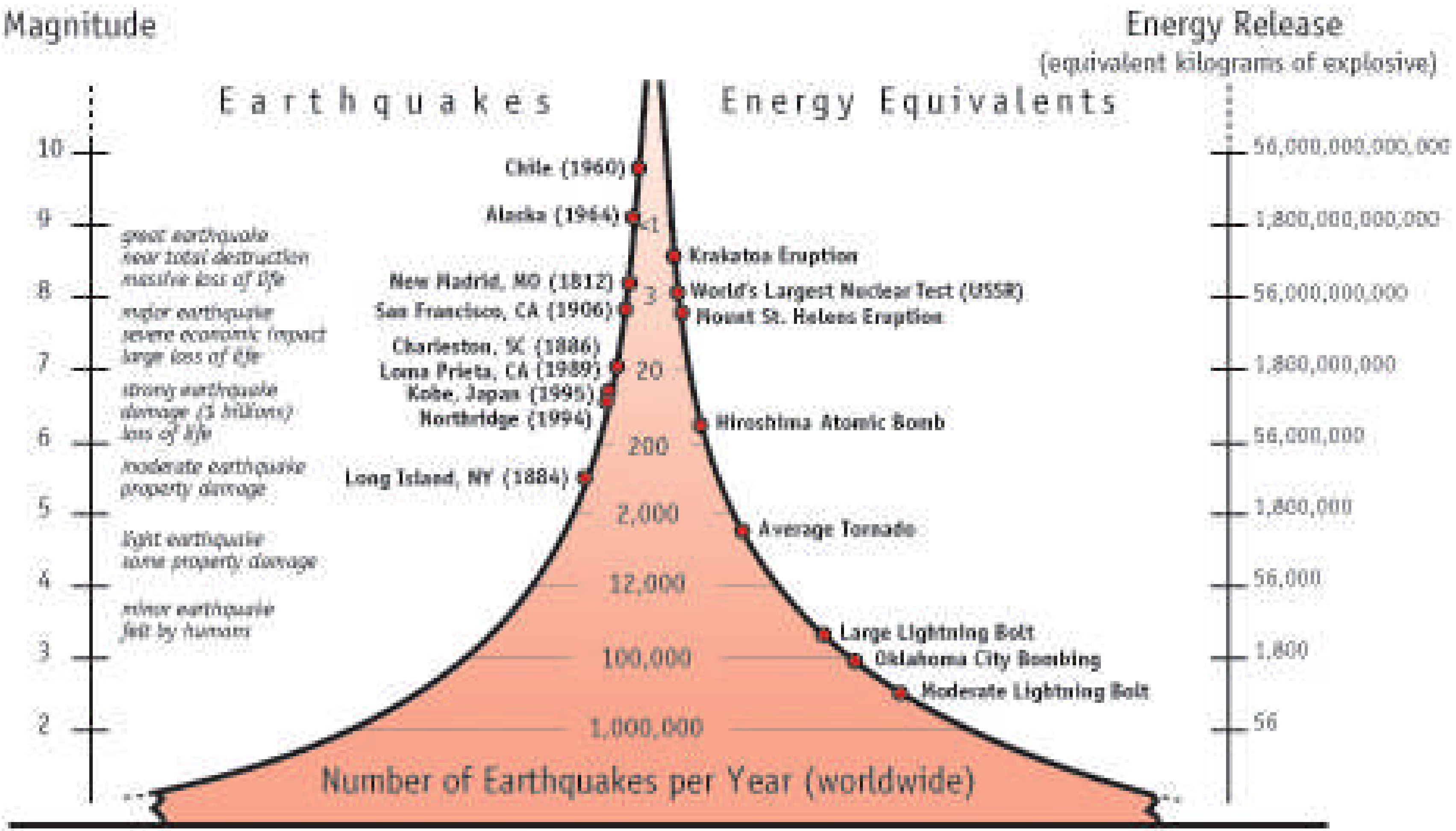
Magnitude Level	Category	Effects	Earthquakes per year
Less than 2.0	Micro	Microearthquakes, not felt, or felt rarely by sensitive people.	Several million per year
2.0–2.9	Minor	Felt slightly by some people. No damage to buildings.	Over one million per year
3.0–3.9	Minor	Often felt by people, but very rarely causes damage.	Over 100,000 per year
4.0–4.9	Light	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage.	10,000 to 15,000 per year
5.0–5.9	Moderate	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone. No Casualties.	1,000 to 1,500 per year
6.0–6.9	Strong	Damage to a moderate number of well built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly-designed structures receive moderate to severe damage. Felt up to hundreds of miles/kilometers from the epicenter. Death toll can range from none to 25,000, depending on location.	100 to 150 per year
7.0–7.9	Major	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Can be felt up to 250 km away from epicenter. Death toll can range from none to 250,000, depending on location.	10 to 20 per year
8.0–8.9	Great	Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions. Death toll can ranges from 1,000 to 1 million.	One per year
9.0 and greater	Great	Near or at total destruction - severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography. Death toll usually over 50,000.	One per 10 to 50 years

<u>Above</u>: caption: “The Richter Magnitude Scale”

“…Earthquakes are measured by a scale in which the numeral 2 corresponds to the smallest shocks ordinarily reported, the numeral 6 corresponds to moderately destructive earthquakes and the numeral 12 corresponds to the largest recorded earthquakes…”

Popular Mechanics, **December 1948**

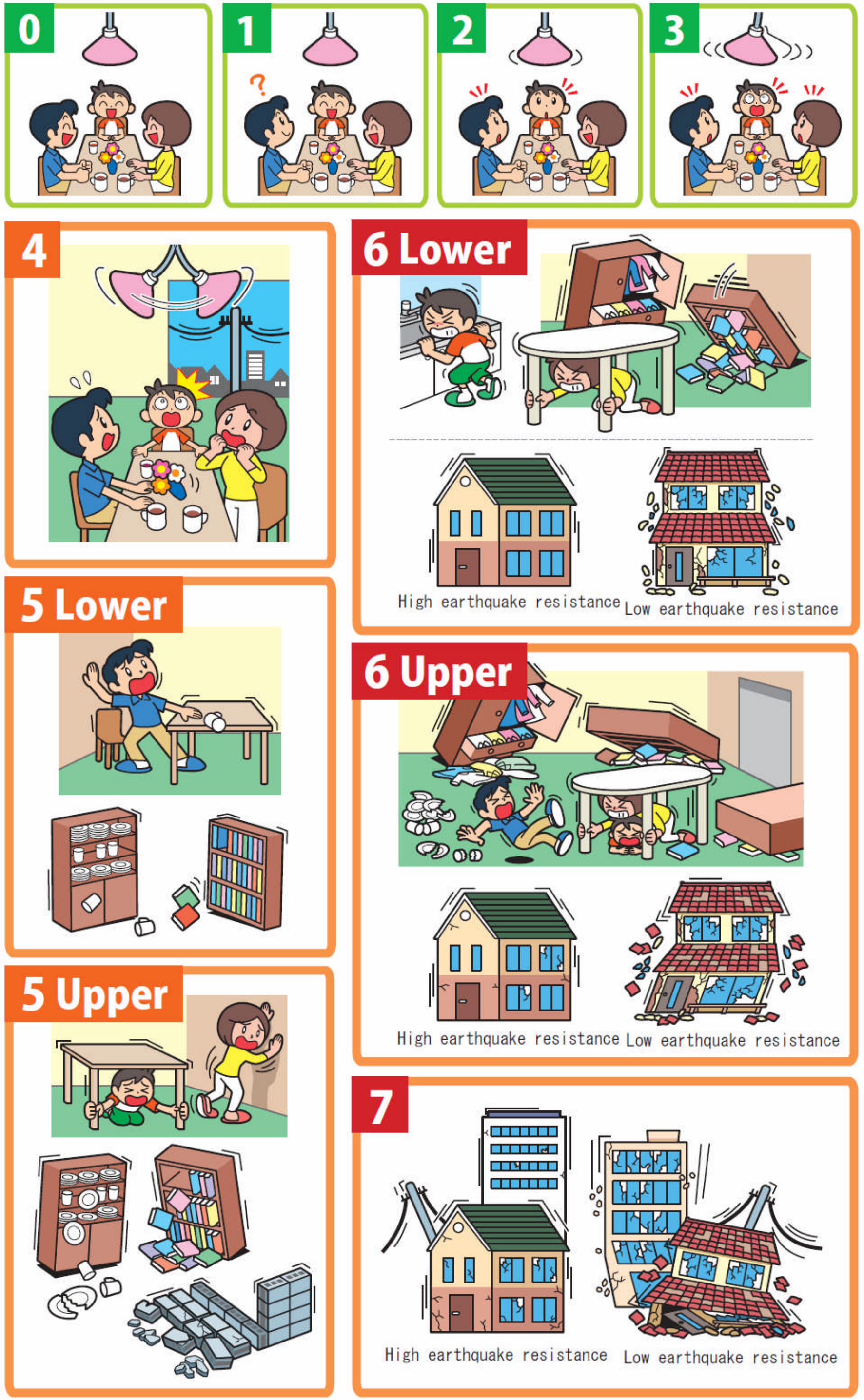
RE: the *Moment Magnitude Scale* (abbreviated as MMS; denoted as Mw or M) is used by seismologists to measure the size of earthquakes in terms of the energy released. The magnitude is based on the seismic moment of the earthquake, which is equal to the rigidity of the Earth multiplied by the average amount of slip on the fault and the size of the area that slipped. The scale was developed in the 1970s to succeed the 1930s-era *Richter Magnitude Scale*. Despite the fact that the formulae are different, the new scale retains the familiar continuum of magnitude values defined by the older one. The MMS is now the scale used to estimate magnitudes for all modern large earthquakes by the USGS.



Popular press reports of earthquake magnitude usually fail to distinguish between magnitude scales and are often reported as “Richter Magnitudes” when the reported magnitude is a *Moment Magnitude* (or a surface-wave or body-wave magnitude). Because the scales are intended to report the same results within their applicable conditions, the confusion is minor.

***B**ody **W**ave **M**agnitude* (BWM) is a method of determining the size of an earthquake by using the amplitude of the initial *P-wave* to calculate the magnitude. The P-wave is a type of body wave that is capable of traveling through the earth at a velocity of around 5 to 8 km/s and is the first wave from an earthquake to reach a seismometer. As such, calculating the body wave magnitude can be the quickest method of determining the size of an earthquake that is distant from the seismometer. Limitations in the calculation method mean that body wave magnitude saturates at around 6-6.5, with the figure staying the same even when the *Moment Magnitude* may be higher. The ***S**urface **W**ave **M**agnitude* (SWM) scale is one of the magnitude scales used in seismology to describe the size of an earthquake. It is based on measurements in *Rayleigh* surface waves that travel primarily along the uppermost layers of the earth. It is currently used in the *People's Republic of China* as a national standard for categorizing earthquakes. Surface wave magnitude was initially developed in the 1950s by the same researchers who developed the *Local Magnitude Scale* in order to improve resolution on larger earthquakes.

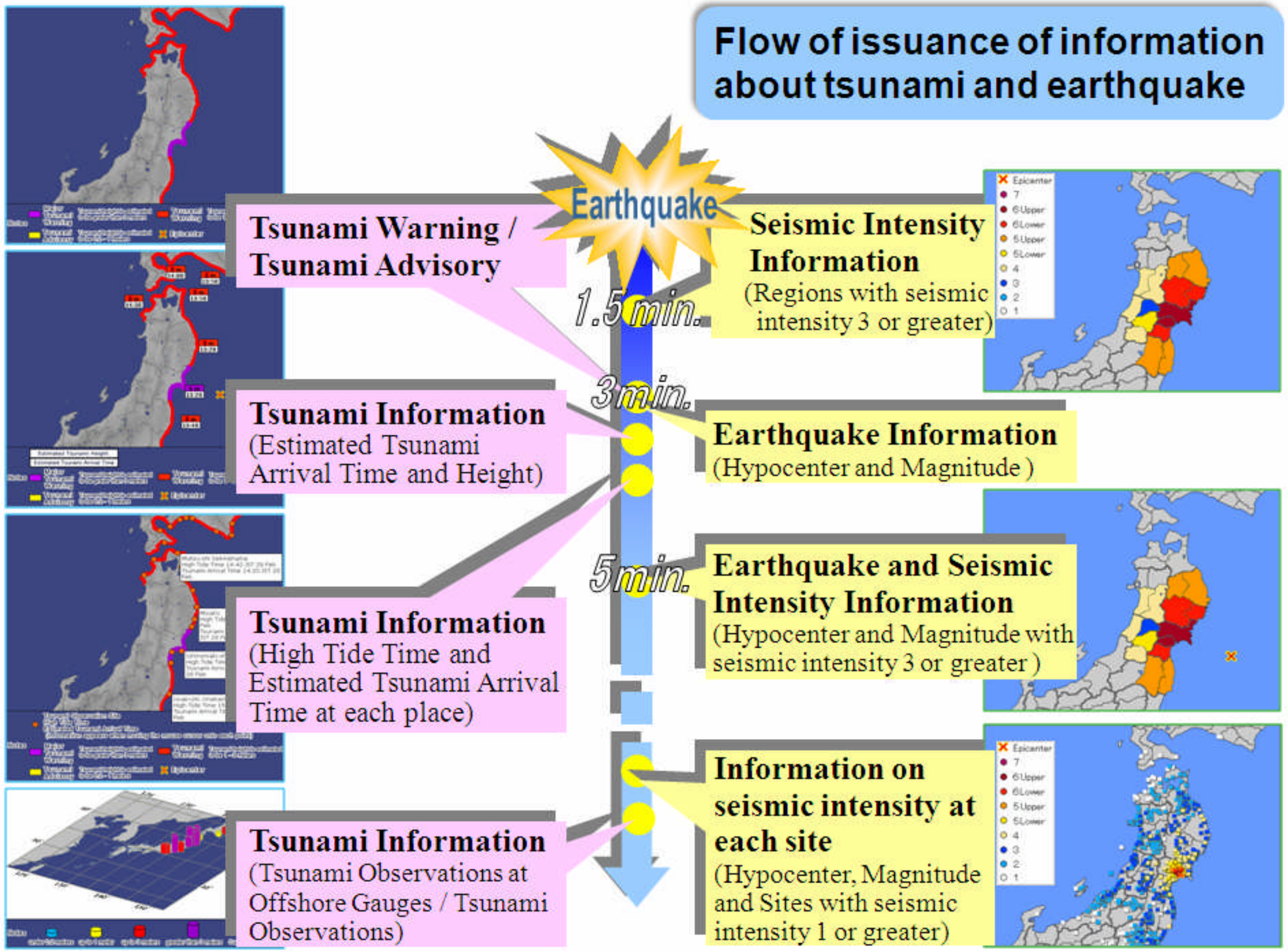
The *C̲hina S̲eismic I̲ntensity S̲cale* (CSIS) is a national standard in the *People's Republic of China* used to measure seismic intensity. Seismic impacts are classified into twelve degrees of intensity ("liedu" = degrees of violence) in Roman numerals from I (Insensible) to XII (Landscape Reshaping). The scale was initially formalized by the *C̲hina E̲arthquake A̲dministration* (CEA) in 1980, therefore often referred to by its original title as "China Seismic Intensity Scale (1980)." It was later revised and adopted as a national standard, ("Guobiao") by the *National Quality and Technology Supervision Administration* (now *General Administration of Quality Supervision, Inspection, and Quarantine of P.R.C*.) in 1999.



The *Japan Meteorological Agency* (JMA) seismic intensity scale is a seismic scale used in Japan and Taiwan to measure the intensity of earthquakes. It is measured in units of *shindo* (degree of shaking). Unlike the *Moment Magnitude Scale* (which measures the energy released by the earthquake), the JMA scale describes the degree of shaking at a point on the Earth's surface and is analogous to the *Mercalli Intensity Scale*. The intensity of an earthquake is not totally determined by its magnitude and varies from place to place. For example, a quake may be described as: "shindo 4 in Tokyo; shindo 3 in Yokohama; shindo 2 in Shizuoka." The JMA operates a network of seismographs and seismic intensity meters and provides real-time earthquake reports to the media and via the internet.

Left: JMA earthquake safety poster describing earthquake intensity effects (1 thru 7)

Flow of issuance of information about tsunami and earthquake



Tsunami Warning / Tsunami Advisory

Tsunami Information
(Estimated Tsunami Arrival Time and Height)

Tsunami Information
(High Tide Time and Estimated Tsunami Arrival Time at each place)

Tsunami Information
(Tsunami Observations at Offshore Gauges / Tsunami Observations)

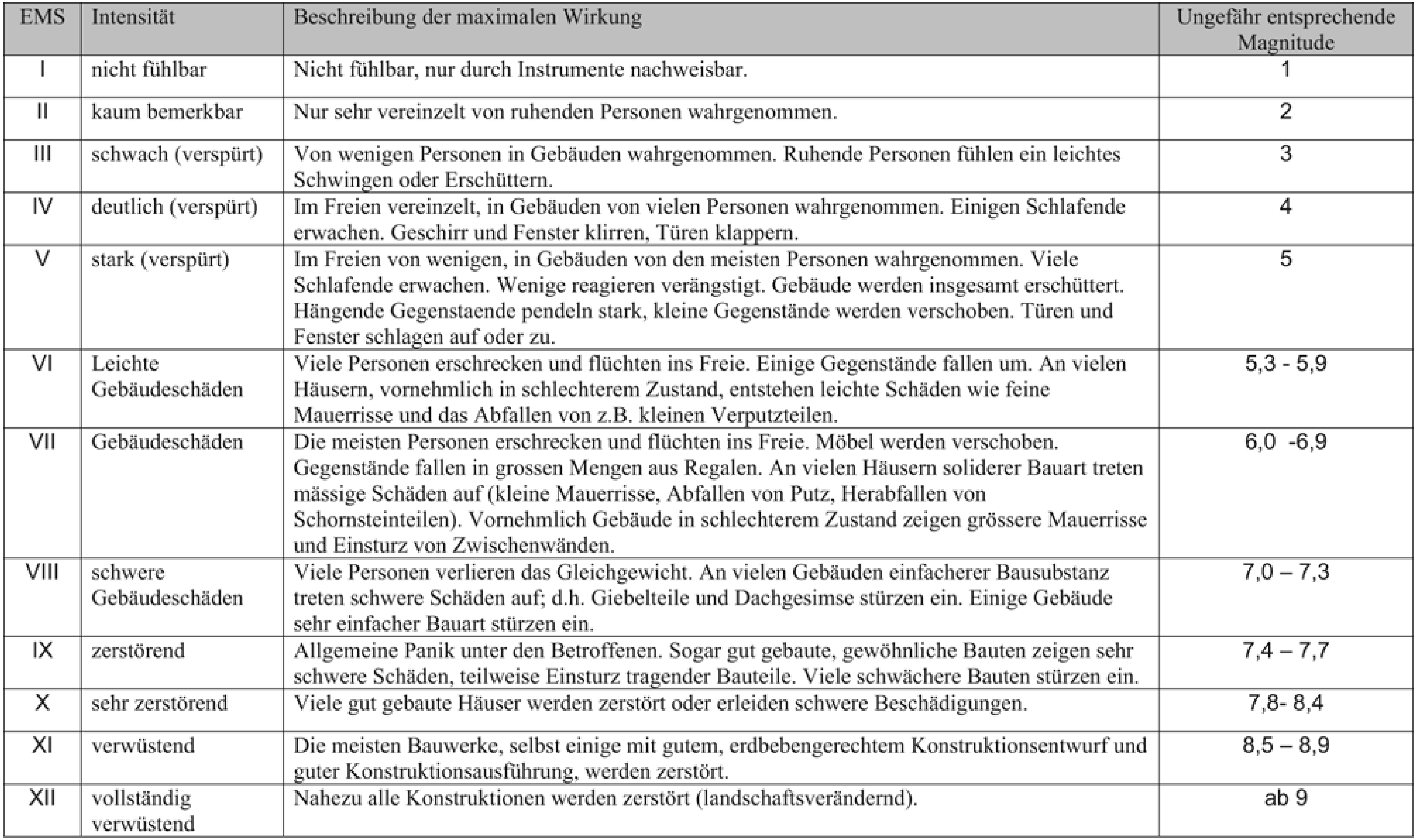
Seismic Intensity Information
(Regions with seismic intensity 3 or greater)

Earthquake Information
(Hypocenter and Magnitude)

Earthquake and Seismic Intensity Information
(Hypocenter and Magnitude with seismic intensity 3 or greater)

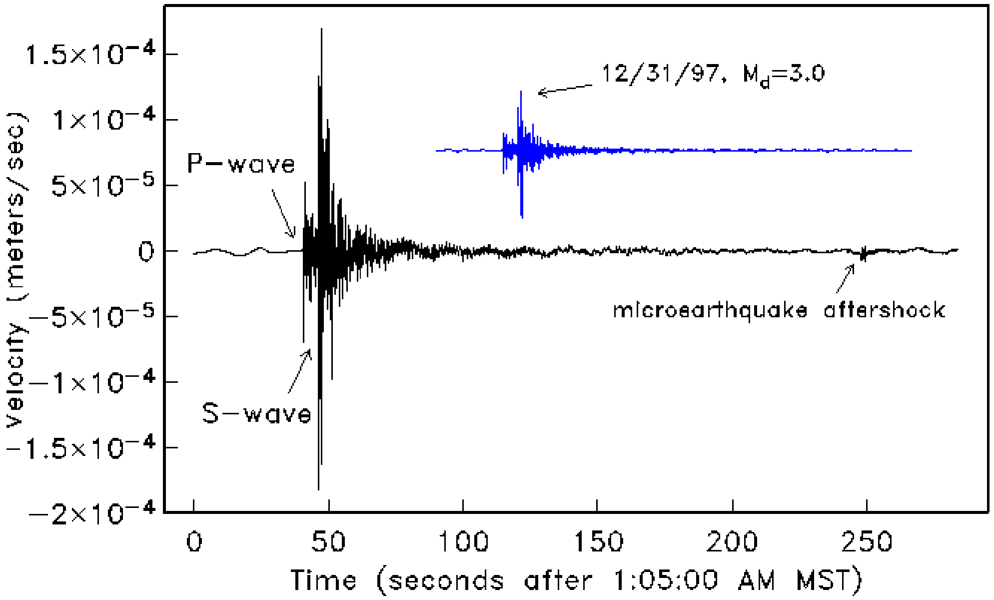
Information on seismic intensity at each site
(Hypocenter, Magnitude and Sites with seismic intensity 1 or greater)

The *European Macroseismic Scale* (EMS) is the basis for evaluation of seismic intensity in European countries and is also used in a number of countries outside Europe. Issued in 1998 as an update of the test version from 1992, the scale is referred to as “EMS-98.” The origins of EMS began in 1988 when the *European Seismological Commission* (ESC) decided to review and update the *Medvedev-Sponheuer-Karnik* scale (MSK-64), which was used in its basic form in Europe for almost a quarter of a century. After more than five years of intensive research and development and a four-year testing period, the new scale was officially released. In 1996, the *XXV General Assembly* of the ESC (meeting in Reykjavik, Iceland) passed a resolution recommending the adoption of the new scale by the member countries of the ESC.



EMS	Intensität	Beschreibung der maximalen Wirkung	Ungefähr entsprechende Magnitude
I	nicht fühlbar	Nicht fühlbar, nur durch Instrumente nachweisbar.	1
II	kaum bemerkbar	Nur sehr vereinzelt von ruhenden Personen wahrgenommen.	2
III	schwach (verspürt)	Von wenigen Personen in Gebäuden wahrgenommen. Ruhende Personen fühlen ein leichtes Schwingen oder Erschüttern.	3
IV	deutlich (verspürt)	Im Freien vereinzelt, in Gebäuden von vielen Personen wahrgenommen. Einigen Schlafende erwachen. Geschirr und Fenster klirren, Türen klappern.	4
V	stark (verspürt)	Im Freien von wenigen, in Gebäuden von den meisten Personen wahrgenommen. Viele Schlafende erwachen. Wenige reagieren verängstigt. Gebäude werden insgesamt erschüttert. Hängende Gegenstaende pendeln stark, kleine Gegenstände werden verschoben. Türen und Fenster schlagen auf oder zu.	5
VI	Leichte Gebäudeschäden	Viele Personen erschrecken und flüchten ins Freie. Einige Gegenstände fallen um. An vielen Häusern, vornehmlich in schlechterem Zustand, entstehen leichte Schäden wie feine Mauerrisse und das Abfallen von z.B. kleinen Verputzteilen.	5,3 - 5,9
VII	Gebäudeschäden	Die meisten Personen erschrecken und flüchten ins Freie. Möbel werden verschoben. Gegenstände fallen in grossen Mengen aus Regalen. An vielen Häusern soliderer Bauart treten mässige Schäden auf (kleine Mauerrisse, Abfallen von Putz, Herabfallen von Schornsteinteilen). Vornehmlich Gebäude in schlechterem Zustand zeigen grössere Mauerrisse und Einsturz von Zwischenwänden.	6,0 -6,9
VIII	schwere Gebäudeschäden	Viele Personen verlieren das Gleichgewicht. An vielen Gebäuden einfacherer Bausubstanz treten schwere Schäden auf; d.h. Giebelteile und Dachgesimse stürzen ein. Einige Gebäude sehr einfacher Bauart stürzen ein.	7,0 – 7,3
IX	zerstörend	Allgemeine Panik unter den Betroffenen. Sogar gut gebaute, gewöhnliche Bauten zeigen sehr schwere Schäden, teilweise Einsturz tragender Bauteile. Viele schwächere Bauten stürzen ein.	7,4 – 7,7
X	sehr zerstörend	Viele gut gebaute Häuser werden zerstört oder erleiden schwere Beschädigungen.	7,8- 8,4
XI	verwüstend	Die meisten Bauwerke, selbst einige mit gutem, erdbebengerechtem Konstruktionsentwurf und guter Konstruktionsausführung, werden zerstört.	8,5 – 8,9
XII	vollständig verwüstend	Nahezu alle Konstruktionen werden zerstört (landschaftsverändernd).	ab 9

EMS-98 was the first seismic intensity scale designed to encourage co-operation between engineers and seismologists (rather than being for use by seismologists alone). Unlike earthquake magnitude scales (which express the seismic energy released by an earthquake), EMS-98 intensity denotes how strongly an earthquake affects a specific place. The EMS has twelve (I thru XII) divisions (above, in German).



The concept of *Earthquake Duration Magnitude* (EDM) - originally proposed by *E. Bisztricsany* in 1958 (using surface waves only) is based on the realization that, on a recorded earthquake seismogram, the total length of the seismic wavetrain (sometimes referred to as the "CODA") reflects its size. Thus, larger earthquakes give longer seismograms (as well as stronger seismic waves) than small ones. The seismic wave interval measured on the time axis of an earthquake record (starting with the first seismic wave onset until the wavetrain amplitude diminishes to at least 10% of its maximum recorded value) is referred to as "Earthquake Duration." It is this concept that Bisztricsany first used to develop his *Earthquake Duration Magnitude Scale* (EDMS) employing surface wave durations.

“…The energy released in a severe earthquake may be greater than that of an atomic bomb. The Hiroshima blast, for example, would rank about 6.3 on the Richter earthquake scale…the Alaska earthquake of 1964 had a Richter magnitude of 8.4 – more than two degrees higher than the Hiroshima devastation. The San Francisco quake of 1906 was of about the same force…”

***Popular Mechanics,* June 1967**

<u>Left</u>: caption: “Alaska 1964: surface rupture develops on road.” On the afternoon of Good Friday, March 27th 1964, the strongest earthquake ever recorded in North America (second strongest ever recorded) occurred in Alaska. The *Great Alaskan Earthquake* was a 9.2 magnitude subduction zone (megathrust) earthquake located at a depth of approx. 25 km. It lasted four minutes and 38 seconds. In all, 131 people died in the earthquake and ensuing tsunamis.

The epicenter of the earthquake was 125 km east of Anchorage, Alaska, where many inadequately engineered houses, buildings and infrastructure were damaged or destroyed. Three hundred km southwest, some areas near Kodiak were permanently raised by 9.1-meters. Southeast of Anchorage, areas around the head of *Turnagain Arm* (near Gird-wood and Portage) dropped as much as 2.4-meters. A massive underwater slide at *Port Valdez* in *Prince William Sound* created an 8.2-meter tsunami that destroyed the village of Chenega, killing 23 of the 68 people who lived there. Post-quake tsunamis severely affected Whittier, Seward, Kodiak and other Alaskan communities, as well as people and property in Oregon, California and British Columbia.

Above L&R: caption: “Anchorage, 4th Avenue Landslide”

Earthquake Picture Story Told On Inside Pages

EXTRA Anchorage Daily Times **EXTRA**

CITY RALLIES FROM QUAKE

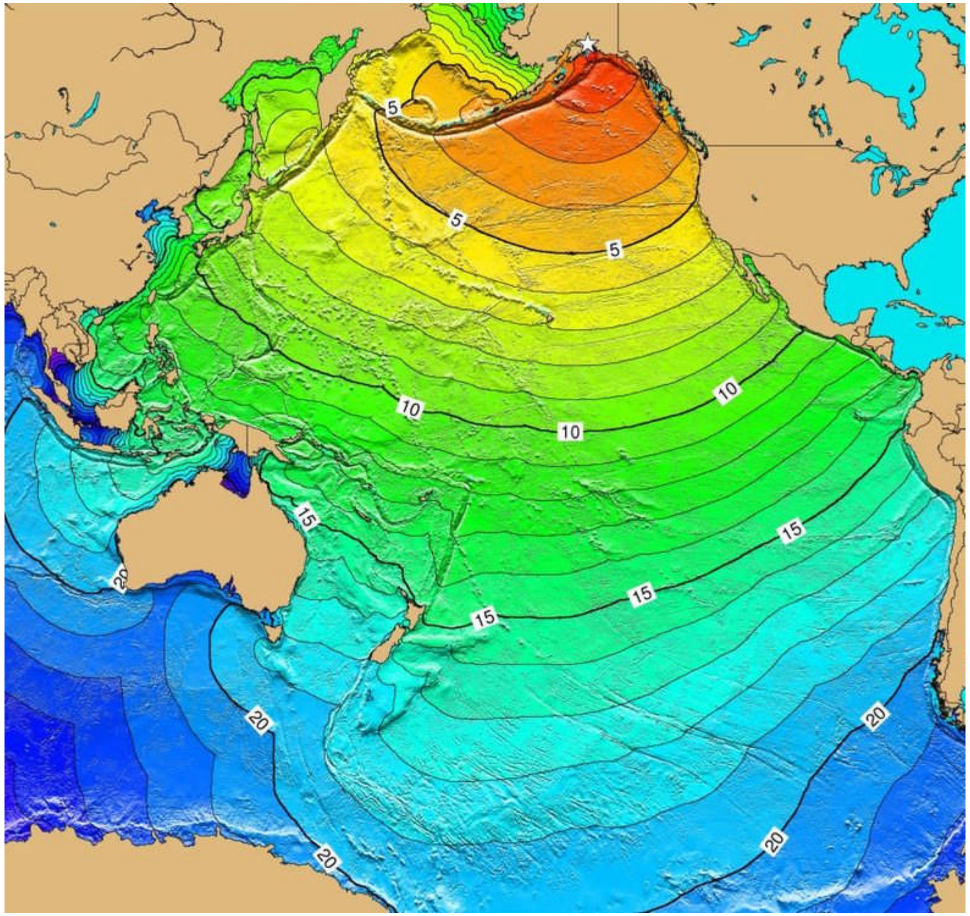
SHOCKWAVE ONE OF MIGHTIEST

OFFICIAL CASUALTY LIST AS OF 2 P.M.

Loss Estimated By Governor At $250 Million

“…An increase of only a point or two on the Richter scale represents a tremendous difference in a quake’s intensity because the scale is based on a mathematical progression in which each degree of magnitude is 32 times greater than the preceding one. A quake force of 7 is 32 times more powerful than one with an intensity of 6, and a magnitude of 8 is 32 times 32 or about 1,000 times more powerful…The most powerful quakes ever recorded range around 8.9 on the scale…”

***Popular Mechanics,* June 1967**



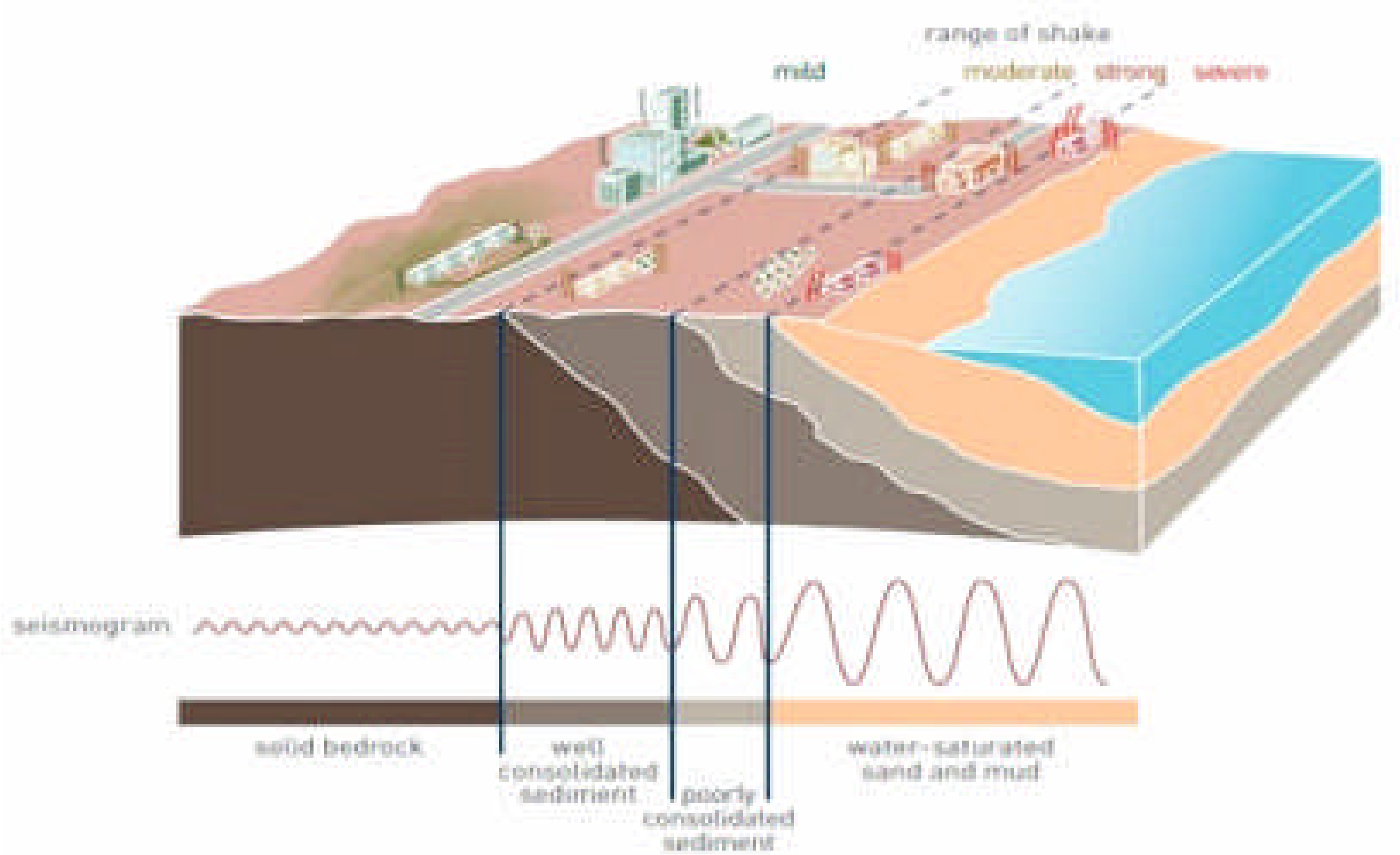
<u>Left</u>: caption: "Calculated travel time map for the tectonic tsunami produced by the 1964 earthquake in Alaska. Map does not show the height or strength of the waves, only the calculated travel times. Number represents time in hours for the wave to reach the destination." Two types of tsunami were produced as a result of the earthquake: a *tectonic tsunami* caused by the movement of the tectonic plates and *subaerial landslide* (or submarine tsunami) caused by underwater landslides. About twenty of these smaller tsunamis were responsible for the majority of the tsunami damage in over twenty countries including Canada, Peru, New Zealand, Papua New Guinea and Japan. The largest recorded wave was at *Shoup Bay*, Alaska, at a height of about 67-meters.

"…knowing where quakes are likely to occur, builders can avoid the use of dangerous sites and building materials and designs that would be vulnerable to earthquake damage. For example, the U.S. Geological Survey in 1959 issued a report warning that there were earthquake hazards in Anchorage, Alaska. The report pointed out that, because of a plastic clay formation underlying the city, big landslides could be triggered by an earthquake. Builders ignored the warning…and the Good Friday earthquake of 1964 sent blocks of clay formation sliding seaward…"

***Popular Mechanics,* June 1967**

<u>Top</u>: caption: "Landslide and slumping effects in the Turnagain Heights area, Anchorage, Alaska. March 27, 1964"

<u>Bottom</u>: caption: "Government Hill School, Anchorage, AK"



"…the intensity with which a structure is shaken depends more on the kind of ground it rests upon than on its precise distance from a quake's epicenter. Solid rock is the best foundation. Filled ground or sand or alluvium, especially when waterlogged, behave like jelly, and buildings on such soils can be severely damaged even by a minor earthquake…"

***Popular Mechanics,* July 1964**

<u>Above</u>: caption: "In comparison with rock, softer soils are particularly prone to substantial local amplification of the seismic waves. Note that the ground displacement amplifies with decrease in soil stiffness."

"…The truth is that foundation conditions can change within a few feet, and a quake that does serious damage to structures on one side of a street may do little damage on the other side where the soil happens to be more stable. This was noticeable in the 1964 Alaskan quake…"

***Popular Mechanics,* July 1964**

<u>Left</u>: caption: "Effects of liquefaction during the 1964 Niigata earthquake." *Soil Liquefaction* describes a phenomenon whereby a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake shaking or other sudden change in stress condition, causing it to behave like a liquid.

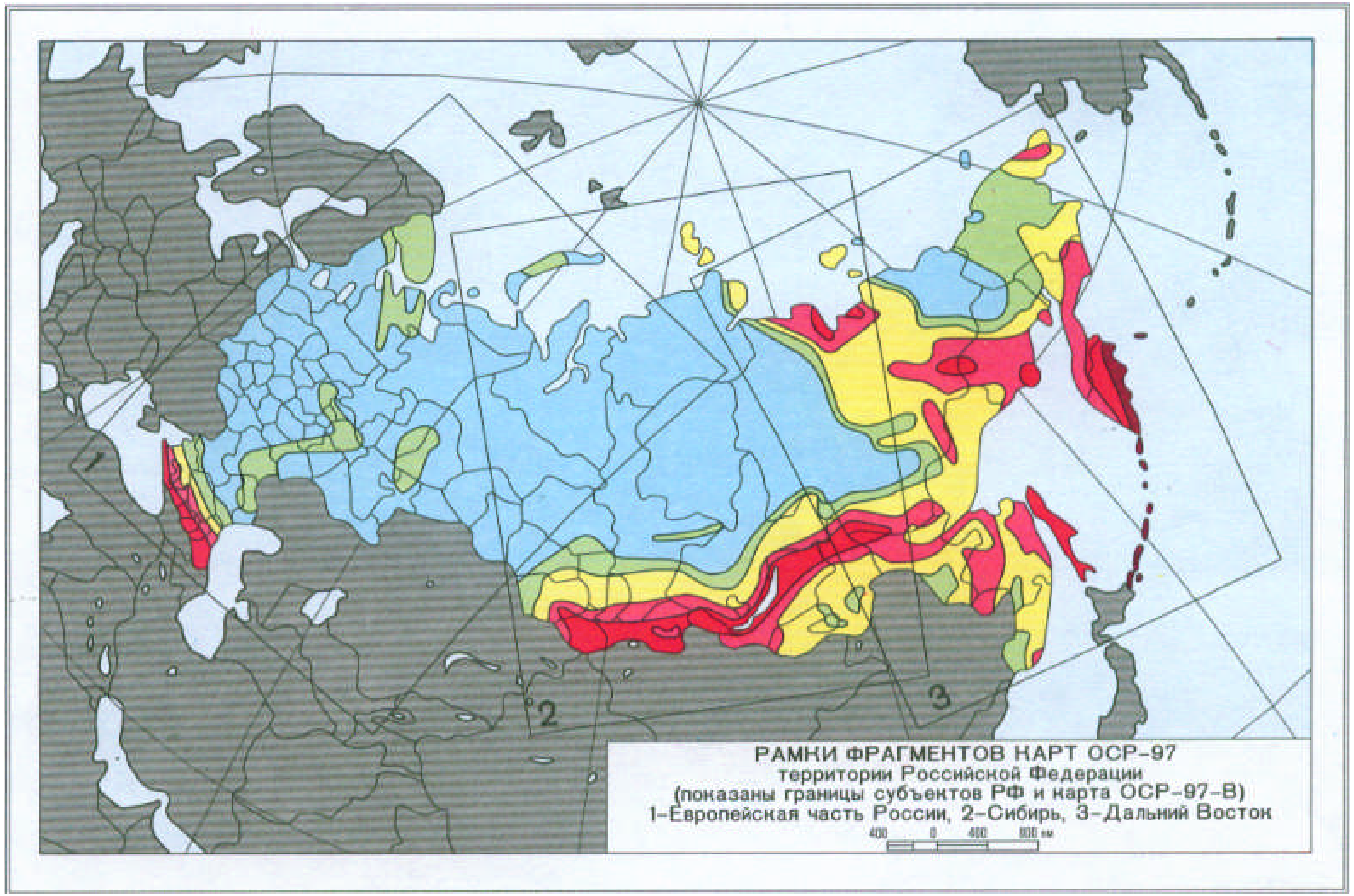
<u>Right</u>: caption: "Five-story J.C. Penney Building, 5th Avenue and Downing Street, Anchorage, Alaska, partly collapsed by the March 28, 1964 earthquake." Note the undamaged buildings in the foreground.

“…There is talk in Anchorage today of converting the most unstable areas of that city into parks, and zoning the rest of the city for light or heavy construction depending on the soil. Russia has mapped much of its territory into risk zones, depending in part on the nature of the soil, and construction must conform to specifications for the zone involved…”

***Popular Mechanics,* July 1964**

Left: caption: “Alaska Earthquake March 27, 1964. Destructive landslides in Anchorage: west part of Turnagain slide”

Right: caption: “Looking NNE over the 1964 Turnagain Heights Slide, several years after event”

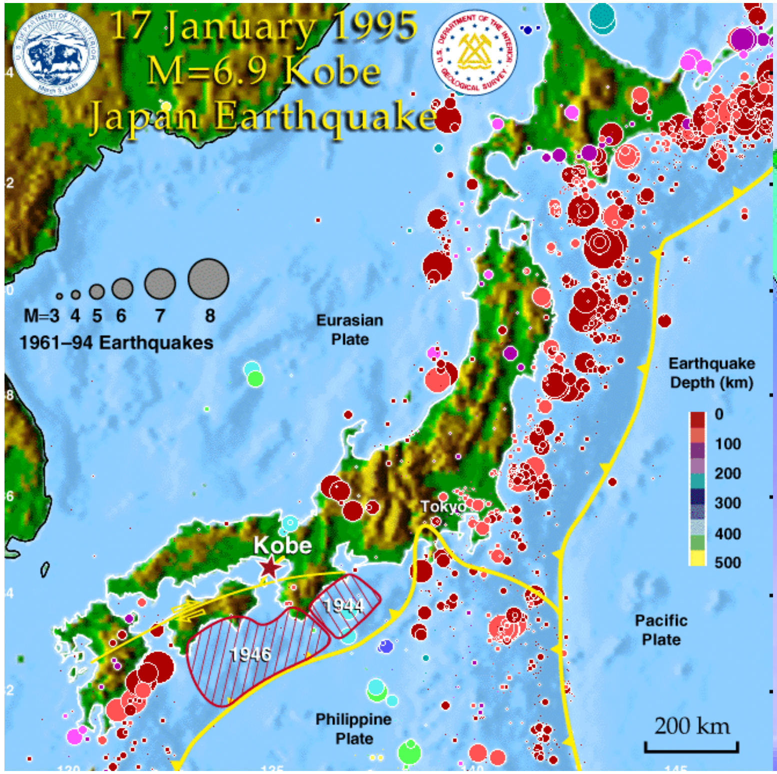


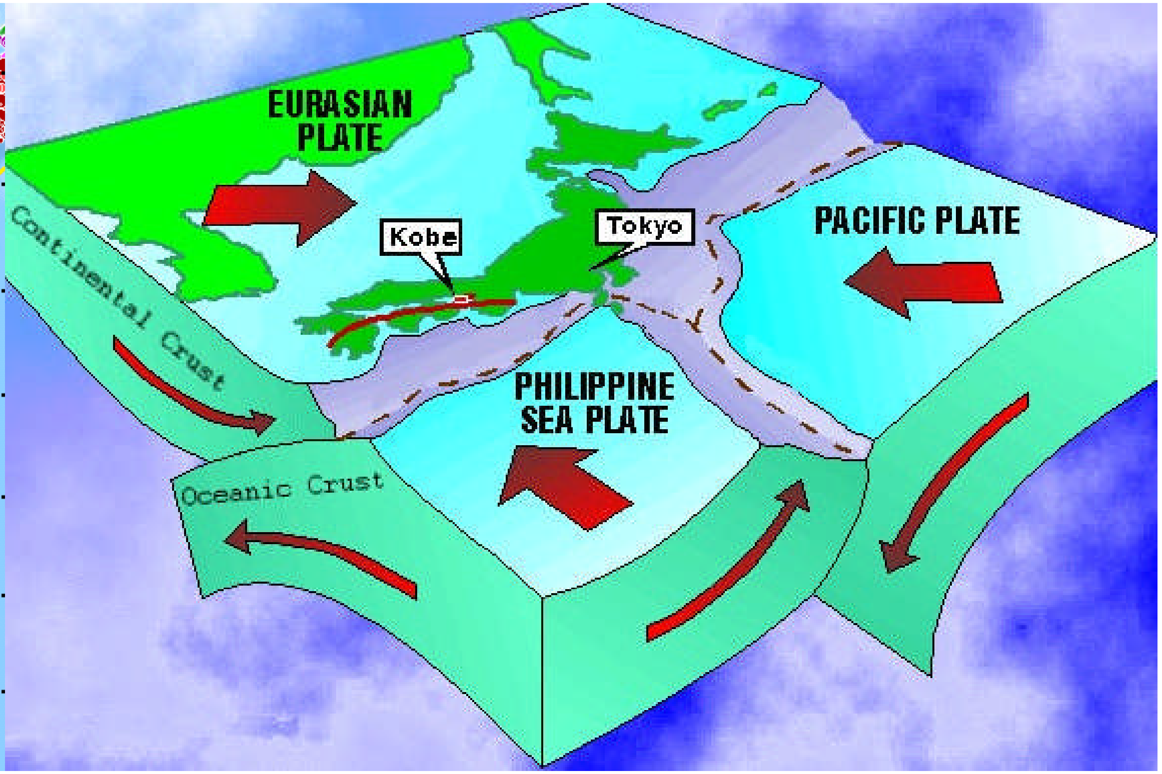
(Map of General Seismic Zoning [GSZ-97] of Russia)

SSI

Most engineered structures involve some type of structural element with direct contact with the ground. Neither the structural displacements nor the ground displacements are independent of each other When external forces such as earthquakes act on these elements. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is referred to as *Soil-Structure Interaction* (SSI).

Conventional structural design methods typically neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. However, the effect of SSI becomes prominent for heavy structures resting on relatively soft soils (i.e. nuclear power plants, high-rise buildings, elevated highways). Damage sustained in recent earthquakes, such as the January 17th 1995 *Kobe* (Japan) *Earthquake* (left), have also highlighted that the seismic behavior of a structure is highly influenced not only by the response of the superstructure, but also by the response of the foundation and the ground as well. Thus, modern seismic design codes typically stipulate that the response analysis should be con-ducted by taking into consideration a whole structural system including superstructure, foundation and soil conditions.



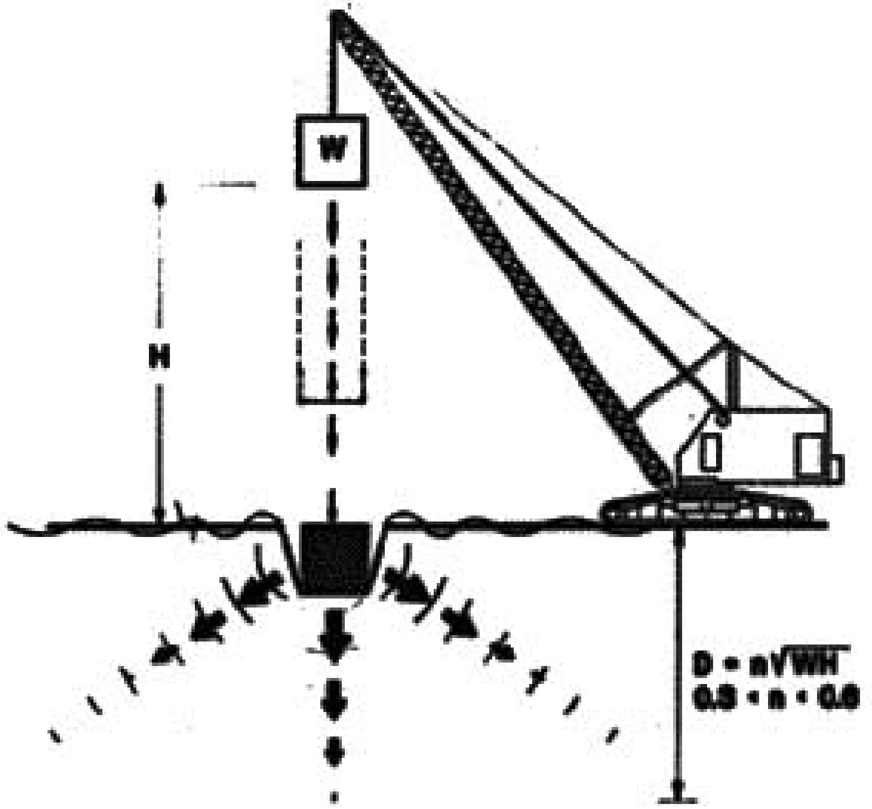


Left: caption: “Two major and very destructive earthquakes occurred in the region in October 4, 1994 and on January 17, 1995. The October 4, 1994 earthquake generated a small tsunami which was damaging in Japan and the Kuril islands but did not pose a Pacific-wide threat. The January 17, 1995 earthquake produced no noticeable tsunami.”

Right: caption: “Kobe lies on a destructive margin where two plates (the Eurasian Plate and the Phillipine Sea Plate) moved towards each other until the Phillipine Plate moved under the Eurasian Plate causing friction resulting in the earthquake”

Dynamic Compaction

Dynamic Compaction **is a method that's used to increase the density of the soil when certain subsurface constraints make other methods inappropriate. It's a method that is used to increase the density of soil deposits. The process involves of dropping a heavy weight repeatedly on the ground at regularly spaced intervals. Weight and height determine the amount of compaction that occurs. The weight that's used (between 8 and 36-tons) depends on the degree of compaction desired. Height varies from 1 to 30-meters. The impact of the free-fall creates stress waves that help in the densification of the soil and can penetrate up to 10-meters. In cohesion-less soils, these waves create liquefaction that is followed by the compaction of the soil and in cohesive soils, they create an increased amount of** ***pore water pressure*** **that is followed by the compaction of the soil (pore water pressure is the pressure of water that is trapped within the particles of rocks and soils).**



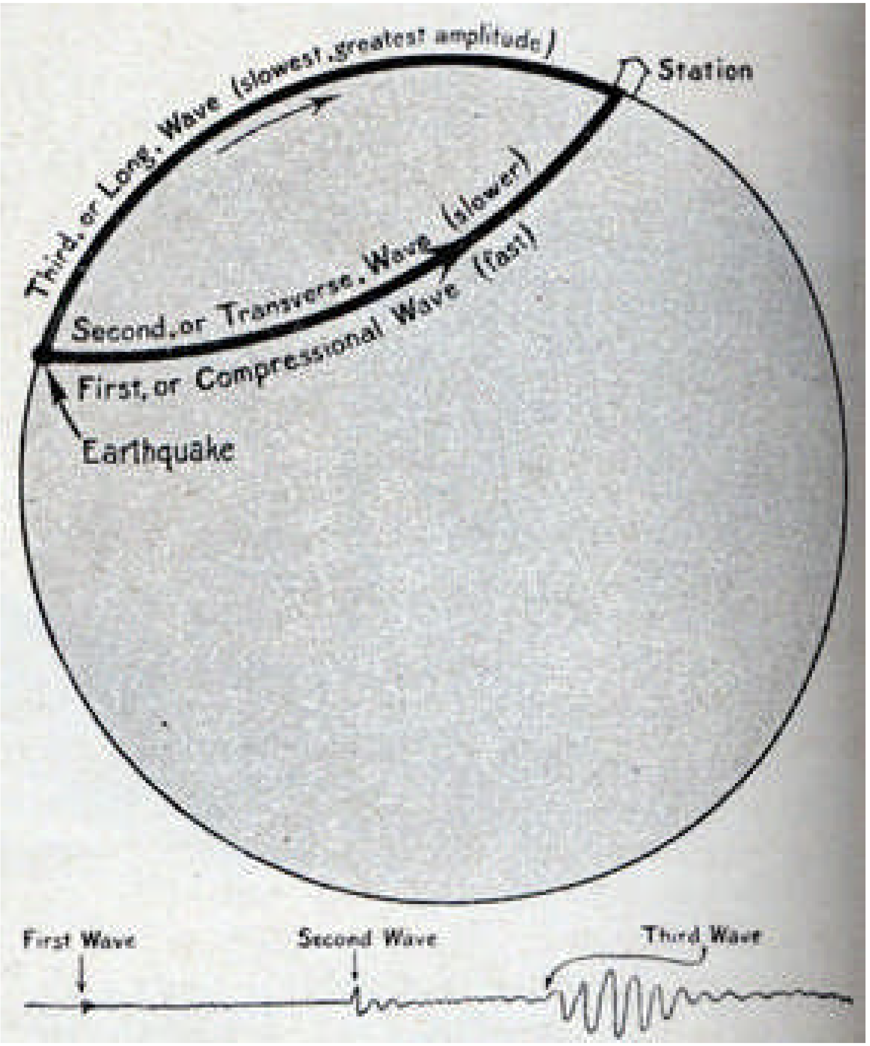
The degree of compaction depends on the weight of the hammer, the height from which the hammer is dropped and the spacing of the locations at which the hammer is dropped. The initial weight dropping has the most impact, and penetrates up to a greater depth. The following drops, if spaced closer to one another, compact the shallower layers and the process is completed by compacting the soil at the surface.

Most soil types can be improved with *Dynamic Compaction*. Old fills and granular soils are most often treated. Soils that are below the water table have to be treated carefully to permit emission of the excess *pore water pressure* that is created when the weight is dropped onto the surface.

Three Kinds

“…When an earthquake occurs, vibrations radiate in all directions from the epicenter like waves from a pebble thrown in a lake. On seismographs three kinds of waves are recorded. The first are compression waves, akin to sound waves. You can often hear a large quake coming by the booming sound that precedes the actual shock. Next come distortion waves, so slight they can hardly be felt. Finally, the devastating surface waves strike with all their fury…”

Popular Mechanics, **October 1939**



"…Briefly, an earthquake sends out three types of waves. Two of these take the same path, either a straight line through the earth, or else a curved line, not departing very much from a straight line. But the waves travel at different speeds. So one of them gets to the seismograph first and its time of arrival is recorded. Then the other wave arrives, and it also is recorded. The difference in time may range from a few seconds to 20 minutes, but each difference corresponds to a certain distance…"

***Modern Mechanics and Inventions,* Dec. 1930**

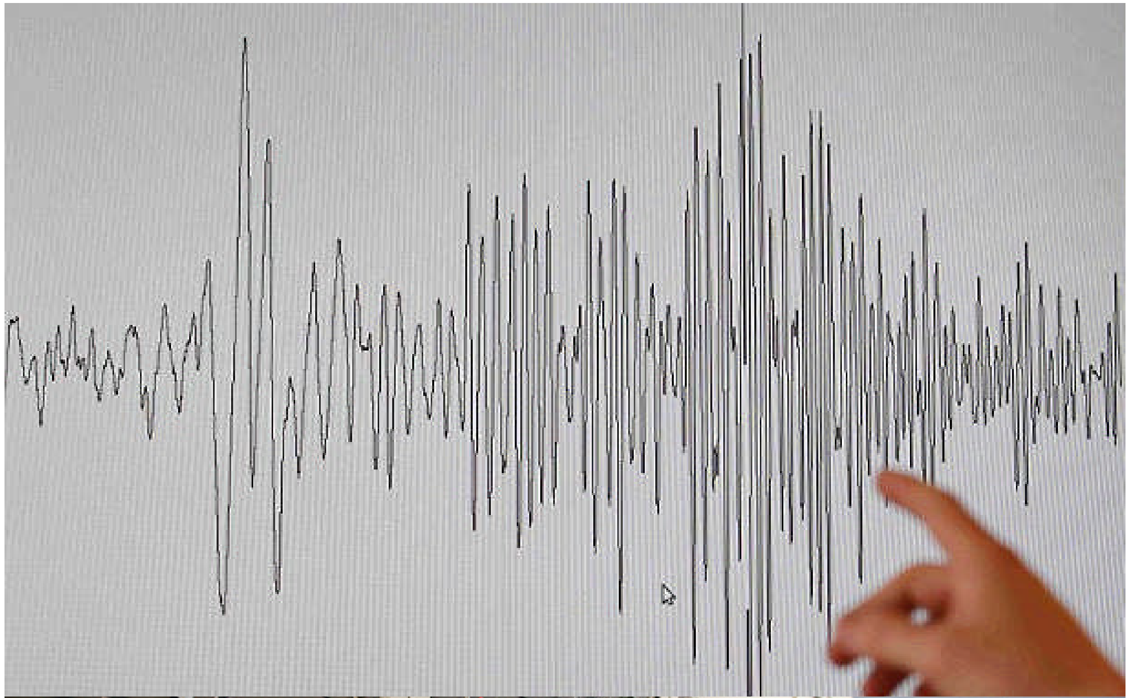
Left: caption: "The first and second waves of an earthquake travel through the earth along the same path, at different speeds; the third, or long wave, travels over the earth's surface at a slower rate than the other two. This difference in speed helps to determine the location of the quake."

“…For instance, the time difference at Cheltenham, Md., for the earthquake of February 28, 1925, was one minute and 57 seconds, and this corresponds to a distance of 670 miles, which agrees well with the results of other stations…”

***Modern Mechanics and Inventions,* December 1930**

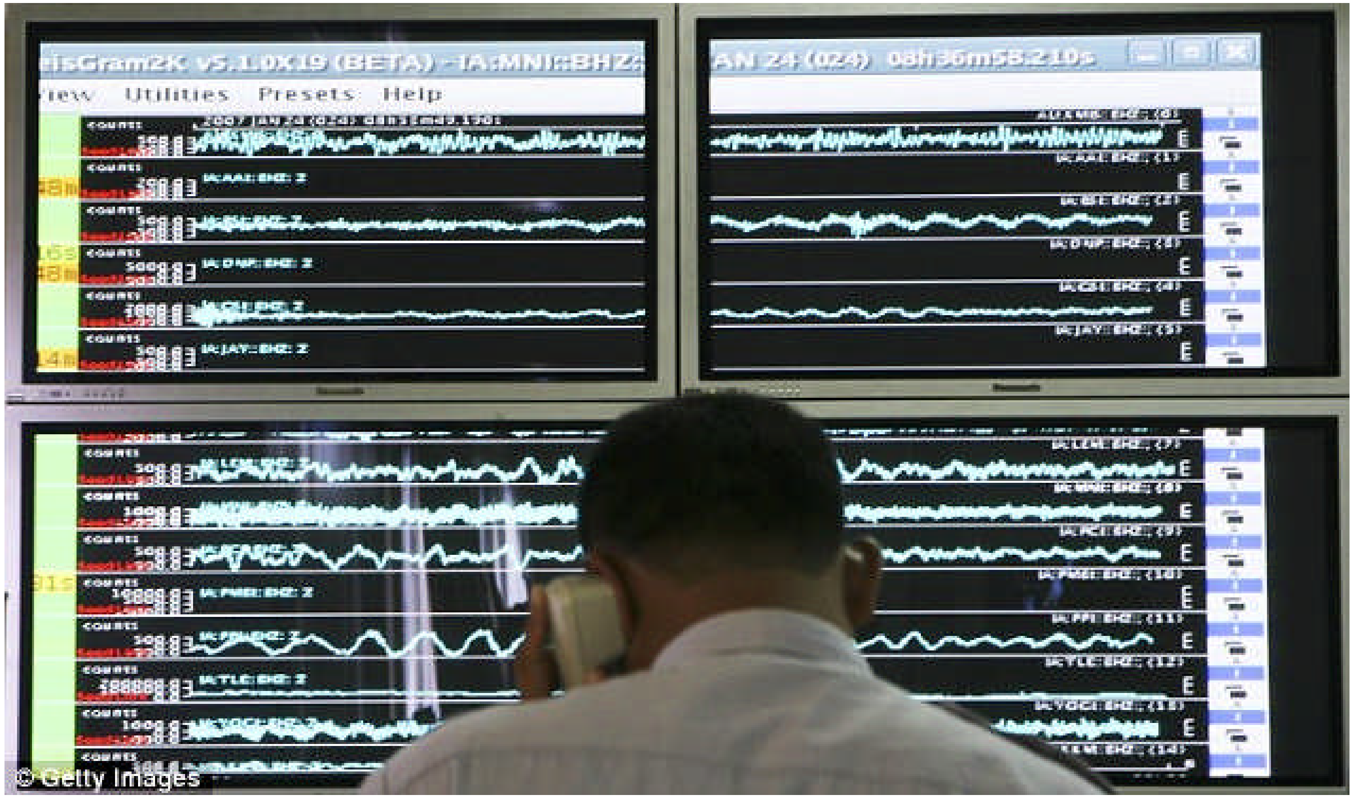
“…The third type of wave travels along the surface of the earth at a still slower rate, and its time of arrival also helps to fix the distance. Actually the waves are reflected and are very complicated, but this is a matter which concerns the seismologist only. In practice the times of the different wave phases are obtained from tables or from curves. These vary somewhat according to the author, but in general the differences are not very considerable. If we know from surface damage the place where earthquakes occurred, then we can use a similar method to get the velocity of the waves from the known distance. In addition to this laboratory system of studying the quake, the reports of eye witnesses are likewise considered to be important. The work of collecting such reports is well organized by our government…”

Modern Mechanics and Inventions, **December 1930**



"…Scientists use the different kinds of waves generated by a quake to measure its distance from a recording station. The first jiggling wave that compresses the earth ahead of it moves at from three and one-half to eight miles a second and the sheer waves that cause swaying travel three-fifths as fast. Both are recorded at the same station and the interval between their reception allows the distance they have traveled to be figured. A third and longer wave moves around the earth's surface at about two miles a second…"

***Popular Mechanics,* July 1935**



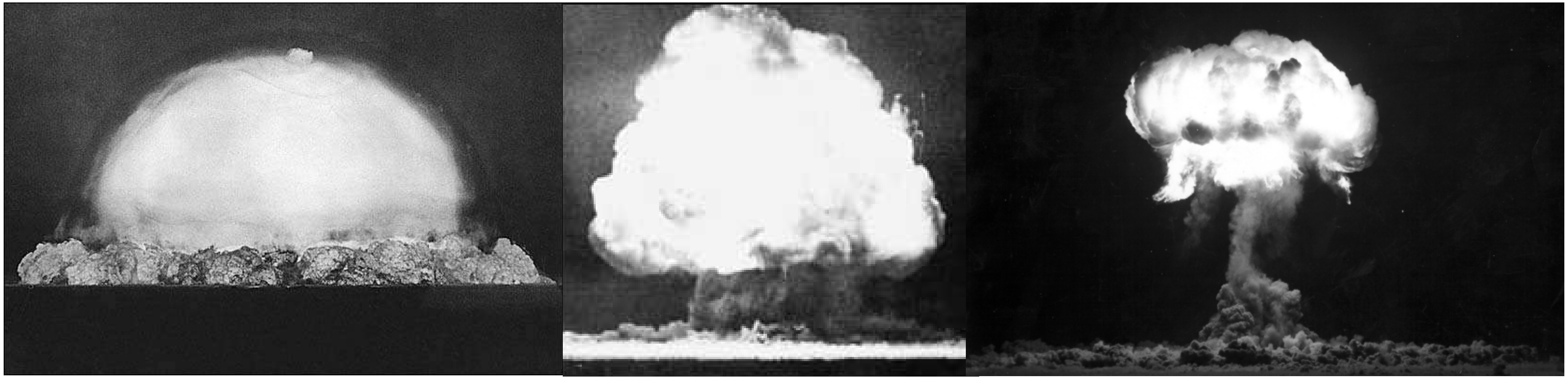
© Getty Images

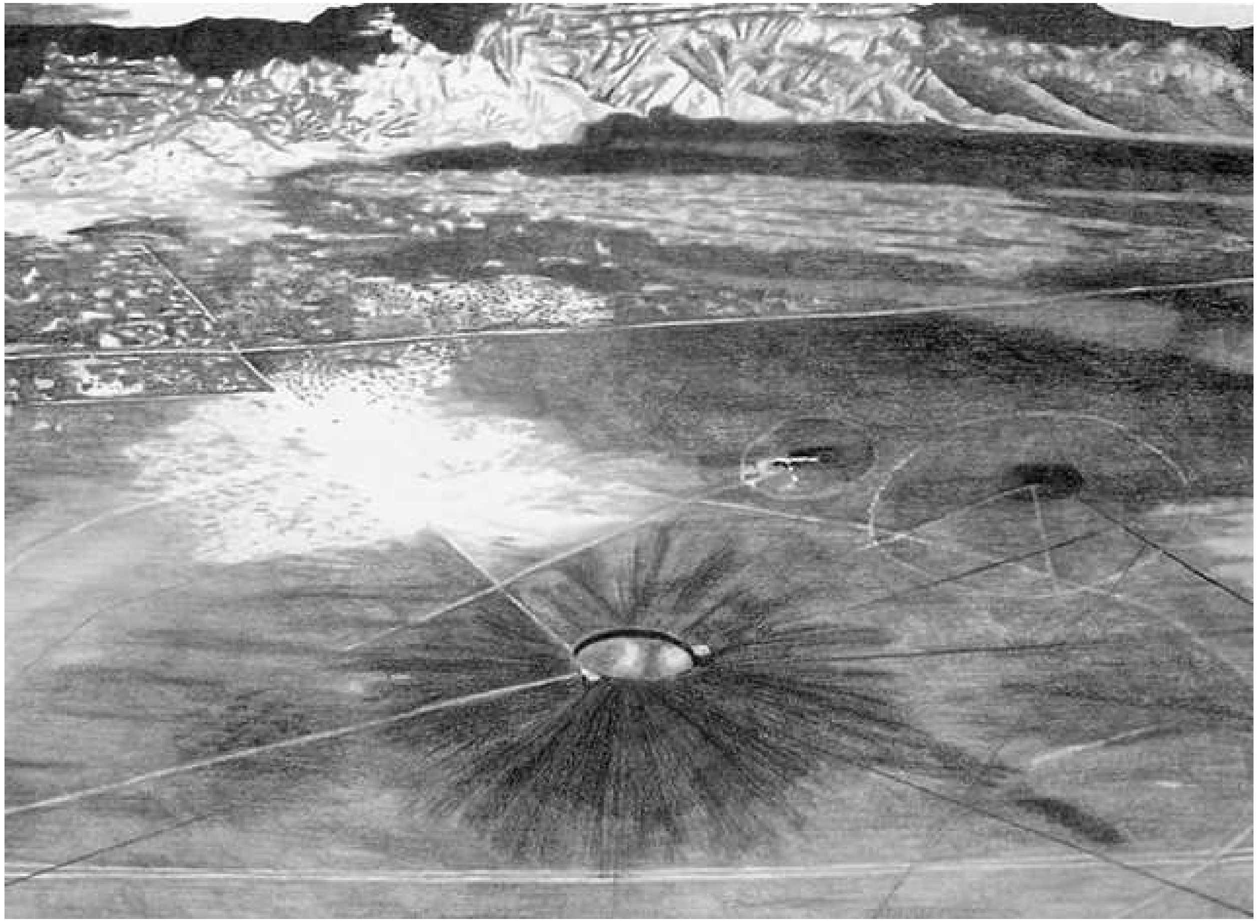
Two Types

“The July 16, 1945 test in Jornada del Muerto, New Mexico, accomplished more than to introduce the atom bomb. It provided seismologists – students of earth movements – with a controlled laboratory to test their theories of earth waves. Many old ideas went overboard. The results led to the discovery that earth waves come in two types: coupled waves which were predicted in 1939 by Dr. L. Don Leet of Harvard University, and hydrodynamic waves…”

***Popular Mechanics*, August 1946**

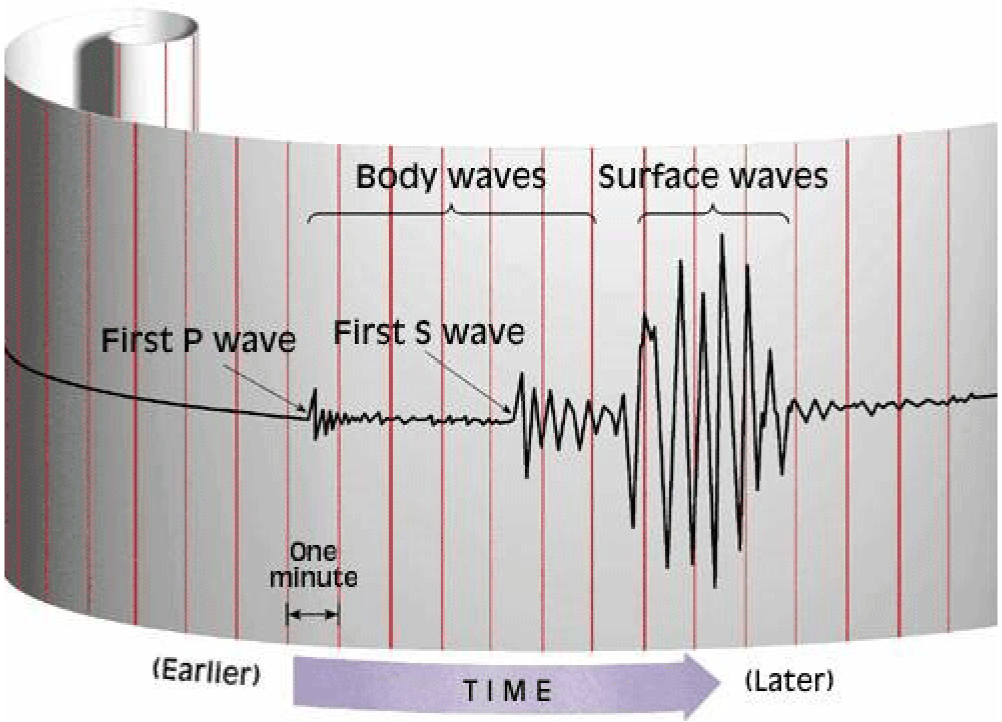
<u>Left</u>: caption: “Trinity Site Obelisk”





“…Whenever there is a disturbance on or below the earth’s crust such as an earthquake, hurricane or explosion of dynamite, energy generates earth waves. They rush through the earth’s strata at terrific speed, often following the warped contours of bedrock. Seismographs at scattered stations record these tremors. There is always a time interval between arrival of preliminary and main waves at the seismograph. However, the first and second waves are sometimes reflected and refracted so that they are superimposed on the graph before the main waves arrive. Using a precision device to time incoming waves, scientists can locate the center of disturbance as accurately as radar…”

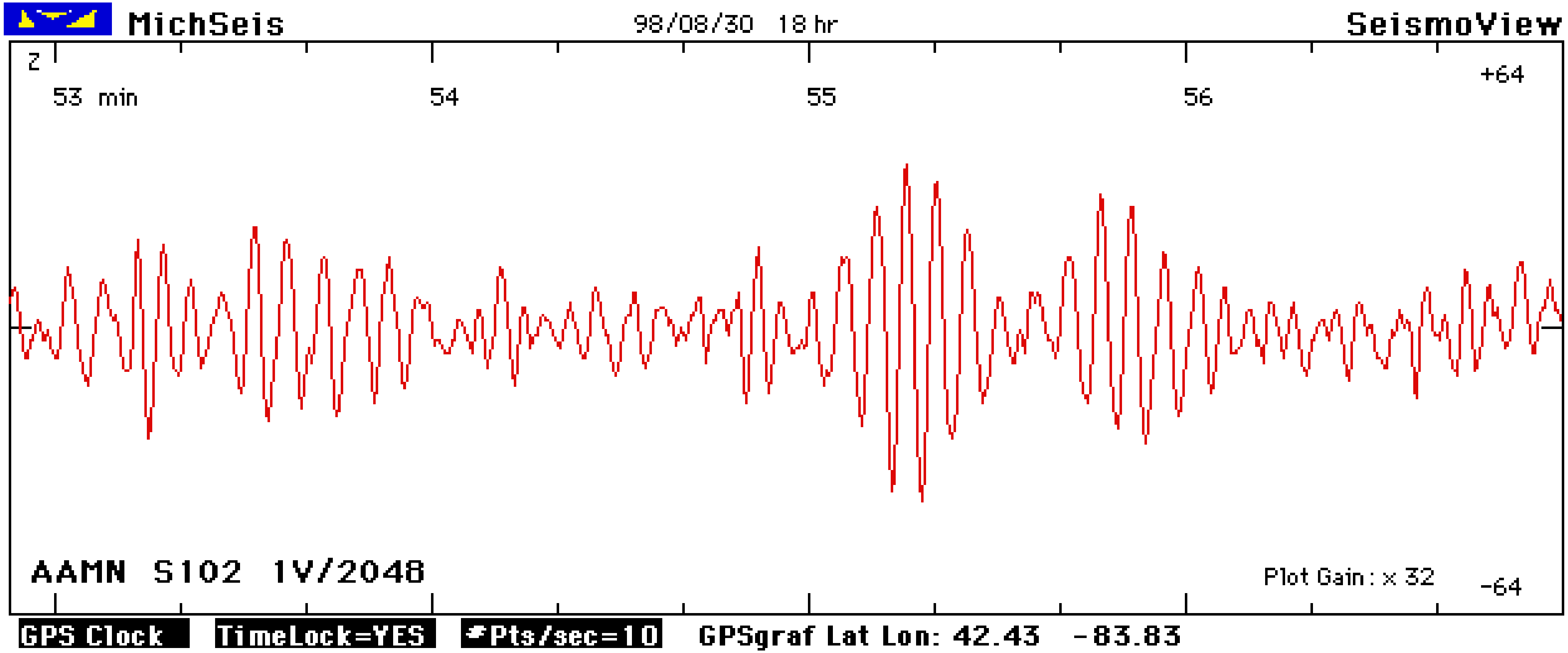
***Popular Mechanics,* August 1946**



"…Suppose an earthquake stirs up a tidal wave. In one of the station seismographs, the needle begins to move slightly, registering the first or primary wave. It continues its small nervous movements until the secondary wave arrives. The speeds of primary and secondary waves are known; the primary is entirely directional and faster than the longitudinal secondary. The difference in time interval between them tells the distance of the disturbance from the station. Then the main wave hits the pier and the needle becomes violent. The direction of earth wave plus the time lapse between the primary and secondary waves locate the center of the earth's misbehavior…"

Popular Mechanics, **August 1946**

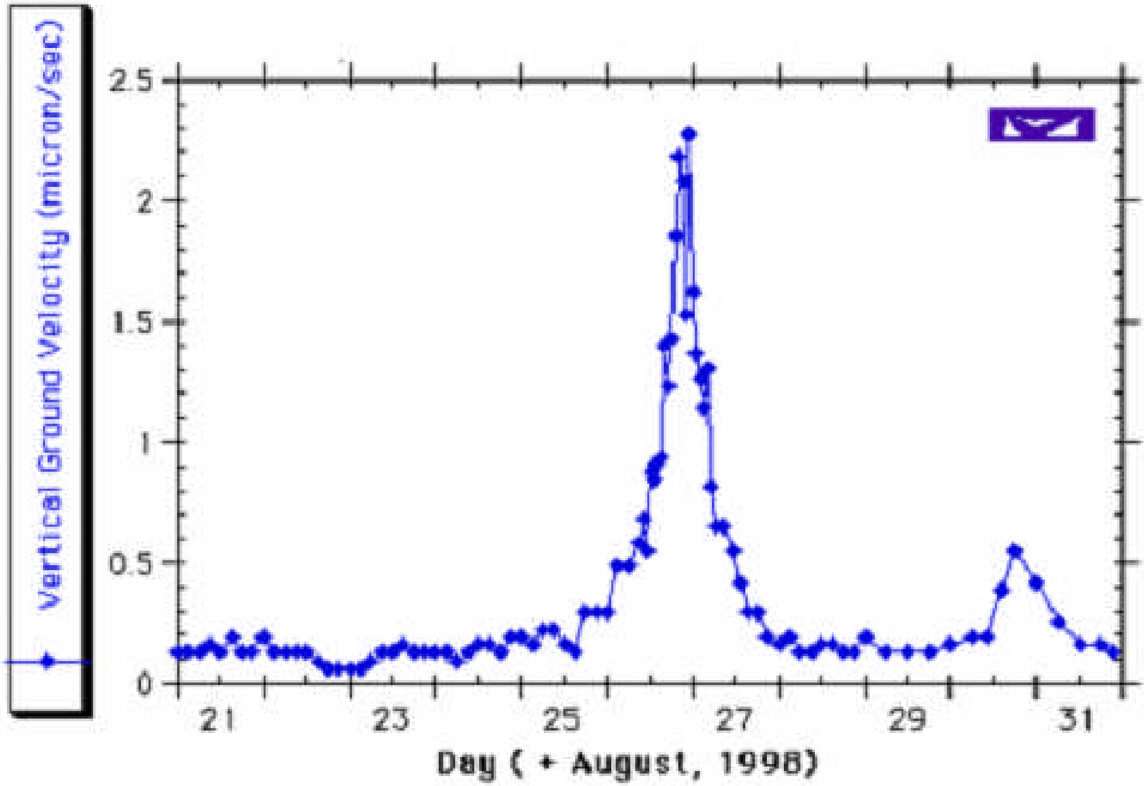
Microseisms



"…Here lies a way of harnessing earth waves, just as we have utilized electromagnetic waves in radio and other electronic instruments. Major earth waves are not necessary. Micro-seisms – small waves – will do just as well…"

***Popular Mechanics*, August 1946**

<u>Above</u>: caption: "Graph of the 5-second microseism amplitude at Mich-Seis station AAMN, just north of Ann Arbor, MI. This graph shows microseism amplitude over 11 days"



"…For instance, a hurricane originates off the Cape Verde coast of equatorial Africa. As the storm moves and gathers strength, it transmutes some of its violent energy into earth waves which race through the ocean floor to seismological stations. Man learns of the hurricane when it is still 1,000 miles away and he traces its course. By the time the storm hits shipping lanes or inhabited areas, he is prepared for it…"

***Popular Mechanics,* August 1946**

<u>Above</u>: caption: "Microseism amplitude level (at period of 5 sec) at AAMN (north of Ann Arbor, MI) during time interval of Hurricane 'Bonnie.' This graph shows microseism amplitude over 11 days."

"…Hurricane warning is not the only possible use of microseisms. Geologists use portable seismographs in prospecting for oil and minerals. A few miles away a scouting party detonates dynamite, creating little waves. Since the geological structure and composition of rocks write their own record on the seismograph, the scientific prospectors know at once whether they struck a mother lode or a dud. In the same way, bedrock can be mapped for whatever engineering structure is planned for a site…"

Popular Mechanics, **August 1946**

Cause and Effect

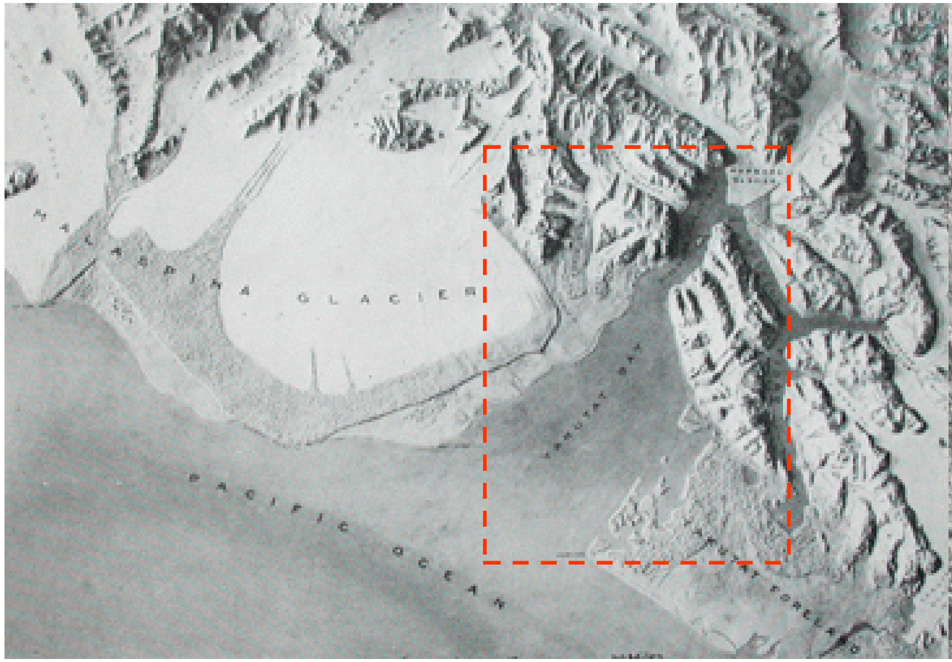
“…Forty or fifty miles below the earth’s surface, rock is soft and plastic because of great heat and pressure. When lateral forces squeeze this material, it either flows out of a volcano’s mouth like toothpaste out of a tube, or bulges beneath the earth to form mountain ranges, When this happens, the brittle outer shell cracks and slips. It is the fracturing of this solid crust that causes out biggest quakes…”

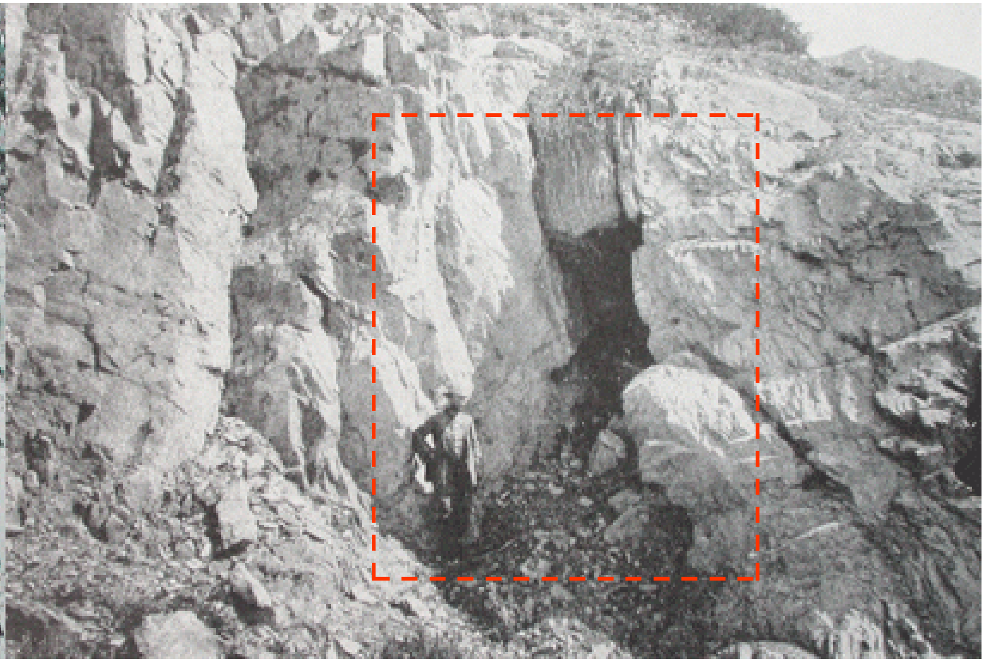
***Popular Mechanics,* October 1939**

"…When the earth cracks, it usually breaks along some line of weakness which geologists call a 'fault line.' Sometimes the shift is horizontal. During the great San Francisco earthquake of 1906, the area on the east-side of the 275-mile San Andreas fault slid south, while that on the west slid north. Every road, pipeline, and fence crossing the fault was displaced – the largest shift being twenty-one feet. Often a vertical shift takes place. The Yakutat Bay quake in Alaska in 1899 resulted in an abrupt vertical displacement that lifted part of the coast forty-seven feet…"

***Popular Mechanics,* October 1939**

<u>Left</u>: caption: "Ground breakage from San Francisco earthquake of 1906"





"Mr. Flenner stated in 1905 that after the first shock on September 3 they rigged up a homemade seismograph, consisting of hunting knives hung so that their points touched and would jingle under a slight oscillation. With this instrument (crude, perhaps, but more delicate than their own perception) they counted 52 shocks on September 10, up to the time of the heavy disturbance (the magnitude 8 earthquake) that caused so much damage."

***Ralph Tarr*, Geologist**

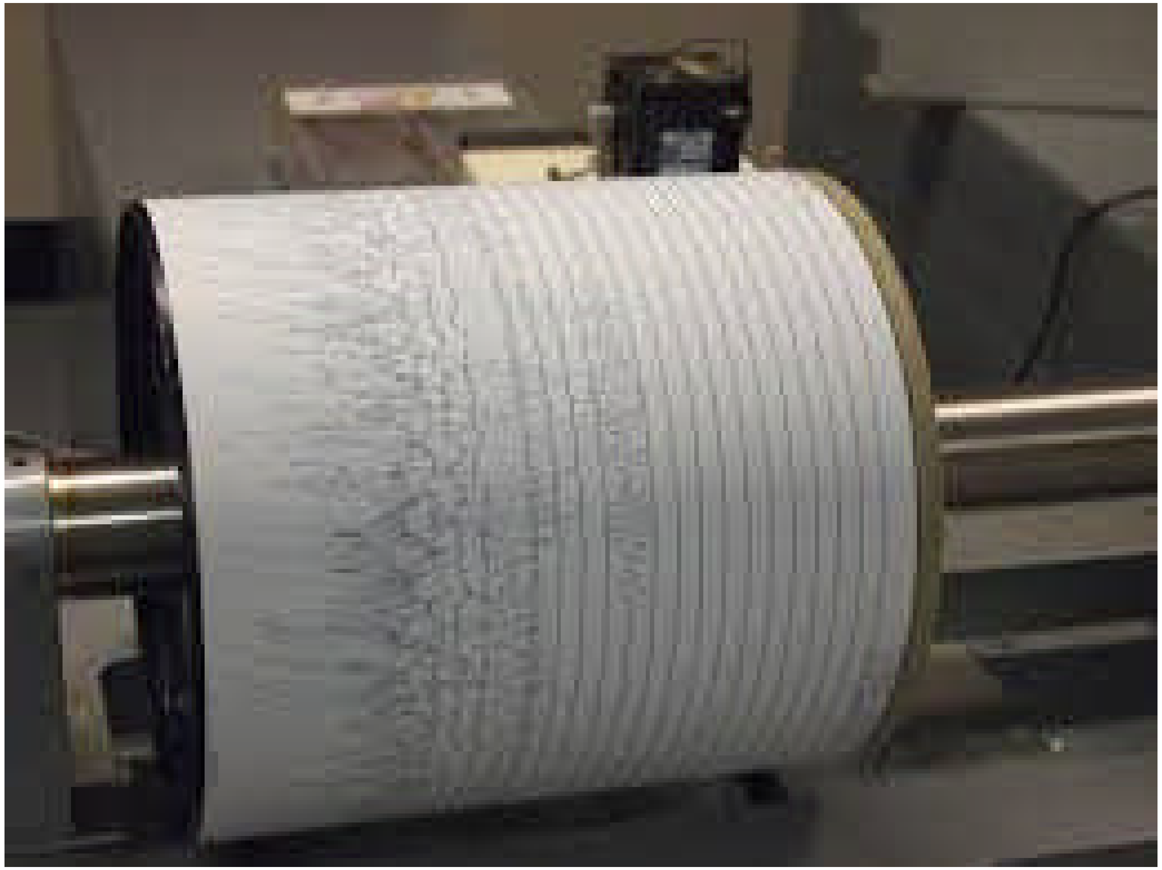
RE: Geologist/s Tarr and *Lawrence Martin,* in the *Yakutat Bay* area in 1905 to study the glaciers, saw things like mussels on rocks 20-feet above the ocean. They observed so much evidence of a giant earthquake they interviewed several prospectors (including *A. Flenner*) and included their stories in a 1912 study entitled: "The earthquakes at Yakutat Bay, Alaska, in September, 1899."

<u>Top</u>: caption: "View of model of region including Yakutat Bay & Malapspina Glacier"

<u>Bottom</u>: "Elevated sea cave (uplifted 17-feet) on east shore of Disenchantment Bay"

“…Smaller quakes are sometimes caused by volcanoes. In Italy, Hawaii and the South Seas, outpouring of lava is often accompanied by temblors. The Dalmatian cost of the Adriatic is noted for quakes caused by collapse of limestone caverns…”

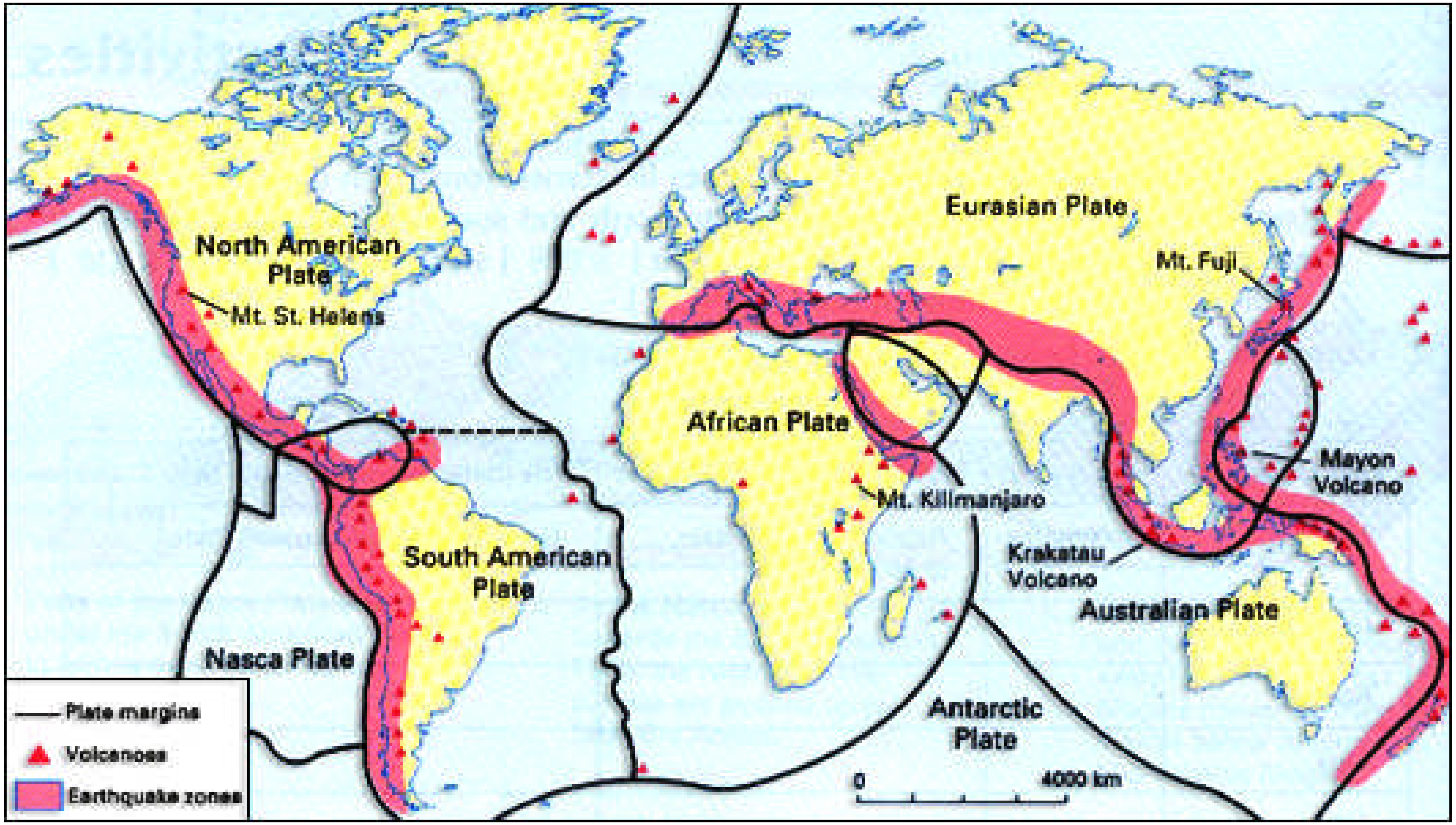
Popular Mechanics, **October 1939**



"…The earthquake vibrations felt by man last from a fraction of a second to as much as forty seconds, as in the great San Francisco quake. Quakes in India have been said to last five minutes. Seismological instruments, however, record temblors long after man ceases to feel them – sometimes for hours…"

Popular Mechanics, **October 1939**

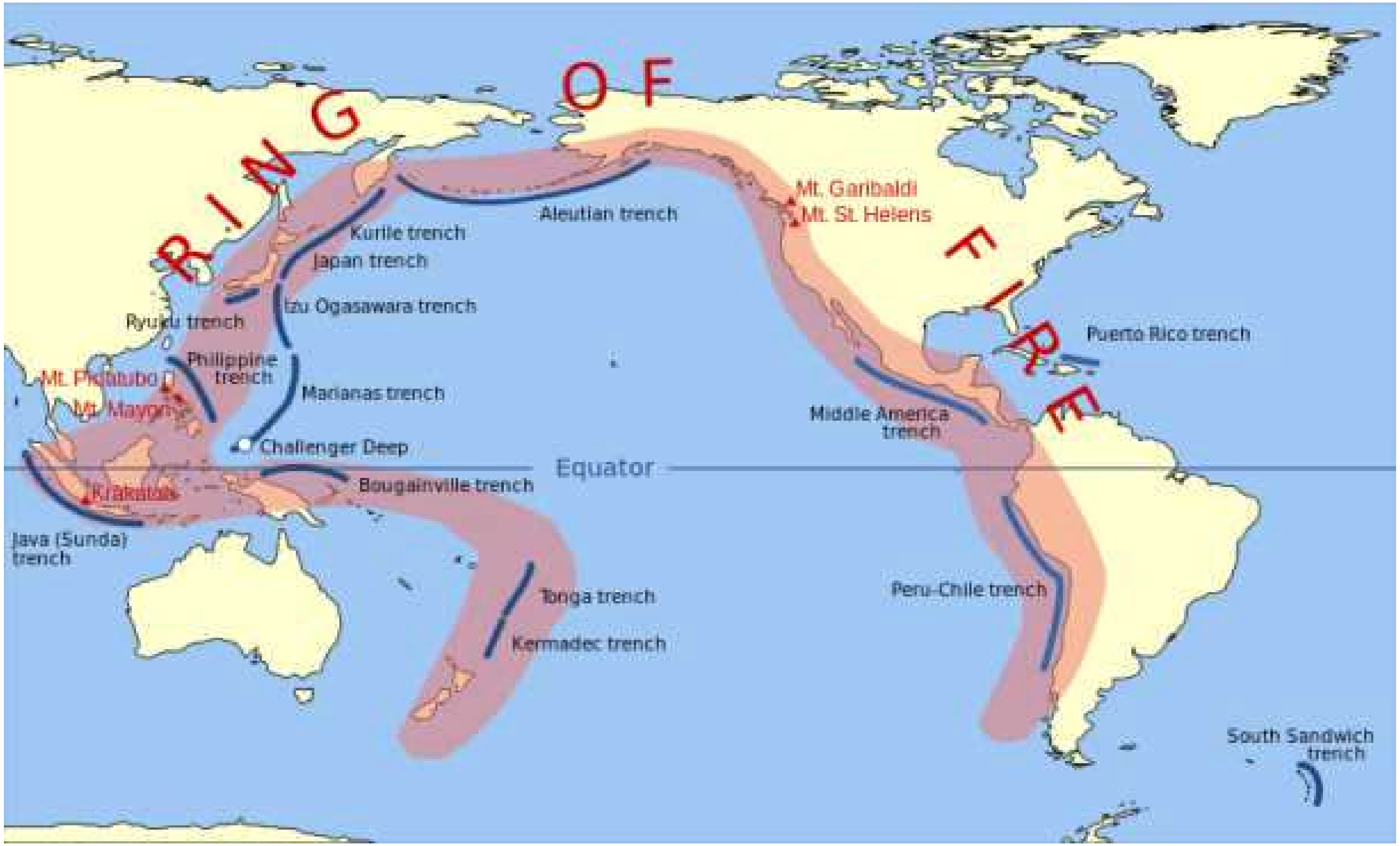
Ring of Fire



"…Two earthquake belts girdle the globe. One lies astride the rim of the Pacific Ocean…while the other passes through the Caribbean Sea and neighboring islands, crosses the Atlantic to pass through the Mediterranean Sea and border islands, follows the south slope of the mountain backbone of Asia and continues through the Malaysian archipelago to New Zealand…"

***Popular Mechanics*, July 1933**

<u>Above</u>: caption: "World Distribution of Earthquakes an Volcanoes"



"…The west coast of the United States lies within one of two great earthquake belts that girdle the globe. One rims the Pacific Ocean from Chile, up through Mexico and California, across Alaska and the Bering Strait, down into Japan, the East Indies, New Zealand and the South Seas. The second great belt extends in a general line from Spain, through the Mediterranean, across the Himalayas to China…"

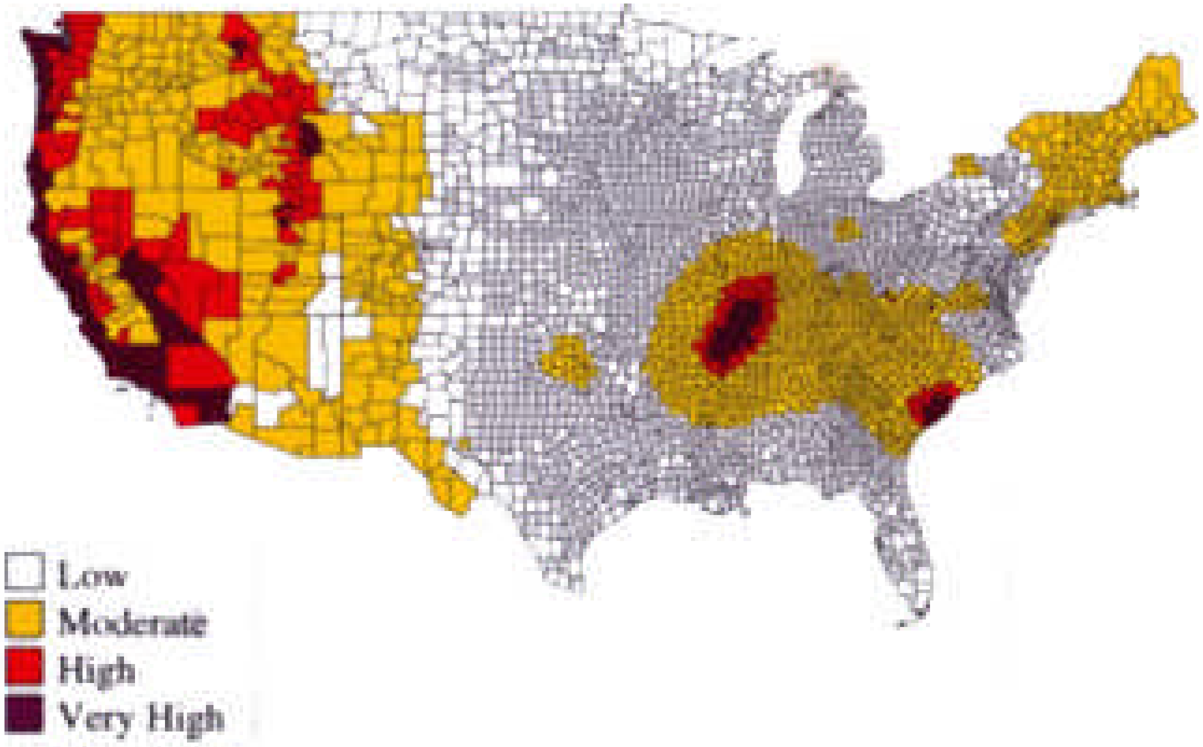
***Popular Mechanics*, October 1939**

Venture to Predict

“…Scientists sometimes venture to predict an earthquake, but without attempting to forecast the time at which the shock will occur. Prof. Martin Hanko, of Hungary, came within two years of predicting the Java temblor of 1931. The method used by the Japanese seismologist, Omori, was to forecast a disturbance as likely in that section of the circum-Pacific belt which had not been relieved by earthquakes in a recent period. This method has been used by other seismologists, also, with success…”

***Popular Mechanics,* July 1933**

The Earth Would Be Doomed



"…After all, there is some good even in an earthquake. Prof. W.A. Parks, of the University of Toronto, cheers us with this assertion: 'If earthquakes ceased, the earth would be doomed, because land would be worn smooth by the erosive actions of the seas.'"

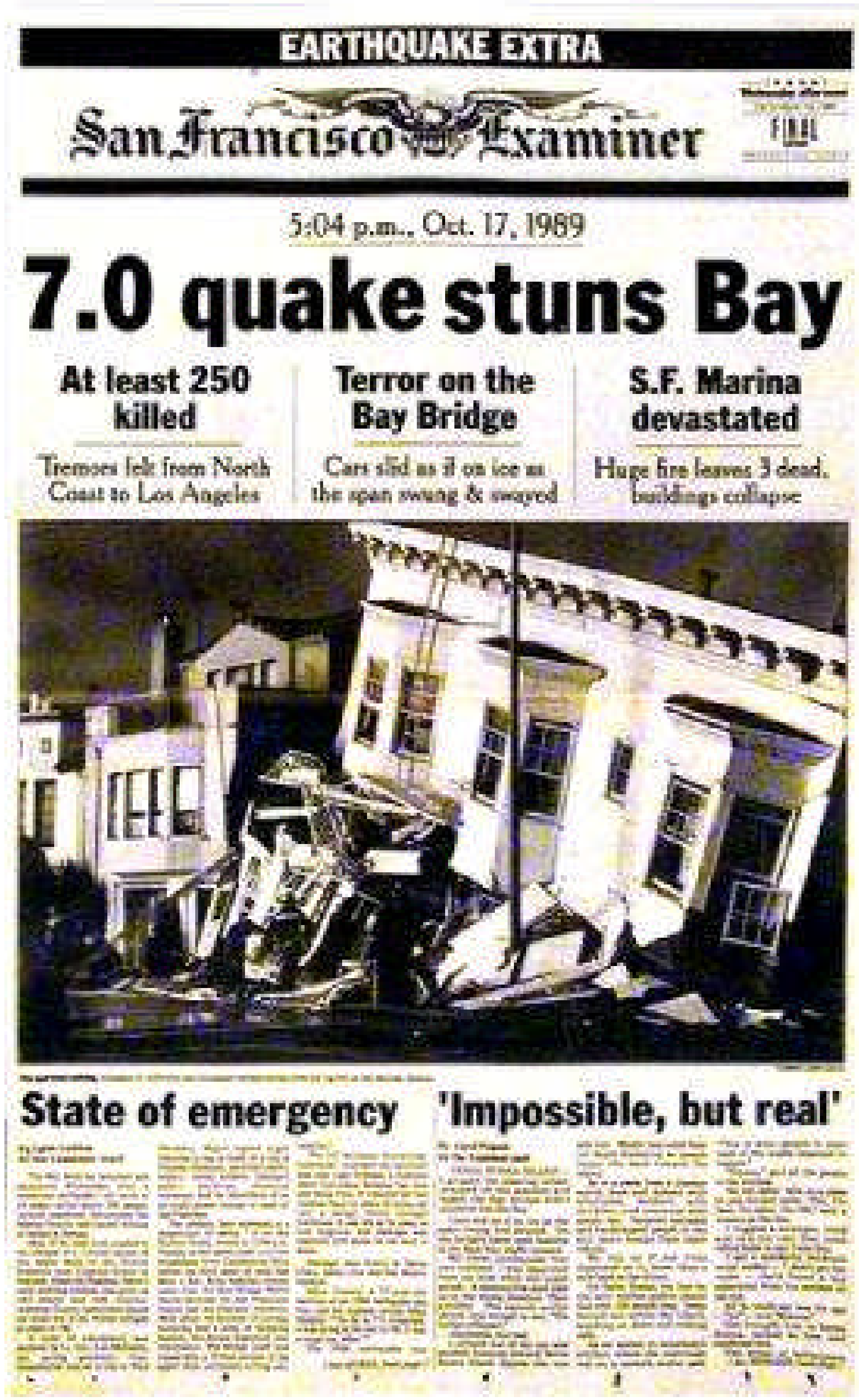
***Popular Mechanics*, July 1933**

<u>Above</u>: caption: "Seismicity of the United States." About half of the states and territories in the U.S. (more than 109 million people and 4.3 million businesses) and most of the other populous regions of the earth are exposed to risks from seismic hazards. In the U.S. alone, the average direct cost of earthquake damage is estimated at $1 billion per year while indirect business losses are estimated to exceed $2 billion per year.

Part 3

The Land of Fruit & Nuts

Their Lives Will Never Be the Same



EARTHQUAKE EXTRA

San Francisco Examiner

FINAL

5:04 p.m., Oct. 17, 1989

7.0 quake stuns Bay

At least 250 killed

Tremors felt from North Coast to Los Angeles

Terror on the Bay Bridge

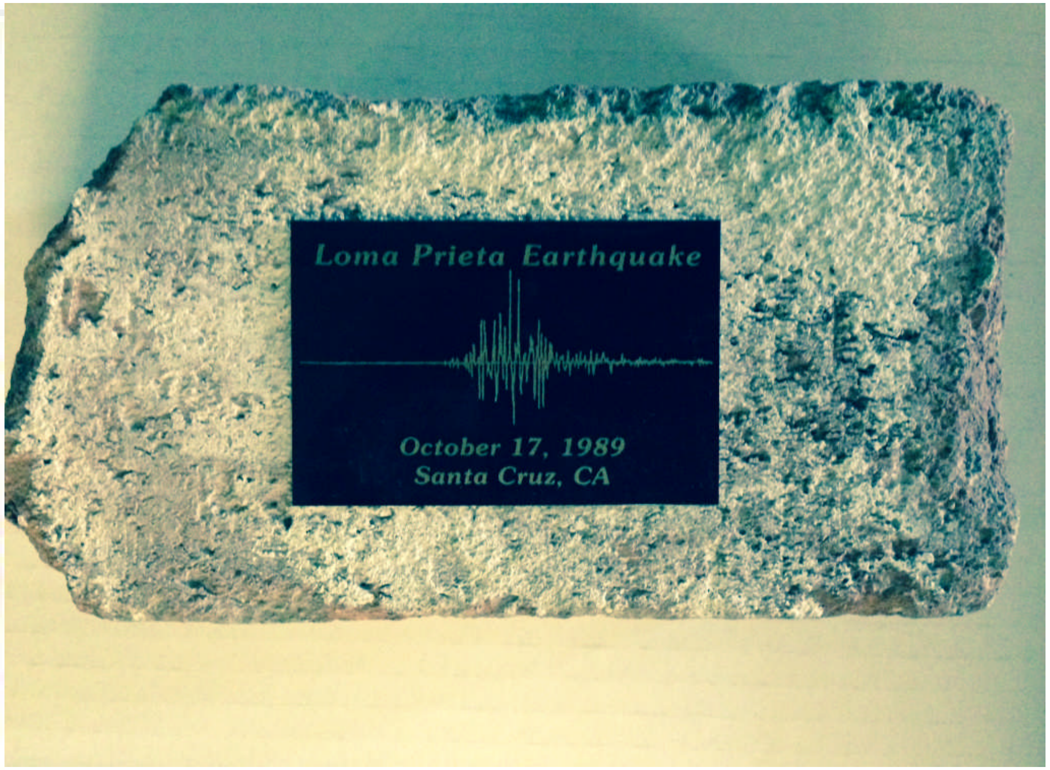
Cars slid as if on ice as the span swung & swayed

S.F. Marina devastated

Huge fire leaves 3 dead, buildings collapse

State of emergency

'Impossible, but real'



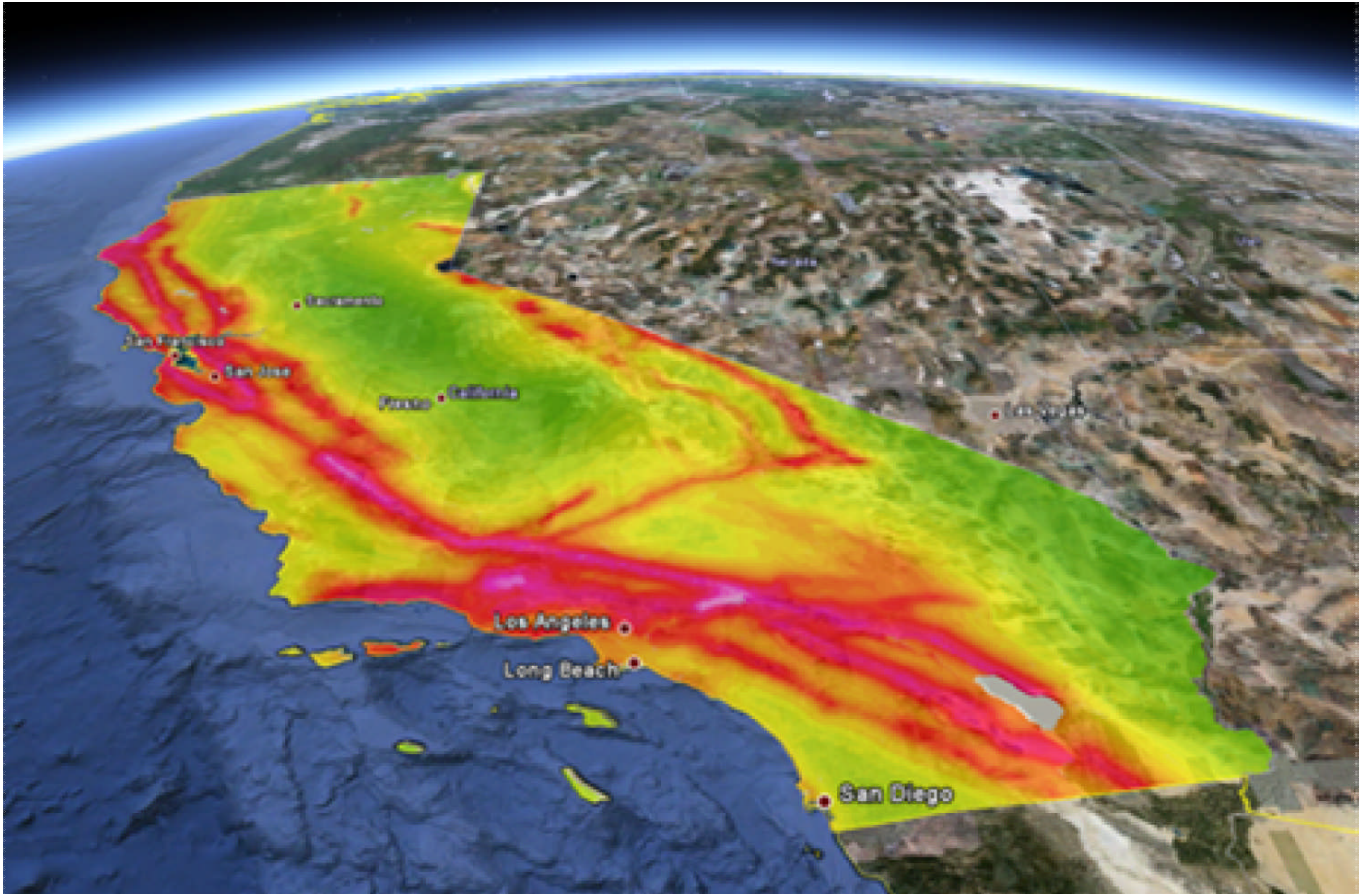
"Those who survived the San Francisco earthquake said, 'Thank God, I'm still alive.' But, of course, those who died, their lives will never be the same again."

Barbara Boxer, U.S. Senator for California

RE: _Loma Prieta Earthquake_ – October 17th 1989

<u>Above</u>: caption: "Brick salvaged in downtown Santa Cruz, after the Loma Prieta Earthquake"

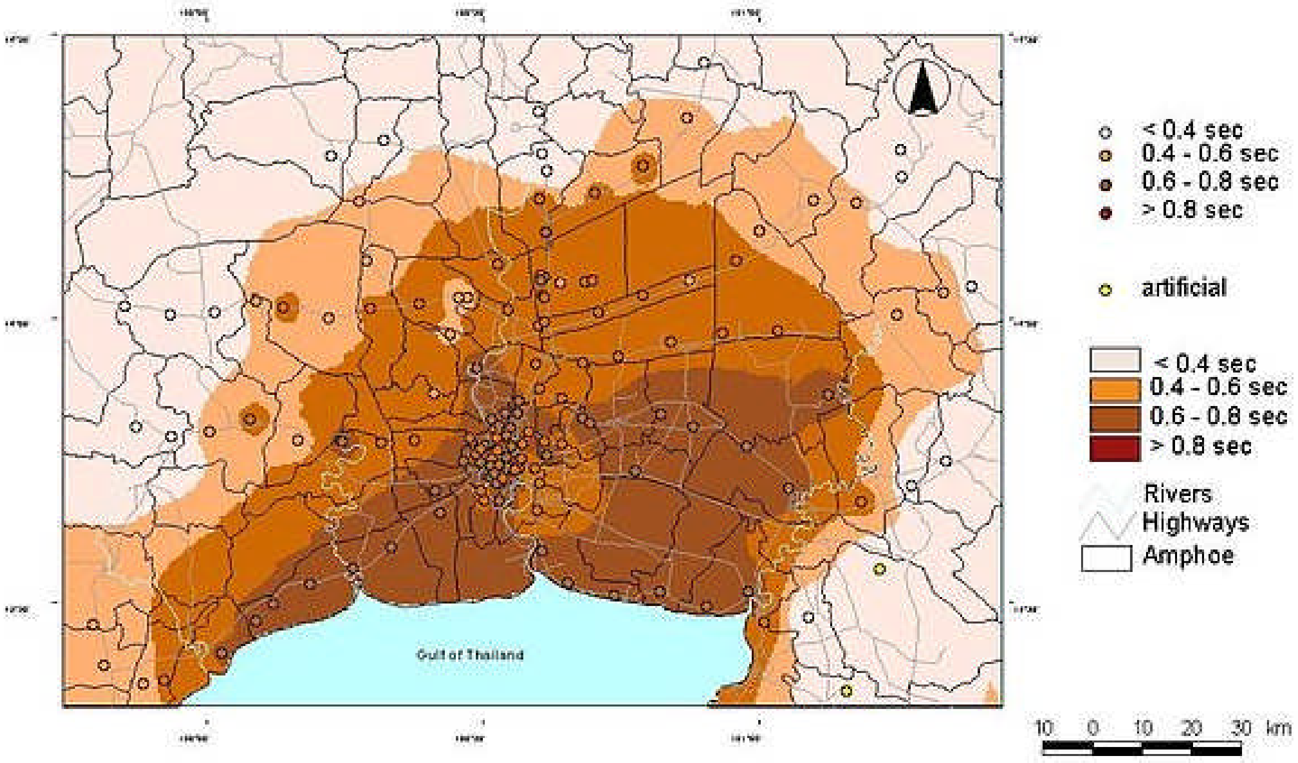
<u>Left</u>: caption: "Front page of the San Francisco Examiner, Oct. 18, 1989. Like just about everyone else, we grossly overstated the Loma Prieta death toll."



Above: caption: “California Earthquake Potential Map”

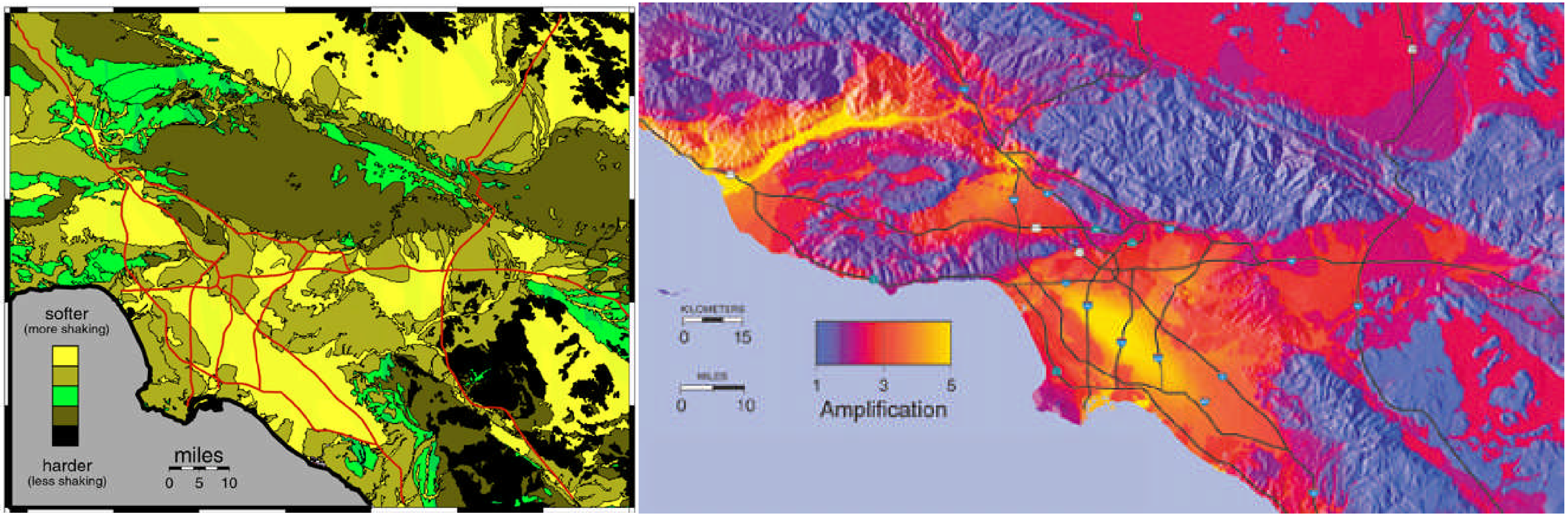
Microzonation

Seismic Microzonation **is defined as the process of sub-dividing a potential seismic or earthquake prone area into zones with respect to some geological and geophysical characteristics of the sites such as ground shaking, liquefaction susceptibility, landslide and rock fall hazard and/or earthquake-related flooding so that seismic hazards at different locations within the area can correctly be identified. Microzonation provides the basis for site-specific risk analysis which assists in the mitigation of earthquake damage. In general terms, seismic microzonation is the process of estimating the response of soil layers under earthquake excitations and thus, the variation of earthquake characteristics on the ground surface.**



Regional geology can have a great effect on the characteristics of ground motion. The site response of the ground motion may vary in different locations of an urban environment according to the local geology. A seismic zonation map for a whole country may, therefore, be inadequate for detailed seismic hazard assessment of cities. This necessitated the development of microzonation maps for big cities for detailed seismic hazard analysis (example above). Microzonation maps can/do serve as a basis for evaluating site-specific risk analysis, which is essential for critical structures like nuclear power plants, subways, bridges, elevated highways and/or dam sites.

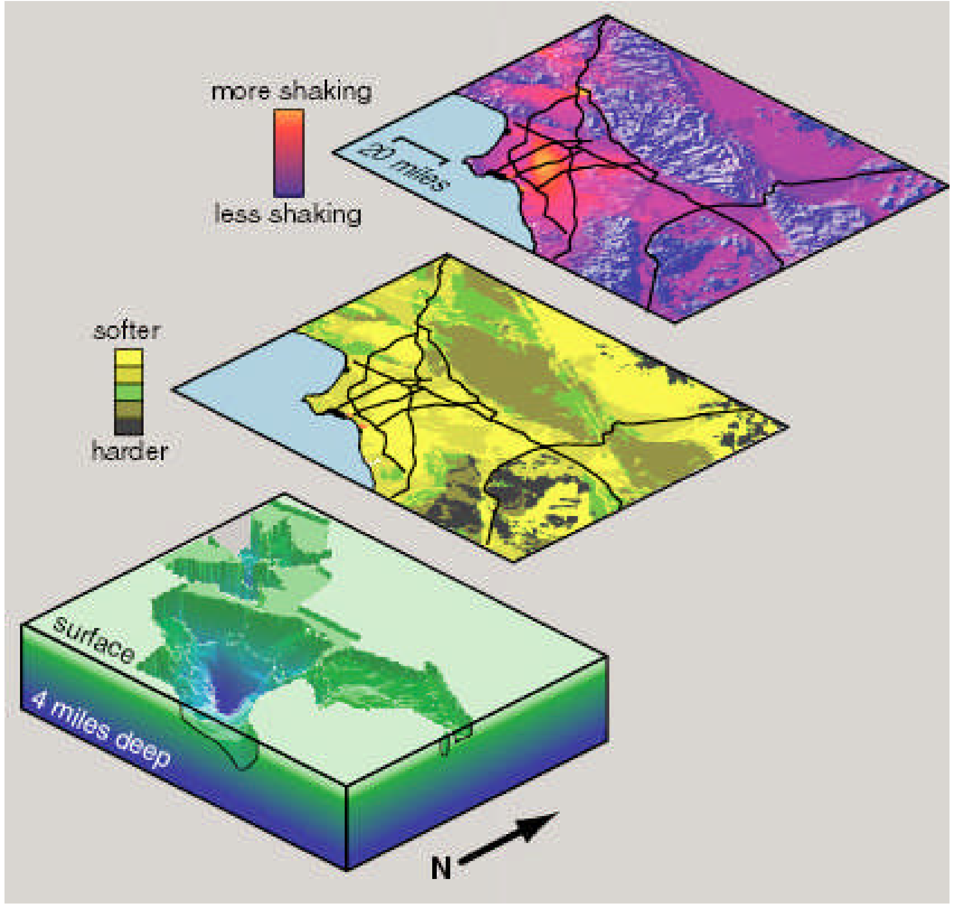
Seismic microzonation can be considered as the preliminary phase of earthquake risk mitigation studies. It requires multi-disciplinary contributions as well as comprehensive understanding of the effects of earthquake generated ground motions on man-made structures. Many large cities around the world have put great effort into developing microzonation maps for a better understanding of earthquake hazard/s within urban environments.



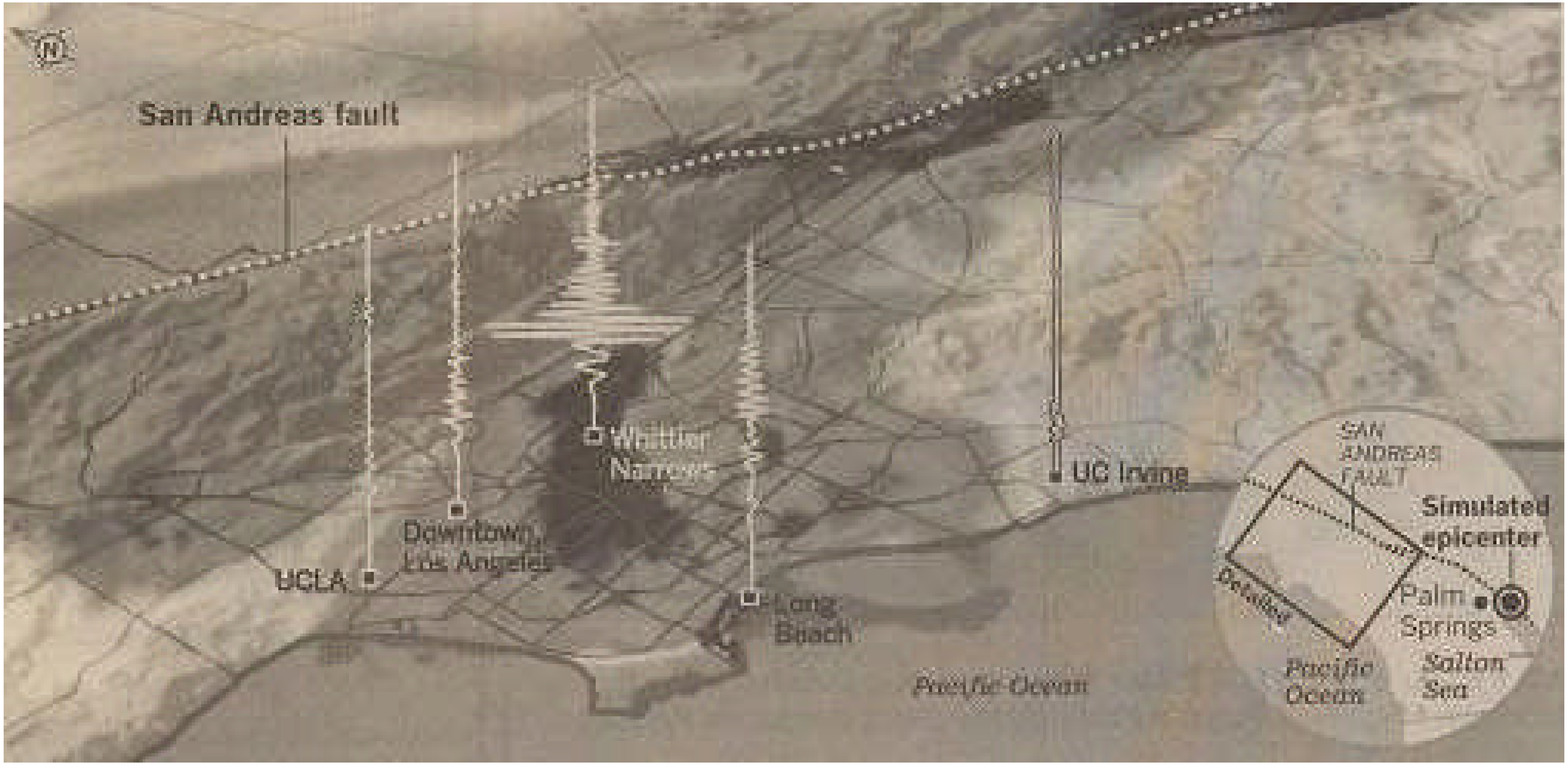
"…The Los Angeles area has been similarly mapped and today the UCLA Earthquake Engineering Laboratory is doing research that may lead to a precise formula for determining the relative safety of any building site. If this can be done, the stringency of building codes would be increased or decreased for any particular parcel of land, depending on how its surface and sub-surface strata react during a quake…"

***Popular Mechanics,* July 1964**

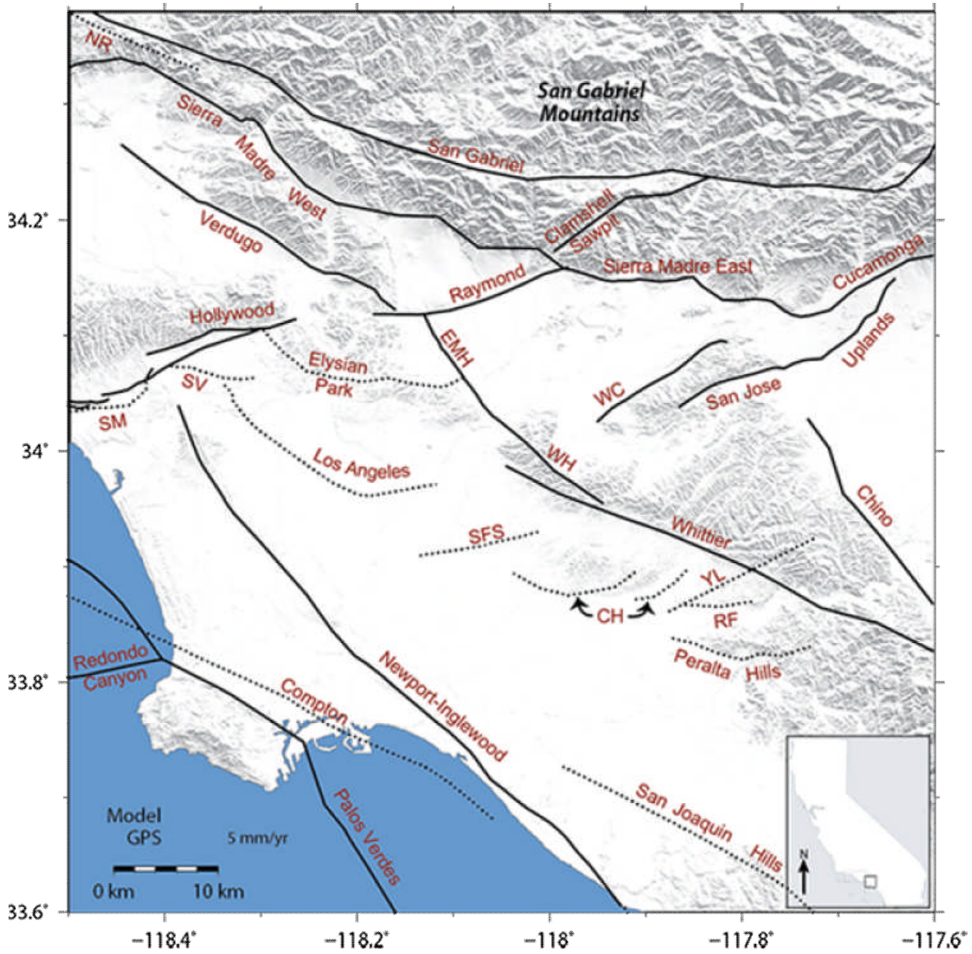
<u>Above L&R</u>: Geology Map (left) and Amplification Map (right) of the *Los Angeles Basin*



<u>Left</u>: caption: “Two important local geologic factors that affect the level of shaking experienced in earthquakes are (1) the softness of the surface rocks and (2) the thickness of surface sediments. In these images of the Los Angeles region, the lowest layer shows the depth of sedimentary basins, and the middle layer shows the softness of near-surface rocks and sediments. The top layer combines this information to predict the total amplification expected in future earthquakes from local geologic conditions or ‘site effects.’ The orange areas are the ‘hotspots’ where this amplification is anticipated to be highest.”



Above: analysis of the magnitude 5.9 *Whittier Earthquake* on October 1st 1987 led to the discovery of a previously undetected blind thrust fault and caused a paradigm shift in *Los Angeles Basin* tectonic studies. The quake claimed eight lives and caused property damage in the hundreds of millions of dollars. The most severe damage was in Uptown Whittier. More than 10K residential and commercial structures were damaged. A study by the *Southern California Earthquake Center* (SCEC) - a consortium of fifteen prestigious core institutions headquartered at USC, suggested much worse to come for the *Whittier Narrows*. The *San Andreas Fault*, not the beach tens of miles to the south or west, demarcates the ever-clashing Pacific and Continental tectonic plates. One of the SCEC program objectives is to pinpoint the degree of shaking that would take place in areas as precise as a block by following earthquake waves from the San Andreas Fault through the different basin soils. Waves from earthquakes along the San Andreas Fault are effectively funneled into the LA Basin's valleys, much like flood water.



<u>Left</u>: caption: “Map showing approximate locations of active fault traces (black lines) of the greater Los Angeles region. Note the complexity and discontinuous nature of the fault structure. The upper tips of blind faults are indicated by black dashed lines. Fault abbreviations are as follows: EMH = East Montebello Hills, CH = Coyote Hills, NR = Northridge, RF = Richfield, SFS = Santa Fe Springs, SM = Santa Monica, SV = San Vicente, WC = Walnut Creek, and YL= Yorba Linda.”

On-the-Spot

“…The city has a separate auxiliary water supply system that includes 100,000-gallon underground cisterns at street intersections every four blocks throughout the downtown area. Fire-department pumpers can lower a suction line into a manhole at any of these locations and get on-the-spot water. The auxiliary system also includes a network of high-strength pipe that carries water at 150 pounds per square inch, delivered to its own special hydrants from its own separate reservoirs. Also, big pumping stations on the waterfront can pump sea water into the system from two different locations…”

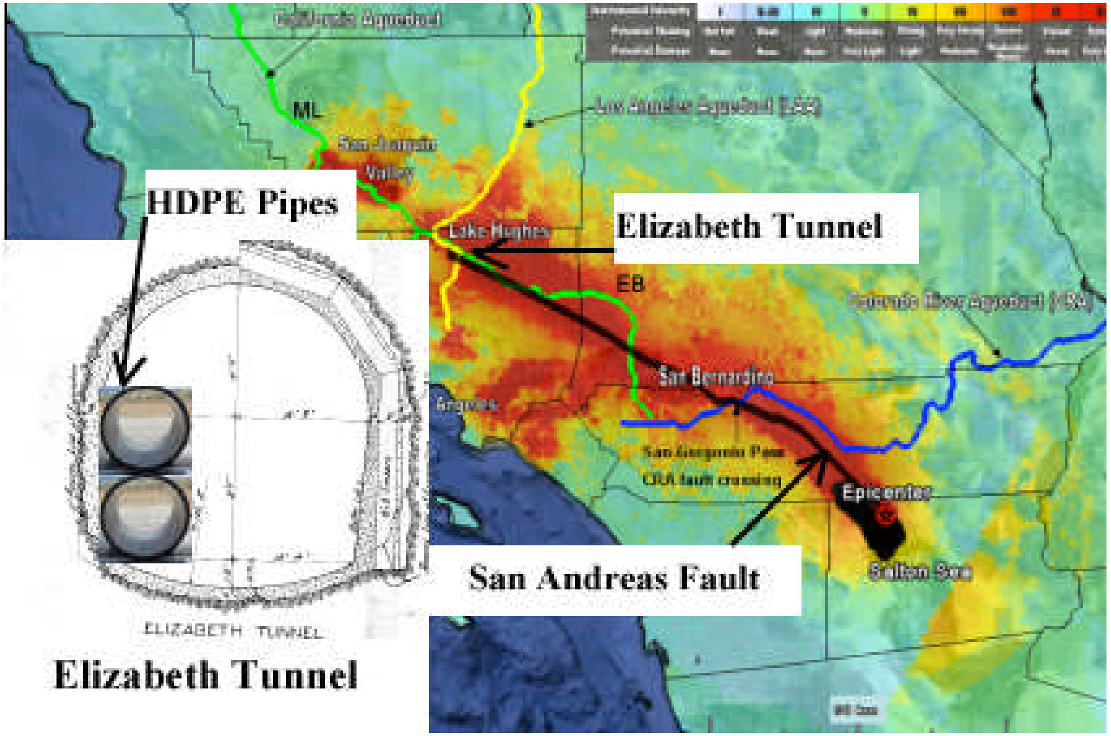
***Popular Mechanics*, July 1964**

Bend, Don’t Break

“It was stunning. Lateral spreading and settlements exceeded two meters for the segmental pipelines, but they didn’t have to replace or repair the polyethylene pipes.”

Thomas O’Rourke

RE: O’Rourke, a professor at *Cornell University*, found that medium and high-density polyethylene pipelines (MDPE and HDPE) survive even when the earth liquefies and shifts. He and his colleagues at Cornell and *<u>R</u>ensselaer <u>P</u>olytechnic <u>I</u>nstitute* (RPI) proved it using a lab at Cornell and a centrifuge at RPI, both part of the *<u>N</u>etwork for <u>E</u>arthquake <u>E</u>ngineering <u>S</u>imulation* (NEES). In Christchurch, New Zealand, which suffered a series of devastating earthquakes in 2010-2011, just 2.5 kilometers of polyethylene pipe was grudgingly installed as a test while more conventional pipe was used for the rest of the repairs. When two earthquakes hit (displacing 2 to 3-meters of earth) the standard segmental pipelines were destroyed, but all of the polyethylene conduits held. Polyethylene pipelines are made by thermo-welding lengths of pipe together to form a continuous pipeline. Segmental pipelines have couplings or joints. The pipe at the joints is often not restrained from pullout under tension. Thus, the joints are generally weaker in bending and tension than a continuous pipeline of the same material.



<u>Above</u>: **building on NEES test results and the favorable Christchurch pipeline performance, in early 2013 the *Los Angeles Department of Water and Power* began preparations to install HDPE pipelines in the *Elizabeth Tunnel*, which carries *Los Angeles Aqueduct* water across the *San Andreas Fault*, providing half of LA's water supply. It will significantly increase the likelihood that water - the most important resource after an earthquake - will be available to 4 million people. The tunnel is approximately 3-meters wide and water moves by gravity flow. The new pipes will provide an auxiliary water supply, conveying water even when the tunnel is virtually cut-off or collapsed (pumps can be added to increase flow). More than 2.5 miles of the 30-foot diameter pipeline will be installed about 2K-feet at a time over an eight-year period, necessitating about a one-month shut-down each time.**

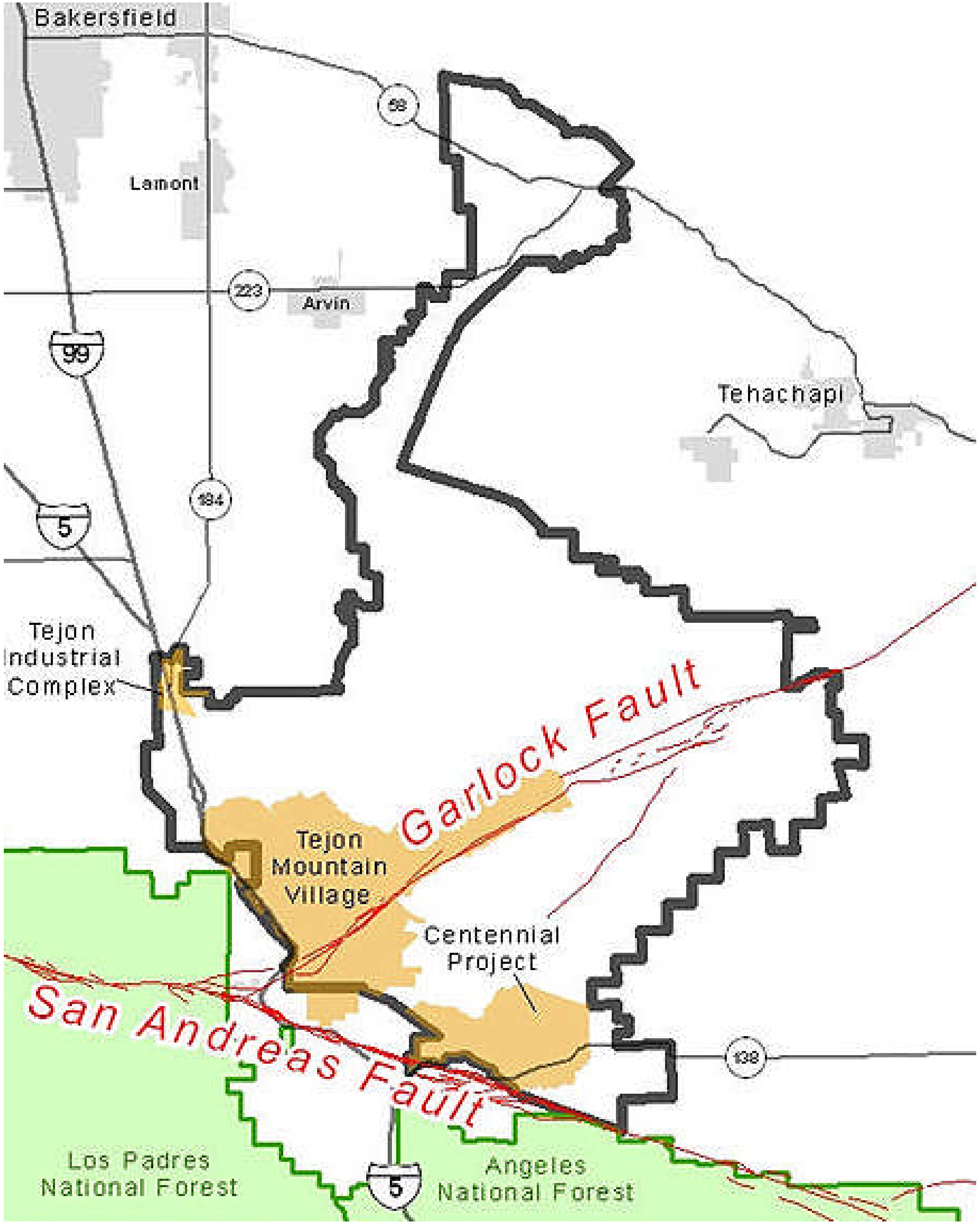
Working Around the Problem

“…All big engineering projects in California have to be designed with a major shake in mind. Aqueducts have gates at frequent intervals so that a portion damaged in a quake can be blocked off and repaired rapidly…”

***Popular Mechanics,* July 1964**

“…In running a pilot tunnel through part of the Tehachapi Mountains for the aqueduct that is to carry Feather River water to southern California state engineers suddenly found that they were in the Garlock fault zone, a main offshoot of the San Andreas. The solid rock ended abruptly in a zone of moist, crushed rock. The engineers drilled ahead, supporting the roof with 8x8 timbers, then found the timbers smashed and crushed over a weekend. The zone extends for over 500 feet and now the engineers are designing an expensive steel-rib tunnel, with heavy steel lagging joining each rib, and that will be lined with concrete, to carry the water through this unstable area…”

***Popular Mechanics,* July 1964**



Left: caption: “The Garlock Fault, the second largest in California, applies monumental pressure on the largest fault in California, the San Andreas, causing it to bulge towards the west in what geologists call the ‘Big Bend.’ The Big Bend gives rise to the transverse ranges of southern California by jamming rocks together that have no place else to go except up.”

Too Close for Comfort

“…People in the Bodega Bay area north of San Francisco are protesting against plans to build a big nuclear power plant there. It’s pointed out that the site is close to the San Andreas fault and that atomic poison might be spewed over the whole area if the plant should be shattered…”

***Popular Mechanics,* July 1964**

"…Farther south, Stanford University is building a $114 million, two-mile long linear electron accelerator (an atom smasher) within 3,000 feet of the San Andreas fault, which slants across the campus. Other sites as far as 25 miles away were found to be less suitable. The accelerator is to be contained in a monolithic concrete tunnel at the bottom of a trench and will be buried under 25 feet of earth. Because of its proximity to the fault zone the tunnel is designed as a hollow beam (with plenty of steel) and is intended to bend in a quake instead of breaking at an angle. This would allow realignment of the accelerator, which must be kept straight to within plus or minus a quarter of an inch over its 10,000 feet of length…"

***Popular Mechanics,* July 1964**

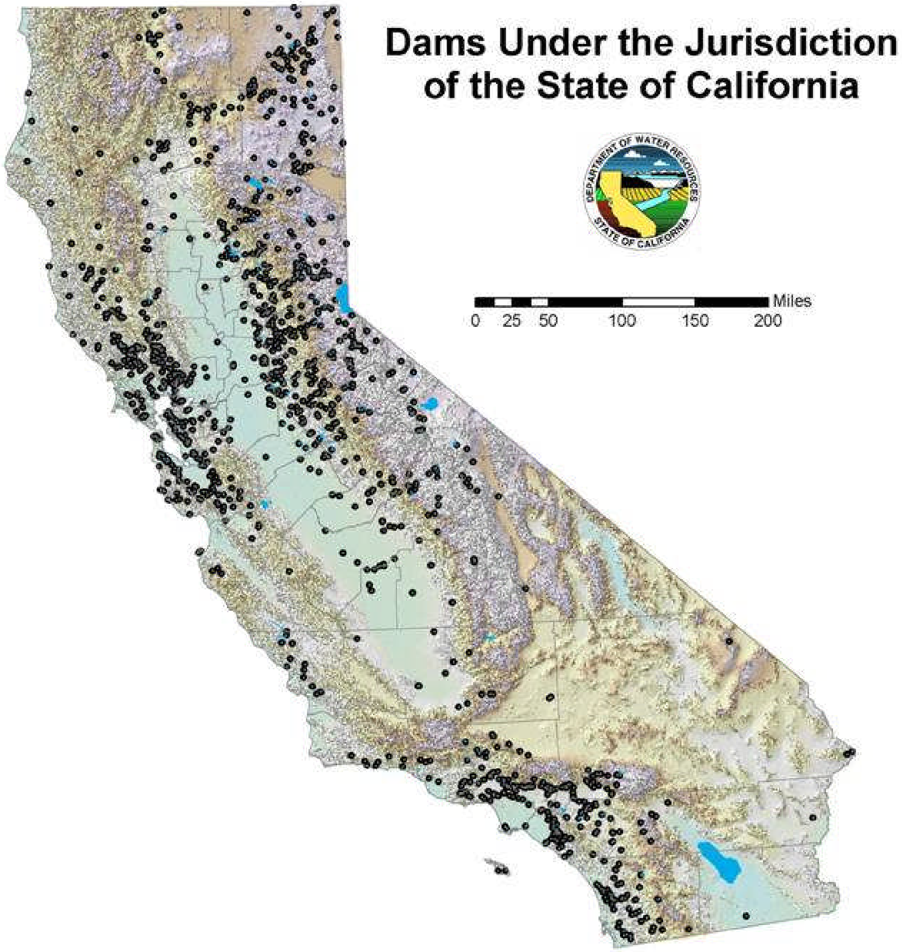
Left: caption: "Aerial photo of the Stanford Linear Accelerator Center (SLAC)"

"…An offset in a fence line near San Francisco had shown more than eight feet of lateral movement along the fault. Bulldozers smoothed over the surface of the fault so a housing development could be built on the land. But the San Andreas fault is still there, beneath the new houses, and is very similar to the North Anatolia fault responsible for the disastrous earthquake of Aug. 19, 1966, near Varto, Turkey…"

***Popular Mechanics*, June 1967**

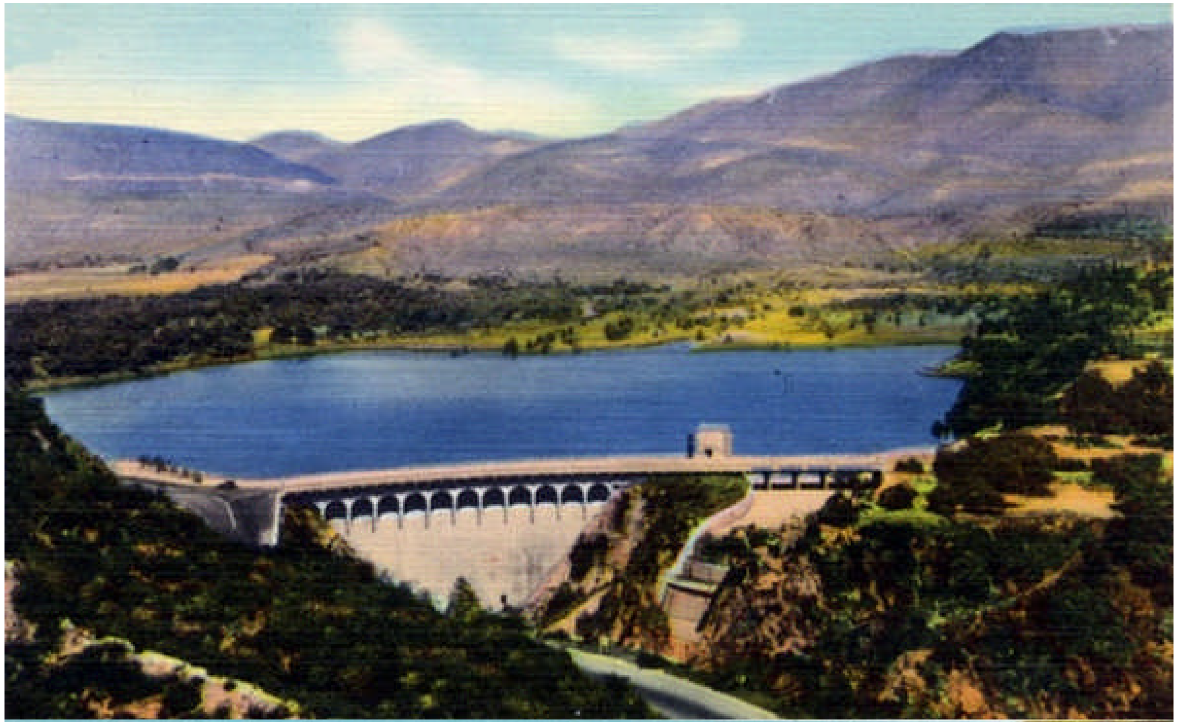
Left: caption: "Turkey Earthquake Aug. 19, 1966. Collapse of a bank building."

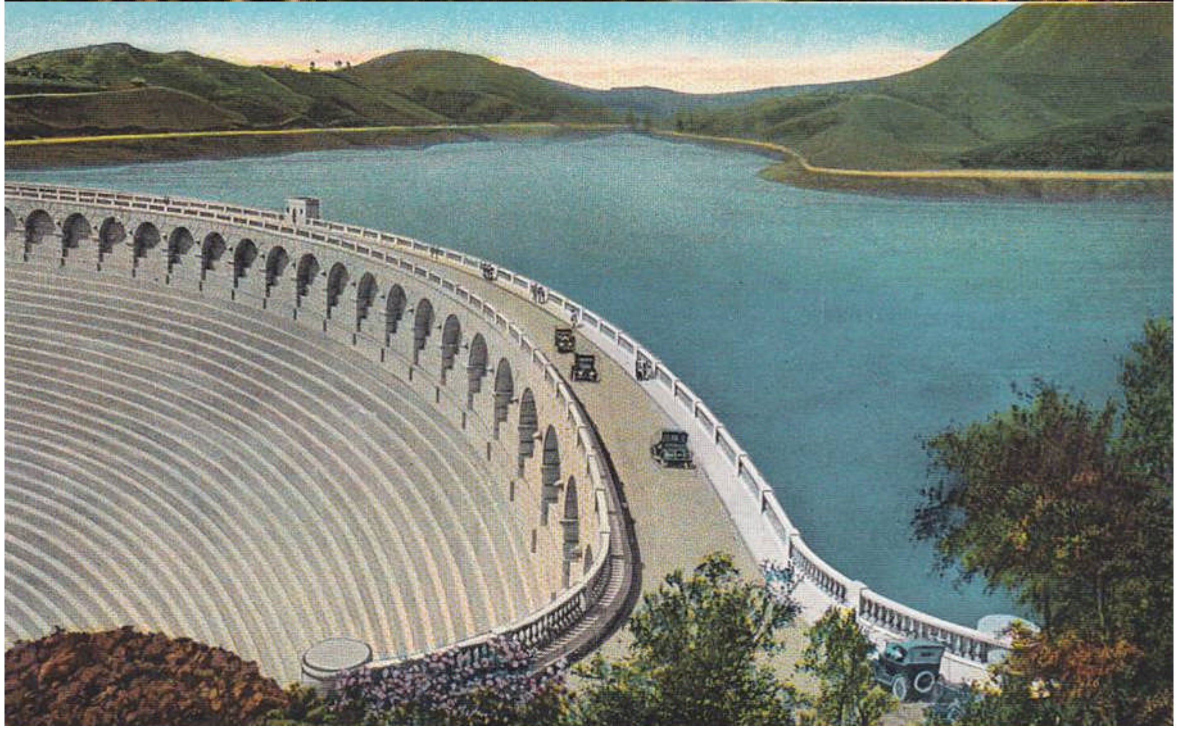
A Very Good Question



"…California has more than 1,000 dams and many of them are up-stream from centers of population. How they will behave during a major earthquake is a very good question indeed. They represent all types, from earth or rock fills to concrete arches, from timbered cribs to concrete gravity dams. A few are almost a century old, and half were built before passage of the state law that requires state engineering approval of site, specifications and construction…"

***Popular Mechanics*, July 1964**





"…As a consequence, Harold Brown, state dam safety engineer, now requires careful inspection at least once a year of all structures that hold back water. A few dams have been ordered out of service. Others have been strengthened or completely rebuilt. If there's a question of the safety of a concrete arch dam, for example, hundreds or thousands of yards of rock are compacted against its downstream face. The original dam becomes a mere concrete facing…"

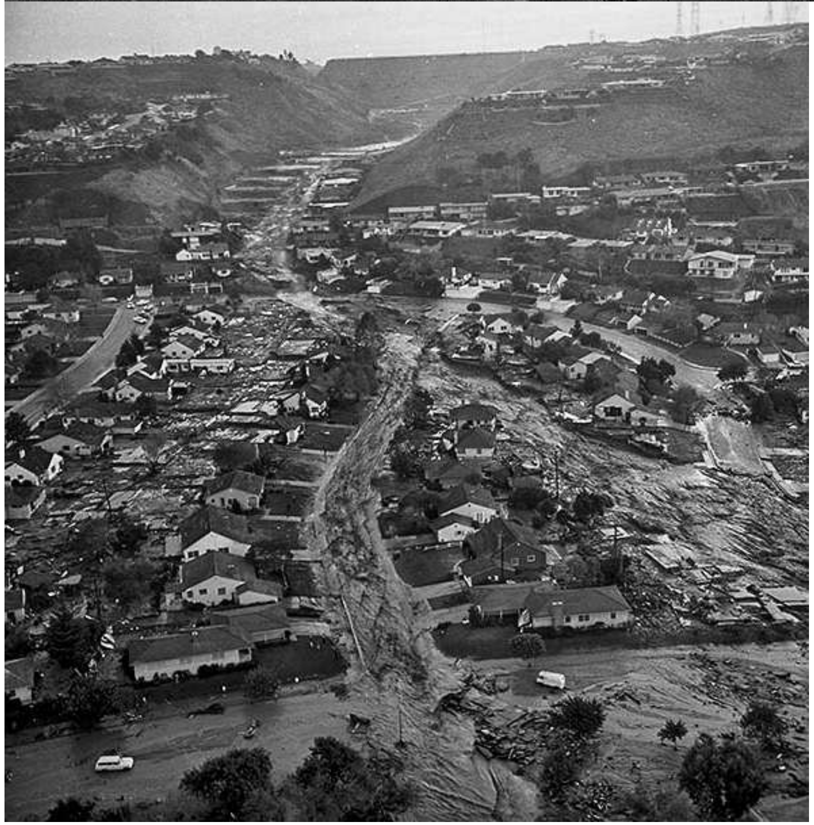
***Popular Mechanics,* July 1964**

<u>Top</u>: caption: "Devil's Gate Dam, Pasadena, California"

<u>Bottom</u>: caption: "Mulholland Dam, Hollywood Reservoir"

“…In the 1925 Santa Barbara earthquake the earthen Sheffield dam failed, but fortunately it was above an untenanted area. Ironically, the 40-foot tall earth-fill San Andreas dam near San Francisco was twisted in 1906 but did not fail. In the 1952 Tehachapi quake a number of dams were damaged, but none failed…”

***Popular Mechanics,* July 1964**



“…Insurance adjustors are quarreling over the reasons why the Baldwin Hills dam in Los Angeles failed last fall, though most geologists attribute the failure to slow earth movements with possible assist in subsidence in a nearby oil field…”

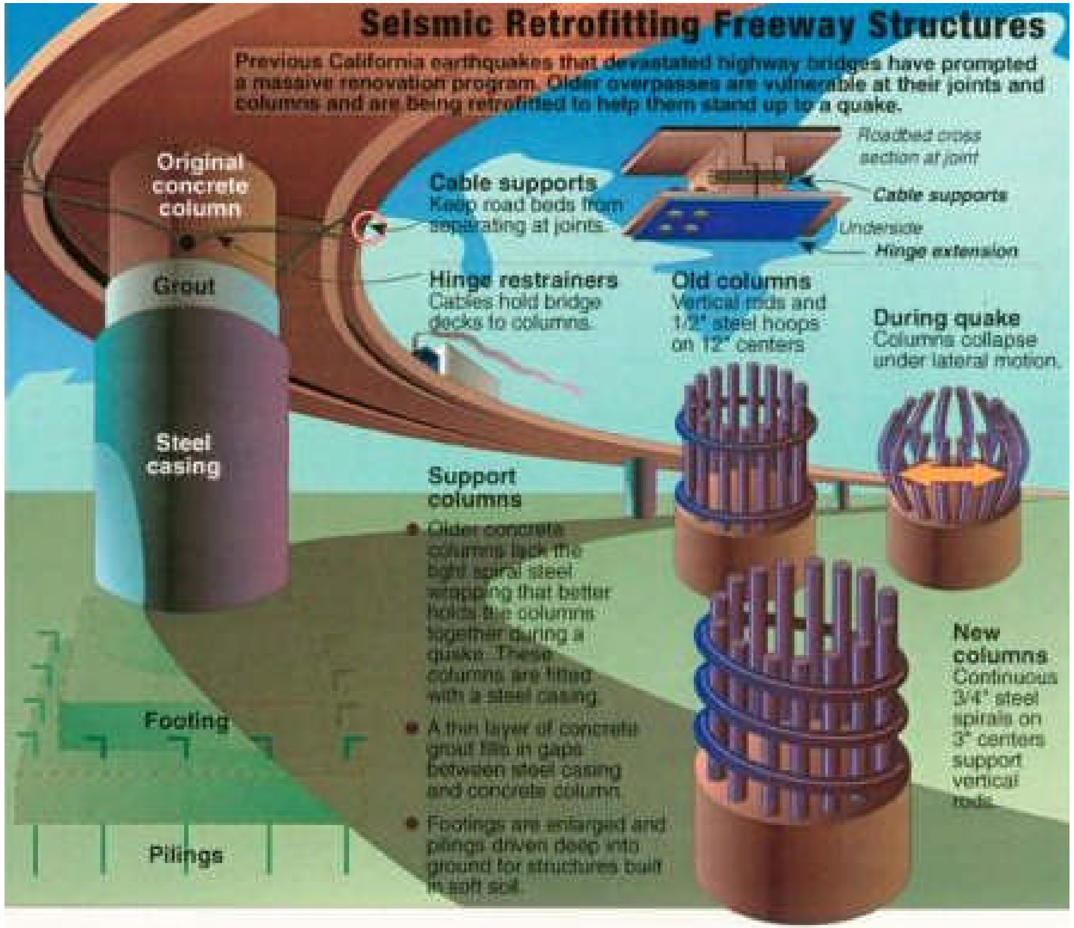
***Popular Mechanics,* July 1964**

<u>Above & Left</u>: on December 14th 1963, the failure of the *Baldwin Hills Reservoir Dam* unleashed a giant wall of water that surged north, killing five people and destroying everything in its path

Northridge

“…the earthquake’s epicenter was 14 miles away in the San Fernando Valley town of Northridge. Magnitude 6.8 on the Richter scale…Already famously overburdened, the freeway network lost six major bridges…Working around the clock, crews are repairing and replacing bridges in an emergency program that will cost approximately $800 million. All six of the spans that fell had been scheduled for major improvements. Bridges that had been recently retrofitted stood up to the Northridge quake…”

***Popular Science*, May 1994**



Seismic Retrofitting Freeway Structures

Previous California earthquakes that devastated highway bridges have prompted a massive renovation program. Older overpasses are vulnerable at their joints and columns and are being retrofitted to help them stand up to a quake.

Cable supports Keep road beds from separating at joints.

Hinge restrainers Cables hold bridge decks to columns.

Old columns Vertical rods and 1/2" steel hoops on 12" centers

During quake Columns collapse under lateral motion.

Support columns

- Older concrete columns lack the tight spiral steel wrapping that better holds the columns together during a quake. These columns are fitted with a steel casing.
- A thin layer of concrete grout fills in gaps between steel casing and concrete column.
- Footings are enlarged and pilings driven deep into ground for structures built in soft soil.

New columns Continuous 3/4" steel spirals on 3" centers support vertical rods.

"…Caltrans, the state's transportation department, is under fire for moving slowly in spending money allocated for bridge improvements following the 6.4 Sylmar earthquake of 1971, which was centered not far from January's event. The retrofitting program includes strengthening concrete support columns by adding steel reinforcing jackets…"

***Popular Science,* May 1994**

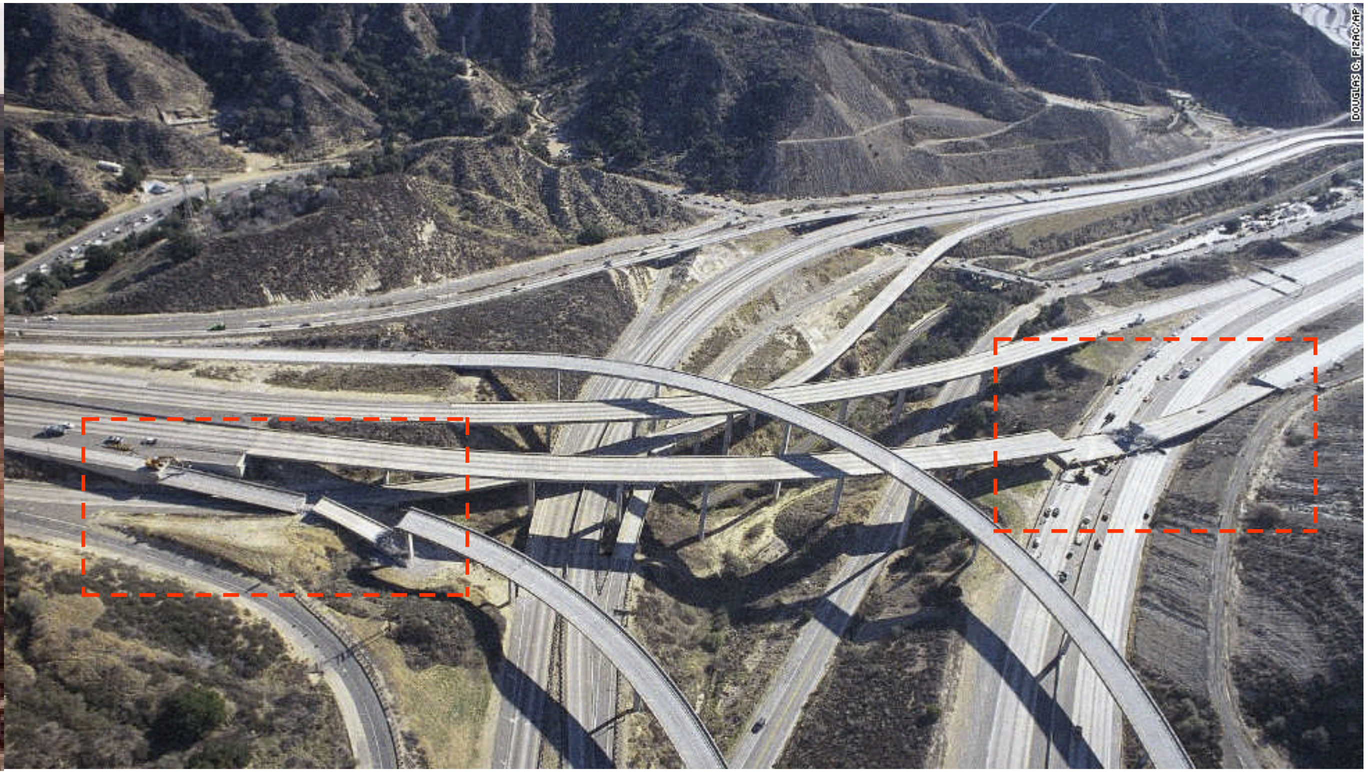
"…Most of the structural engineering lessons learned from the recent quakes involve redesigning these columns. New ones should be built using plenty of vertical internal steel reinforcing bars, generously wrapped with steel hoops. Tall, single-column supports with graceful flared tops function poorly, it turns out. The flares make the columns so stiff that they break rather than bend…"

Popular Science, **May 1994**

RE: the design of flared columns to resist earthquake-loading is a complex issue due to the changing cross-section along the column length. It was believed that, if the flares had low longitudinal and transverse reinforcement ratios, they would fail during earthquakes. Therefore, the column core would be the element remaining to resist the earthquake. Past earthquakes have demonstrated that flared columns are susceptible to premature shear failures. During the 1994 *Northridge Earthquake*, shear failures were caused by plastic hinge formation at the base of the flare and a subsequent increase in the level of column shear demand in excess of design tolerances.

Above: caption: “Collapsed section of westbound Santa Monica Freeway (I-10) between Venice Boulevard and LaCienega. Failure is attributed to pre-1971 column design. This structure was scheduled for column retrofitting in February 1994.”

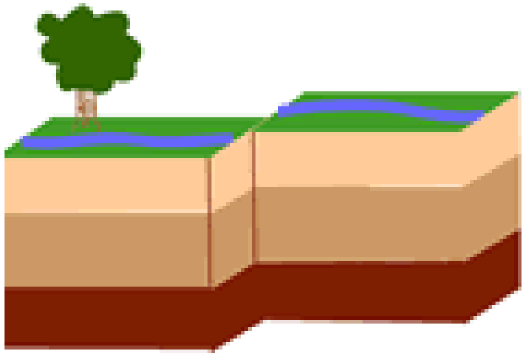
Left: caption: “Crushed column supporting the Santa Monica Freeway (I-10) near Venice Boulevard. Pre-1971 column designs did not provide sufficient concrete-core confinement and resulted in ‘birdcaging’ effect of steel reinforcement.”


DOUGLAS C. PIZAC/AP

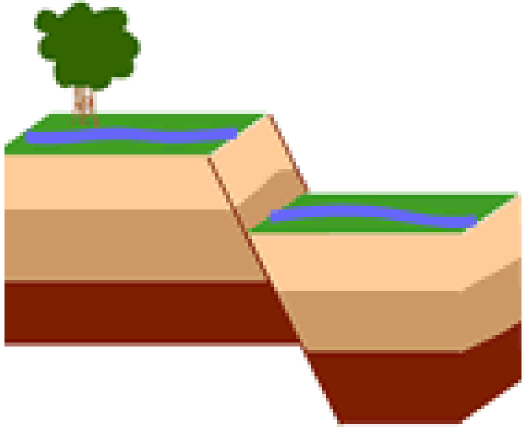
Above: caption: “Neighbors use a bucket brigade to fight the flames in the 11700 block of Balboa Boulevard in Granada Hills. The Northridge quake struck at 4:31 a.m. on Jan. 17, 1994. By the time the tremors had stopped, 57 people had lost their lives due to the magnitude 6.7-quake.”

Top Left: caption: “The body of LAPD Officer Clarence W. Dean lies near his motorcycle, which plunged off the 14 Freeway overpass that collapsed onto the 5 Freeway during the earthquake.”

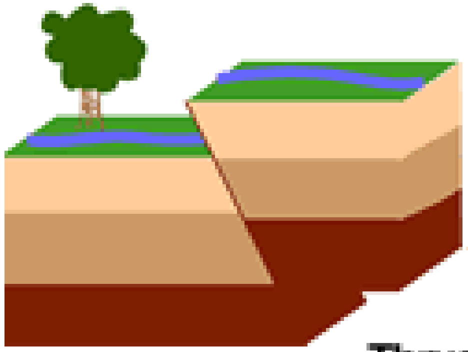
Bottom Left: caption: “A row of cars is crushed beneath a collapsed apt. building in Canoga Park”



Strike-slip



Normal

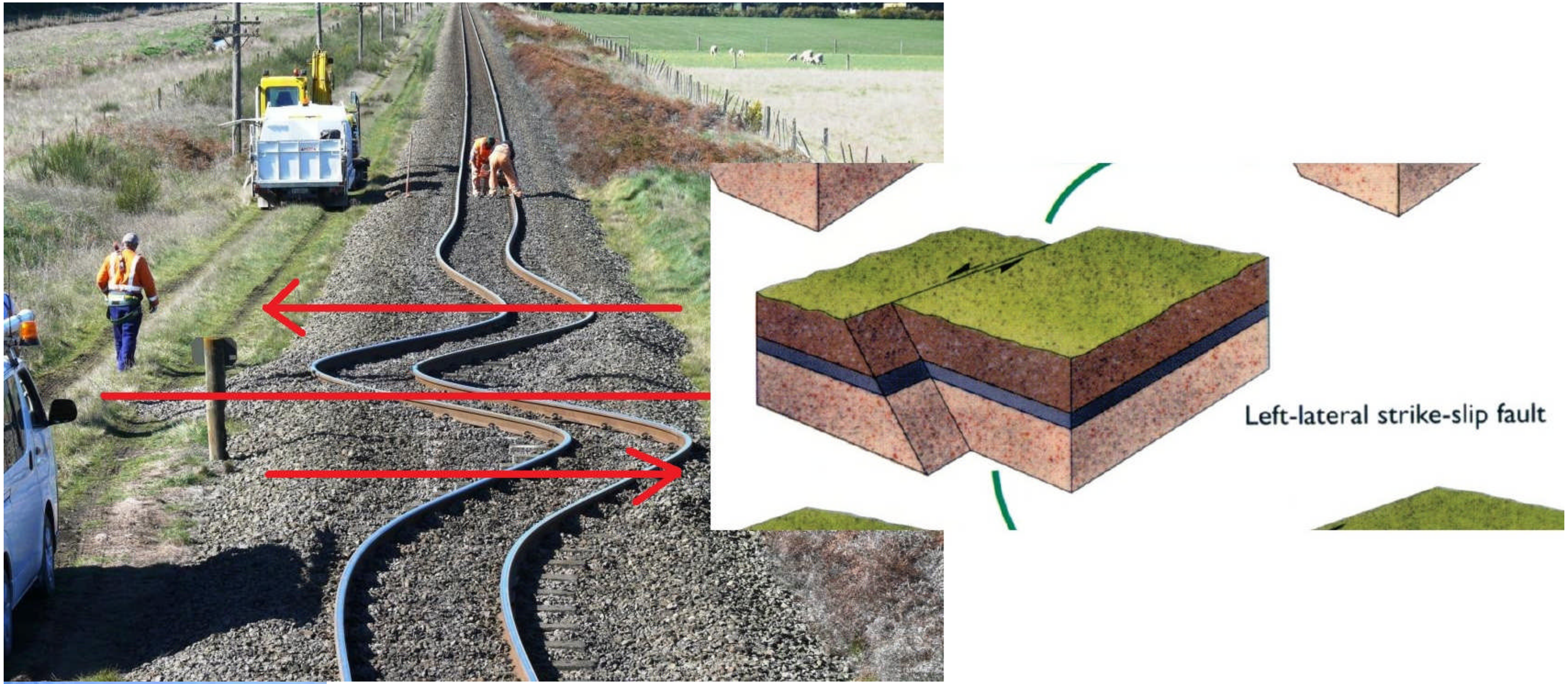


Thrust

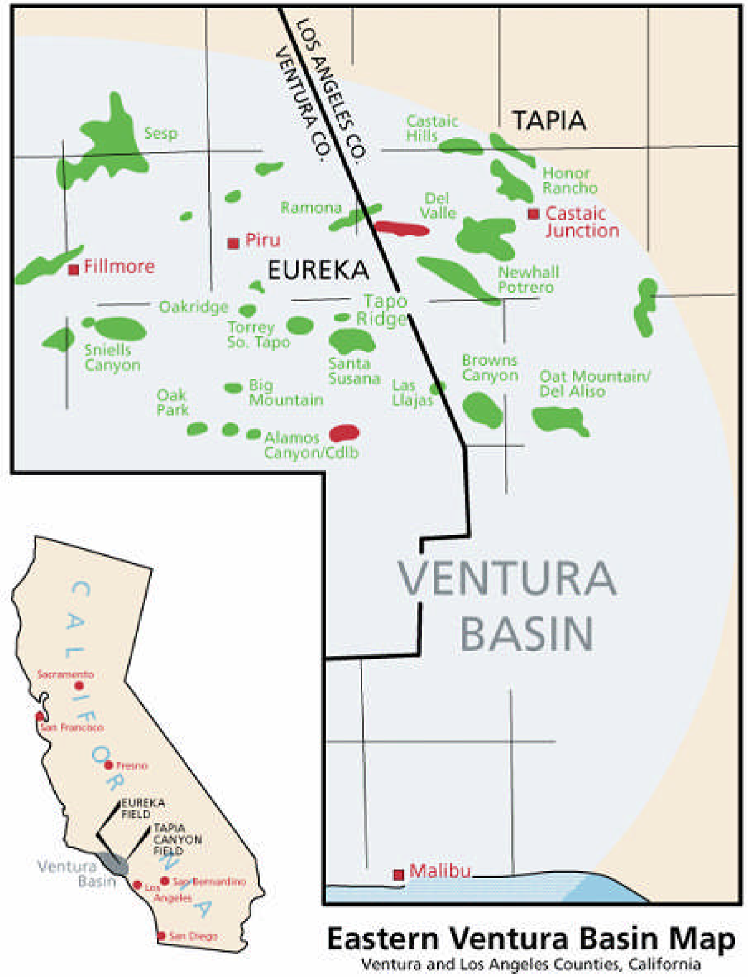
"…Southern California traditionally experienced strike-slip earthquakes, which produce lateral motions as sections of the earth's crust slide past each other in opposite directions. The Northridge quake, emanating from a blind, or hidden fault, instead hit the area with powerful vertical motions. It was a 'thrust' event, common in other parts of the world, caused by one section of crust riding up over its neighbor. The resulting shocks propagated through deep layers of sediment that amplified the seismic waves…"

Popular Science, **May 1994**

<u>Left</u>: *Strike-slip* faults are vertical (or nearly vertical) fractures where the blocks have mostly moved horizontally. If the block opposite an observer looking across the fault moves to the right, the slip-style is termed *right lateral*; if the block moves to the left, the motion is termed *left lateral*. *Normal* (a/k/a "Dip-slip") faults are inclined fractures where the blocks have mostly shifted vertically. If the rock mass above an inclined fault moves down, the fault is termed *normal*, whereas if the rock above the fault moves up, the fault is termed *reverse*. A *Thrust* fault is a reverse fault with a dip of 45-degrees or less.



__Above__: caption: “A magnitude-7.0 earthquake shook New Zealand on Sept. 4, 2010. The force of that quake bent about five kilometers of rail line.” New Zealand experiences frequent seismic activity because it sits on the plate boundary between the Pacific and Australian plates. Much of the displacement between these two plates occurs along the *Marlborough Fault System* (left), a complicated system that passes through New Zealand’s South Island. The Marlborough Fault System consists of four large strike-slip faults and other, smaller strike-slip and thrust faults.



Eastern Ventura Basin Map
Ventura and Los Angeles Counties, California

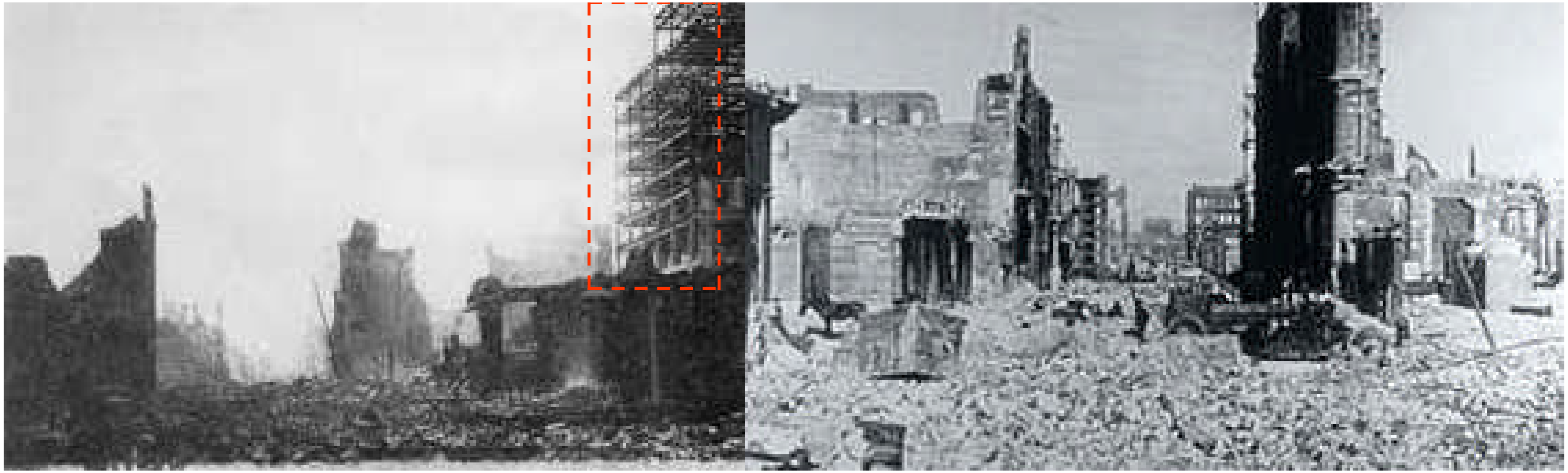
"…The quake occurred along a fault of the Ventura Basin, one of the deepest sedimentary basins on earth…This 9.3-mile deep geological feature stretches from the Pacific Ocean into the San Fernando Valley…last November a geophysicist at NASA's Jet Propulsion Laboratory predicted that the deep faults within the Ventura Basin might cause an earthquake with an approximate magnitude of 6.4…"

***Popular Science*, May 1994**

Richter 8-or-Higher

“…Many scientists at the United States Geological Survey estimate that when the next Richter 8-or-higher quake hits a populated area in California it will cause between 8,500 and 10,000 deaths, approximately 40,000 injuries and between $10 and $40 billion worth of property damage…”

Popular Mechanics, **January 1977**



“…Dr. Ray Clough, director of the Earthquake Engineering Research Center at the University of California – Berkeley, says that quake prediction is only half the battle. ‘We expect damage in an earthquake,’ he points out. ‘But what we’re endeavoring to learn is the way various types of structures and materials behave in earthquakes, and how they fail under the stress imposed on them. If we know these things, we can make buildings strong enough so they won’t collapse…”

Popular Mechanics, **January 1977**

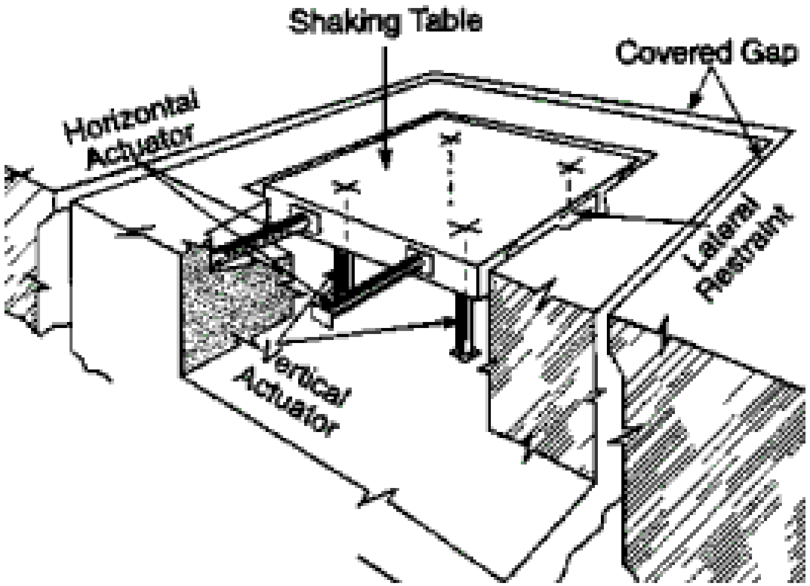
Left: caption: “O’Farrel Street. A new steel building which was being erected shown at the right.” During the April 1906 *San Francisco Earthquake*, masonry buildings suffered the most damage, causing many of the deaths and $400 million in property damage. In the photograph above, the steel-framed building is intact while all around it masonry buildings lay shattered and in ruins.

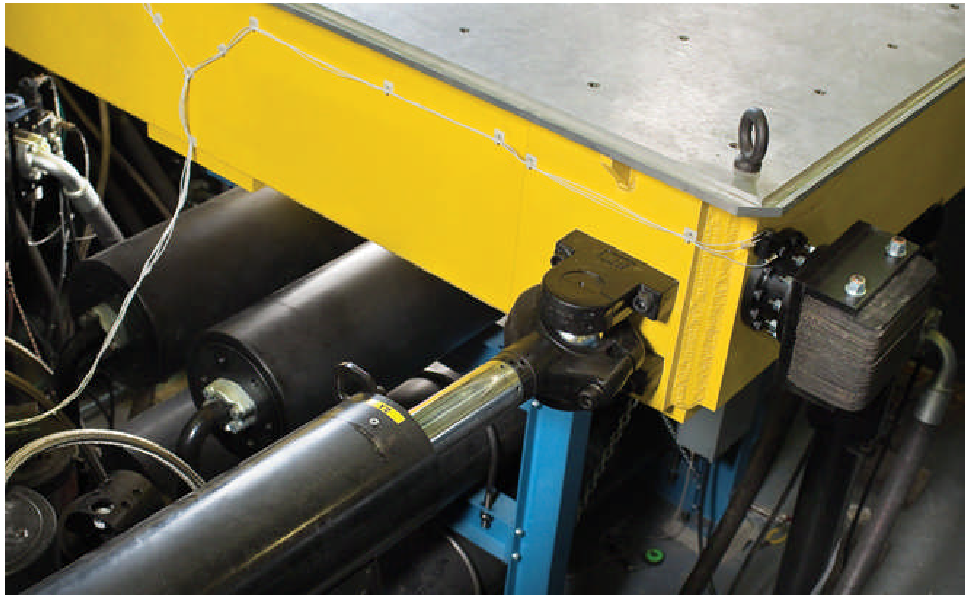
Right: caption: “The great earthquake of 1906 devastated San Francisco”

"…The Berkeley team (one of many working on this problem) is pursuing the answers in a cavernous laboratory that holds massive quake-simulating machines. The lab has one of the few large Universal Testing machines in the United States. It's used primarily for full-scale structural component testing and can apply 3 million pounds in tension and 4 million pounds in compression to sample building sections…"

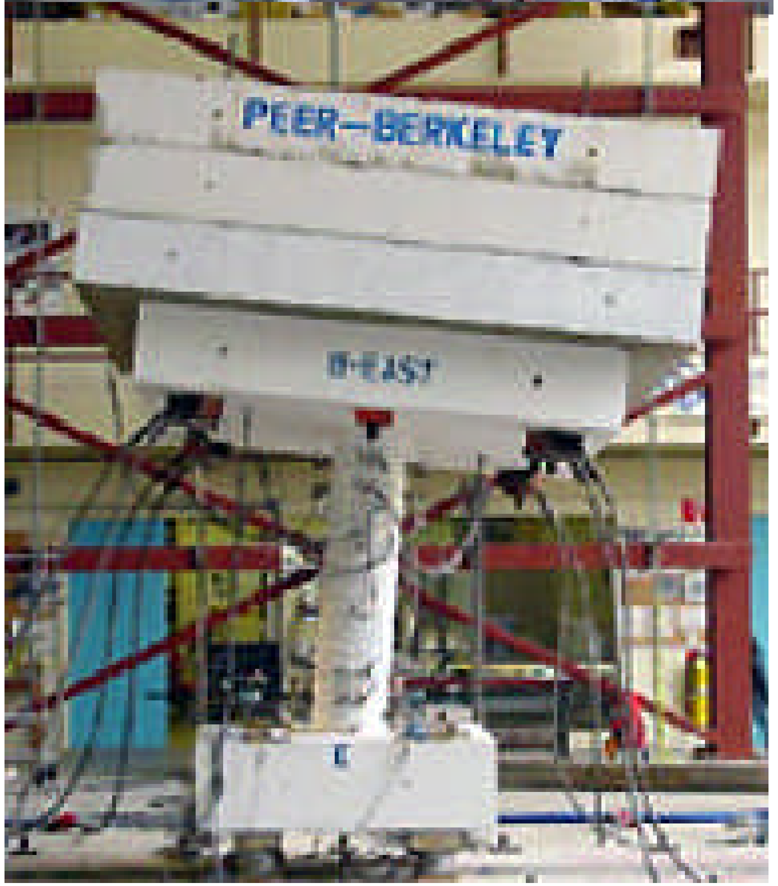
Popular Mechanics, January 1977

Left: caption: "Shake Table Testing of Friction Pendulum System. The objectives of this research program center around the verification of anticipated seismic performance of double- and triple-concave Friction Pendulum (FP) bearings and the validation of nonlinear analytical models and solution algorithms employed by commercially available structural analysis software to predict observable response quantities (June-July 2006)"



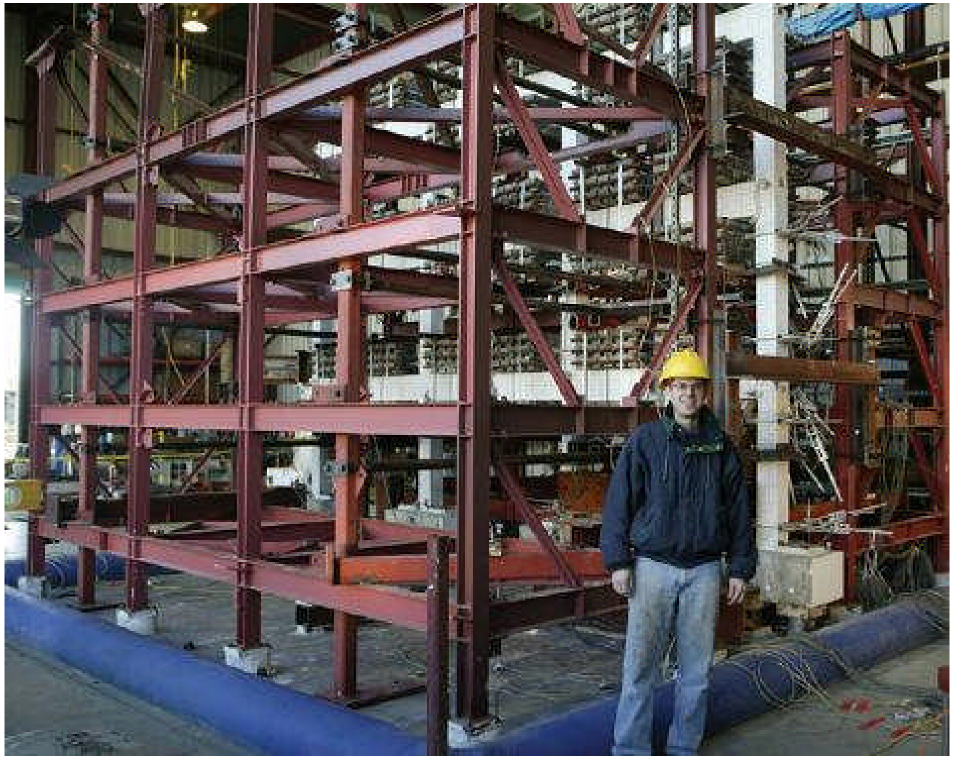


<u>Above L&R</u>: there are several different experimental techniques that can be used to test the response of structures to verify their seismic performance, one of which is the use of an *earthquake shaking table* (a/k/a "shake table"). This is a device for shaking structural models or building components with a wide range of simulated ground motions, including reproductions of recorded earthquakes' time-histories. While modern tables typically consist of a rectangular platform that is driven in up to six *<u>D</u>egrees <u>o</u>f <u>F</u>reedom* (DOF) by servo-hydraulic or other types of actuators, the earliest shake table (invented at the *University of Tokyo* in 1893 to categorize types of building construction) ran on a simple wheel mechanism. Test specimens are fixed to the platform and shaken, often to the point of failure. Using video records and data from transducers, it is possible to interpret the dynamic behavior of the specimen. Earthquake shaking tables are used extensively in seismic research since they provide the means to excite structures in such a way that they are subjected to conditions representative of true earthquake ground motions. They are also used in other fields of engineering to test and qualify vehicles and components of vehicles that must respect heavy vibration requirements and standards (i.e. aerospace, military standards etc.)



<u>**Top**</u>**: caption: “Reinforced Concrete Frame Validation Tests. The goal of the project was to develop validation data and non-linear models for nonlinear response, component failure mechanisms, and internal force redistribution as collapse occurs in a building frame representative of older concrete construction (Feb. 2006).”**

<u>**Bottom**</u>**: caption: “Earthquake Simulation Tests on Reducing Residual Displacements of Reinforced Concrete Bridge Columns. The goal of the project was to validate the new system to reduce the residual displacement using the partially un-bonded post-tensioning tendon. Two 1/4.5-scaled circular columns were designed and constructed for the tests: a model of a conventionally designed reinforced concrete bridge column and a model of the proposed design (May-June 2004).”**



"…But it's the shake table that's most impressive. This giant 20-by-20-foot steel platform, weighing 95,000 pounds, serves as the foundation for scaled-down model buildings. A computer-controlled system of huge hydraulic rams can move the table and the structure on it through the complicated horizontal and vertical motions caused by any type of quake…"

***Popular Mechanics,* January 1977**

“…‘What we’re trying to find out,’ said Clough, ‘is how to reinforce beams and other building components. To do this, our facilities are presently being used to give us the figures we need to devise mathematical models, which will be fed into the computers, The computers will then give us the data needed to build the real, practical structures that will stand up under the most severe quakes.’ Scientists have already learned a lot about how different types of buildings are affected by quakes…”

Popular Mechanics, **January 1977**

First-to-Go

"…The structural material getting the biggest workout on Berkeley's shake table is masonry. Bricks, block and mortar are notoriously bad materials to be near in an earthquake. Window and door lintels are often the first components to go, causing walls to buckle and collapsing roofs and upper floors on those people trapped below…"

***Popular Mechanics,* January 1977**

<u>Above</u>: caption: "Damage to masonry from a 5.8 Earthquake Centered in Mineral, Virginia"

An *Unreinforced Masonry Building* (UMB) is a type of building whereby load-bearing walls, non-load bearing walls or other structures (i.e. chimneys) are made of brick, concrete block, tiles, adobe or other masonry material/s that is not braced by reinforcing. The term is used in earthquake engineering as a classification of certain structures for earthquake safety purposes and is subject to minor variation from locale to locale. UMB structures are vulnerable to collapse in an earthquake (most mortar used to hold bricks together is not strong enough to resist seismic movement. Also, masonry elements may "peel" from the building, posing a danger to building occupants and/or passersby.

> ***"…The solutions for concrete-block structures are available right now, Clough says, 'Running steel reinforcing rods down through the block cells, then filling the cells with concrete, goes a long way toward preventing disintegration in violent movement.' Brick and mortar walls are another story. Steel corner ties and bracing devices are under study at Berkeley. The feeling is that quake-proof brick houses are possible but may prove too costly to be practical…"***

Popular Mechanics,
January 1977

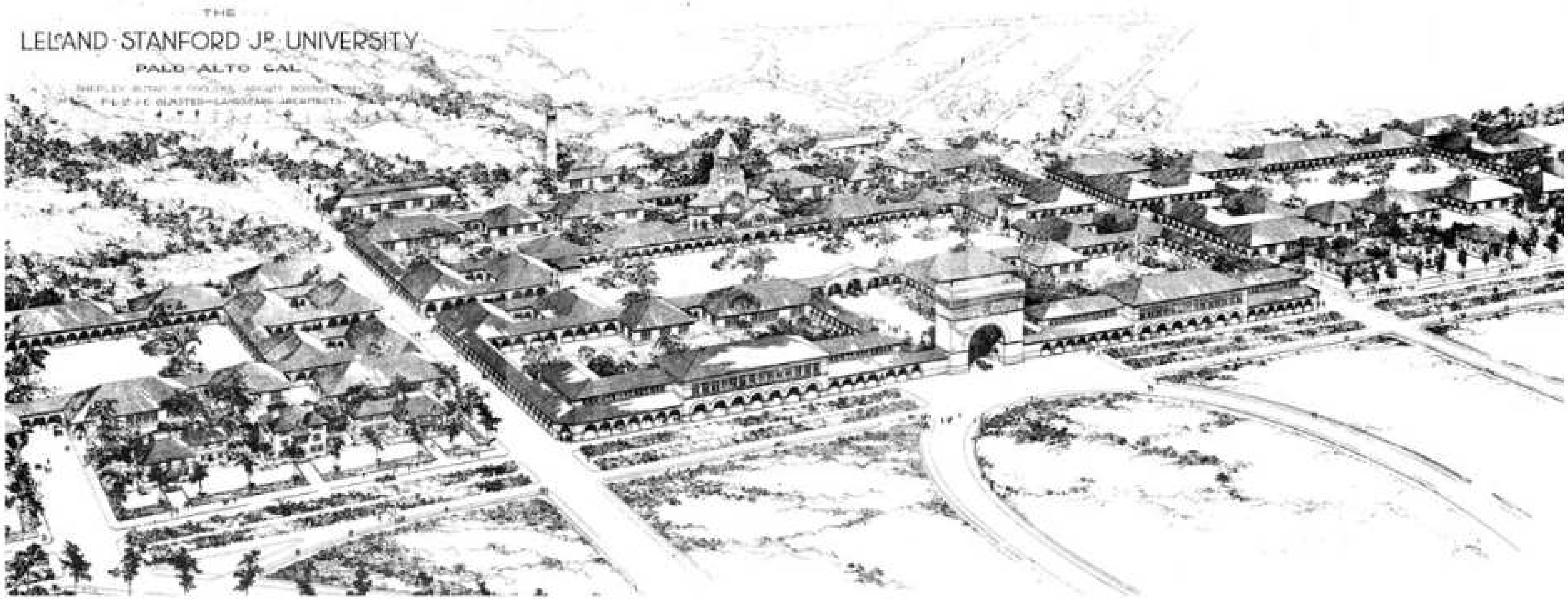
Quake-Safe

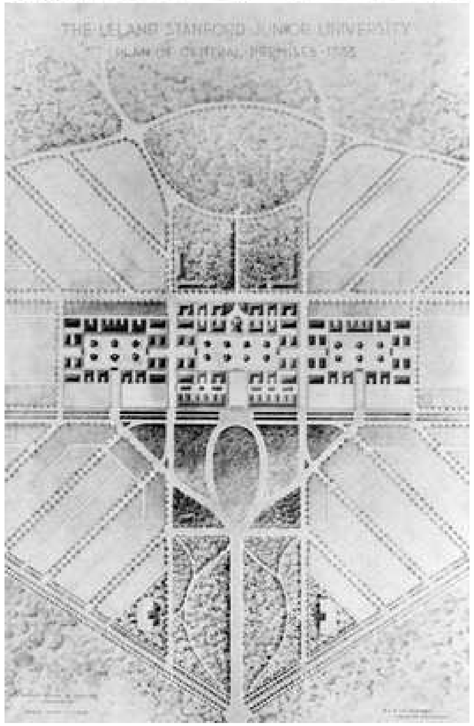
"…Concentrated field work is also underway across the country to quake-safe (if not to proof) older buildings. The culprits here are crumbling masonry facades and decorative details. Occasionally a decorative stone gargoyle will break loose all on its own. There have been several fatalities as a result; one in Chicago spurred a city-wide search for potential masonry bombs by building inspectors with binoculars…"

***Popular Mechanics,* January 1977**

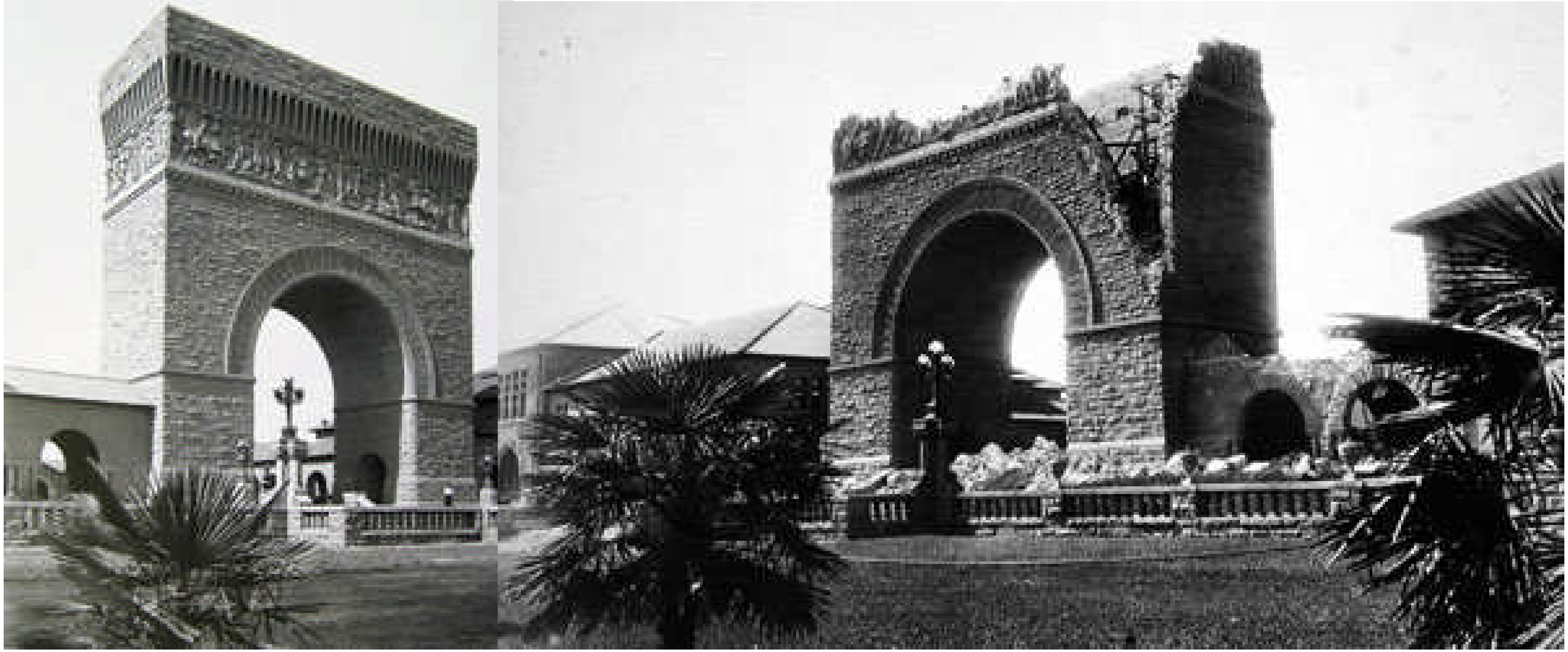
Left: caption: "On August 23rd 2011, the east coast experienced a 5.8 magnitude quake. It was the strongest felt in the region in almost seventy years and was centered just 84 miles outside the nation's capitol, in Mineral, Virginia."

Out of the Ashes





The destruction caused by the 1906 San Francisco earthquake marked the beginning of a long and rich history of research and innovation in engineering, seismology and geology at *Stanford University*. Most of the Stanford campus buildings (above) were constructed of un-reinforced masonry and were concentrated within a central quadrangle (left). Several buildings on campus were destroyed or severely damaged during the quake, including the newly built gymnasium, the library and museum and *Memorial Church.* In the aftermath, Professor *William Rogers* developed the first instrument to experimentally investigate soil effects during earthquakes.



“…Stanford’s traditional sandstone buildings, most of which were damaged in the 1906 quake and then superficially repaired, are undergoing reconstruction now. One by one, their interior wooden floors and bracing are being replaced with steel frames and reinforced concrete floors. Each exterior stone is being tied to the new frame or to a reinforced concrete inner wall…”

***Popular Mechanics,* July 1964**

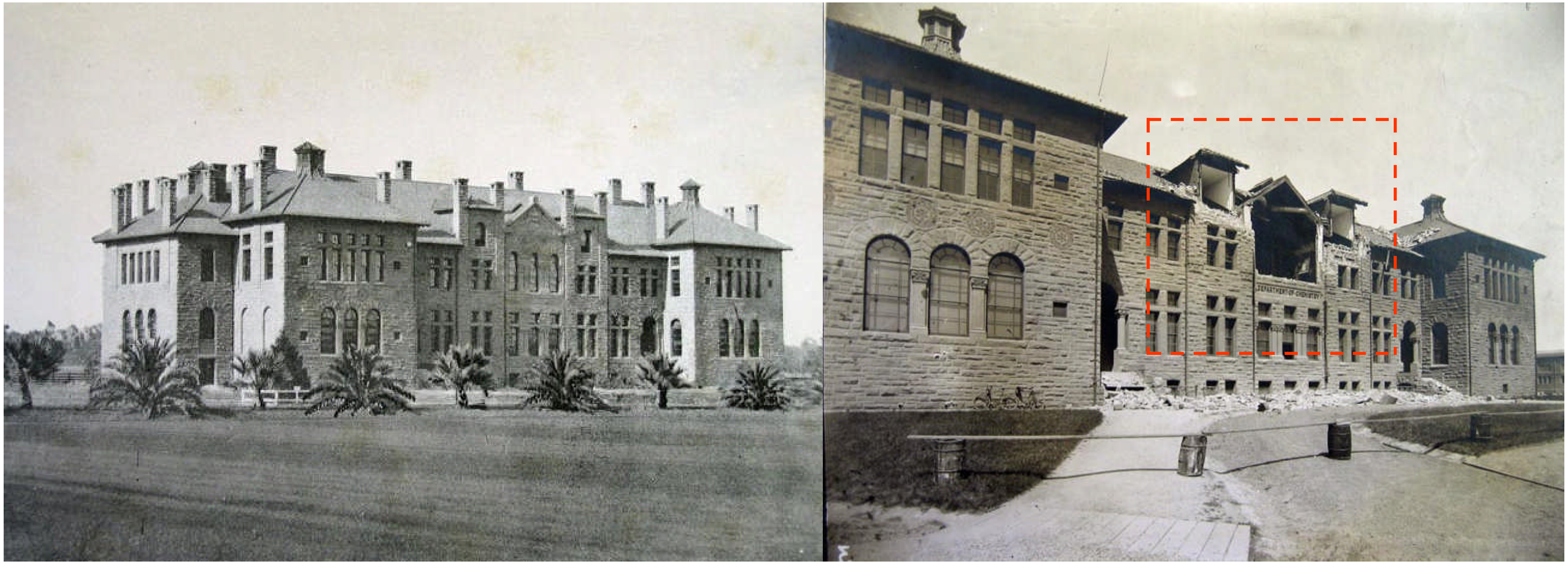

MEMORIAL CHURCH FROM
THE QUADRANGLE


MEMORIAL CHURCH
ERECTED TO THE GLORY OF GOD AND IN LOVING MEMORY OF MY HUSBAND LELAND STANFORD

“…Emergency instructions that are posted inside all buildings at Stanford contain the warning: ‘Stand in doorway or get under a table during an earthquake. Don’t attempt to go outside.’ This warning could well be posted in every building in the state. Even an interior doorway is a haven from falling plaster or structural members, and people who flee outside are apt to be struck by heavy debris falling from the building itself…”

***Popular Mechanics,* July 1964**


GYMNASIUM BLDG.
STANFORD UNIVERSITY



"…The multi-million dollar project has a special dividend: The original high ceilings permit four floors installed in what were once three…"

***Popular Mechanics,* July 1964**

<u>Above L&R</u>: Stanford University's *Chemistry Building* before (top) and after (bottom) the April 1906 *San Francisco Earthquake.* Compared to the damage suffered by other un-reinforced masonry buildings on the campus, it stood up fairly well.

What Kind?

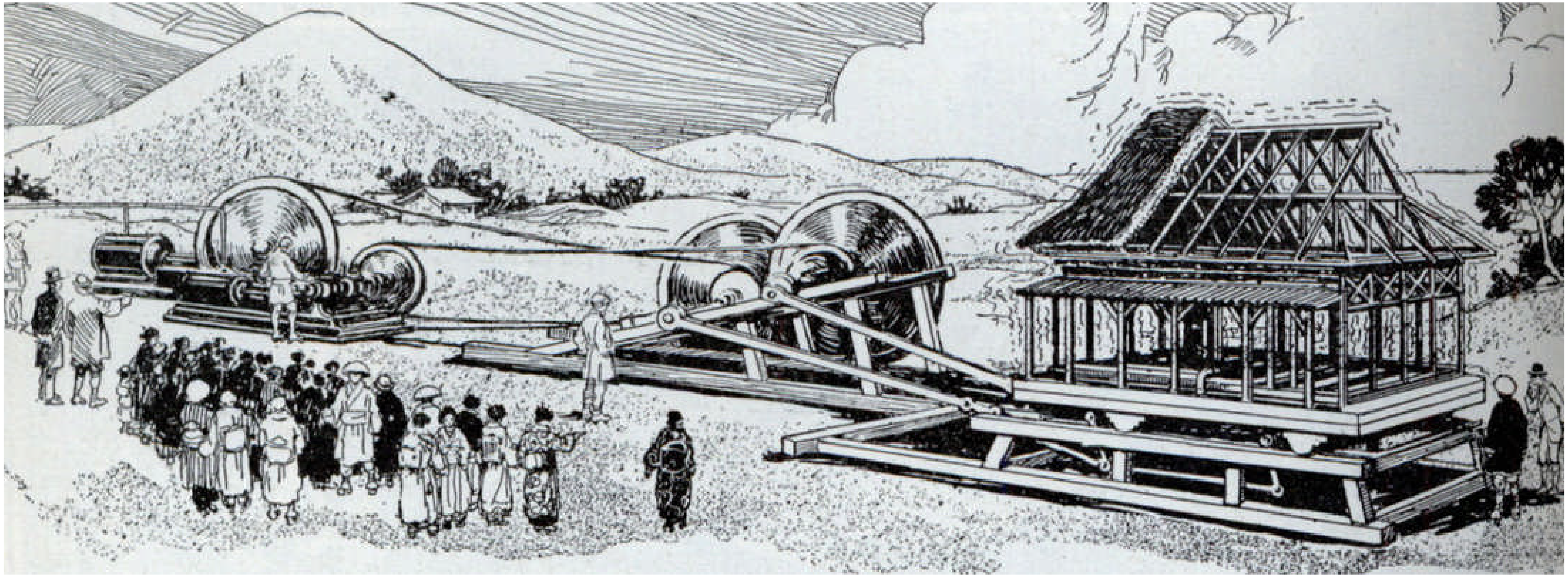
“…What kind of building is best fitted to survive an earthquake? This is the problem scientists at the Massachusetts Institute of Technology and two California institutions have been trying to solve by means of elaborate tests. On platforms mounted on steel spring columns, tiny reproductions of buildings are being subjected to miniature quakes which are expected to reveal the weaknesses of present construction and the requirements of quake-proof structures…”

***Popular Science*, May 1933**

Mechanical Earthquakes

“…Man has learned much by studying working models of buildings erected on large shaking platforms. By subjecting these structures to synthetic quakes, engineers and architects have developed theories that have been applied with considerable success to construction of shock-resisting homes, offices, schools and factories…”

Popular Mechanics, **July 1933**



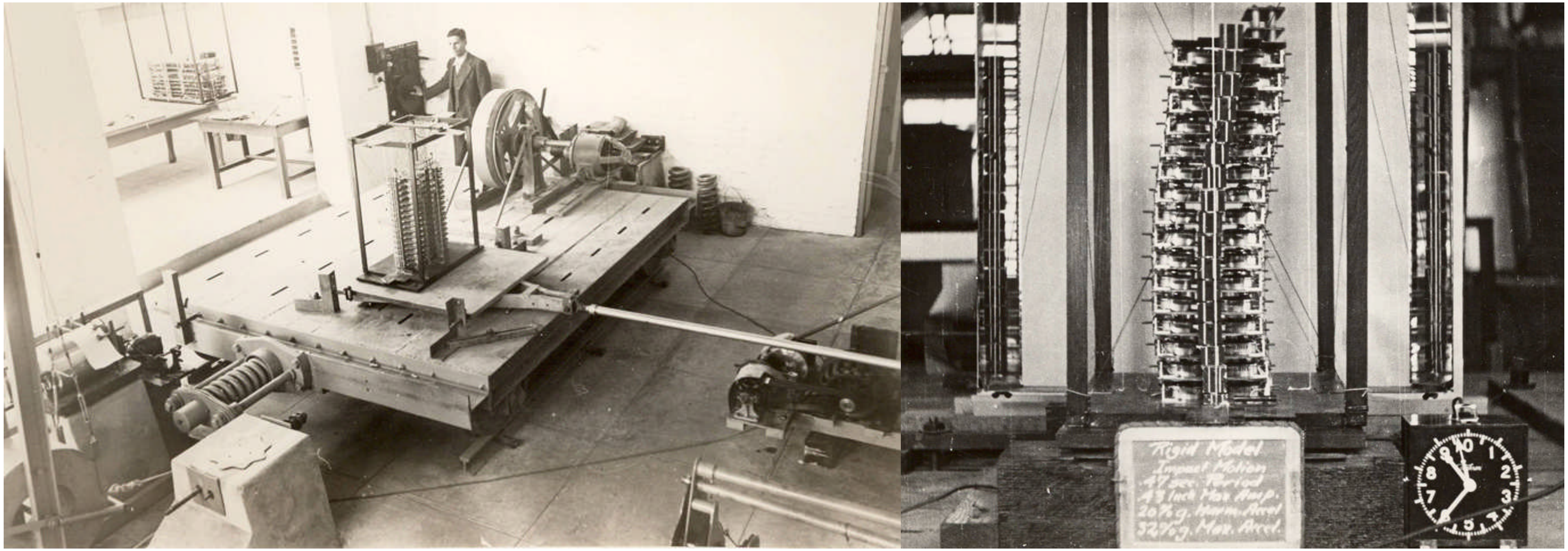
“Tests to determine the type of building best adapted to withstand earthquakes are made on a machine which reproduces, with realistic intensity, the horizontal and vertical vibrations caused by a genuine tremor. The device is the invention of two Japanese professors, and consists of a platform on which a model house is constructed on a reduced scale. The base is then made to sway and shake as the surface of the earth does in a seismic disturbance, by means of levers The longer the house is able to withstand the vibrations, the better suited it is to resist the earthquake’s power…”

***Popular Mechanics*, March 1924**

Above: caption: “Trying to shake a building to pieces with a ‘Quake-Maker’ that produces varying intensity vibrations of a real earthquake on a moving platform.” A model building was placed on the platform that was vibrated horizontally and vertically by means of eccentrics and levers to simulate typical earthquake movements.

“…At Stanford University, a heavy metal wheel, swinging like a pendulum, periodically strikes the platform in imitation of the shock of slipping rock strata. Other laboratories use heavy, off-center fly-wheels to shake the testing floors. In the earthquake room at the California Institute of Technology, several kinds of buildings, reproduced in miniature, dance and vibrate in the grip of mechanical quakes while delicate instruments record the minute stresses and strains of the tiny buildings…”

***Popular Science*, May 1933**



Through the 1930s, research at *Stanford University* continued, laying the foundation for many current analytical and design approaches, particularly through the work of Professor *Bailey* “Earthquake” *Willis* (following the 1925 *Santa Barbara Earthquake*). In 1934, Professor *Lydik Jacobsen* and his student, *John Blume*, developed the first field instrument for strong shaking of structures and investigated the performance of several buildings. Together, they created one of the earliest multi-dimensional building models and studied its performance on a shaking table. During the 1940s, an impact table (for simulating earthquake ground motions) was used to study the mechanical performance of large shear walls, masonry structures, frames and other structural elements. These experiments were important for understanding building vibrations and the implications of dynamic performance on static design.

<u>Above L&R</u>: caption: “ Original Shaking Table at Stanford University”

"…One of these complicated testing machines looked like a cross between a stock-ticker and a large mechanical toy. It consisted of a small electric motor, a little model of a six-story building, four strips of paper, four electric coils, and a queer irregular-edged board…"

***Popular Science,* May 1933**

Left: caption: "When the motor starts shaking this structure, which represents a seven-story building, the four paper strips also move and electric sparks perforate them, and record movements"

“…Professor R.R. Martel, in charge of the experiments, started the electric motor. It drew the paper strips past tiny metal points at each floor of the miniature building. Then he inserted the board in a slot at the base of the testing machine. Its wavy line represented the vibrations of an earthquake and produced pulsations that shook the little structure. Instantly there was a sound like the buzzing of a thousand infuriated bees. It was produced by sparks jumping between the high tension points. Professor Martel explained that these sparks punch holes in the paper. The pattern formed on the moving strips by these holes show graphically the movement of the various parts of the building and indicate the stresses the laboratory quakes produce…”

Popular Science, **May 1933**

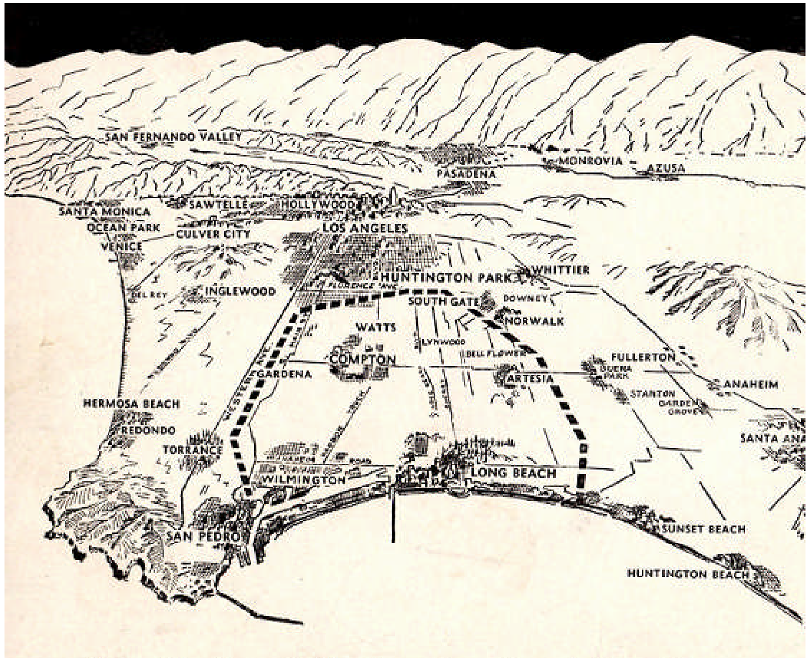
"…With such models, scientists are verifying mathematical models that will aid architects to build sounder structures in earthquake regions. New formulas may be possible when the data collected by the government heavy-duty seismographs have been made available for use in the calculations. Heretofore the motions of the laboratory quakes have been admittedly only an approximation of the vibrations resulting from real tremors…"

***Popular Science*, May 1933**

The Long Beach Temblor

“Designed for studying the destructive effects of earthquakes on buildings and other structures, a new type of shaking table duplicates in the laboratory the various temblor motions directly from seismograph records. An electric eye follows the wavy outline of a shadowgraph of an actual earthquake, such as that at Long Beach, Calif., in 1933, a pencil of light being the only connection between the shadowgraph and the shaking table. In one test a scale model of an elevated water tank was erected on the table. Driving mechanism includes an oil-actuated piston which moves the table under the control of a very sensitive, quick-acting valve that transmits to the piston every detail of the earthquake waves as they are seen on the shadowgraph by the electric eye. The machine makes it possible to determine just what might have happened to a full-sized water tank in the Long Beach temblor.”

Popular Mechanics, **April 1936**



Map of Southern California region affected. Dotted line indicates area where destruction was most severe.

"All the News That's Fit to Print."

VOL. LXXXII....No. 27,440.

123 KILLED BY EARTHQUAKE IN SOUTH CALIFORNIA CITIES; 4,150 ARE REPORTED INJURED

PROPERTY DAMAGE HEAVY

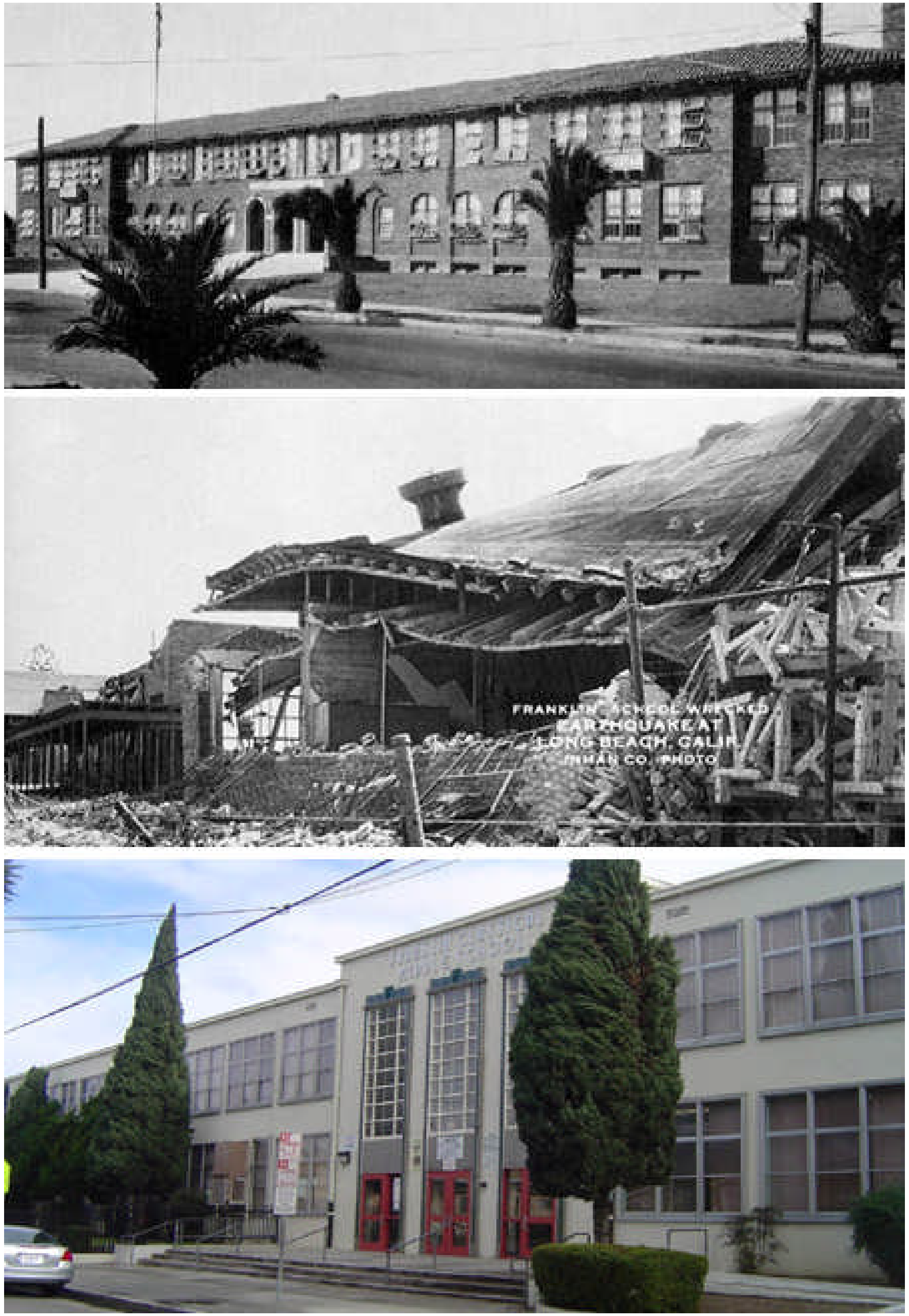
Long Beach Is Hardest Hit, With From 65 to 100 Dead.

GREAT FIRE RAGING THERE

Los Angeles Thrown Into Panic

SCENE OF THE CALIFORNI. EARTHQUAKE.

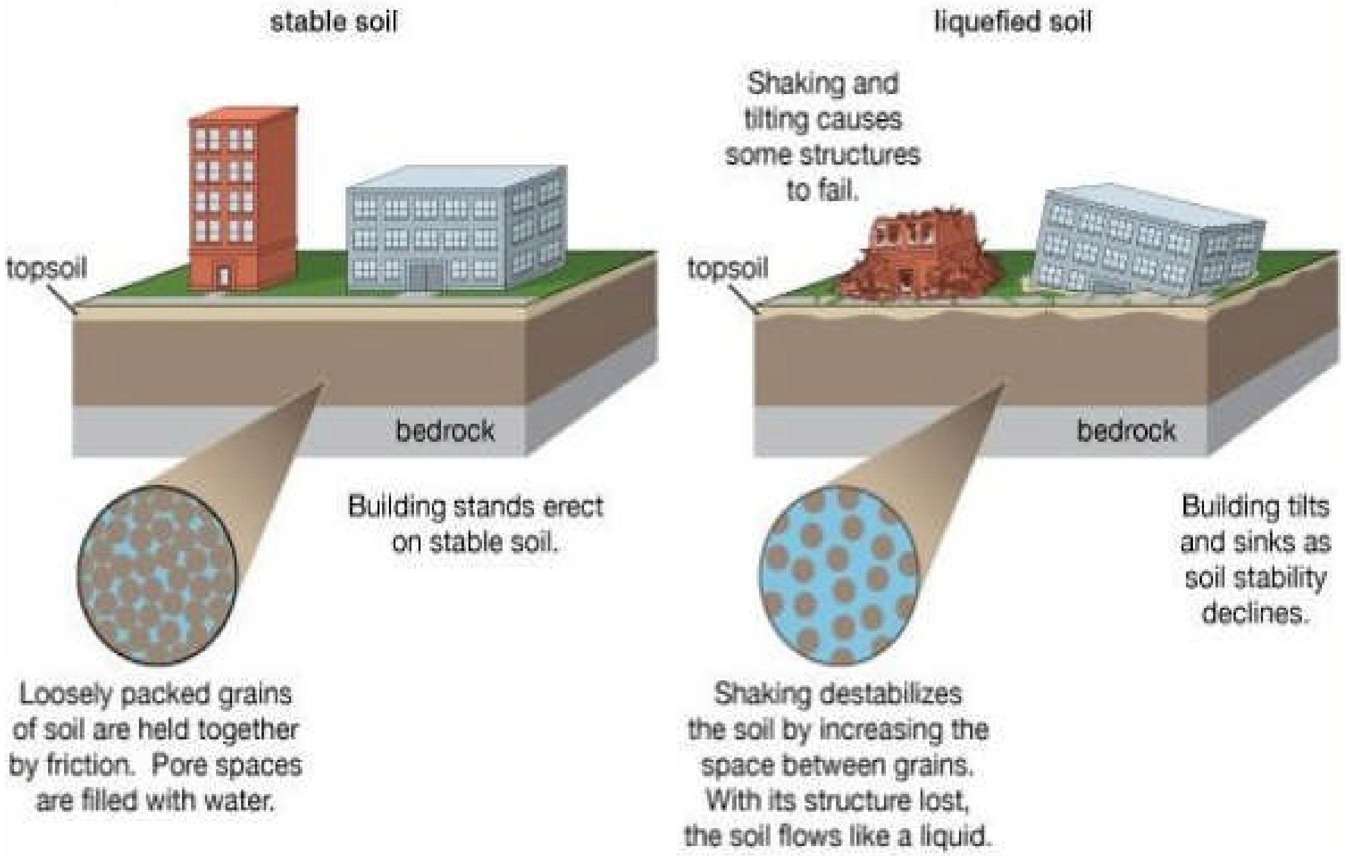
On March 10th 1933, at exactly 5:55 P.M., an earthquake with a magnitude of 6.4 struck Southern California. Damage to buildings was widespread, especially affecting the cities of Compton, Long Beach and Huntington Park, leaving them without water for days due to collapsed water towers and broken water mains. An estimated $50 million worth of property was destroyed or damaged and 120 lives were lost. More than two-thirds of the deaths occurred when people ran outside and were struck by falling debris. Among the buildings severely damaged and/or destroyed were many schools. Had the quake occurred a few hours earlier, while children were still in school, the death toll might have numbered in the thousands. The poor performance of school buildings in the earthquake led to the passage of the *Field Act*. This legislation analyzed K-12 schools all over California as to whether or not they could withstand a severe earthquake. Named for *Charles Field,* the law was passed on April 10th 1933. To date, no Field Act school has structurally failed.



Most of the structural damage was due to landfill, deep water-soaked alluvium or sand and to poorly designed buildings. At Compton, almost every building in a three-block radius on unconsolidated material and landfill was destroyed. At Long Beach, buildings collapsed, houses were pushed from foundations, walls were knocked down and chimneys fell through roofs. Damage to K-12 school buildings (which were among the structures most commonly and severely damaged by the earthquake) led to the *California State Legislature* passing the *Field Act* just one month later, regulating building construction practices in California. This destructive earthquake was associated with the *Newport-Inglewood Fault*.

Left: caption: “Franklin Junior High School in Long Beach, top-to-bottom: before the earthquake; after the earthquake and today”

Soil liquefaction



Shaking and tilting causes some structures to fail.

Building stands erect on stable soil.

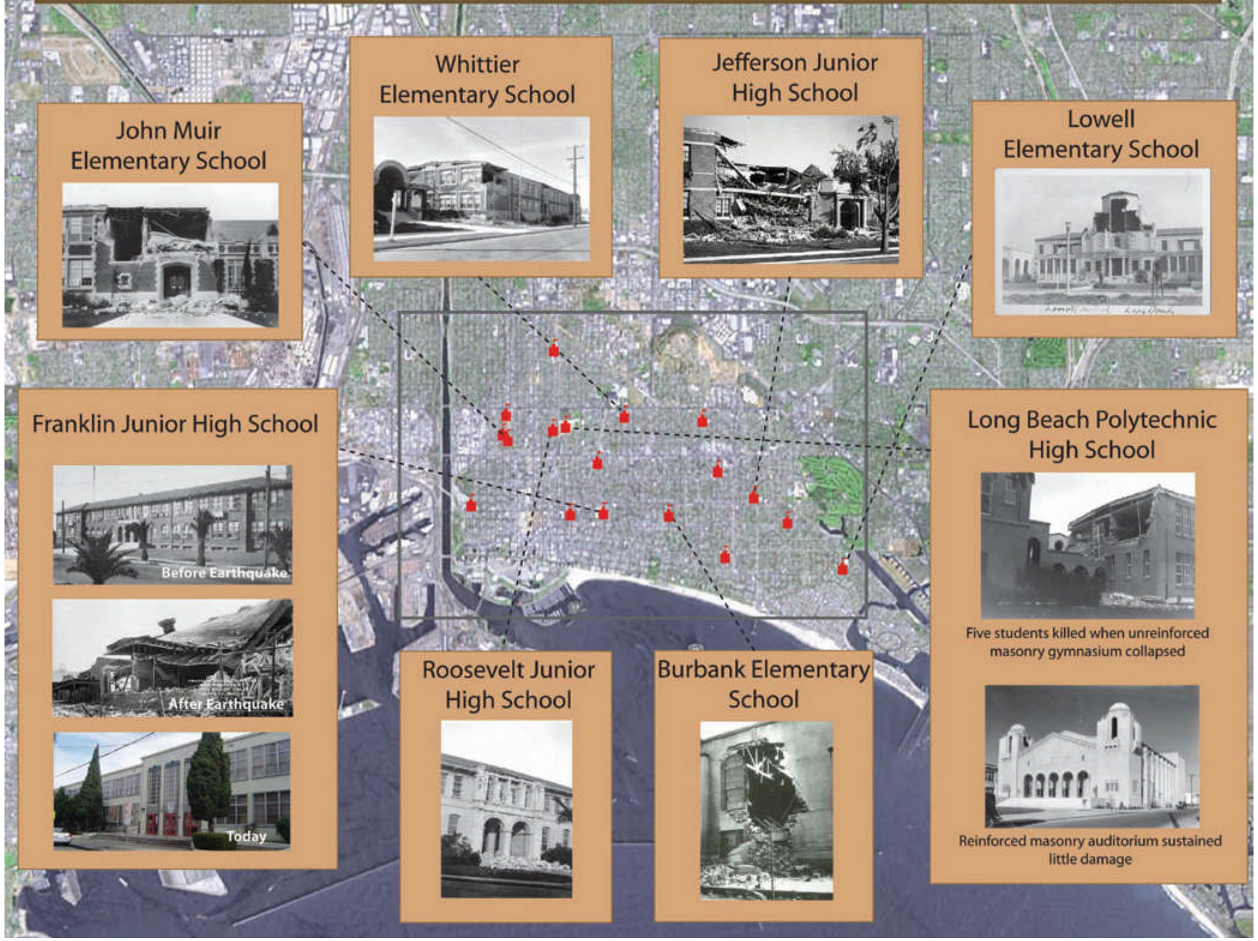
Loosely packed grains of soil are held together by friction. Pore spaces are filled with water.

Building tilts and sinks as soil stability declines.

Shaking destabilizes the soil by increasing the space between grains. With its structure lost, the soil flows like a liquid.

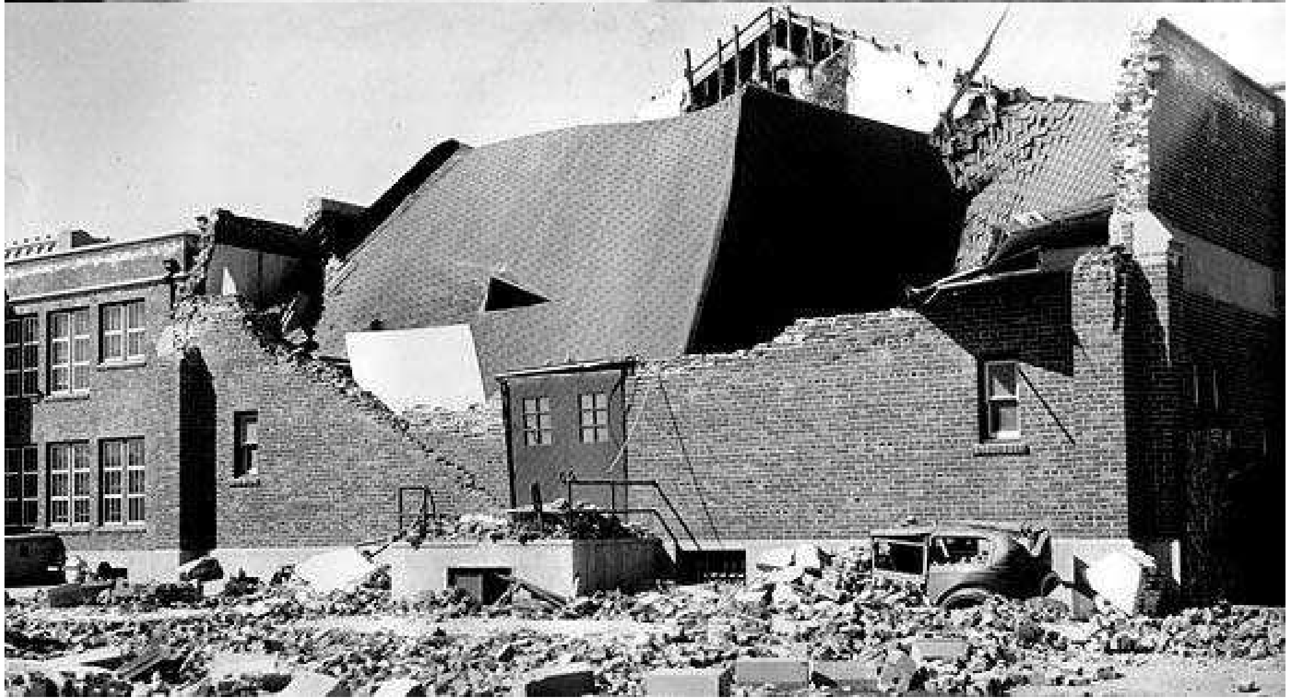
75th Anniversary - 1933 Long Beach Earthquake

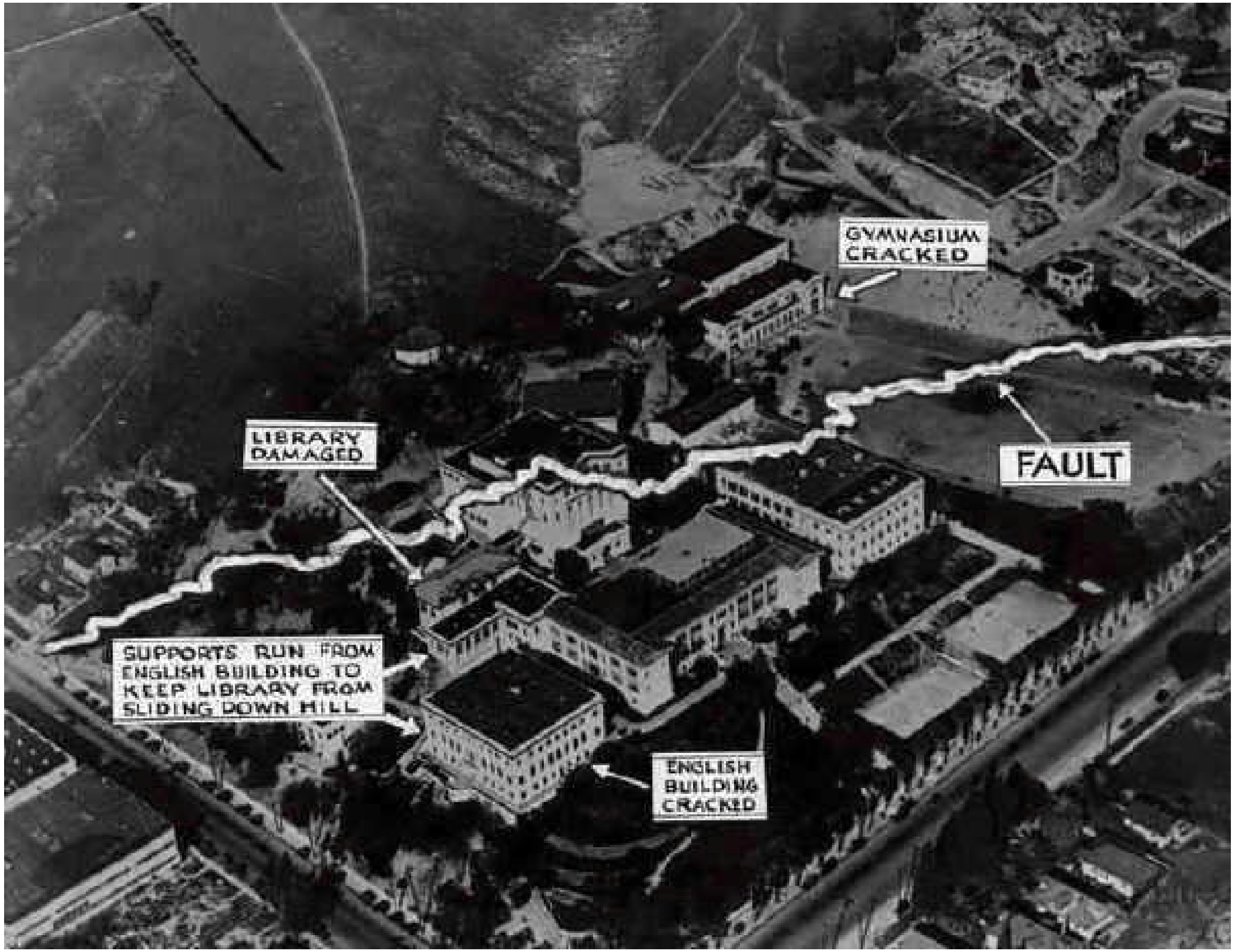
PERVASIVE AND SEVERE DAMAGE TO PUBLIC SCHOOLS IN THE LONG BEACH AREA DEMONSTRATED A NEED FOR THE FIELD ACT



Five students killed when unreinforced masonry gymnasium collapsed

Reinforced masonry auditorium sustained little damage




GYMNASIUM CRACKED
LIBRARY DAMAGED
FAULT
SUPPORTS RUN FROM ENGLISH BUILDING TO KEEP LIBRARY FROM SLIDING DOWN HILL
ENGLISH BUILDING CRACKED

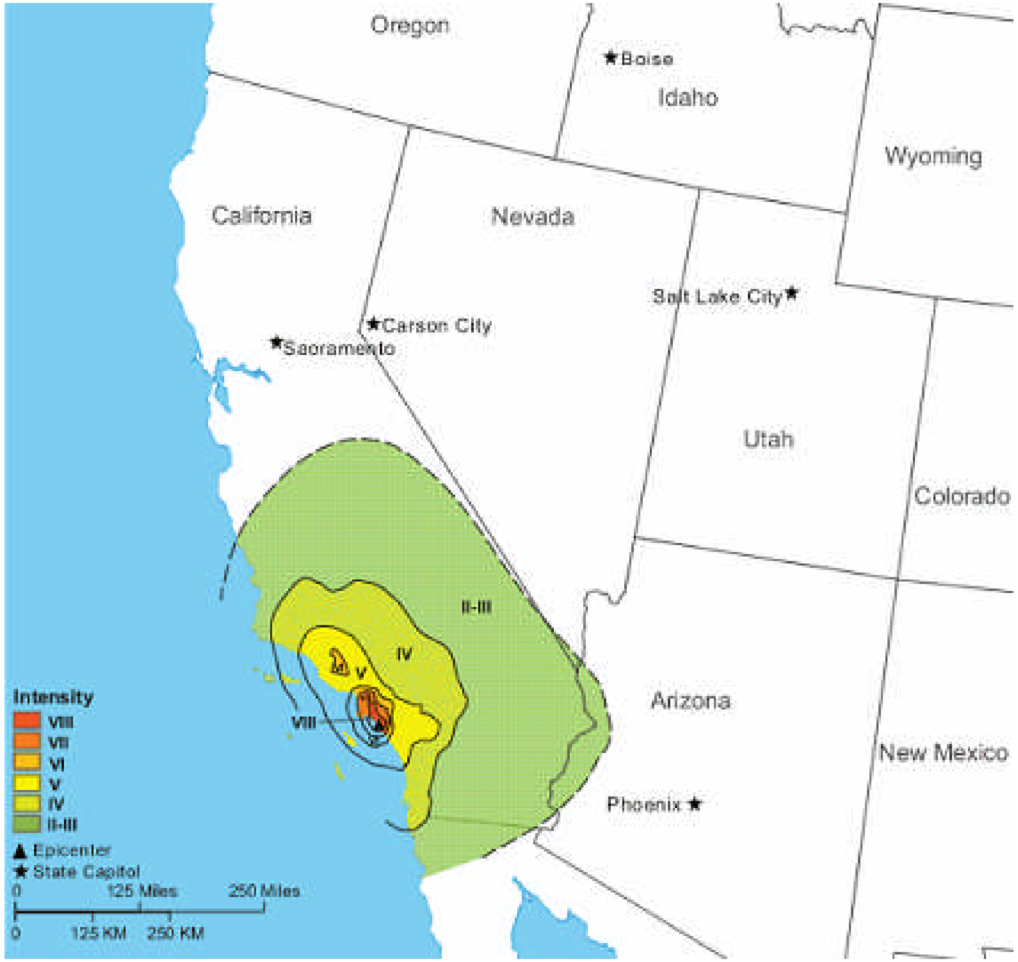
The Mysterious Foe

“When the worst earthquake in recent American history rocked southern California, leaving its dead, its injured, and its $50,000,000 trail of wreckage, it gave to science the first accurate record of how the ground moves near the center of a violent tremor…In these records, they hope to find facts that will help them pull the teeth of earthquakes by designing building proof against their shocks. The California disaster, bringing the menace of earthquakes once more into the spotlight, is spurring on the efforts of the American scientists who, in observatories that form a battle-line from coast to coast, are seeking to plumb the secrets of their mysterious foe…”

***Popular Science,* May 1933**

Writing its Own History

“…Latest developments in the attempt to chain the earthquake are instruments that record its different movements. In this work, the United States Coast and Geodetic Survey, co-operating with scientists, has played a leading part…”
***Popular Mechanics*, July 1933**



"…The only records of this type are three accelerograms revealing the violence of the earthquake on March 10, 1933, in southern California. The first shock automatically put recording instruments to work, thus trapping the temblor into writing its own history…"

***Popular Mechanics*, July 1933**

RE: although only moderate in terms of magnitude (6.4), the March 10th 1933 earthquake (left) caused serious damage to weak masonry structures on landfill from Los Angeles south to Laguna Beach. The earthquake was felt almost everywhere in the ten southern counties of California and at some points farther to the northwest and north.

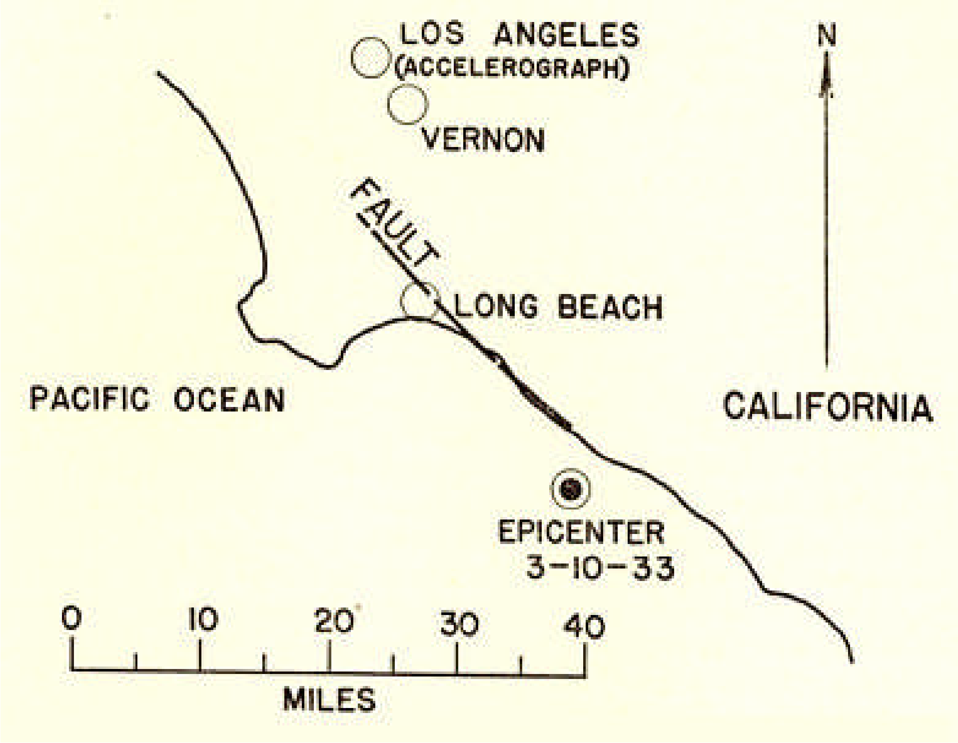
"…Only a few weeks before, new listening posts in the greatest war on earthquakes had been established in the region. Scientific traps, special seismographs, or tremor-recorders, designed to withstand heavy shocks, had been set up by the U.S. Coast and Geodetic Survey in various parts of southern California. As this is written, experts are studying the records, examining the effects of the more than thirty distinct shocks that sent buildings crashing to the ground in twenty towns and cities…"

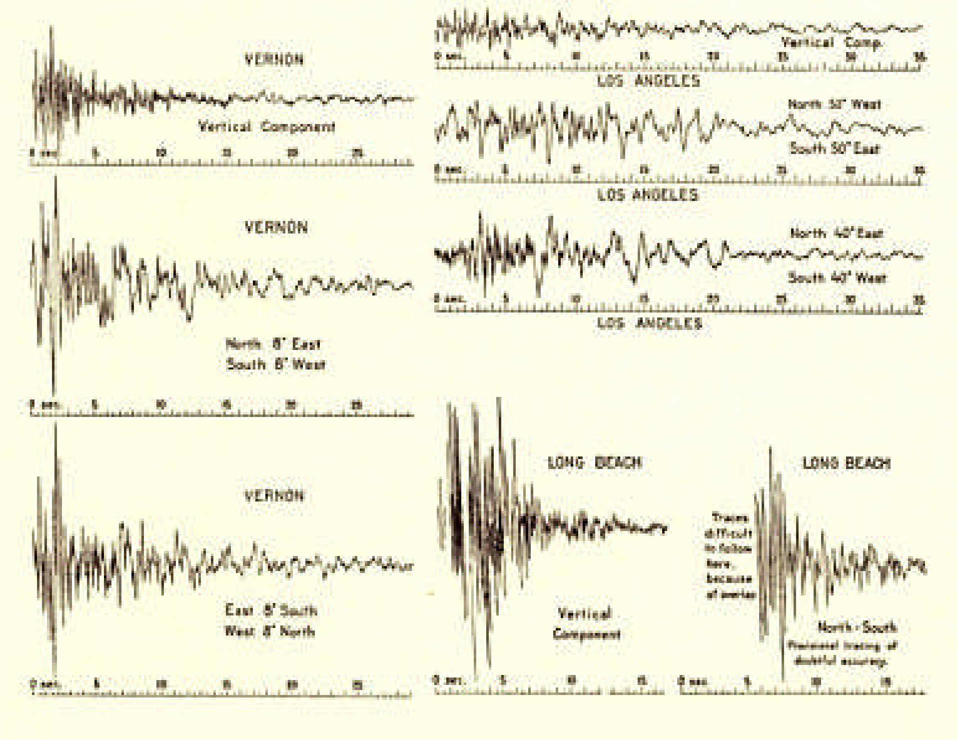
***Popular Science*, May 1933**

Left: caption: "CIT Geology Field Trip"

“…Preliminary examination of the data collected during the shocks on the west coast reveal that at times the tremor waves seem to run forward in circles giving the buildings a swirling motion. At other times, they have a snap-the-whip effect upon the structures and at others they shake them back and forth as though they were attached to a piston…”

***Popular Science,* May 1933**





"…these records reveal a very strong up-and-down motion of the ground at Long Beach on March 10, as well as a sidewise movement. There really were two vertical motions, one a slow rise and fall of the ground and the other a rapid up-and-down tremor…the fast tremors may have crumbled the mortar between the bricks of buildings so that the walls were shaken down more easily by later shocks. The ground moved in almost every direction before the earthquake was over…"

***Popular Mechanics,* July 1933**

<u>Left</u>: caption: "Relation between epicenter of Long Beach earthquake of March 10, 1933, fault, and accelerograph"

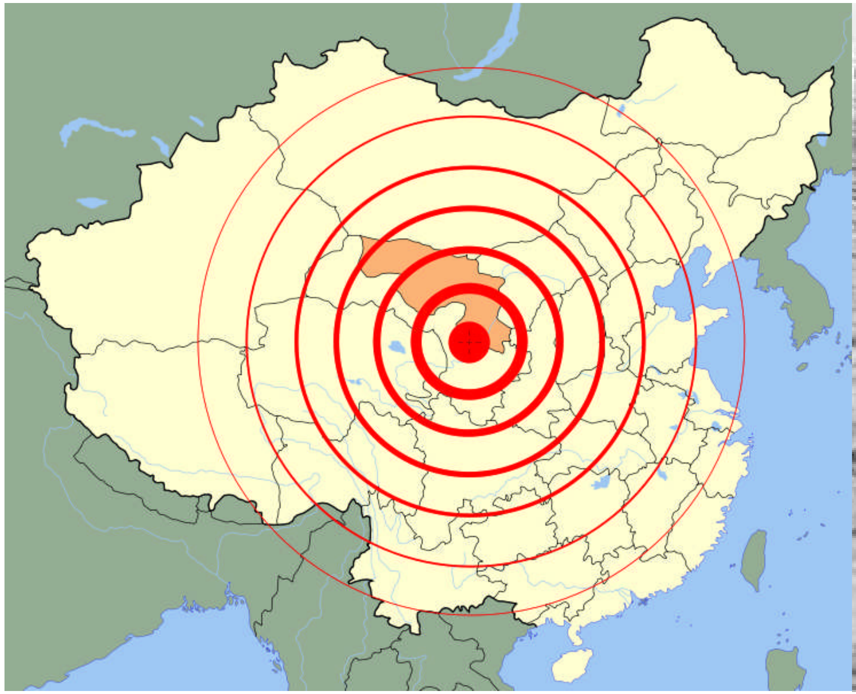
<u>Right</u>: caption: "Tracings of accelerograph records of Long Beach earthquake"

“…Often in the past, the delicate seismographs which picked up far-away tremors satisfactorily were jarred out of commission by a heavy quake, just when their record would have been most valuable. So, up to the time of California’s quake, no records were available for study which showed exactly how the earth rocked at the center of violence during a major disturbance…”

***Popular Science*, May 1933**

“…the seismographs of the Coast and Geodetic Survey were made many times stronger than the ordinary instrument. They were designed to record a number of shocks, great tremors lasting four seconds, without resetting. Ten of them, on duty along the Pacific coast, caught movements of the earth in three directions, east and west, north and south, and up and down…”

***Popular Science,* May 1933**



"…In some quakes of the past, the vertical vibrations have been so severe that boulders were observed jumping up and down like peas on the head of a drum. Such movements are particularly dangerous in regions built up of sand or alluvial deposits. The 1920 quake in Kansu, China, snuffed out nearly 200,000 lives when hills formed of dust carried by the wind from the Mongolian deserts plunged into the valleys and buried whole villages. Survivors told of lost rivers, buried cities, and 'mountains that walked in the night'…"

Popular Science, **May 1933**

<u>Left</u>: caption: "1920 Gansu earthquake map"

<u>Right</u>: caption: "The Dec. 16, 1920 Kansu earthquake registered 7.8 magnitude on the Richter scale and affected seven provinces and was felt as far away as Norway. The earthquake caused rivers to change course while others were dammed. It sent landslides pouring down mountainsides, inundating whole villages."

“…In western states, the new-type seismographs that trapped the record of the Los Angeles tremors, were planted on dams and bridges and in the basements of buildings. Other instruments of the same kind keep watch in New England and the Middle West. Eventually, the Coast and Geodetic Survey plans to dot the country with these automatic record-keepers…”

Popular Science, **May 1933**

“…Only a few days after the Coast and Geodetic Survey had laid its trap line of strong-motion seismographs along the California coast, it caught its first record of a heavy quake. Investigation revealed that the center of disturbance was near Tonopah, Nev., a thousand miles away. The shock was computed by seismologists as even more severe than the quake that occurred at San Francisco, almost thirty years ago. Yet, because it took place far from centers of population, it caused little damage and received slight public attention…”

***Popular Science*, May 1933**


TONOPAH
LODGING HOUSE

"…A special phase of the researches in the laboratories concerns vibrations set up in buildings by earth tremors. If a building gets in tune with the earthquake vibrations, it will crumble, just as a bridge will collapse if an army marches across it in step. But does the earthquake stay in tune once the ground begins its tremors? The seismograph records will be studied to find out…"

***Popular Science,* May 1933**

“…Another line of research concerns the influence of the weather and electrical phenomena upon earthquakes. Some scientists believe that the changing pressure of the air upon different parts of the globe is the natural phenomenon that sets off quakes…”

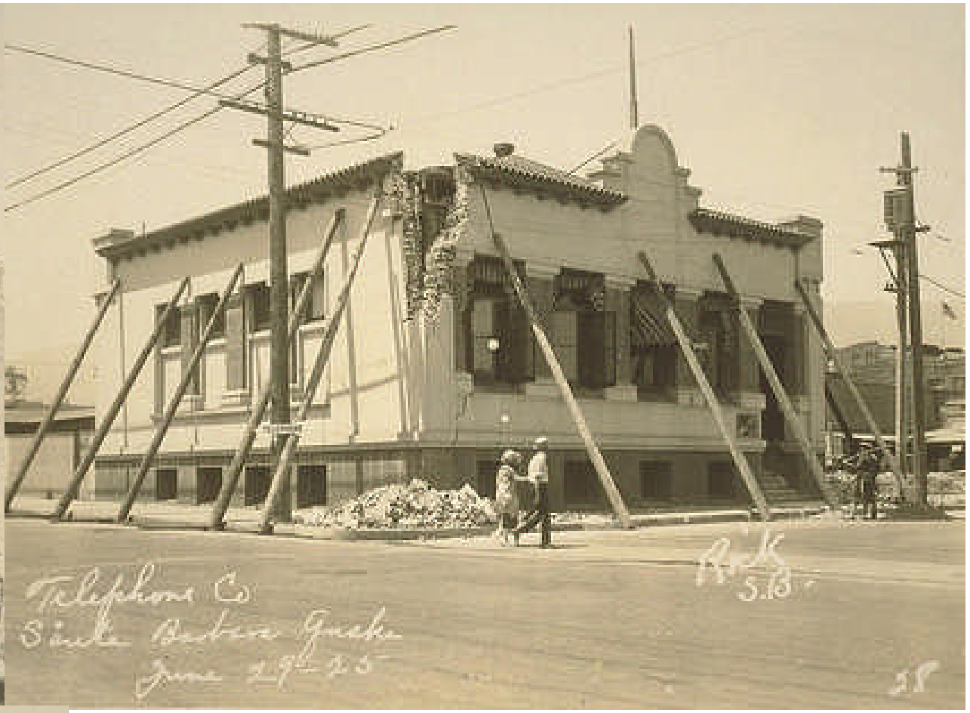
***Popular Science,* May 1933**

The Summer of ‘25

"The whole earth rose and seemed to shake itself with the motion of a spaniel fresh from the water...From Sola Street south to the ocean front, a total of approximately 40 buildings were either demolished, or so badly wrecked, that rebuilding will be necessary. The San Marcos building at Anapamu and State streets was almost entirely demolished. One wing of the four-story structure, completed less than two years ago, lies flat on the ground. The State Street frontage is one-half demolished and in the wreckage are believed to be bodies of several employees of the Sterling Drug Company. The Arlington Hotel, California's first great tourist hotel, and famous on two continents, is a wreck. The entire front section of the hostelry crashed to the ground, scores of guests barely escaping with their lives. Other large buildings wrecked were the public library, one of the most beautiful in the state; the First National Bank; the Trinity Church; the First Congregational Church; the Hotel Carillo (first two floors); the Clock Building; the Edgerley Court Apartments; the W.F. Higby Automotive building; the Church of Our Lady of Sorrows; the New Hotel California, finished less than a month ago, and a large number of others. Immediately after the first shock, all electric power and gas mains were shut off. Traffic came to a standstill and special police and naval reserves took charge of the downtown situation. A search of the wreckage for bodies was begun with huge wrecking machines and tractors dragging the debris from the streets…"

***The Oja*i, Vol. XXXIV, No. 25 (Friday, July 3rd 1925)**

RE: on June 29th 1925, the city of Santa Barbara, CA, was forever changed by a powerful earthquake. The *Southern California Earthquake Data Center* (SCEDC) estimates that the quake registered 6.3 on the Richter scale. Thirteen people were killed.



"…The first efforts of the salvage crews were hampered by the crowds of curious who flocked to the stricken zone, before the Granada Theatre, an 8-story structure which survived the tremblor, thousands gathered to watch the workmen. Recurring shocks soon sent them scurrying to a place of safety, however, and when the big building began to rock above their heads there was a general scampering in all directions…"

The Ojai**, July 3rd 1925**

<u>Above & Left</u>: scenes from the 6/29/25 Santa Barbara Earthquake


HOTEL CALI
CARNATION MUSH

Earthquake Weather (?)

“…In the summer of 1925, when the Santa Barbara tremors occurred in California and shocks were felt in other parts of the United States, it was noted that the weather was remarkable for its humidity, high barometric pressures, and its frequent thunderstorms. Electrical disturbances originating far down in the earth’s interior are thought by many geologists to control the snapping of the earth’s crust. Such disturbances, accompanied by marked climatic changes, occur in violent outbursts that come in ten or twelve year cycles. Sunspots are also linked to earthquakes by many scientists…”

***Popular Science*, May 1933**

“…A world-wide chain of observation depots for the collection of weather and electrical data, which can be compared with astronomical and seismological facts collected by other observatories, would be of infinite value in increasing our understanding of quakes…”

***Popular Science*, May 1933**

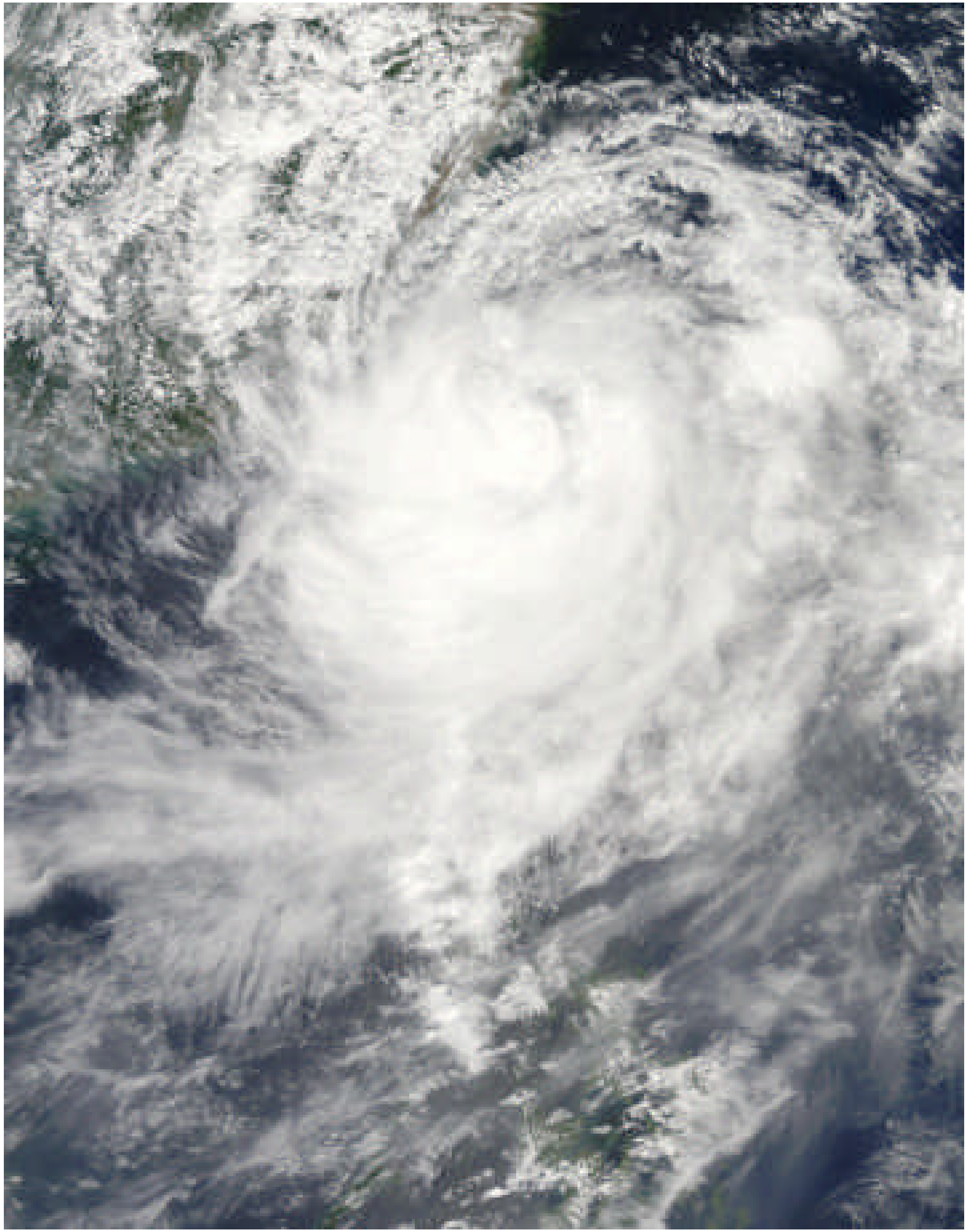
“…There is no typical ‘earthquake weather’ and most quakes do not occur in the evening as many believe. Minor shocks are noticed in the evening because people are quiet and are more apt to feel them. There is no assurance that an area that has experienced a major shock will escape another for a long time…”

***Popular Mechanics,* July 1935**

"The old notion of earthquake weather…was very prevalent - the idea that earthquakes and weather were related somehow"

***Susan Hough*, USGS seismologist**

RE: the ancient Greeks are credited with espousing the first relationship between weather and seismic activity. In the fourth century B.C., *Aristotle* surmised that trapped subterranean winds caused earthquakes when they shifted about or, in the case of large earthquakes, broke through the ground to escape into the atmosphere. In more recent times, people have thought, for example, that earthquakes are more likely when it is hot and dry due to the seemingly frequent co-occurrence of such conditions, particularly in California. For the most part, studies of the relationship between weather and seismicity have not held up under scientific scrutiny and earthquake researchers have set them aside as intriguing, but unfounded ideas.



The USGS website states, it in no uncertain terms: "There is no such thing as 'earthquake weather.'" However, earthquakes and heavy rainstorms do occasionally produce comparable results on the planet's surface. Recently, new efforts to identify effects of weather-related or, in some cases, climate-related, processes on seismicity have drawn new interest. Shifting masses of seawater (i.e. oscillations in *El Nino* patterns in the *Pacific Ocean*) have been tentatively linked to increased seismicity in the underlying seafloor. A 2009 study in *Nature* noted a connection in Japan between changes in atmospheric pressure during typhoons and the occurrence of so-called "slow" earthquakes (which often go undetected because they release energy slowly over longer periods than regular quakes).

Left: caption: "Typhoon Morakot passes over Taiwan on Aug. 7, 2009. It was followed by two large earthquakes, one later in 2009 and one in 2010."

“We started looking at this relation after the 2010 Haiti earthquake, which occurred 18 months after a very severe hurricane season in Haiti.”

Shimon Wdowinski*, Geophysicist – *University of Miami

<u>Left</u>: caption: “An aerial view of Haiti’s capital, Port-au-Prince, about two months after a magnitude-7 earthquake struck nearby. A landslide is evident among crowded hillside houses and buildings.”

<u>Right</u>: caption: “A landslide near Haiti’s southern coast erodes tremendous amounts of sediment from the mountains, a process that can change the stress loads on faults.”

"When you look at the seismicity along the <u>M</u>ain <u>H</u>imalayan <u>T</u>hrust (MHT) Fault , you see that you have more seismicity in the winter than you do in the summer…you see that there seems to be a response to the load due to the monsoon"

Thomas Ader*, Graduate Student - *Caltech Seismological Laboratory

<u>Left</u>: caption: "Researchers have correlated the timing of slight ground motions in the Himalayas using GPS measurements, including from this GPS station near Simikot in northwestern Nepal, to cyclic variations in seismicity beneath the mountains and the annual monsoon."

"It's a very pronounced signal that these magnitude-6 and above earthquakes occur after wet typhoons…By unloading the system, it makes it easier for the forces applied by tectonic plates to actually rupture the fault and cause an earthquake…We have observations showing these very strong relations between the timing of the earthquakes with respect to the wet typhoons"

Shimon Wdowinski*, Geophysicist – *University of Miami

<u>Above</u>: caption: "Taiwanese temple that collapsed during the magnitude-7.6 Chi-chi earthquake - also known as the '921 earthquake' - that struck the island on Sept. 21, 1999. The earthquake was preceded by Typhoon Herb in 1996."

Body of Evidence

“…As these strong-motion records accumulate, experts hope to gather information that will guide the building industry and that some day may enable science to predict accurately the moment at which an earthquake will strike a certain area…”

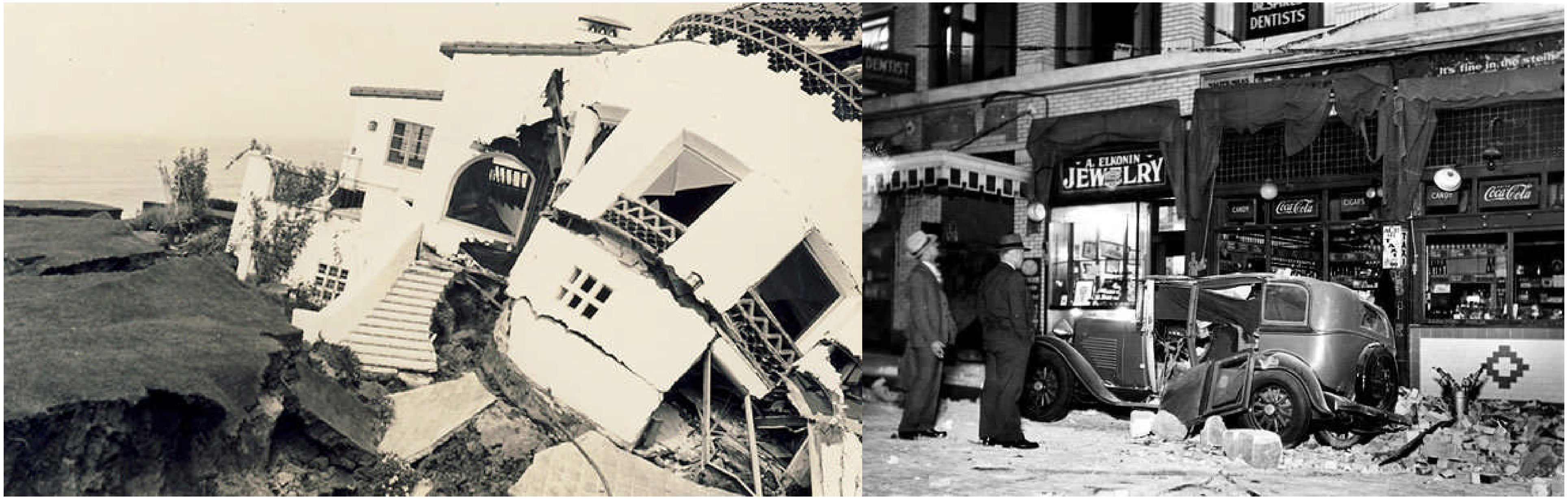
***Popular Mechanics*, July 1933**

“…At the Carnegie Seismological Laboratory in Pasadena earthquakes are being studied in the hope that the accumulated knowledge may lead eventually to foretelling when a major shock is due…eleven seismographs are recording the characteristics of every tremor that occurs and this nest of machines is linked through radio time signals to a network of outlying stations in southern California. From the mass of records the seismologists have observed a shifting pattern of activity. Frequent quakes in one section seem to be followed by lulls during which more quakes occur in adjoining regions. During the last seven years the scientists have found that some heavily faulted regions are constantly active while other areas seem to have spells of action…”

***Popular Mechanics,* July 1935**

“…The seismologists think that study of the minor shocks may lead to anticipation of the time or place when a greater upheaval is due. In some cases a major earthquake seems to be preceded by an increasing number of small preliminary tremors…”

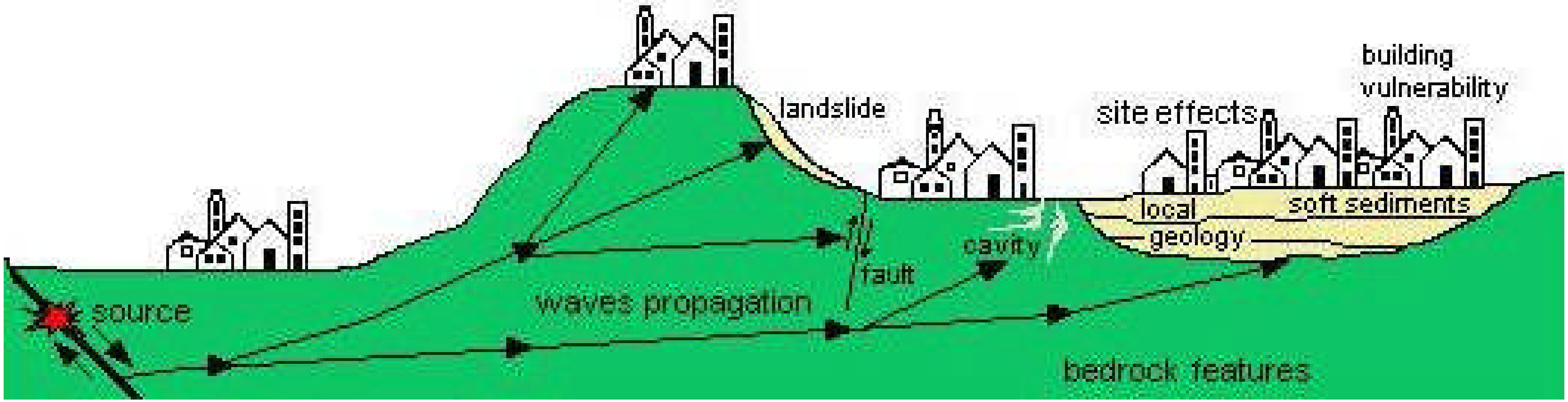
***Popular Mechanics*, July 1935**



"…In spite of the tremendous forces involved in an earthquake the actual motion of the ground usually is slight. In the Long Beach quake of two years ago, described by scientists as a moderate tremor, the shock was manifested by a series of sharp jigglings almost too small to measure, accompanied by slow swaying motions that moved the ground back and forth about an inch. Even this was enough to cause great damage since the jiggles loosened things and the swaying caused them to fall…"

***Popular Mechanics*, July 1935**

<u>Above L&R</u>: scenes from the aftermath of the 1933 Long Beach quake



"…Many of the thirty-five tremors which shook cities in southern California were formed by reflected waves running through the rock layers. Such echoes often produce more damage than the original shifting of the earth's crust…"

***Popular Science,* May 1933**

<u>Above</u>: caption: "Sketch showing the influences that can affect a seismic signal propagating from the source to the free surface of a terrain." The influence of local geological features on ground motion peculiarities and damage due to earthquakes is well known. Studies concerning the *San Francisco* (1906) and the *Messina* (1908) *Earthquake/s*, respectively, demonstrated that the damage distribution is a function of different site conditions existing in various areas affected by the same shock. Similar effects have been observed during all destructive earthquakes to the present-day. Site effects occur as a result of several physical phenomena such as multiple reflections, diffraction, focusing, resonance etc., to which the incoming wavefront is subjected. This is a consequence of the various mechanical properties of terrains, the presence of heterogeneities and discontinuities as well as the geometry of shallower layers and the existence of topographical irregularities above and/or below the surface.

Part 4

The Big One

Blame for the Strain

“…Geologists have been trying to determine a method by which quakes can be predicted. ‘But as yet,’ declares Prof. Byerly, ‘there is no evidence to show that quakes can be forecast.’ Sunspots and the relative positions of sun and moon are said to influence earthquakes, but such theories are largely hypothetical. Japanese scientists claim that a slight tilting of the earth’s surface precedes a large quake. Four tilt-meters have been installed at the University of California to test this theory but not enough information has been yielded yet…”

Popular Mechanics, **October 1939**

"…Earthquakes result from rupturings in the earth, sudden slippings between blocks of rocks down to forty miles below the surface. Blame for the strains that cause these readjustments may be laid to tidal forces, erosion and deposition, and possibly to the wobbling of the earth on its axis. At Harvard University studies are being conducted that may link earthquakes definitely to the moon, infinitesimal movements of the earth's crust already having been traced to the daily movement of the tides in the oceans miles away. The shifting of tremendous quantities of water causes a give and take in the earth along the coast equal to the tilting of a sixty-five-mile pole one inch at the end…Aside from the responsibility for ocean tides, the moon exerts a measurable gravitational pull that causes the crust of the whole earth to expand and contract. In California some investigators have found a definite relationship between some earth movements and certain phases of the moon…"

***Popular Mechanics,* July 1935**

“…Japanese seismologists advanced a theory that the surface of a region assumes a tilt during the hours preceding a quake. In the United States sensitive instruments have recorded violent ‘tilt storms’ that change ground contours as much as an inch per hundred feet in a few hours but these temporary movements are mostly regarded as being caused by shifting temperatures at the surface or by the amounts of water in the ground instead of being connected to any deep-seated condition that might result in an earthquake…”

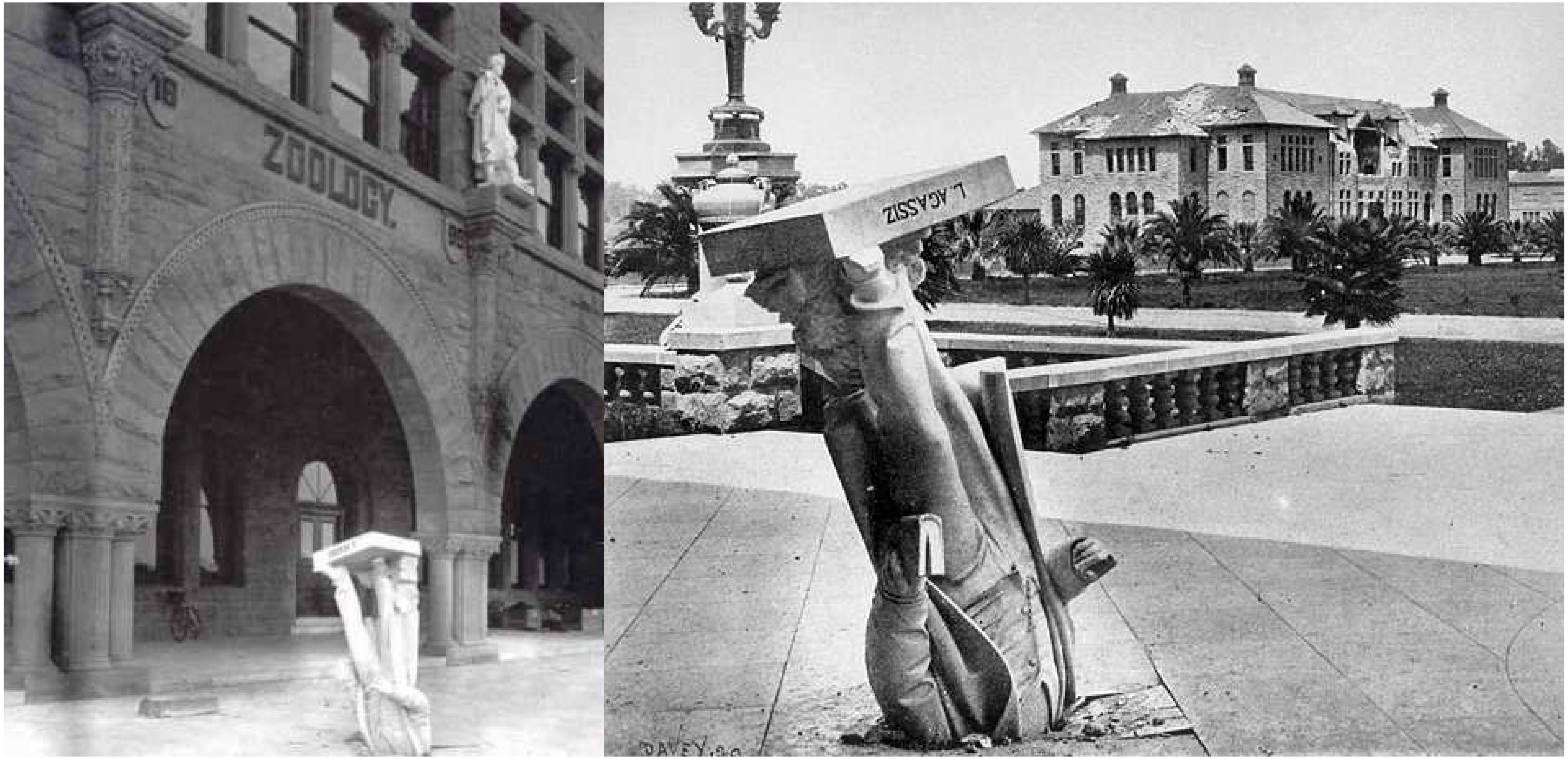
Popular Mechanics, **July 1935**

Death Be Not Proud

“…The United States has suffered several memorable quakes including the Charleston, S.C., earthquake of 1886; San Francisco in 1906; Santa Barbara in 1925; Long Beach in 1933 and the Helena, Mont., quakes of 1935. These disasters, however, were insignificant compared with major quakes in other parts of the world. The great Lisbon quake of 1755 killed 50,000 persons; the 1897 quake in Assam, India, covered an area of destruction of 160,000 square miles; and the great Japanese earthquake of 1923 took 250,000 lives…”

***Popular Mechanics,* October 1939**

Strange and Spectacular



"…Aside from the damage earthquakes cause, they sometimes do strange and spectacular things. A heavy temblor in India in 1897 tossed stones into the air and shot posts out of their holes. Earthquakes that cause shifts in the ground along fault lines have played tricks on property owners like shifting the front walk to a house fifteen feet beyond the front porch…"

***Popular Mechanics,* July 1935**

<u>Above</u>: *Zoology Building – Stanford University*, after the 1906 SF earthquake

Left: this famous picture shows what happened to the statue of the great naturalist and geologist *Louis Aggasiz* (1807-1873) during the 1906 *San Francisco Earthquake*. The marble statue of Agassiz toppled off the pedestal where it stood on the second floor level of Stanford University's *Zoology Building*, plunging headfirst into the pavement below. The great scientist, with his head buried in the ground, his upturned body sticking up into air and finger pointing, became an iconic image of the earthquake. Many stories were told of Agassiz's natural instinct that compelled him to stick his head underground in order to find out what was going on in the earth below when the earthquake struck. The only damage to the statue was a broken nose which was refastened and the statue placed back atop its pedestal. Of the four statues on the Zoology Building, only that of Louis Agassiz was curious enough to see just what was going on underground.

Old Man Superstition

"…Contrary to popular belief, the earth doesn't open up and swallow houses or people. Large fissures are rarely opened up by quakes and these almost invariably remain open. …"

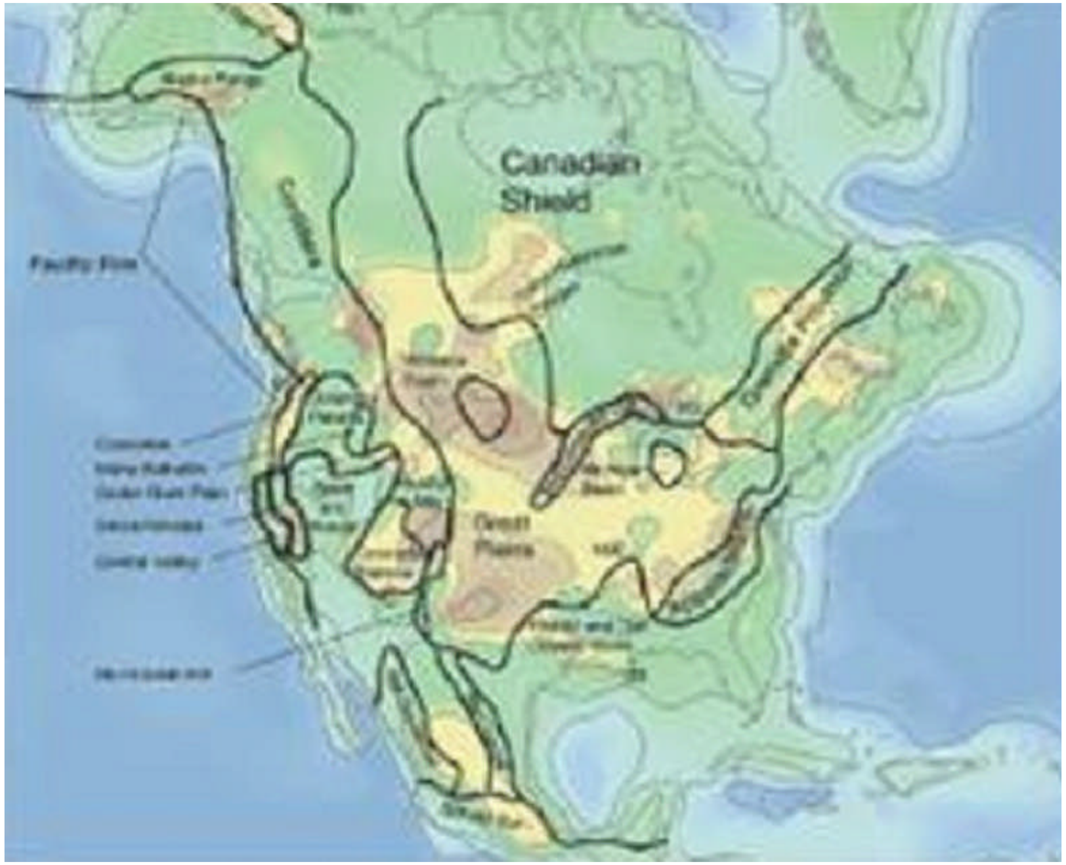
***Popular Mechanics*, July 1935**

<u>Above</u>: caption: "Valencia Street after the 1906 San Francisco earthquake"

Lines of Weakness

“…Cutting like great scars across the map of North America, are geological fault lines, weak places in the crust of the earth, where rock strata have slipped in the past and where tremors are likely to occur. Geologists have plotted the exact location of these lines of weakness and have found that some of our largest centers of population lie along their course…”

***Popular Science,* May 1933**



"…One line, running down the Atlantic coast from Labrador and the Greenland Sea, passes close to Boston, New York City, Philadelphia, and Washington D.C. Others cut across the Great Lakes, cleave the Mississippi Valley, swing across the Southwest and follow the Pacific coast line from Alaska down to lower California…"

***Popular Science,* May 1933**

Left: caption: "This U.S. Geological Survey (USGS) map shows the major earthquake hazard areas within the U.S., Canada and Mexico based on known fault lines"

“…Chicago, Ill., New Orleans, La., as well as Los Angeles and San Francisco, Calif., are crowded centers of population situated in parts of the country where earthquakes are always possible...”

***Popular Science*, May 1933**

The Great Earthquake of the West

"…One of the dozen greatest earthquakes of all times occurred little more than 100 years ago in the heart of the Mississippi valley, yet damage was very slight, simply because the country affected was sparsely settled. That was the New Madrid, Mo., quake of 1812, which was responsible for the formation of Reelfoot lake, in northwestern Tennessee, and for the sinking of all northeast Arkansas and southeast Missouri, a region still known, therefore, as the sunken country…"

***Popular Mechanics,* June 1928**

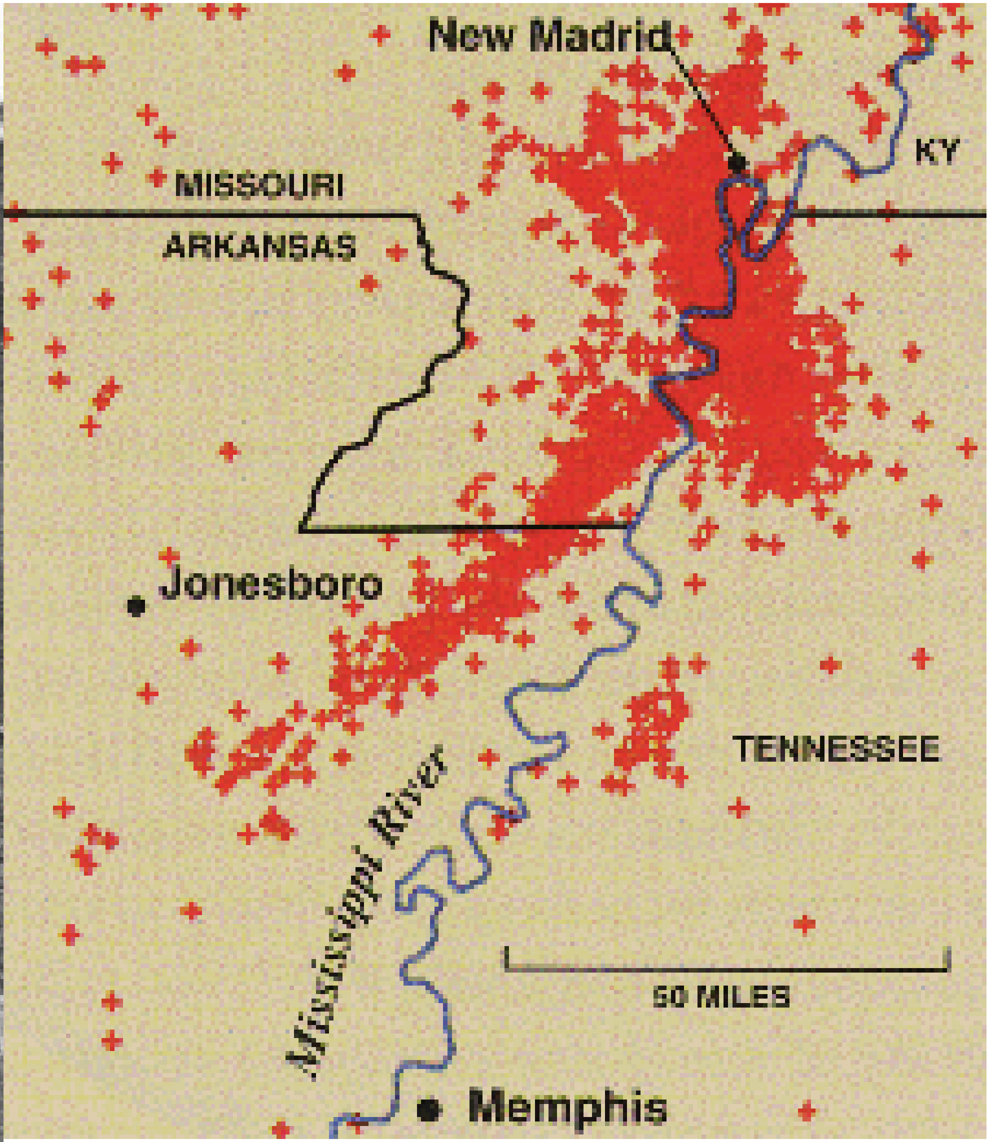
Left: caption: “Lower end of Reelfoot Lake, Tennessee, showing trunks of trees killed when the land was submerged by the December 16, 1811, northeast Arkansas earthquake. Photograph taken about 100 years after the earthquake.”

Right: caption: “Trees with double sets of roots. Elevated trees left by scooping out of sand by overflowing Mississippi waters south end of Reelfoot Lake. The surface is now about at its original level and the original tree trunk can be seen continuing down to the level of the ground. Later the tree was buried by sand to a depth of 5-feet and new roots formed. Still later the sand was removed. New Madrid earthquake. Lake County, Tennessee. 1904.”

Aside from the New Madrid quake, a damaging earthquake on December 18th 1737, near New York City, was felt throughout most of New Jersey. Other strong East Coast earthquakes include:

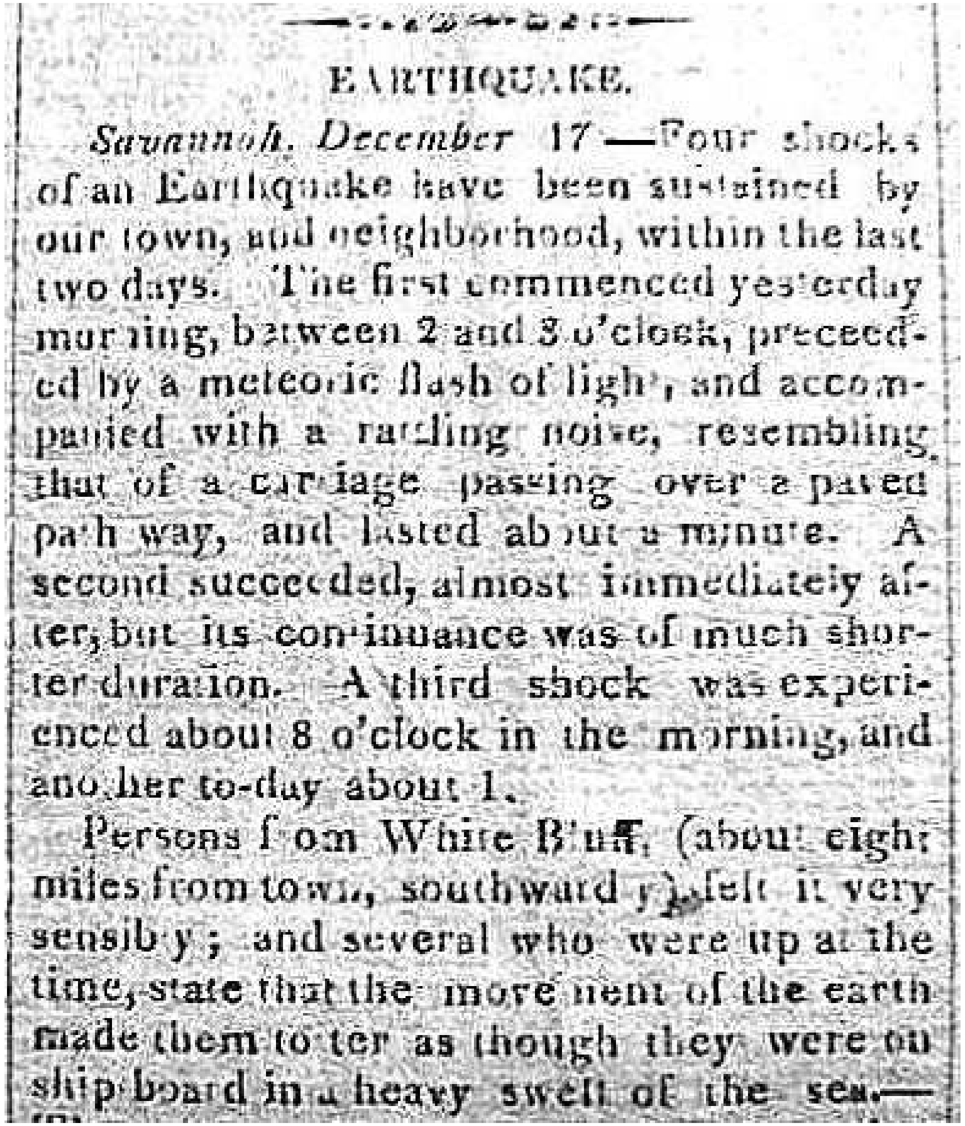
- **Off Cape Ann, Massachusetts, in 1755;**
- **Riviere-Ouelle, Canada, in 1860;**
- **Wilmington, Delaware, in 1871,**
- **NYC, in 1884;**
- **Charleston, South Carolina, in 1886, and;**
- **High Bridge, NJ, in 1895**

The worst by far was the *New Madrid Earthquake* of 1811-12 (it had a magnitude of 8.0). Almost the entire United States was shaken. During the New Madrid quake, there were many changes in the landscape; large areas of land sunk in forming new lakes and the *Mississippi River* changed its course. People in the area first felt the shaking was on December 6th 1811. One local said he felt it at 3:00 am. He also stated that the earthquake traveled from west to east. Some sections of the Mississippi appeared to run backward for a short time. Sand blows were common throughout the area and can still be seen from the air in cultivated fields. Shockwaves were felt as far away as Pittsburgh, PA & Norfolk, VA. Church bells were reported to ring as far away as Boston, Mass., and York, Ontario, Canada.



<u>Above</u>: caption: "Map of Affected Area"

<u>Left</u>: caption: "Earthquake fissure filled with intruded sand, formed at the time of the New Madrid earthquake"



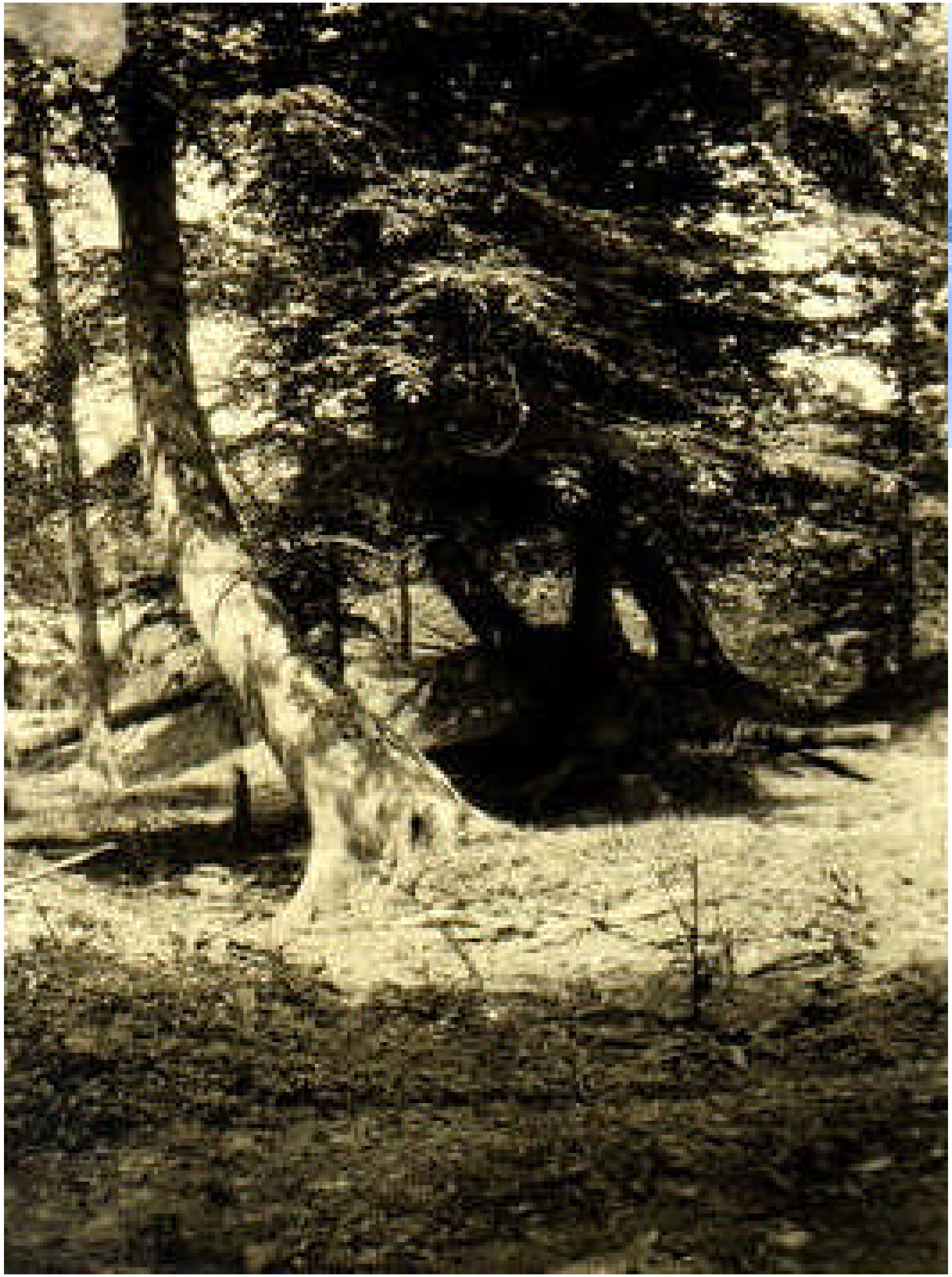
EARTHQUAKE.

Savannah, December 17—Four shocks of an Earthquake have been sustained by our town, and neighborhood, within the last two days. The first commenced yesterday morning, between 2 and 3 o'clock, preceded by a meteoric flash of light, and accompanied with a rattling noise, resembling that of a carriage passing over a paved path way, and lasted about a minute. A second succeeded, almost immediately after, but its continuance was of much shorter duration. A third shock was experienced about 8 o'clock in the morning, and another to-day about 1.

Persons from White Bluff, (about eight miles from town, southward y) felt it very sensibly; and several who were up at the time, state that the movement of the earth made them totter as though they were on ship board in a heavy swell of the sea.—

"Beginning December 16, 1811, there were violent earthquakes in the area throughout the winter months. On some days the atmosphere was so completely saturated with sulfurous vapors as to cause total darkness. Trees cracked and fell into the roaring Mississippi. The waters of the river gathered up like a mountain, rising 15 to 20 feet perpendicularly, then receding within its banks with such violence that it took whole groves of cottonwoods which edged its borders. Fissures in the earth vomited forth sand and water, some closing again immediately. The Chickasaw Indians, the primary residents of the area in those days and never ones to quarrel with the wrath of gods, had their own version of the lake's creation."

***Eliza Bryan*, New Madrid, MO resident**

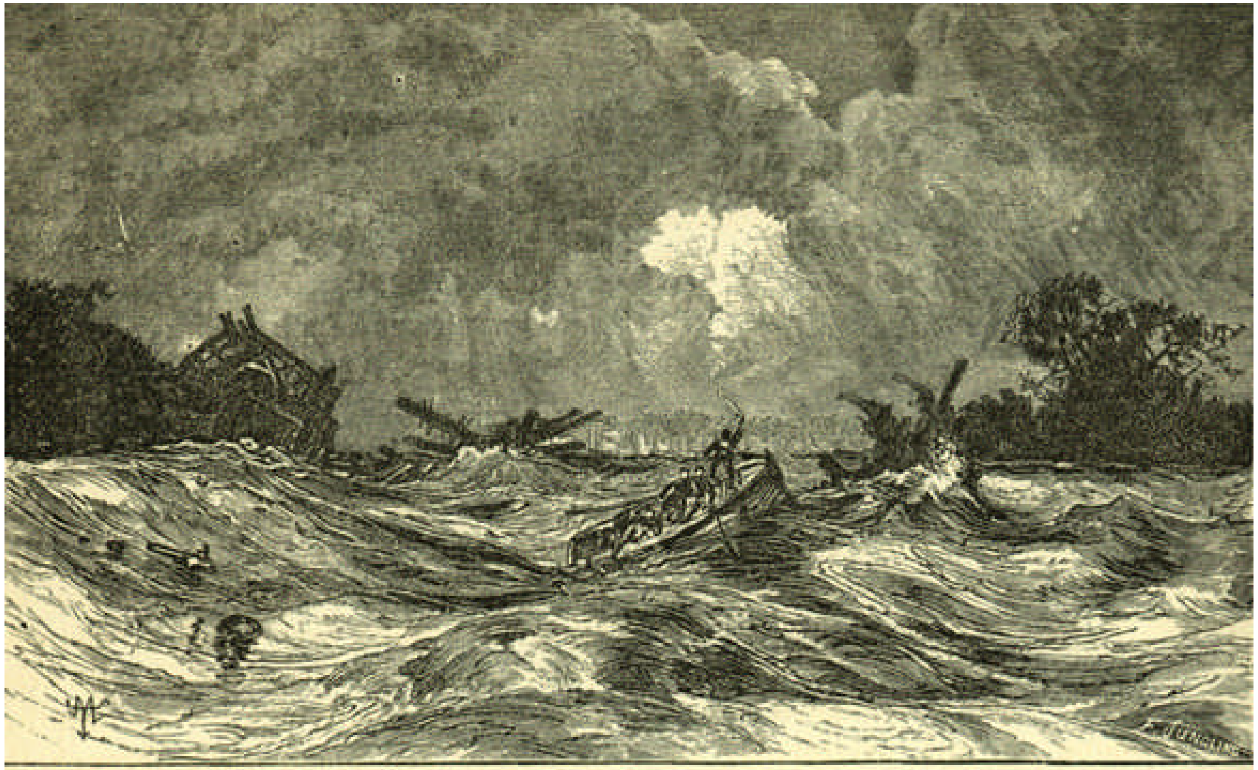


Above: *Reelfoot Lake*. The 13K-acre lake in the northwestern corner of Tennessee averages only 5 to 6-feet in depth (about 18-feet at it's deepest point). The old forest which stood before the earthquake still lies just beneath the surface.

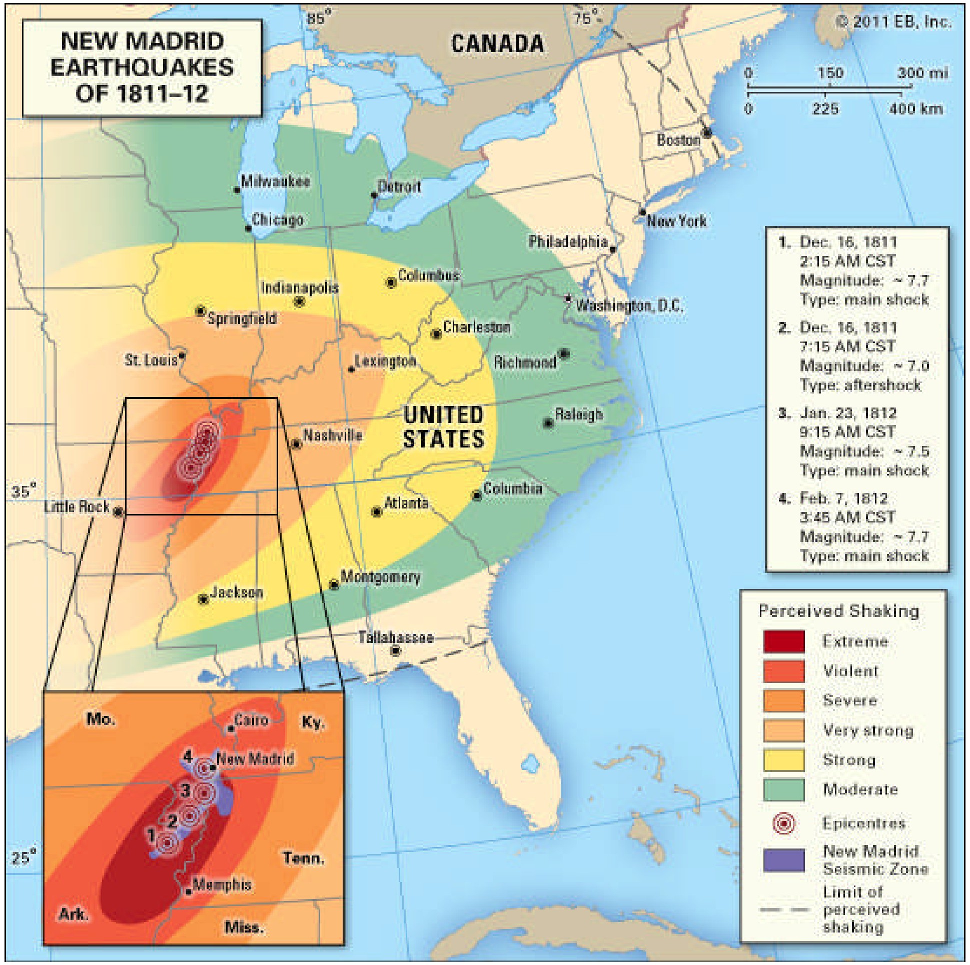
Left: caption: "Trees tilted by New Madrid earthquake, Chickasaw bluffs east side of Reelfoot Lake. Note twist of trees into upright position."

“There was a great shaking of the earth this morning. Tables and chairs turned over and knocked around - all of us knocked out of bed. The roar I thought would leave us deaf if we lived. It was not a storm. when you could hear, all you cold hear was screams from people and animals. It was the worst thing that I have ever witnessed. It was still dark and you could not see nothing. I thought the shaking and the loud roaring sound would never stop. You could not hold onto nothing neither man or woman was strong enough - the shaking would knock you lose like knocking hickory nuts out of a tree. I don’t know how we lived through it. None of us was killed - we was all banged up and some of us knocked out for awhile and blood was every where. When it got day break you could see the damage done all around. We still had our home it was some damage. Some people that the home was not built to strong did not. We will have to hunt our animals. Every body is scared to death. we still do not know if anybody was killed. I made my mind to one thing. If this earthquake or what ever it was did not happen in the Territory of Indiana then me and my family is moving to Pigeon Roost as soon as I can get things together.”

***George Heinrich Crist,* Nelson County (North-Central Kentucky), December 16th 1811**



SCENE OF THE GREAT EARTHQUAKE IN THE WEST.



"…Last year, at the height of the Mississippi floods, the same region suffered another quake, this time a slight one, which did no particular damage. A heavy temblor in the same zone, according to E. Lester Jones, director of the U.S. Coast and Geodesic Survey, might shake down old and poorly constructed buildings within that area…"

***Popular Mechanics*, June 1928**

Alas!

"The morning of September first was stormy. A strong wind was blowing, and I could scarcely hold an umbrella. It was raining heavily, but when I reached my office it began to clear up, and the dark sky changed to a cheerful blue. At 11:58 o'clock I heard a strange sound from the earth through the building wall, but since it was so slight, and, because I afterwards learned that other men did not notice it, I paid little attention. Soon afterwards, the building began to shake very softly. Inasmuch as we Japanese are familiar with small earthquakes, I paid little attention to it and felt that it would soon pass, but, alas! it grew into an uncomfortable shock…"

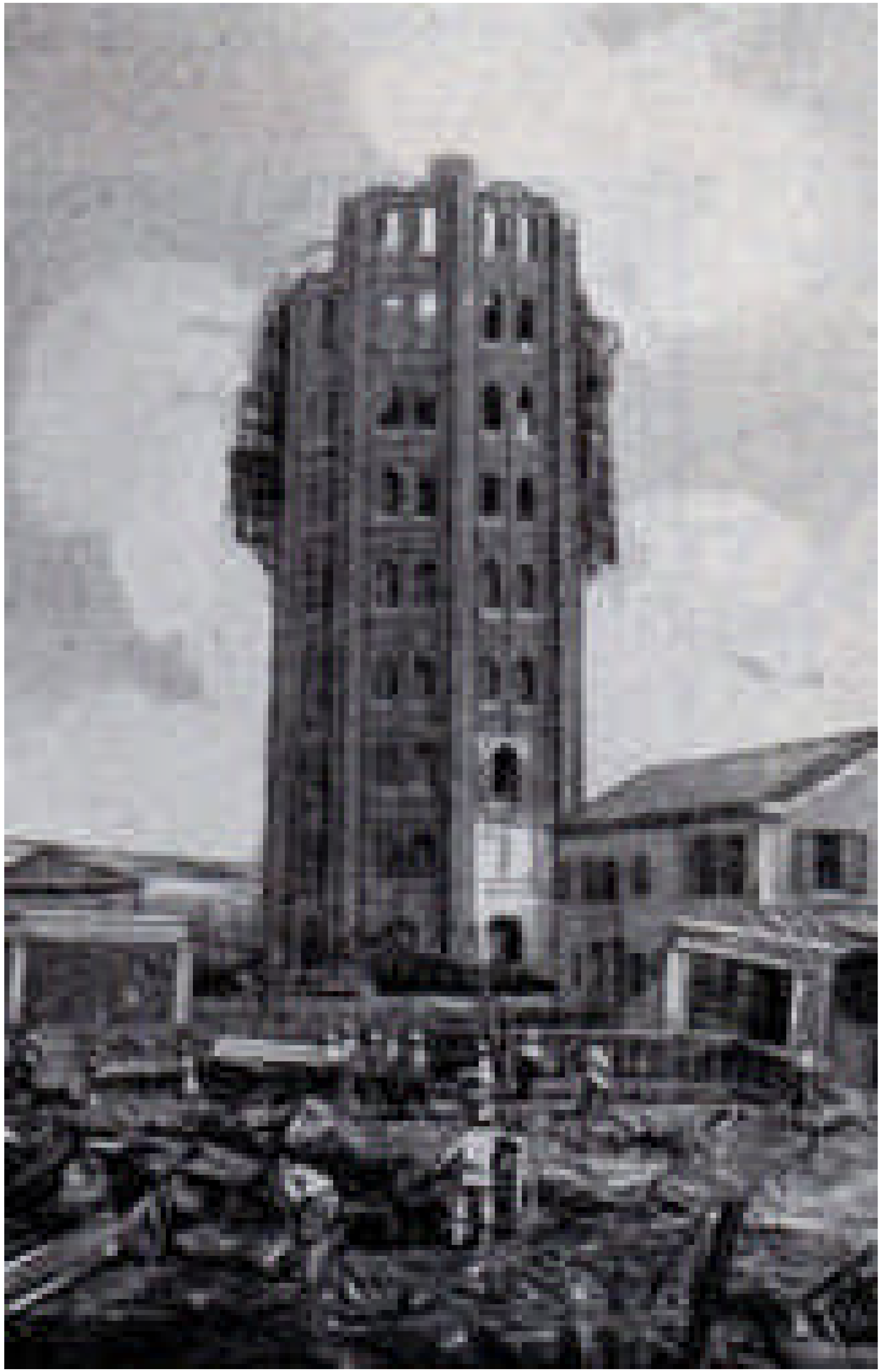
N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

RE: Tokyo (formerly known as *Edo*) was/is the political, economic and bureaucratic center of Japan. Between 1900 and 1923, the population of metropolitan Tokyo virtually doubled; from 1.12 million in 1900 to 2.17 million by 1920.

東京市全景(五) TOKYO (本所方面遠望)

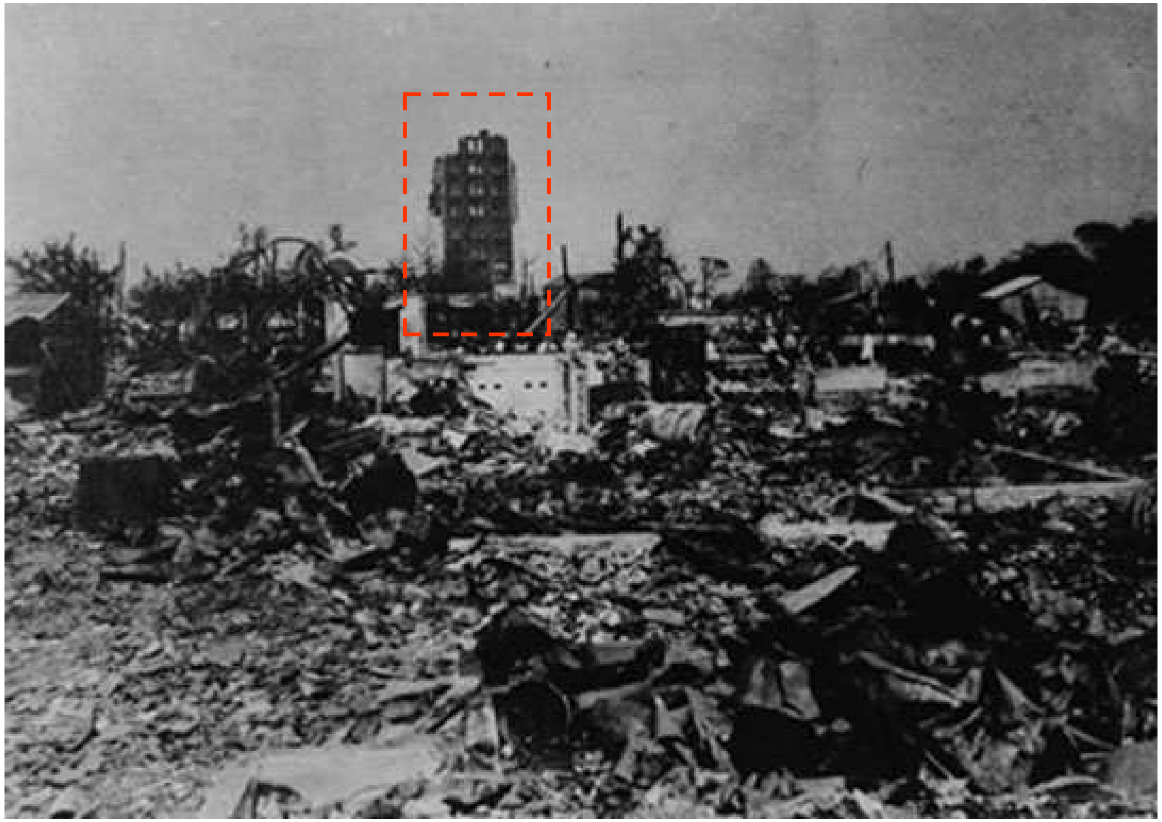
日本橋通リノ美観
NIHONBASHI DORI TOKYO


TEIKOKU SEIMA KAISHA LTD.
Nipponbashi, Tokyo
東京日本橋ノ景



"…I heard the crying of women and the sounds of the cracking of the adjacent building walls. We had in our room a large case for filing papers which measured about 10 feet high and 20 feet wide. This now began to sway from left to right, and back. Finally, it fell over forward. The bookcase crashed to the floor and my writing cabinet fell over. The huge body of the office building was still shaking, giving off an indescribable sound…"

N. Sakata **- Tokyo correspondent for** ***Popular Mechanics*** **magazine, January 1924**



"…The movement of the first shock still continued, and I cannot tell you how dreadful it was to me. The walls had not cracked in my room, but I could hear them from all sides. I supposed, of course, that my room would finally crush in, and in my mind I said farewell to all my brothers, my mother, and my sister. I crawled under the heavy desk, hoping that I might thus be saved…"

N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

Above: caption: "Desolation of Nihonbashi and Kanda seen from the Roof of Daiichi Sogo Building, Kyobashi." The *Great Kanto Earthquake* occurred on Saturday, September 1st 1923 at 11:58:44 A.M., striking the *Kanto Plain* on the main Japanese island of Honshu. The quake lasted from four to ten minutes.

“…After the first tremendous shock, I resolved to go to the Imperial Palace Square, which is a very wide field and near our building. As I rushed out the front door, I noticed that the huge buildings all about me were broken. A man, terribly hurt,, was sitting on the ground by the building. I ran on to the square…”

N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

“…Many fires now arose throughout the city. Black smoke and red flames were cast over the sky. I could not see the natural color of the sky anywhere because of the dense smoke. Hunger and thirst came next…”

N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

RE: because the earthquake struck at lunchtime, when people were cooking meals over fires, many large fires broke out. Some fires developed into firestorms that swept across cities (many people died when their feet became stuck on melting tarmac). The single greatest loss of life was caused by a fire tornado that engulfed the *Rikugun Honjo Hifukusho* in downtown Tokyo, where about 38K people were incinerated after taking shelter there.

"…Indeed, the first night of the earthquake, September first, was a very dreadful one. I still find it difficult to believe that it is all true. In every direction one might look, the city was a mass of flames. The Imperial Palace Square was the middle of a great furnace. Crimson flames and billowing clouds of smoke covered the city…"

N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

RE: the *Great Kanto Earthquake* had a magnitude of 7.9 on the *Moment Magnitude Scale*, with its focus deep beneath *Izu Oshima Island* in *Sagami Bay*. The cause was a rupture of part of the convergent boundary where the *Philippine Sea Plate* is subducting beneath the *Okhotsk Plate* along the line of the *Sagami Trough*.

“…Fire, and not the shaking, is responsible for a great part of the loss of life and property when a quake rocks a densely populated modern city. Stoves and open fires spill live coals into the ruins, broken gas mains are touched off by chance sparks, and, at the same time, the water mains are broken and rendered useless…”

***Popular Mechanics,* June 1928**

<u>Above</u>: caption: “Metropolitan Police Department burning at Marunouchi, near Hibiya Park”

“…We could find no light or gas in the square, for these had been extinguished at the producing station because of the danger of fire. There was, however, no need of man-made illumination, for the holocaust provided as brilliant a light at night as the sun did in the daytime. The temperature of the air being raised, we were forced to breathe quickly, the heavy air almost stifling us. I could not sleep, for I was nearly frantic thinking about my mother and sister whom I had left at home…”

N. Sakata **- Tokyo correspondent for** ***Popular Mechanics*** **magazine, January 1924**

RE: the earthquake broke water mains all over the city so putting out the multitude of fires took nearly two full days (until late in the morning of September 3rd). An estimated 6,400 people died and 381,000 houses were destroyed by the fire alone. In the aftermath of the 1906 ***San Francisco Earthquake*****, it was found that the only way such a conflagration could be stopped was by the use of dynamite and back-firing.**

“…Hunger attacked us. Tokyo is very cold in September, and although the flames gave off great heat, the midnight air chilled us. I tried to get out of the crowds. There were more than 100,000 gathered in this small square, so it was very difficult to get away. Indeed, I could not get a bit of space to stand up. It took me 30 minutes of crawling and stumbling to move 200 feet, but finally I emerged…”

N. Sakata **- Tokyo correspondent for** ***Popular Mechanics*** **magazine, January 1924**

RE: a strong typhoon struck ***Tokyo Bay*** **at about the same time as the earthquake. Winds from the typhoon caused fires off the coast of** ***Noto Peninsula*** **(in** ***Ishikawa Prefecture*****) to spread rapidly.**

The *Great Kanto Earthquake* devastated Tokyo, the port city of Yokohama and surrounding prefectures of *Chiba*, *Kanagawa*, and *Shizuoka* and caused widespread damage throughout the Kanto region. Its force was so great that in Kamakura, +37 miles from the epicenter of the quake, the Great Buddha statue (which weighs about 93 short tons) was moved almost two-feet.

Left: caption: "Great Buddha 1923. Great Kanto Earthquake damage"

“…After a very long time, and by devious routes, I reached my home. Alas! I found my house burned to ashes, and I could not find any members of my household. I searched and searched in the clouds of smoke for my mother and sister. The smoke filled my eves and I could not see. I tried to find even a bit of my mother’s burned body, but I could not. After hours of vain search, my eyesight nearly gone from smoke, I had to stop, and I could only hope that my mother might have escaped to safety somewhere. I could not think of any place she might be. All the homes of my relatives were destroyed. ‘Oh, where could she be!’ I asked myself, and cried and cried. I thought that I might not be able to find them anywhere any more in this world. All my courage had disappeared…”

N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

“…It was in this state that, as I was walking along the river which is near my house, I saw a woman dimly through the smoke - just an outline. The phantom shape seemed to resemble my mother. I approached and asked her who she was, and then, I could not believe it was real! I thought it must be a dream, but it was not. It was my mother! It was my mother! She and I embraced each other again and again, thanking God, and again I cried and cried for joy…”

N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

“…Coming home from my office I saw hundreds of dead bodies of men and women. I had had nothing to eat for more than three days, and the odd odor of the hot wind often caused me to fall down fainting. But my mother and sister were safe, so my courage had returned to me. Everywhere, I saw thousands of people running to escape from the city to the suburbs. I had taken my mother and sister to the suburbs, and was trying to get into the city. I understood fully that I might be wounded or killed by fire and falling buildings, but we nevertheless kept on our way…”

N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

RE: estimated casualties totaled about 142,800 deaths, including about 40K who went missing and were presumed dead. A report issued in September 2004 confirmed a total of 105,385 deaths as a result of the *Great Kanto Earthquake* of 1923.

“…Occasionally I was asked who I was by a policeman. They urged me to stay out of the city, and at times even attempted to prevent me, for by this time the government had declared the city under martial law, and soldiers stood on the road with their guns loaded and swords bared. If we insisted, then it would mean we would be shot or cut down. Sometimes we were attacked by flames and smoke. Frequently, to protect ourselves against such terrors, we were forced to dash into the water and get ourselves wet from head to foot. It was very dangerous work. The fire continued eight days…”

N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

RE: the damage resultant from the *Great Kanto Earthquake* was the greatest sustained by prewar Japan. In 1960, the Japanese government declared September 1st - the annual anniversary of the quake, “Disaster Prevention Day.”

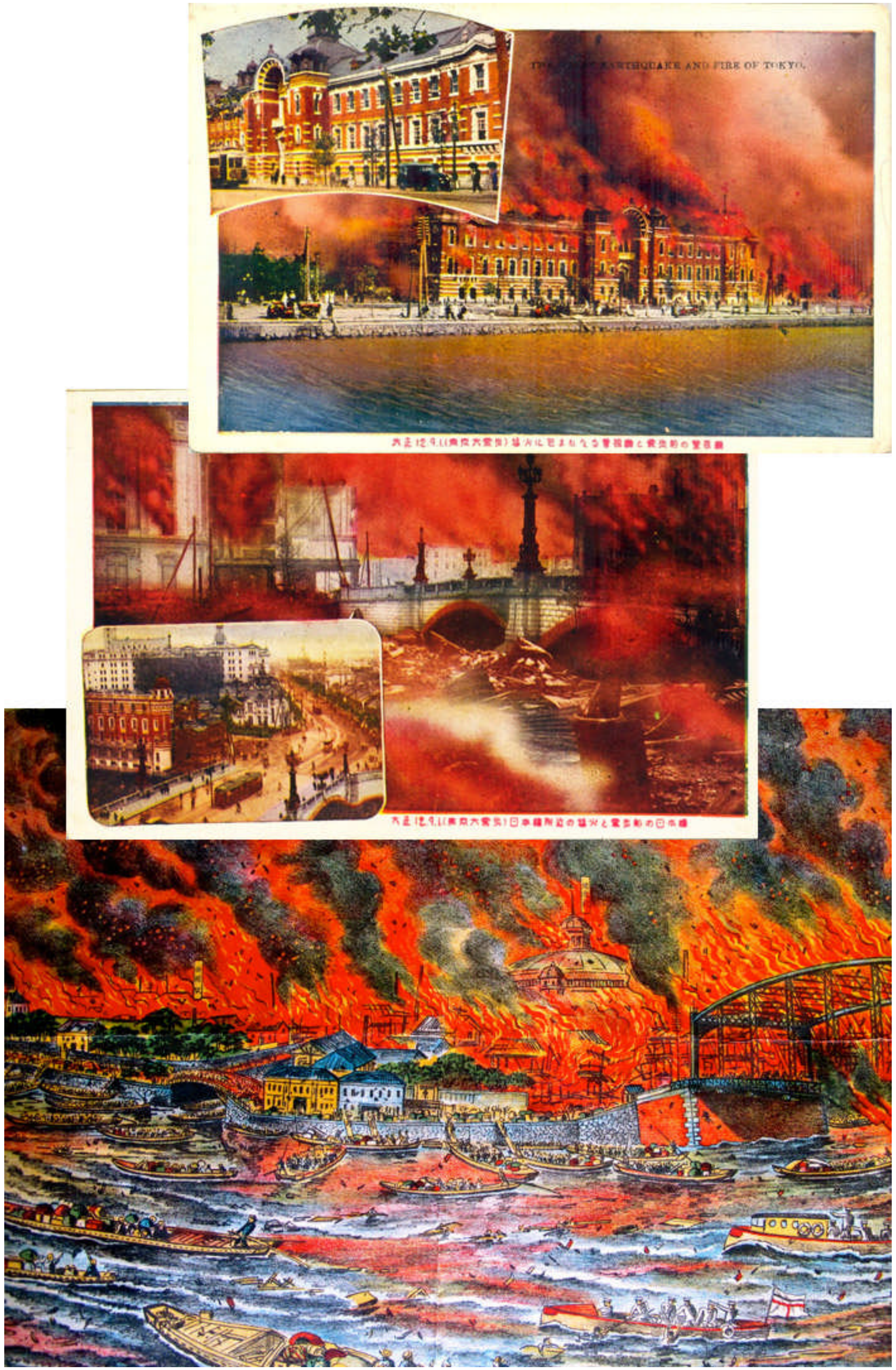
“…The tragedy prompted countless acts of heroism. Thomas Ryan, a 22-year-old U.S. naval ensign, freed a woman trapped inside the Grand Hotel in Yokohama, then carried the victim - who had suffered two broken legs - to safety, seconds ahead of a fire that engulfed the ruins. Capt. Samuel Robinson, the Canadian skipper of the Empress of Australia, took hundreds of refugees aboard, organized a fire brigade that kept the ship from being incinerated by advancing flames, then steered the crippled vessel to safety in the outer harbor…”

***Smithsonian* magazine**

“…We Japanese have one thing in mind to tell you; that is, our great thanks for the wonderful help you gave us. If you will, please, print on your pages that the Japanese people are thanking the American people, and will never forget your kindness at this time. I am now at Shibaura, which is the shipping center on Tokyo Bay. I can see many ships flying the American flag on the calm sea. It is an inspiring sight, and I thank God for it.”

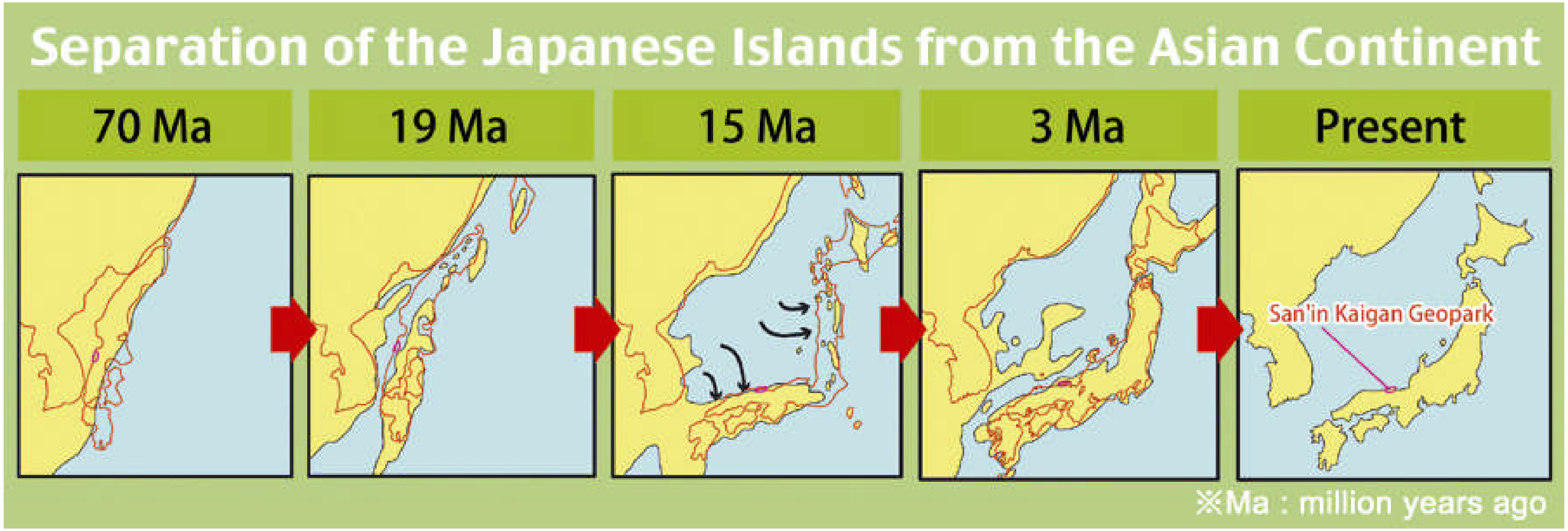
N. Sakata **- Tokyo correspondent for *Popular Mechanics* magazine, January 1924**

Hell on Earth



On September 1st 1923, Tokyo's vulnerabilities were exposed unambiguously. At two minutes to noon a magnitude approximate 7.9 earthquake toppled structures, crushed people and unsettled everyone who survived. Minutes later, another intense seismic wave battered eastern Japan. This earthquake killed scores more and triggered widespread panic across the capital. Over the next three days, survivors experienced nearly two-thousand aftershocks and a series of hellacious conflagrations that unleashed widespread pandemonium, killed tens of thousands and burned large swaths of Tokyo and Yokohama. The sights and smells of death and the cries of seriously wounded, half dead survivors amid this vanquished landscape led one anonymous chronicler to ask the question: *"If this were not Hell, where would Hell be?"* Tokyo had become a hell on earth.

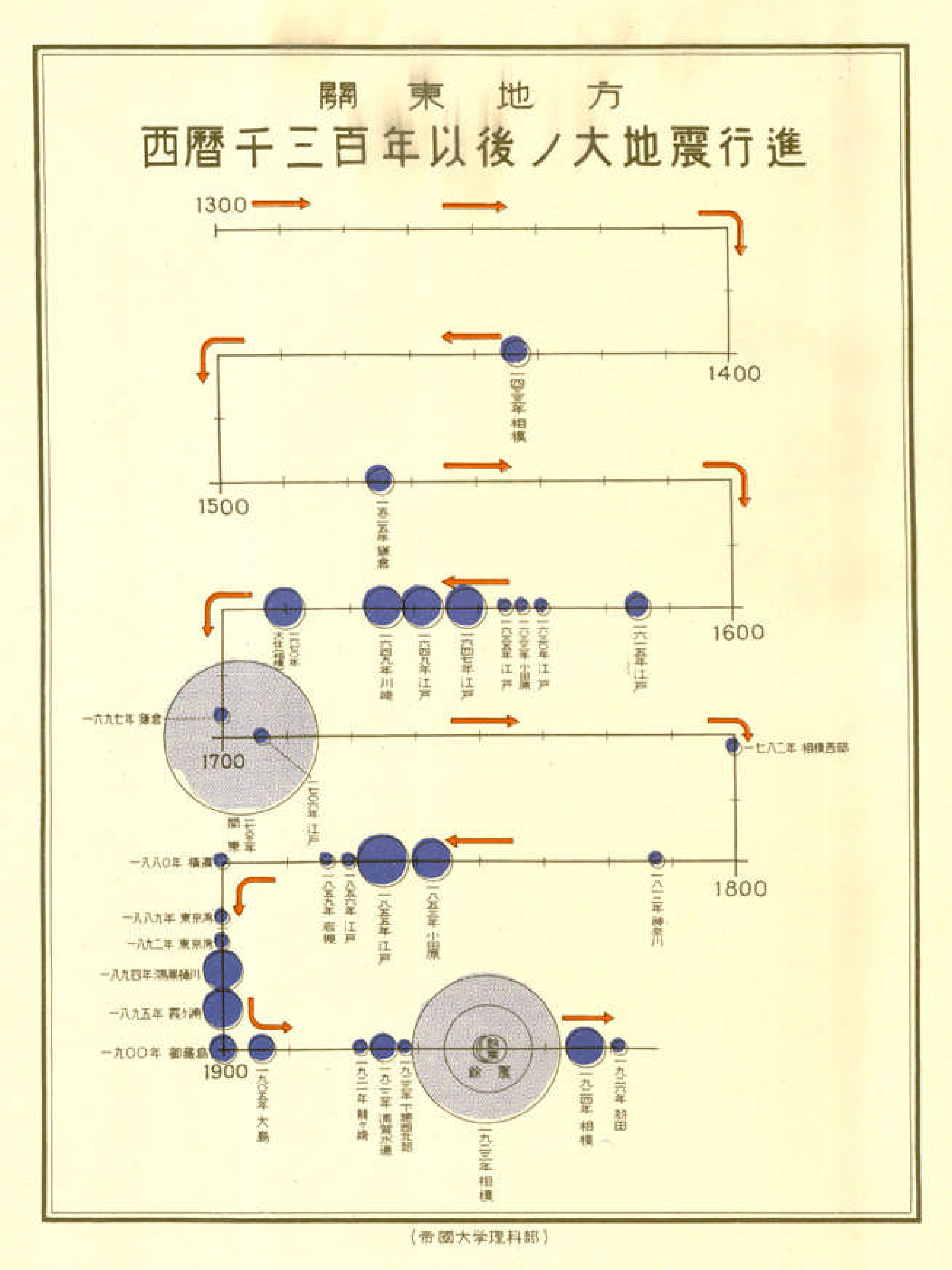
The *Kanto Region*, which includes the population centers of Tokyo, Yokohama and Kawasaki, is one of the most seismically vulnerable places on Planet Earth. Deep below the waters of the *Pacific Ocean*, roughly 275 km east of Tokyo and running north along Japan's east coast, the Pacific tectonic plate subducts beneath the *North American-Okhotsk* tectonic plate. Earthquakes along the boundary have rattled the eastern coast of Japan from Hokkaido in the north, southward to the island of *Iwo Jima* since time immemorial. Subduction along this plate triggered one of Japan's largest earthquakes, the magnitude 9.0 *Tohoku Earthquake* of March 11th 2011.



"…At one time, Japan was part of the mainland of Asia. Probably an earthquake tore it from its moorings, the sea flowed through a rent in the earth, and Japan became an island. Of volcanic origin, it has been subject to frequent earthquakes, each taking its human toll and exacting from the people a frightful tax in the from of property loss…"

***Popular Mechanics,* November 1923**

<u>Above</u>: caption: "Although Japanese islands used to be a part of the Asian continent, they began to separate from the mainland about 20 million years ago and formed the Sea of Japan"



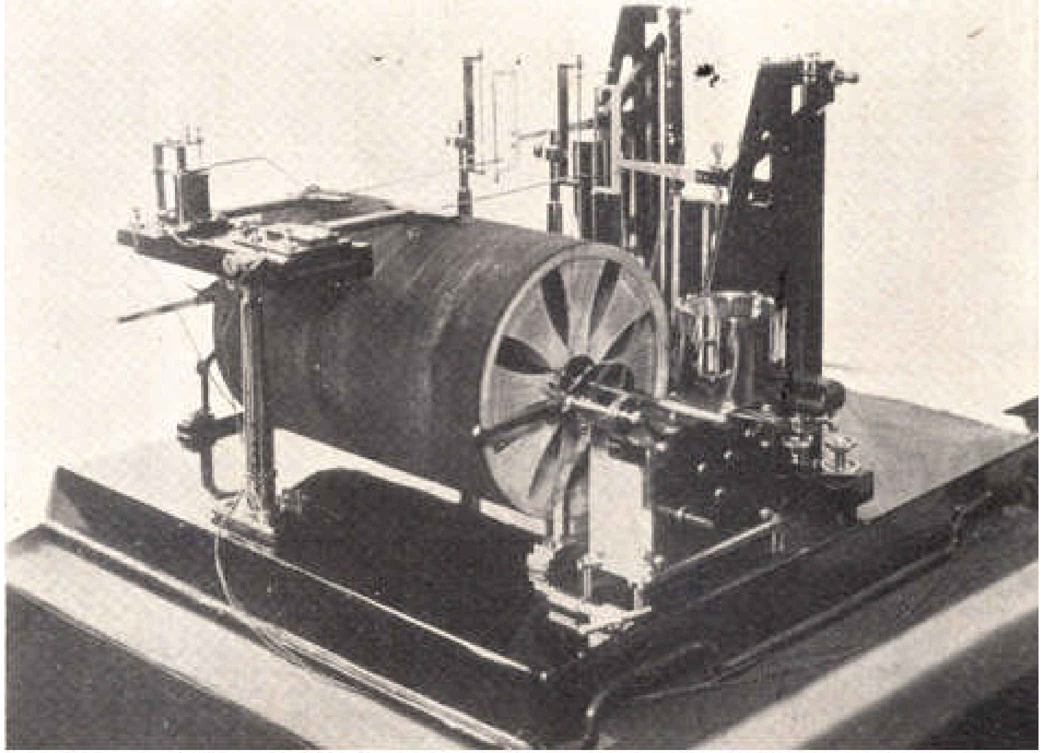
"…Of volcanic origin, it has been subject to frequent earthquakes, each taking its human toll and exacting from the people a frightful tax in the from of property loss…"

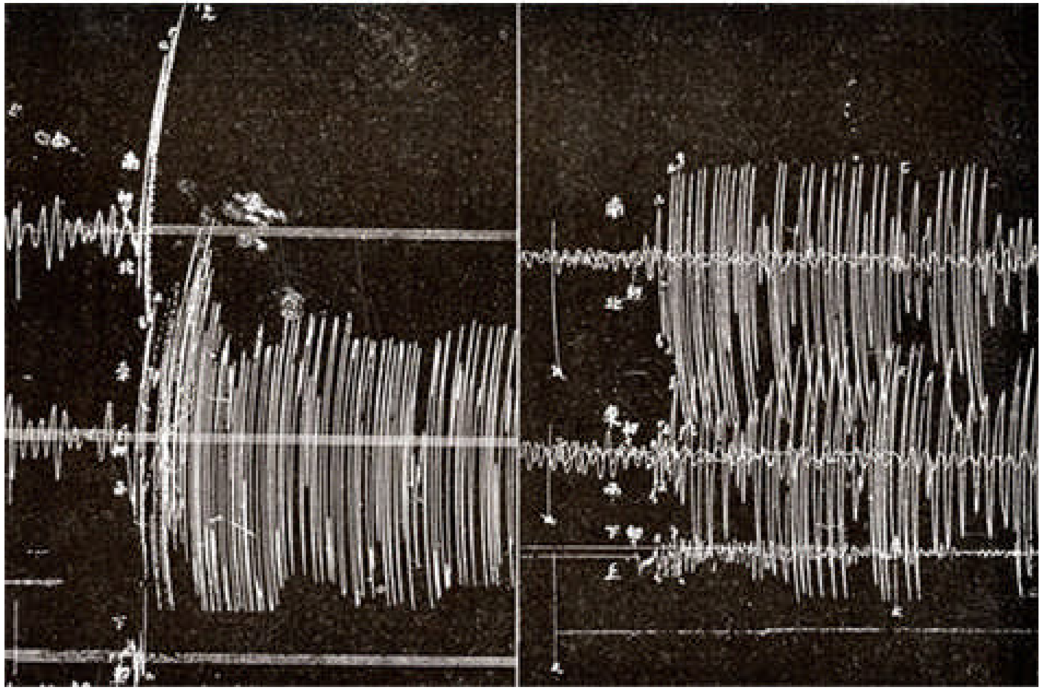
Popular Mechanics, **November 1923**

<u>Left</u>: Japanese chart demonstrating the history of earthquakes and their varying intensity/s, staring in the year 1300 through to the *Great Kanto Earthquake* of 1923

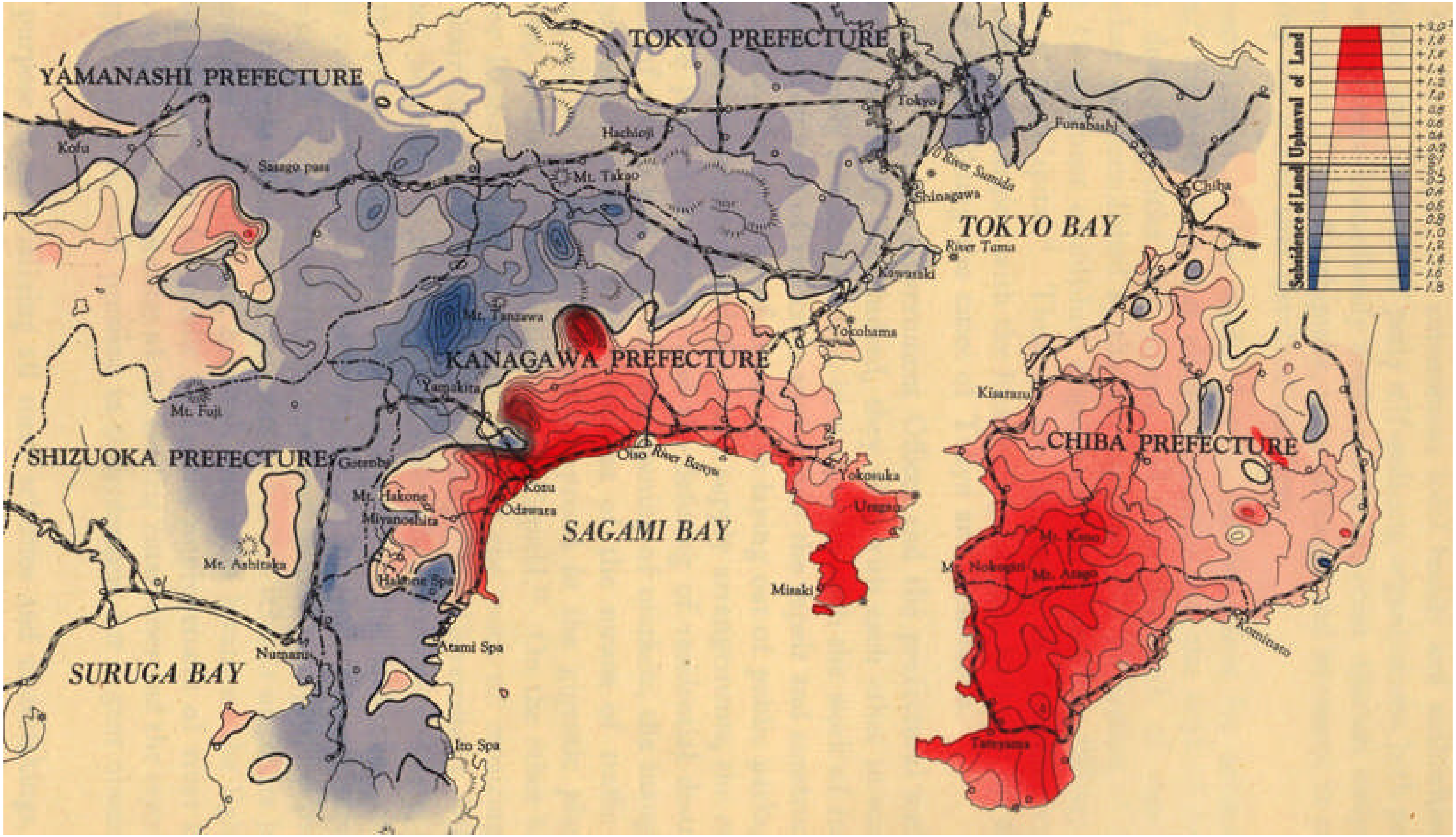
A scene of appalling devastation along the waterfront of Yokohama, following the terrific earthquake and tidal wave of September. Scientists believe now that most earthquakes are caused by the fracture and slipping of the earth's crust as the earth contracts (see diagram at the left). Some quakes, however, are believed to be the result of subterranean volcanic action, as shown at the right

<u>Above</u>: caption: " A scene of appalling devastation along the waterfront of Yokohama, following the terrific earthquake and tidal wave of September. Scientist believe now that most earthquakes are caused by fracture and slipping of the earth's crust as the earth contracts (lower left). Some quakes, however, are believed to be the result of sub-terranean volcanic action (lower right)."





The population centers of eastern Japan are also vulnerable to the movements of two other tectonic plates that have triggered catastrophic earthquakes: the *Philippine Sea* tectonic plate and the *Eurasian* tectonic plate. The subduction zone created by the intersection of these two plates sits roughly 100 km south of Tokyo virtually bisecting *Sagami Bay*. Movements associated with these two tectonic plates triggered the 8.2 magnitude approximate *Genroku Earthquake* of 1703 and the 7.9 magnitude *Great Kanto Earthquake* of 1923. Recent scholarship suggests that Tokyo is vulnerable to earthquakes triggered by the movement of yet another tectonic plate (or “dislodged plate fragment”) located directly beneath the *Kanto Plain* upon which Tokyo and approximately 33 million people presently reside.



<u>Above</u>: caption: "'The Perpendicular Changes of Lands by the Earthquake of 1923 in Kwanto Districts.' This map shows the actual condition of upheaval and subsidence caused by lands, revealed from resurveying of the standard water level of the trigonometrical point after the Great Earthquake of 1923."

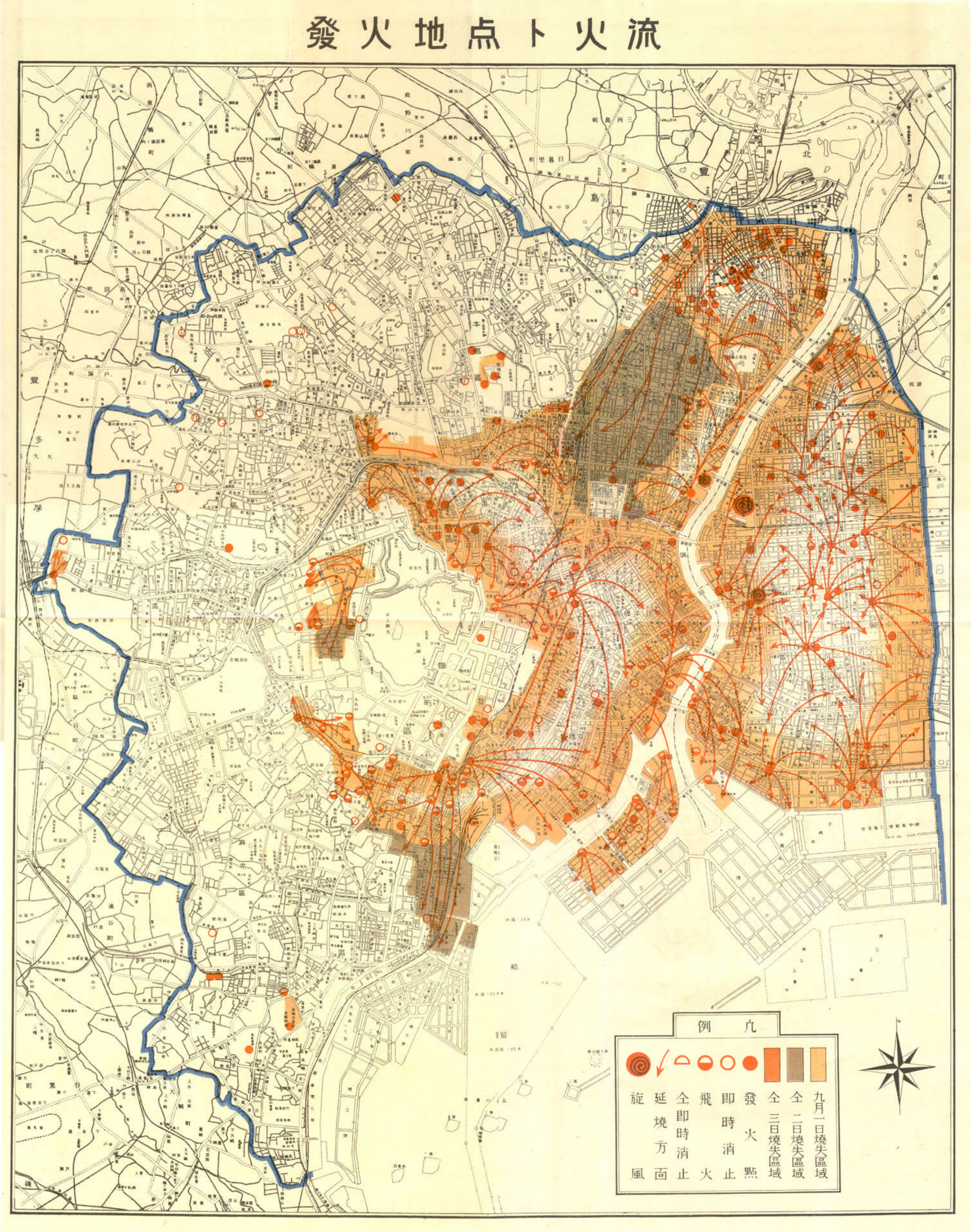
（復興祭記念•慘禍の憶出）　大激震を物語る大地割

箱根登山鐵道の大破　（教育擁護同盟）

Sea of Fire

As destructive and dislocating as the earthquake and aftershocks were to people of eastern Japan in September 1923, a far more deadly phenomenon erupted shortly after the initial seismic upheaval: fire. Within 30 minutes of the first tremor more than 130 major fires broke out across Tokyo alone. Many were clustered in the densely populated and highly vulnerable eastern sections of the city including *Asakusa, Kanda, Nihonbashi, Kyobashi, Honjo, Fukagawa, Shitaya* and the *Ginza District* in central Tokyo.

More dramatically, five independent whirlwind firestorms erupted across Tokyo and burned everything in their path. One individual who witnessed an approaching firestorm, described it as: *"an enormous wall of fire…like a tidal wave as if released from Hell itself,"* which: *"turned the air as hot as melting rock."* Reporters for the *Kyushu nippo* (a newspaper published on the southern island of *Kyushu*) suggested that Japan's once great capital had been transformed into a "sea of fire" (zenshi hi no umi). Tokyo resembled what could only be described as a "burning Hell."



Within hours of the first seismic upheaval hundreds of thousands of people attempted to flee burning Tokyo. Streets, alleyways, bridges, rivers, canals and open spaces became virtually impossible to navigate in the face of catastrophe. While many residents eventually escaped, tens of thousands did not. Some drowned in the *Sumida River* that snakes through Tokyo after jumping from crowded riverbanks or burning bridges to escape approaching fires. Others burned to death in streets, alleyways, parks and in the few open spaces that existed in Tokyo. Of the roughly 120K people who perished, a majority died as a result of fire.

<u>Left</u>: caption: “Map showing initial starting points and spread of Tokyo fires”

The areas that once comprised Tokyo and Yokohama had become defined by death, destruction and upheaval. However deadly and confronting the earthquake calamity had been, the hardest tasks for government officials and for the citizens of eastern Japan lie ahead; restoration of order, relief and recovery. It would prove to be an undertaking of enormous magnitude.

After All is Said and Done

“…Not everyone has sufficient money to build of steel and concrete, and after all is said and done, are such buildings any safer than ordinary wooden houses? Probably not. A one-story building constructed of wood and thatch, may withstand an earthquake than one built of stone or concrete. To build skyscrapers in a land where earthquakes are frequent would be folly…”

***Popular Mechanics,* November 1923**

This explains why such cities as Yokohama and Tokyo are composed mainly of one-story buildings, which stretch for miles in every direction. Experience has taught the Japanese many things, but the problem of how to protect themselves from the devastation caused by earthquake, is still unsolved…”

***Popular Mechanics*, November 1923**

“…Japan in area is no larger than the states of Illinois and New York, but it has a population exceeding forty-seven million. A land teeming with human life, honeycombed with volcanoes, undermined by subterranean caverns in which seethe the mighty forces of nature. Is there a way to escape extermination?...”

***Popular Mechanics,* November 1923**

◆行届いた救援と救護◆

市役所前の求職者

芝浦に陸上げした救濟品の山

洪水中に配給米の施與

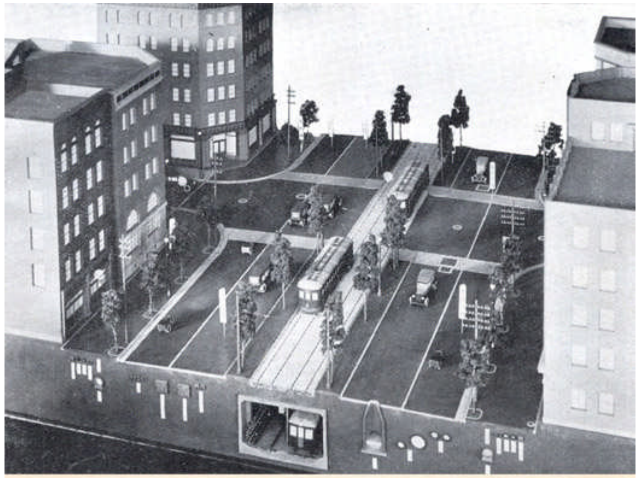
握り飯貰ひの行列

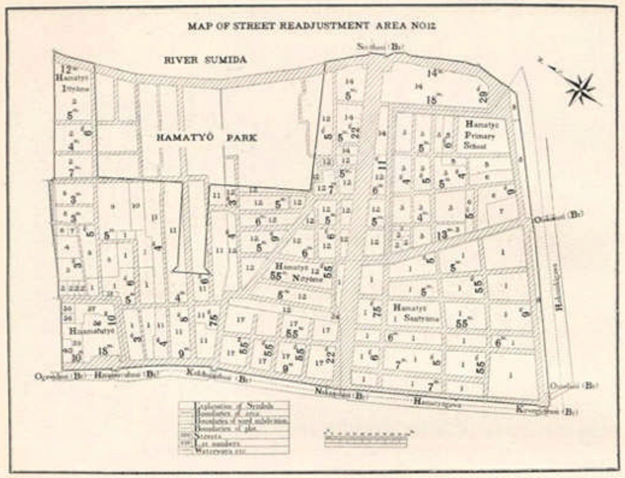
Lesson Learned

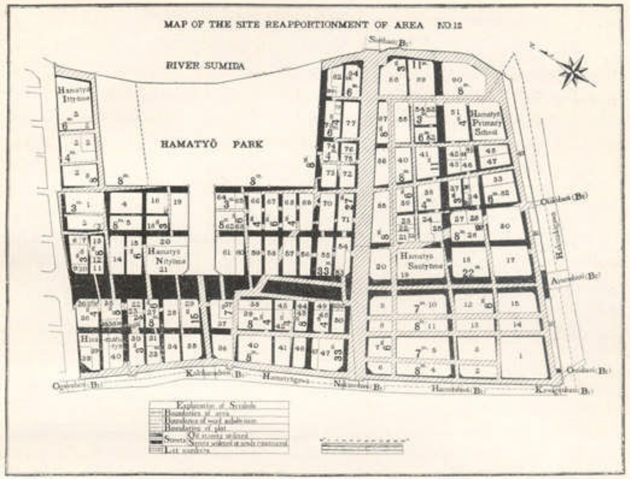
"…The Japanese government took the lessons of that quake to heart, and rebuilt the destroyed capital along modern lines. Residential, commercial and industrial districts were segregated, six great avenues, 100 to 150 feet in width, were cut through the most crowded portions of the city, and 122 broad streets replaced a maze of narrow winding alleys. Parks were dotted over the city as refugee centers, three large ones and fifty-two smaller areas being opened for the purpose…"

***Popular Mechanics*, June 1928**

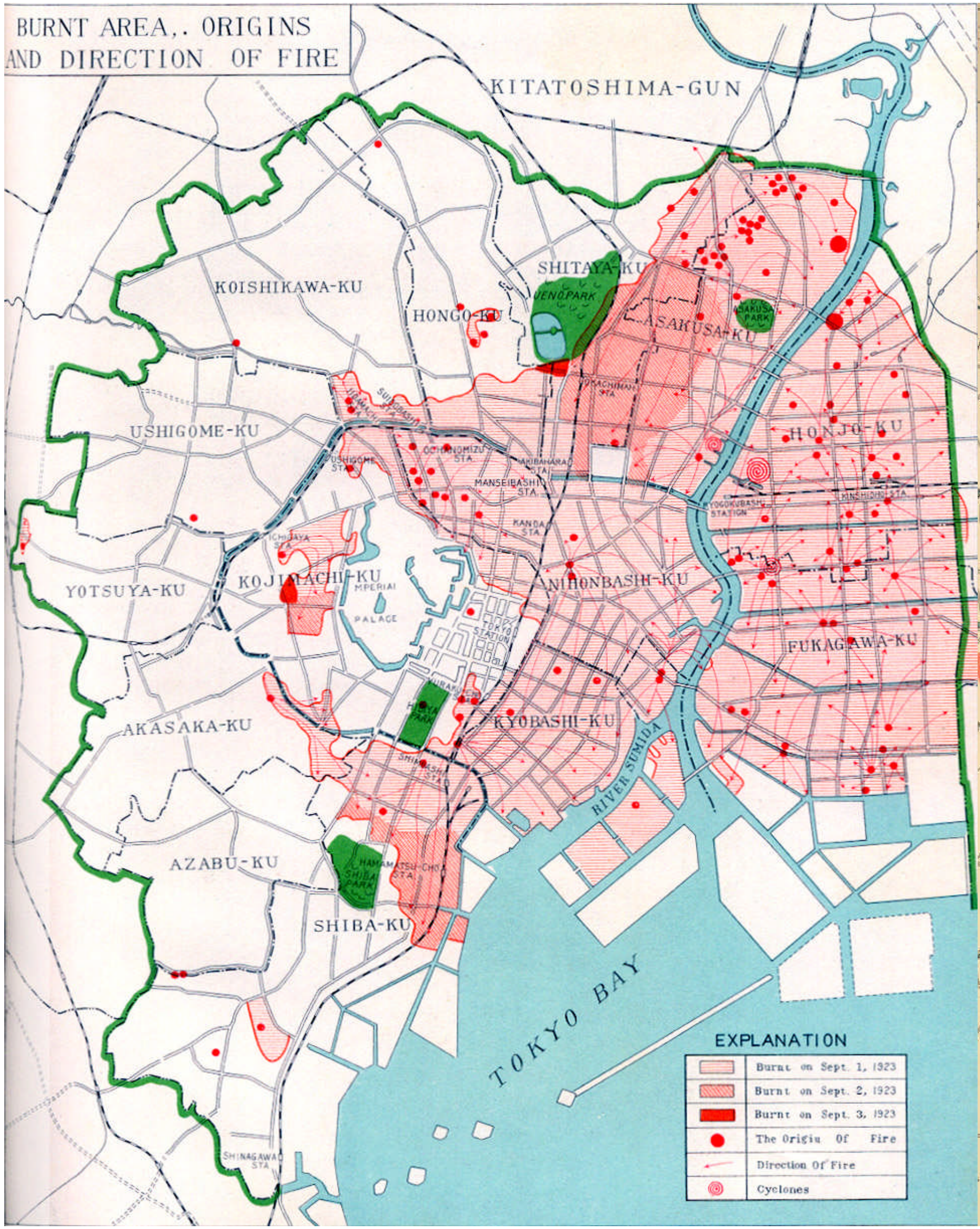
Above: caption: "Postcards highlighting reconstruction accomplishments"

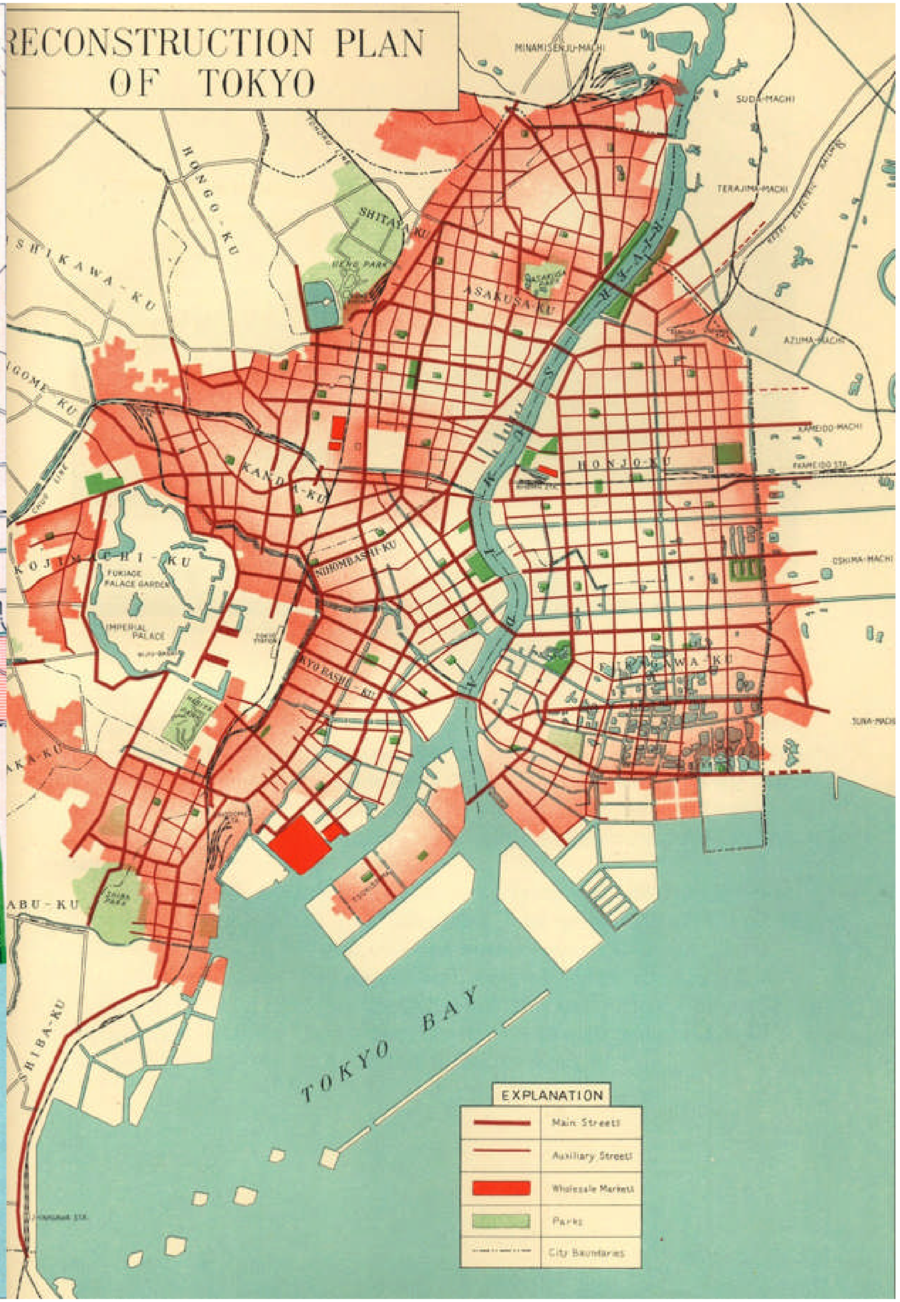






The reconstruction of Tokyo following the *Great Kanto Earthquake* was a monumental undertaking. Government buildings, homes, shops, roads, parks, and bridges that existed on nearly 33 million square-meters of land had been destroyed. Rubble had to be cleared, lots surveyed, plans devised and construction material sourced to rebuild a disaster-ravaged city. Amidst the ruins, however, many individuals saw an opportunity to build a city of the future. To urban planners, social welfare advocates and policy activists who saw the burnt our remains of Tokyo as an empty landscape of destruction, the opportunities for creation seemed endless, bound only by the limits of the imagination. However desolate old Tokyo looked to observers in September 1923, it was not a blank slate awaiting creation. The capital of tomorrow could not be conjured into existence through innovative plans alone. Myriad property owners, shopkeepers, and families returned to where their lives once centered and sought a return to normalcy, not the beginning of a brave new metropolis. Moreover, building the city of the future would take time, money, and a concentration of political power that did not exist in 1923 Japan.





Left: caption: “Burnt Area. Origins and Direction of Fire”
Right: caption: “Reconstruction Plan of Tokyo”

"…The final surveys for that quake showed the comparative loss from earth shocks and fire, even under the conditions of the old capital, where buildings were shaken down with ease. The number of houses totally destroyed by the quake was 128,266, while 447,128 structures were claimed by fire…"

Popular Mechanics, **June 1928**

<u>Above</u>: caption: "At the time of the quake Tokyo had a population of 2.5 million and the area struck by the quake had 12 million"


日本橋通り

With a scaled-back reconstruction budget, city officials were forced to use a process of land readjustment to redevelop devastated parts of the city. Under the *Special Urban Planning Law* (promulgated by parliament on December 24th 1923), the government gained the ability to employ land readjustment to alter the boundaries of residential property lots within Tokyo. Through land readjustment, the government gained the ability to claim 10% of all property and turn it into public space; without monetary compensation. City officials divided the roughly 33 million square-meters of devastated Tokyo into sixty-six *Land Readjustment Districts* (fifteen fell under the jurisdiction of the *Home Ministry* while fifty-one were administered by the *City of Tokyo*).

Between the years 1925 and 1934, there was an unprecedented construction boom of government buildings in Tokyo's *Kasumigaseki District* that coincided with the recovery from the *Great Kanto Earthquake*.

<u>Top Left</u>: caption: "The Metropolitan Police Department building"

<u>Top Right</u>: caption: "The building of the Ministry of Education"

<u>Left</u>: caption: "The Ministry of the Interior building"

Land readjustment committees were elected in each of the sixty-six districts by landowners and business leaseholders. These committees gained influence over how individual parcels of land would be readjusted to make plots and entire neighborhoods more rational, how much compensation money was to be paid to landholders who experienced a loss of more than 10% of their property and the size and location of substitution lots. They also deliberated over thousands of petitions from landholders and residents over the speed, scope and scale of readjustment. Of the 24.9 million square-meters of land that fell under the city's readjustment jurisdiction, 18.7 million square-meters were designated as residential land before readjustment.






The post-readjustment total amounted to 15.8 million square-meters while the total reduction of residential land stood at roughly 2.9 million square-meters. Much of this land was used to build roads, sidewalks, small parks and social welfare facilities in Tokyo. Moreover, in many places, lots were rationalized but by no means made uniform. While few, if any, individuals experienced catastrophic reduction of their land, virtually every landholder suffered major inconveniences and upheavals during the six-year project. More than 200K buildings that had been built as "temporary" structures after the disaster were forced to move (sometimes only meters, sometimes to different plots) during this monumental undertaking.


清洲橋

For the Living and the Dead

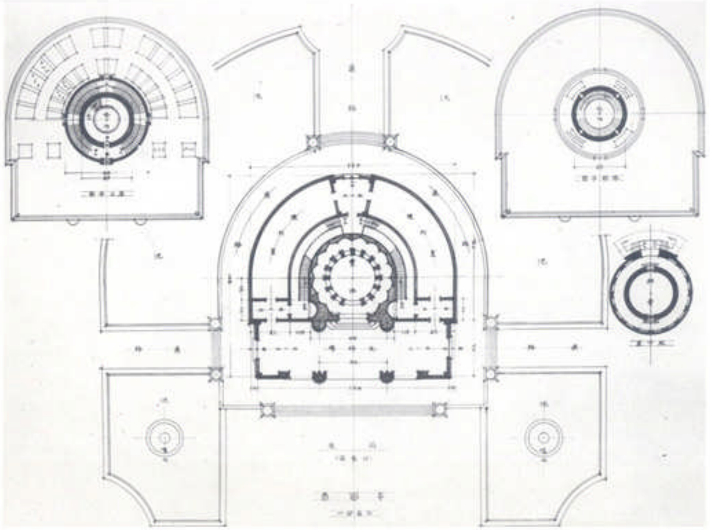
“Designed as an impressive pledge to the living and dead that the new capital of Japan will be, so far as humanly possible, both fire and earthquake-proof, an elaborate memorial hall is to be built in the center of the Honjo District, where 38,000 persons perished in the fire following the September earthquake of 1923. The memorial, to cost a million yen, will be financed by popular subscription. Its site, formerly occupied by the military clothing depot, was the center of one of the most terrifying disasters in connection with the quake and conflagration. Owing to the burning of the antiquated wooden bridges which connected the Honjo ward with the city, 38,000 people were trapped and burned in the streets.”

***Popular Mechanics*, December 1925**

Above: caption: “Scenes of chaos: Survivors of the Great Kanto Earthquake”

(First) A number about three million a dead body of a chothing department in Tokyo.
東京被服廠跡累々たる死體其數實に三万（其一部）

<u>Above</u>: at the 6.7 hectare site of what was once a large production and storage facility operated by the Clothing Department of the *Imperial Japanese Army*, referred to in 1923 as the site of the *Honjo Clothing Depot* (Hifu-kusho ato), over 35K peopled burned to death as a result of a whirlwind firestorm that enveloped that area on the night of September 1-2, 1923.



In June 1924, the municipal government of Tokyo created the institution known as the *Taisho Earthquake Disaster Memorial Project Association* to oversee the construction of an earthquake memorial. The site of the *Honjo Clothing Depot* was selected to house the monument and a national competition was launched to select the design of the memorial hall. Committee members set a deadline of February 28th 1925 for the contest and by its close, 220 engineers and architects from across Japan had submitted designs. For two weeks, seven judges deliberated over the submission. In March 1925, Maeda Kenjiro's design (left T&B) was awarded first place. The winning design featured a 53-meter high tower with a diameter of 8.8-meters. Made of reinforced concrete, the tower was an impressive design that included ten stories and a basement measuring 1,093 square-meters of total space. Directly above the charnel house and in the middle of the large tower, Kenjiro placed a sacred white marble pillar that would represent the spirits of the dead.

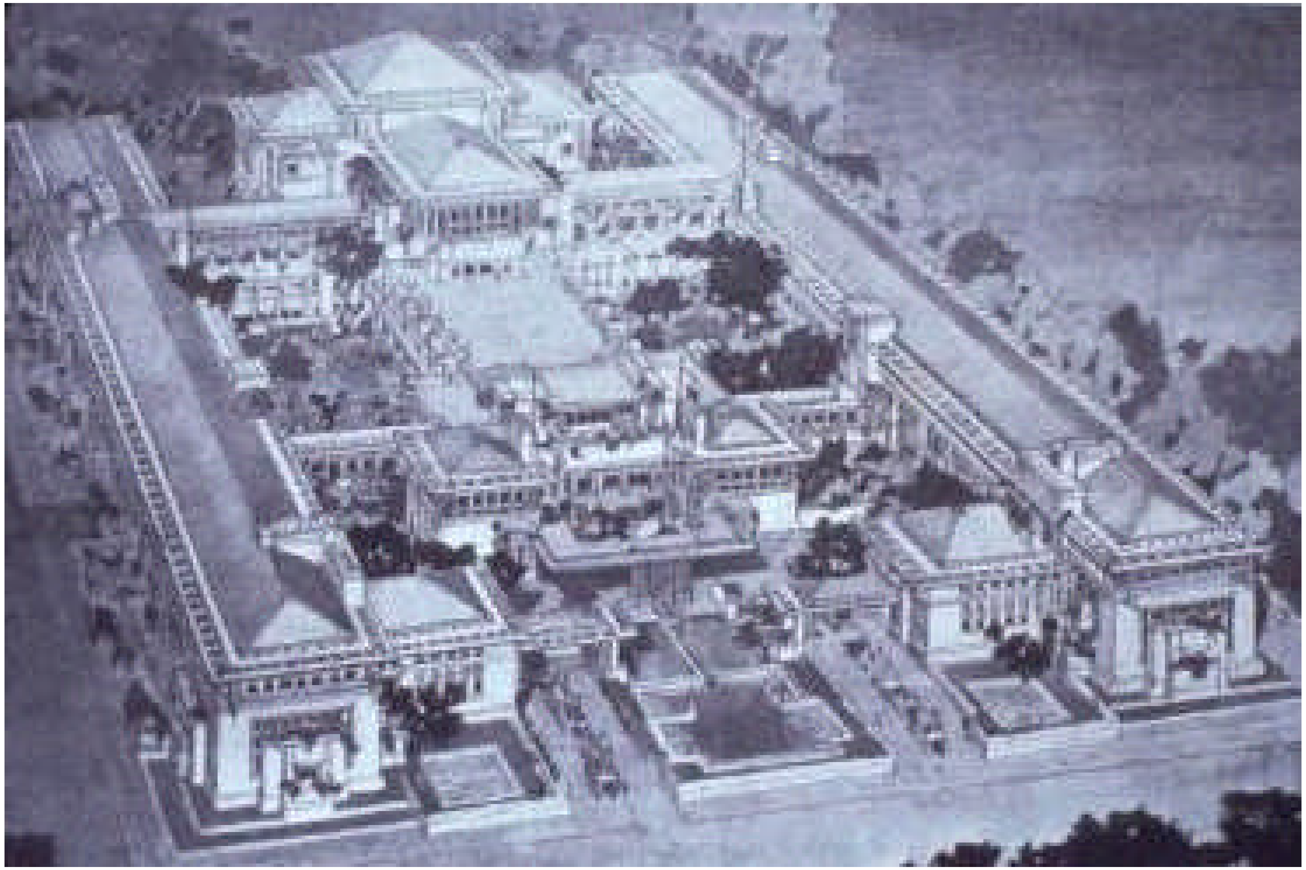
When the design was displayed to the public at the *Tokyo Municipal Hall* in *Ueno Park* (from March 21-23, 1925), cries of protest and disgust immediately filtered back to the Memorial Association judges. Some claimed the building was too “Western” in appearance while others claimed it was a reproduction of a Prussian triumphal tower. Still others argued that Maeda Kenjiro’s design did not conform to the Japanese people’s religious and/or spiritual values. The *Japan Buddhist Federation* took the lead role in fomenting dissent against the planned Memorial Hall design and collected signatures on petitions that requested a new design be selected. They were joined by a number of local politicians from *Honjo Ward*. Eventually, the Memorial Association judges agreed to scrap Kenjiro’s design and, under the direction of *Ito Chuta*, created a design that appealed to Buddhists and residents alike (above L&R).

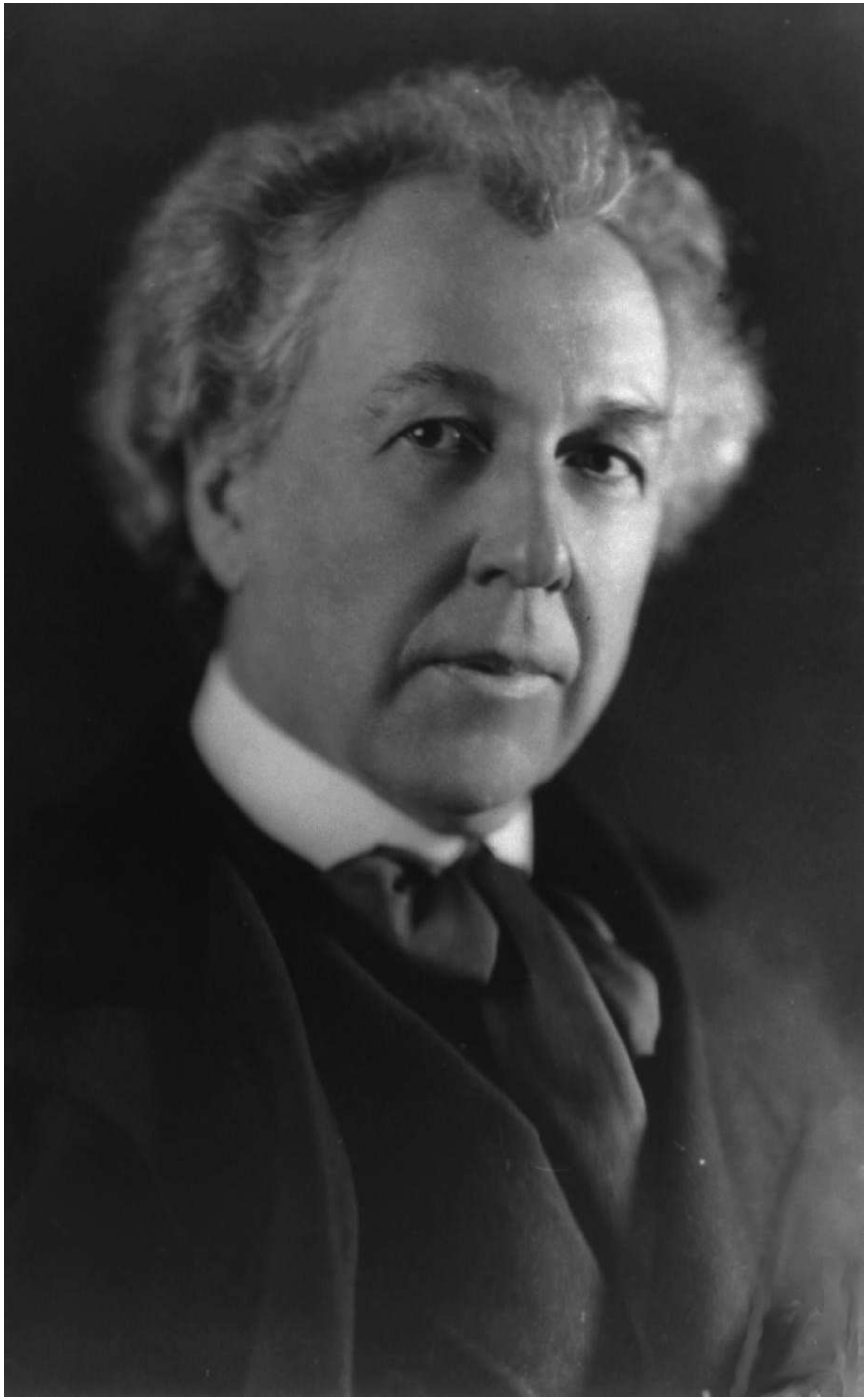
The Master Knows Best

"…That practically quake-proof building is possible was demonstrated during the great Japanese earthquake of 1923, which did such enormous damage to Tokyo and Yokohama. Steel and concrete buildings came through the disturbance with slight damage, while more flimsy structures fell in ruins and then burst into flames which spread into a new trail of destruction…"

***Popular Mechanics,* June 1928**

RE: American architect *Frank Lloyd Wright* received credit for designing Tokyo's *Imperial Hotel* to withstand earthquake forces (in fact, the building was damaged, but not destroyed, by the quake). However, the destruction of the U.S. embassy caused Ambassador *Cyrus Woods* to relocate the embassy to the hotel.





"…The worst type of building for an earthquake zone, according to the famous American architect, Frank Lloyd Wright, is one with a steel framework, curtain walls of masonry and floors built into them for support. A structure with a low center of gravity, shallow foundation and light roof, he says, has the best chance of surviving the shocks of an earthquake. One of the buildings designed by Wright is the Imperial Hotel at Tokyo, Japan. It was one of the few structures that withstood the quake of 1923…"

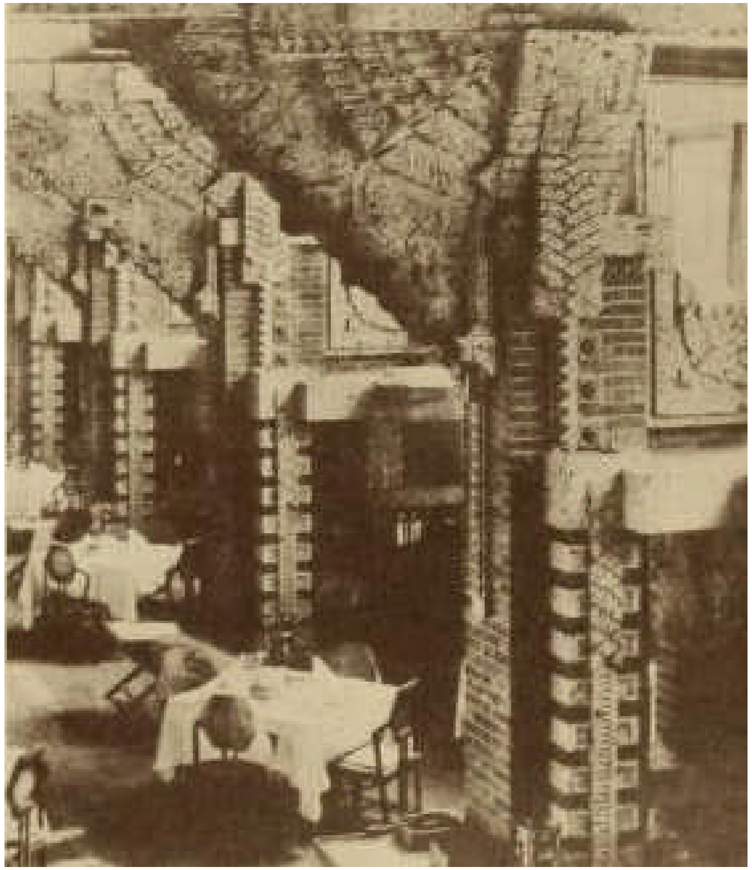
***Popular Mechanics,* July 1933**

From Her Knees to Her Feet

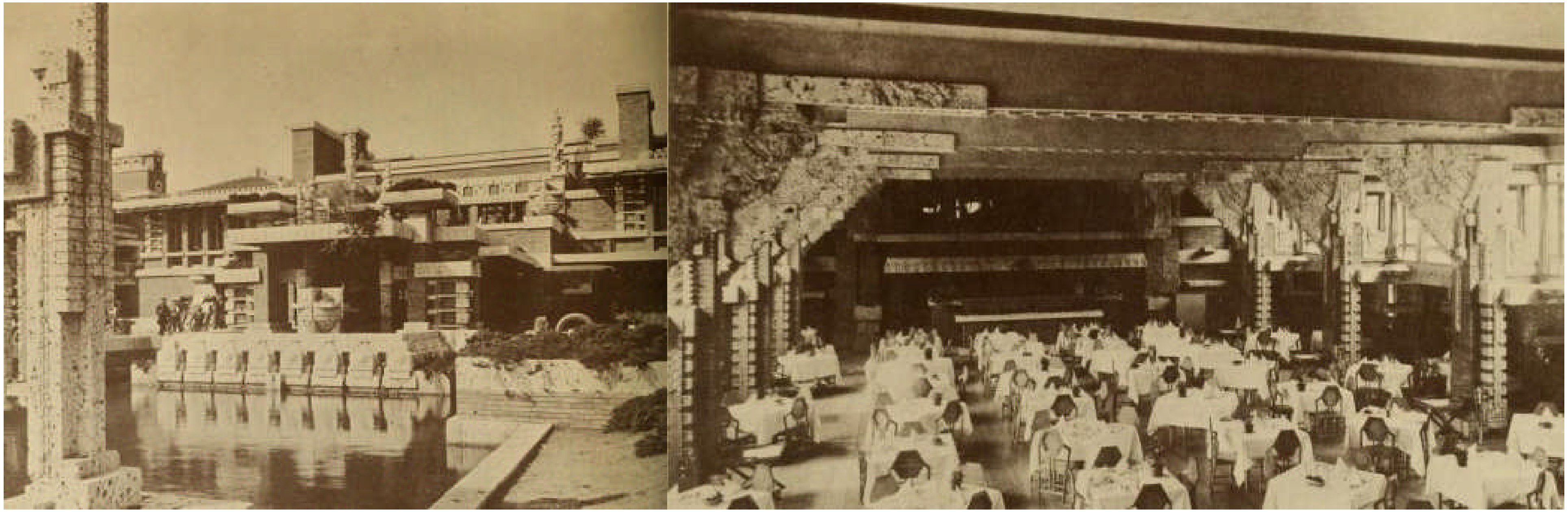
"…After 1915, Wright's rebirth in architecture took the form of creative audacity on a grand scale. Commissioned in 1916 to build the new Imperial Hotel in Tokyo, he produced one of the marvels of modern construction. A vast, low building on a symmetrical plan, it was Wright's first ambitious use of the cantilever principle, which allowed him to rest each concrete floor slab on a central support, like a tray on a waiter's fingers. He roofed the building with light copper sheathing, made the center of gravity low as a ship's. And like a ship, the Imperial was made to float. Instead of sinking deep piers to bedrock, the architect rested his building on hundreds of slender, pointed 8-ft. piles, distributing the weight evenly on a 60-ft. pad of mud. Wright finished his work in 1920. He was in Los Angeles when the big quake hit Tokyo three years later. After ten days of anxious waiting, Wright learned by cable from his friend and client, Baron Okura, that the building had ridden out the quake unharmed while other modern buildings were shaking their masonry into the streets…"

TIME **magazine, January 17th 1938**

RE: FLW had long been intrigued by Japanese culture as an avid collector of Japanese prints. Commissioned in 1916, the *Imperial Hotel* was to represent the emergence of Japan as a modern nation and symbolize its relation to the West. To that end, FLW designed the building as a hybrid of Japanese and Western architecture.



Left: caption: “The Imperial Hotel, built for the Royal household of Japan, was a tribute to Japan as she was rising from her knees to her feet. She had been eating from the floor, sleeping on the floor, and now had to learn how to sit at tables and climb into bed to sleep. The building was intended to harmonize with those around the moat across the park before it. The Royal household was shocked when I decided to use oyo, the stone ordinaire under foot in Tokyo for the structure, with a brick handmade in Japan for the first time. The architect persevered, finally got what he wanted, and great blocks of oyo began floating down by sea and canal from the quarries of Nikko to the site…” Excerpt from catalog of an exhibition held October 22nd - December 13th 1953 at the *Solomon R. Guggenheim Museum, New York City* entitled: “Sixty Years of Living Architecture: The Work of Frank Lloyd Wright.”



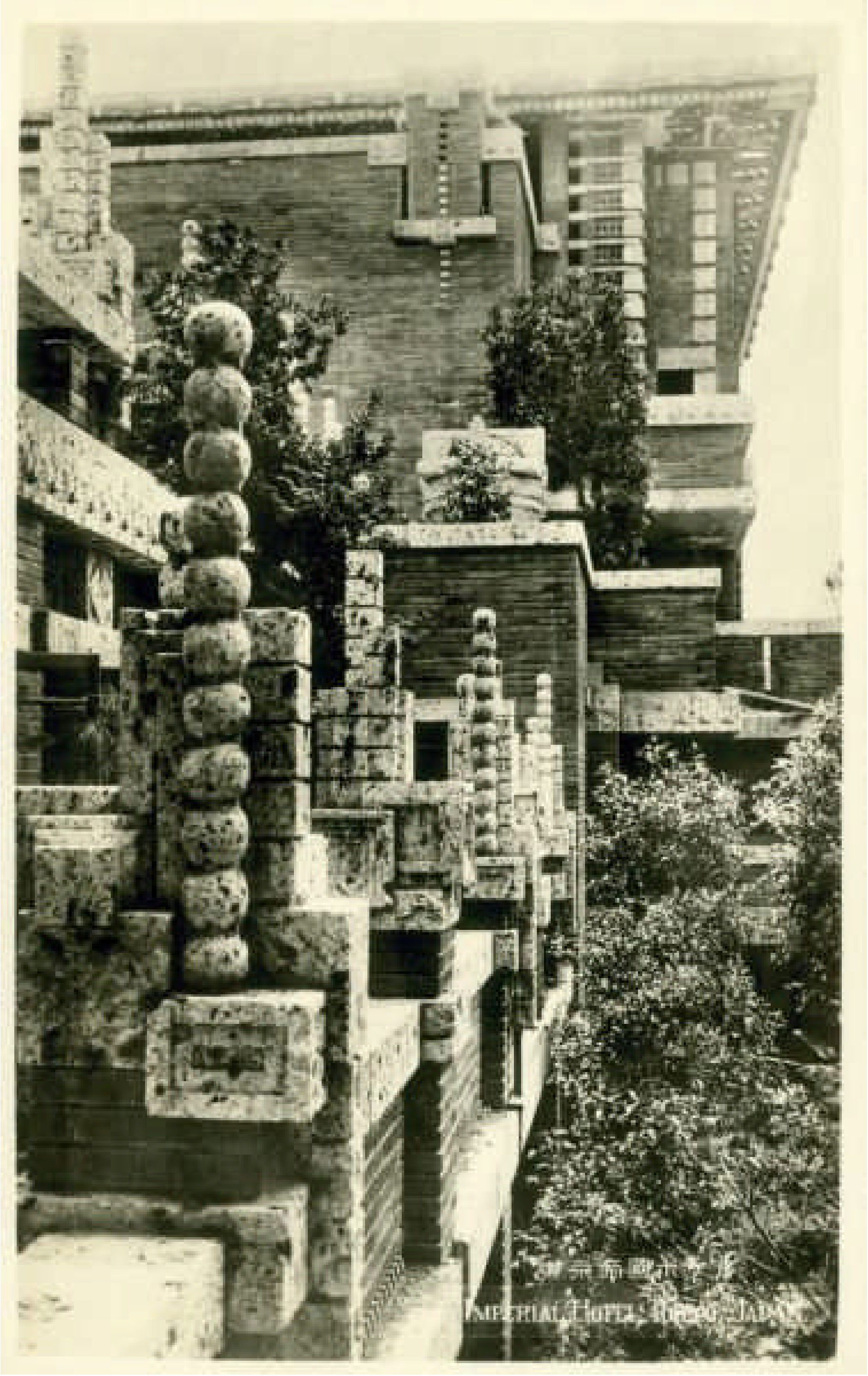
Above: caption: “…But a permit to build the building was awaited in vain. Finally a meeting with the authorities was held at which they took the view that a world famous architect would not come to Japan to build something that would fall down under any circumstances. They could not understand the propositions we made but were willing to watch and wait and probably learn something worth learning. Accordingly we proceeded – to build the building with all the help they could give. I have sometimes been asked why I did not make the opus more ‘modern.’ The answer is that there was a tradition there worthy of respect and I felt it my duty as well as my privilege to make the building belong to them as far as I might. The principle of flexibility instead of rigidity here vindicated itself with inspiring results. But the A.I.A. commission sent to study the great temblor of 1922 made no mention of the structure.” Excerpt from *Sixty Years of Living Architecture: The Work of Frank Lloyd Wright.*

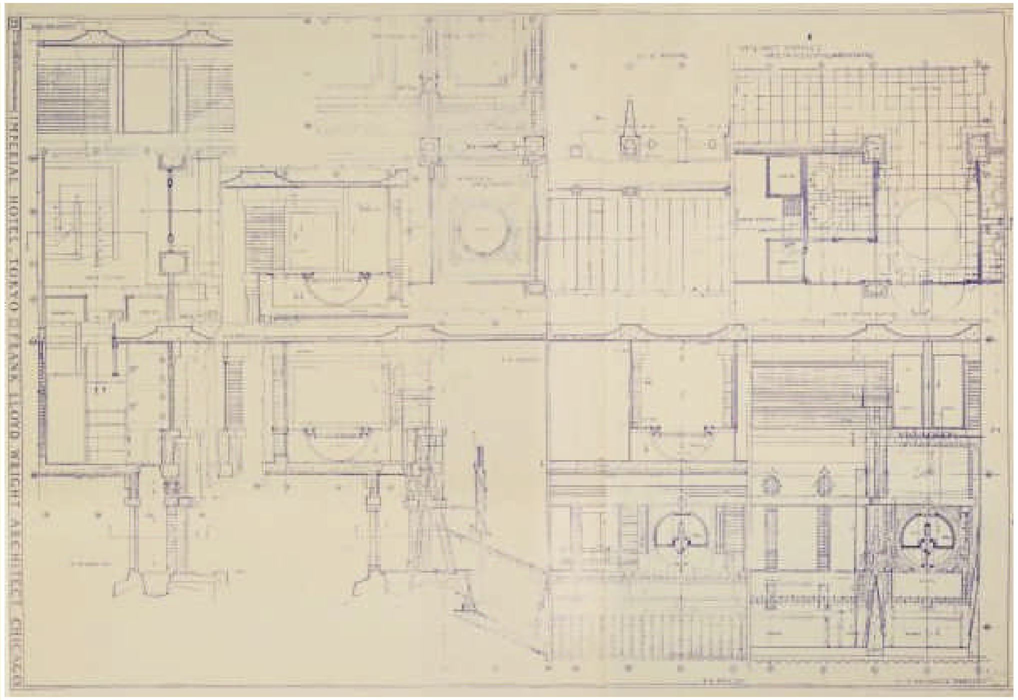
“It’s originality is so antiquated that it embalms and mummifies the brains of the beholder”

Architect and Engineer **magazine**

RE: though the sumptuous design of the *Imperial Hotel* was a hit in Japan, it failed to draw any accolades for FLW at home. Having survived intact the *Great Kanto Earthquake* of 1923 was its most significant achievement (as far as the architectural press in America was concerned).

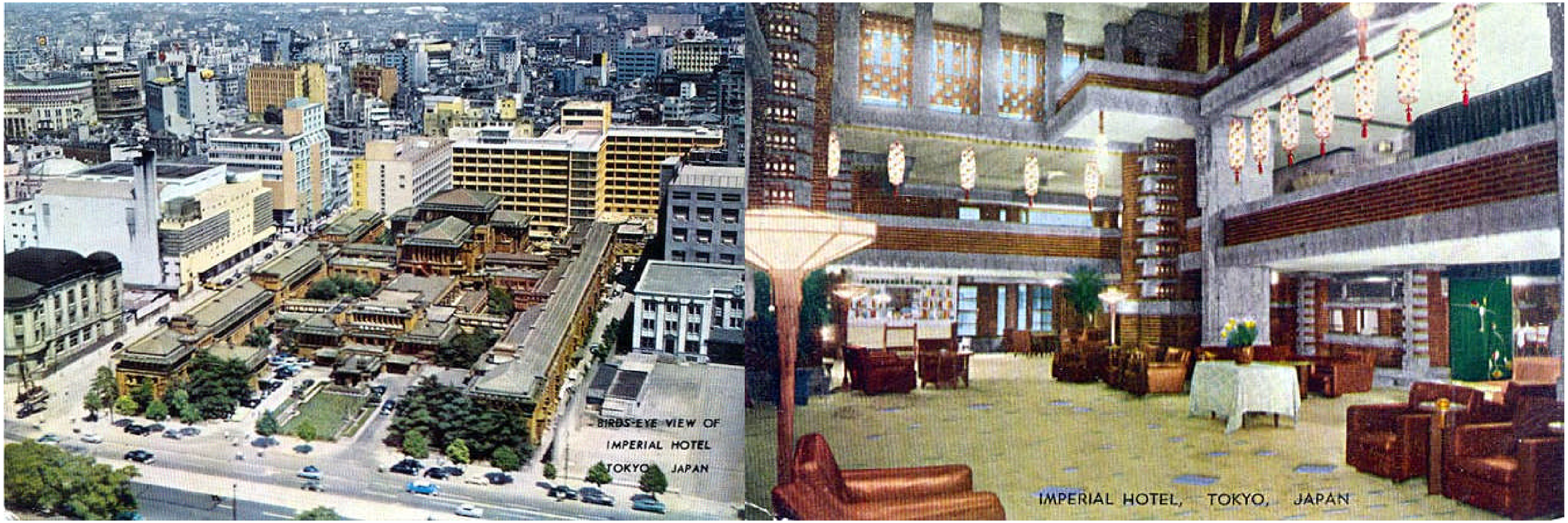
Above: caption: “Imperial Hotel during the Great Kanto Earthquake of 1923”





<u>Above</u>: caption: "Architectural drawing reproduction of a portion of the Imperial Hotel, Tokyo, Japan, designed by architect Frank Lloyd Wright. The drawing is titled 'No. 25: Promenade and Private Dining Room Entrance.'"

<u>Left</u>: caption: "Exterior details of the Imperial Hotel, Tokyo, Japan, designed by F.L. Wright."



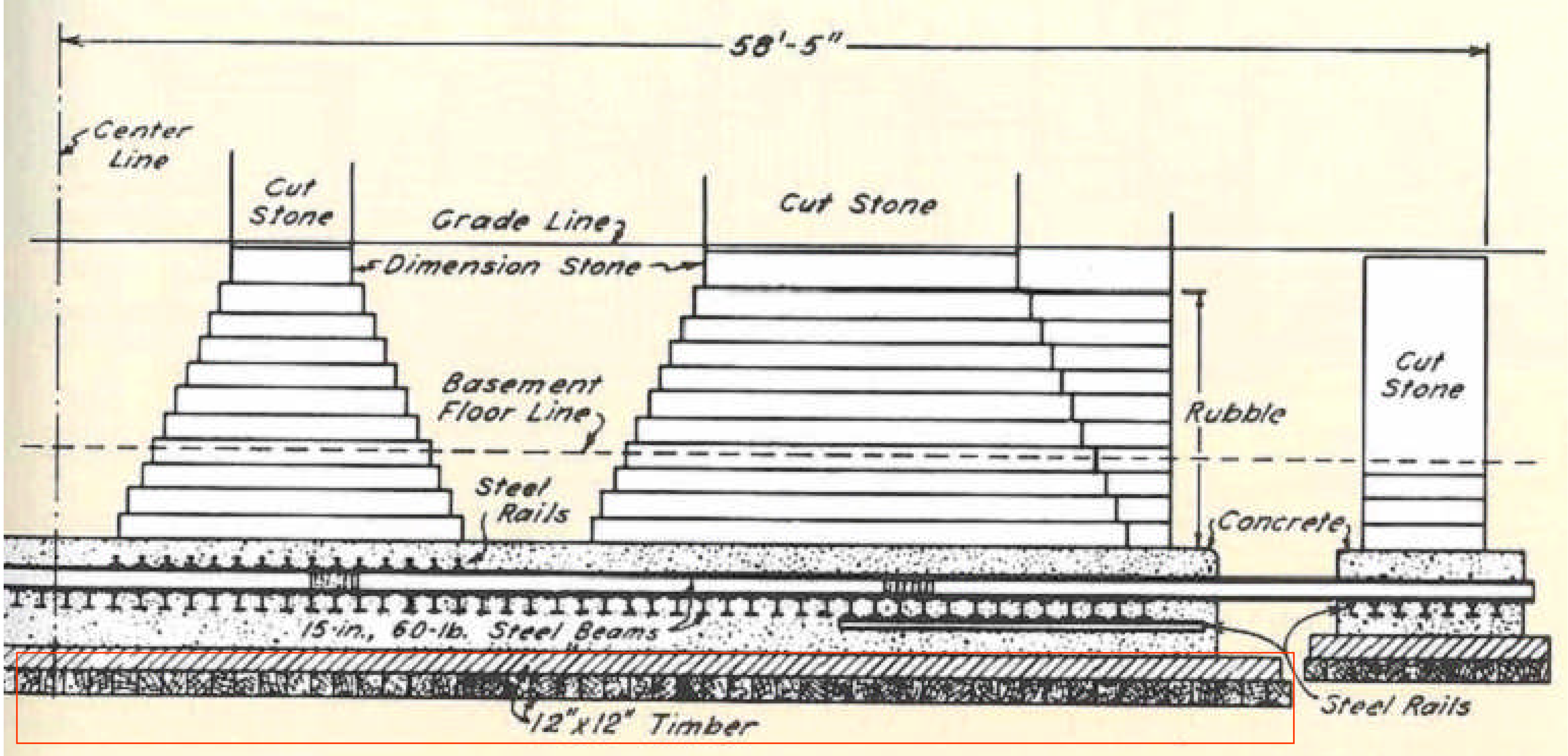
"…The fact is that, despite their flaunting of all acceptable standards of architectural soundness, Wright's buildings have shown both astonishing practicality and remarkable durability. The Imperial Hotel in Tokyo, built like a vast float riding on a jellylike foundation of mud, has, in fact, survived some of Japan's worst earthquakes and has sustained its only injuries recently under the pounding of American bombs…"

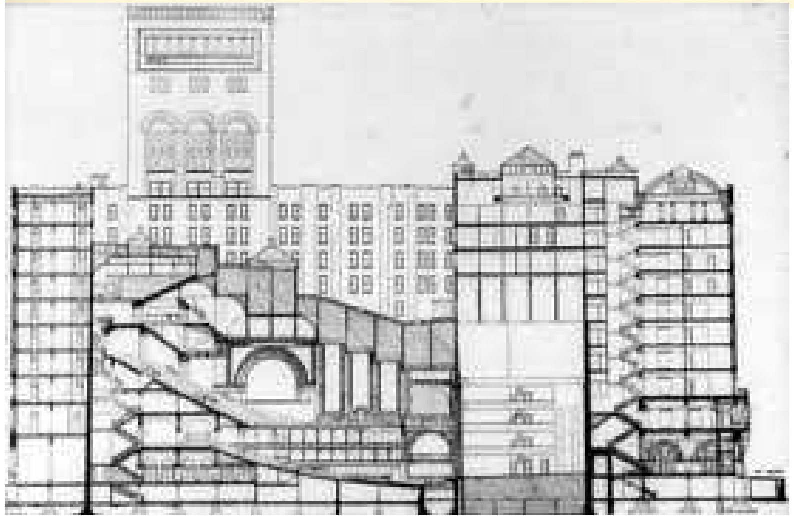
***LIFE* magazine, August 12th 1946**

<u>Above L&R</u>: *Imperial Hotel* postcards. Demolished in 1968, the entrance lobby was preserved and reconstructed at the *Meiji Mura* museum in *Nagoya*.

“…although he claimed otherwise, engineering had never been Wrights strong suit – especially, it appears, when it came to calculation. Many of his early houses, projects executed just after leaving Adler and Sullivan, had in fact suffered from his mediocre structural skills. Wright apparently understood his limitations. After his string of Oak Park houses, when he began landing larger projects that involved real engineering challenges, he brought in a German immigrant named Paul Mueller, who had been Dankmar Adler’s protege during Wright’s tenure with Adler and Sullivan. Mueller made important contributions to all of Wright’s major concrete buildings before Fallingwater, including the Unity Temple, the Larkin Building, and San Marcos in the Desert; the engineer even accompanied Wright to Tokyo to oversee the construction of the Imperial Hotel. And it was a good thing. While it was Wright who thought of using a floating foundation for the earthquake-prone city, Mueller had actually designed one – a raft foundation of crisscrossed railroad ties for the Auditorium Building, built in Chicago’s soft blue clay…”

RE: excerpt from *The Fellowship*





Above: caption: "Foundation section of the Auditorium Building constructed in 1887-89, The theatre is a Chicago Landmark and one of the best-known designs of Dankmar Adler and Louis Sullivan."

Left: caption: "Longitudinal elevation/section – Auditorium Building"

Top Left: caption: “Postcard showing the entrance courtyard of the Imperial Hotel, Tokyo”

Top Right: caption: “The hotel (left) shortly after the 1923 earthquake (on the right burning is the Kangyo Bank)”

Left: caption: “The entrance courtyard of Wright's Imperial Hotel, Meiji-Mura Museum”

Father of Earthquake-proof Design

"…That earthquake-proof buildings are possible was demonstrated during the 1923 tremors that struck the Tokyo area, shattering 250,000 homes. Nearly all of the multi-story buildings in the city were damaged. The exceptions were the Imperial Hotel, designed by Frank Lloyd Wright, and buildings designed by Tachu Naito…"

***Popular Mechanics*, June 1967**

"…Naito reportedly conceived of the idea of using partition walls of reinforced concrete slabs after noting that partitioned suitcases withstood rough handling at railroad stations while ordinary suitcases were likely to be smashed…"

***Popular Mechanics,* June 1967**

RE: *Tachu Naito* (1886-1970) was a Japanese architect, engineer and professor. He went to the U.S. in 1916 as an international student where he devised his seismic theory of the earthquake-proof wall. While traveling by railroad, he made observations about the movements of the luggage depending on the trains acceleration after noticing the scattered trunks when the train made sudden stops. The lack of partitions in the luggage compartment and the disarray of the trunks led him to the structural idea of the earthquake-proof wall, effectively a *Shear Wall*. Using a seismic structural theory that he devised, he engineered the *Industrial Bank of Japan* main office. Three months after the building's completion in 1923, the *Great Kanto Earthquake* struck. The structure withstood the destructive forces of the powerful earthquake. He became known as the "Father of Earthquake-proof Design." Naito applied his seismic-theories to many of the broadcasting and observation towers he designed, such as *Tsutenkaku Tower* of 1956 (left).

Fuller Built

"Fuller-Built" Landmarks

THE building of a terminal such as the Pennsylvania Station, in the heart of New York City, called for experience in building construction and engineering service embracing practically every known phase of building work, and ability to solve many new problems that had never presented themselves before in a building operation.

Working in close harmony with the architect and engineers of the Pennsylvania Railroad, these problems were met and handled by the George A. Fuller Company in a way that is typical of the character of service that is available to any architect, engineer or owner.

Other notable Fuller-Built Terminals are:

Kansas City Terminal, Kansas City, — Jarvis Hunt, Architect, Chicago.
Chicago & Northw'n Railway Terminal, Chicago, — Frost & Granger, Architects, Chicago.
Michigan Central Terminal, Detroit, — N.Y. Central Railroad Co., Architects, Geo. H. Webb, Chief Engineer.
Wabash Depot, Pittsburgh, — Theodore C. Link, Architect, St. Louis.
Hudson Terminal, Hudson Tubes, New York, — Clinton & Russell, Architects.
New Pennsylvania R. R. Freight Terminal, Chicago, — Price & McLanahan, Architects.
Canadian Pacific Terminal, Montreal, — Frank L. Ellingwood, Chief Engineer.

Whether your contemplated building operation is usual or unusual, there is experience here that will aid you to solve it most effectively and economically.

Consultations invited through any of our offices.

George A. Fuller Company

New York
Boston
Philadelphia
Montreal
New Orleans

Washington
Baltimore
Pittsburgh
Cleveland

Chicago
Detroit
St. Louis
Kansas City
Buffalo

"Private advices from our agents in Japan assure us that at least three of the large buildings we erected in Tokyo withstood the terrible earthquake. We completed the last of these, which are respectively eight, seven, and eight stories high, in the fall of 1922, and a little more than a year ago they went through quite a severe shock with practically no damage, except the scaling off of a small amount of tile used on the face of one of them…"

James Baird, **President – *George A. Fuller Company* (Nov. 1923)**

<u>Left</u>: advertisement for the *G.A. Fuller Company* (ca. 1910) featuring their recently completed *Pennsylvania Station* in NYC

“…Earthquakes do their damage on buildings that yield, because part of the building is thrown in one direction and part in another. Scientists, architects, and engineers have studied earthquake effects, and have decided on adopting many features to make the building rigid and resistant…”

***James Baird,* President – *George A. Fuller Company* (November 1923)**

"…In the first place, the buildings contain steel skeletons of extra weight and strength. Extra plates are used to join steel beams on to the steel columns. Each floor level has very substantial steel braces extending from the columns to the floor beams, and at the roof line heavy plates are placed on the top of columns connected to the cross beams. A very great number of rivets are used. There are perhaps three or four times as many rivets as in ordinary construction in this country. So it would seem that earthquake construction is very similar to what we call 'wind bracing' in this country. The object is to stiffen the entire frame to resist choppy stresses…"

***James Baird*, President – *George A. Fuller Company* (November 1923)**

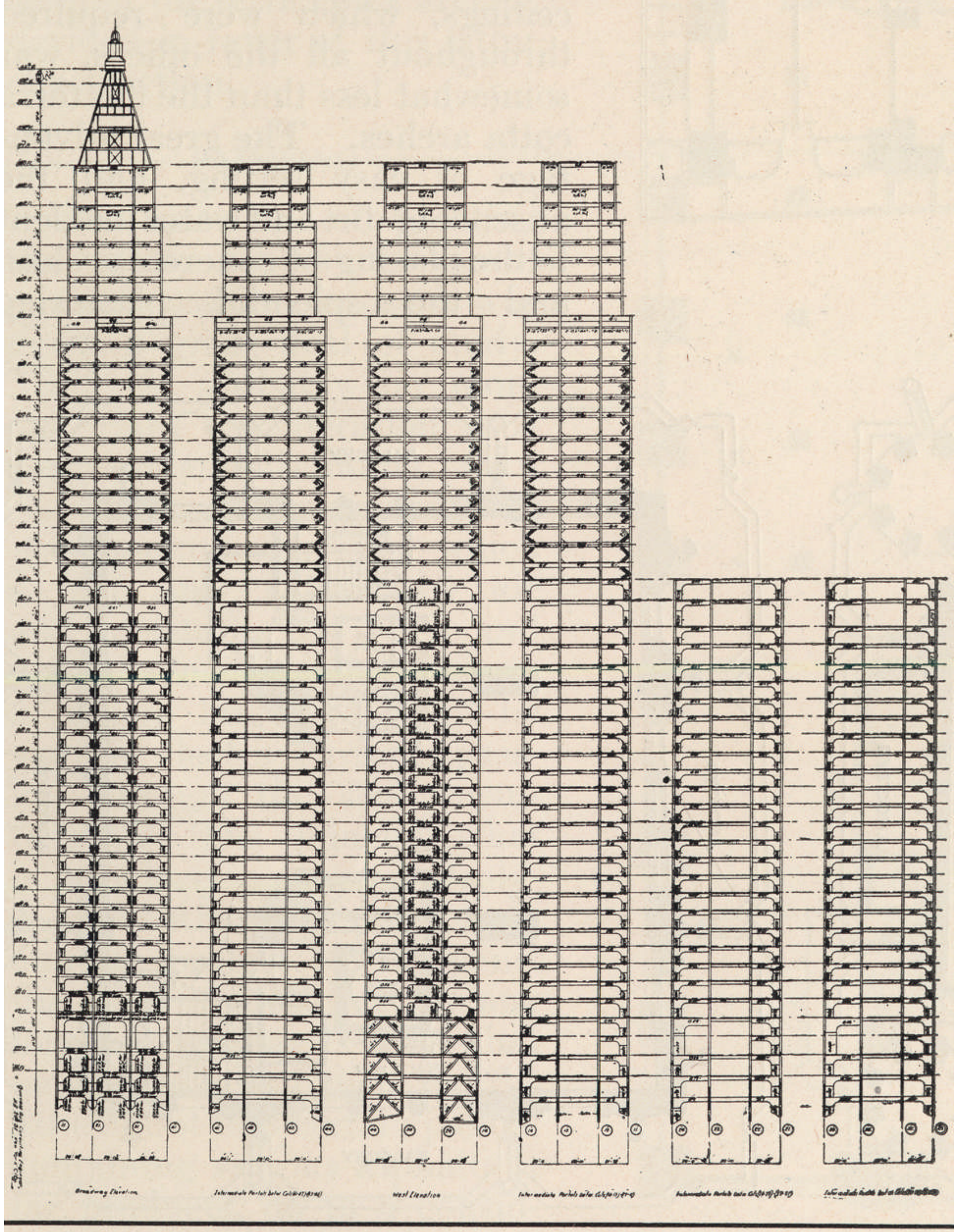


DIAGRAM OF TOWER WIND BRACING

To resist wind pressure, the columns and beams of the *Woolworth Building* (NYC) were connected in such a way as to form braces. The diagram at left shows the variety of bracing strategies that structural engineer *Gunvald Aus* used to provide the required strength in a configuration that allowed window and hallway openings. Below the 30th floor setback, Aus relied primarily on portal braces, which rigidly connected the columns with arches made from steel. Above the setback, knee braces that formed a K-shape were used at the corners of the tower. At the base of the tower, Aus employed full-height diagonal braces.

TYPES OF WIND BRACING

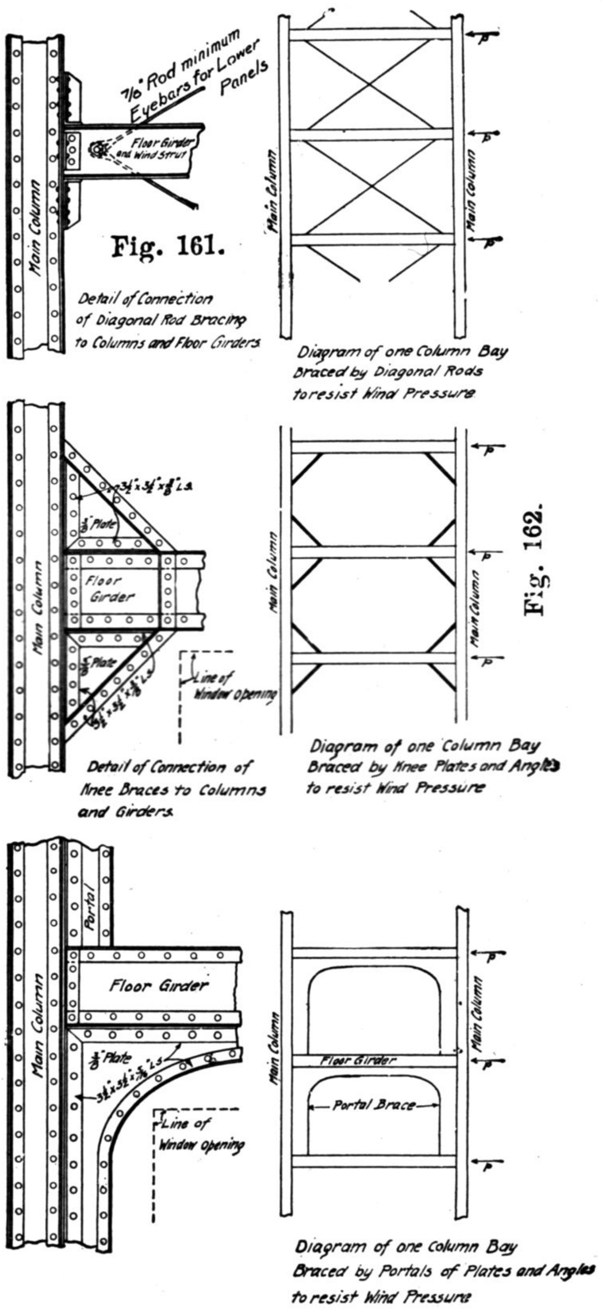


Fig. 163.

The wind-induced collapse of the *Tay Bridge* in Scotland in 1879 illustrated the vulnerability of tall metal frames to lateral forces. In the wake of this calamity, a revolution in structural methods followed, culminating in the mid-1890s with the invention of the riveted all-steel skeleton frame and the elimination of thick masonry shear walls. The first generation of wind-braced skyscraper metal frames relied on bridge-like systems of cross-bracing or ship-like systems of knee-bracing, but these structures intruded into rentable spaces. The second generation of frames better exploited the material properties of steel, making stiff connections between girders and columns that, when multiplied throughout the building, could collectively resist lateral forces without such intrusions. Steel, which had replaced cast-iron as a structural material by 1895, excelled in this role because it could be rolled into efficient, workable shapes and riveted to form tight connections.

Left: caption: “Types of Wind Bracing”

“…At the California Institute of Technology, special tests with cross-bracing have been carried out with model buildings to discover ways of overcoming earthquake vibrations in various types of large structures. Other experiments are under way not only to discover how elastic a building must be to withstand the earth’s movements in three directions but also how rigid it must be to pull itself quickly back into shape…”

***Popular Science*, May 1933**

Experiences and Facts

“…Our confidence is based on various experiences and facts, of which we have knowledge, among them being the following:

<u>First</u> - During the great Baltimore disaster, brick and stone buildings crumbled and were practically flattened to the earth, but the steel structures, though they were gutted by fire, did not fall;

<u>Second</u> – During the San Francisco earthquake, substantial stone and brick buildings collapsed and were completely destroyed, but the steel-framed buildings survived with small damage;

<u>Third</u> – In wrecking steel structures it has been found practically impossible to tear the work apart or rupture it in any way, other than by cutting out all connecting rivets…”

***James Baird,* President – *George A. Fuller Company* (November 1923)**

Left: with almost eerie foresight, additional fire insurance was placed on the *Pacific Mutual Home Office Building* in San Francisco, additional vaults were constructed and older vaults were reinforced. These actions were completed by early April of 1906. On April 18th 1906, a 48-second long earthquake rocked San Francisco leveling hundreds of city blocks. Although Pacific Mutual's seven-story Home Office Building survived the initial earthquake, the structure was sacrificed as a firebreak (to prevent further damage to the city).

"…The various cables received by us from the institutions owning the buildings in Japan that were equipped with special steel skeletons, all indicate that they are quite safe and have come through practically unharmed.'

***James Baird,* President – *George A. Fuller Company* (November 1923)**

"…In the Baltimore fire, in a few cases, the fireproofing was broken from around columns, and the terrific heat melted the steel, but the beams were thereby put in tension, and although the floors sagged, yet there was no giving way, regardless of the fact that the weight from the six or eight floors above was left without support…"

***James Baird,* President – *George A. Fuller Company* (November 1923)**

<u>Above</u>: caption: "This panorama of downtown Baltimore after the 'Great Fire' in 1904 shows the incredible destruction of the two day blaze." The *Great Baltimore Fire* of 1904 started on February 7th 1904 and raged on until 5 p.m. the next day. The fire began inside the *John E. Hurst & Company Building*, causing an explosion that sent flames on to adjacent buildings. In minutes, surrounding buildings were ablaze and the fire continued to sweep through parts of downtown, in large part due to wind and lack of standardized fire-fighting equipment. Calls for help were telegraphed to other cities including Philadelphia, New York and Washington D.C., which sent assistance. In about 30 hours, 140 acres of downtown Baltimore had burned, taking down 1,526 buildings.

EXTRA **THE SUN** EXTRA

TWENTY-FOUR BLOCKS BURNED IN HEART OF BALTIMORE

CITY'S MOST VALUABLE BUILDINGS IN RUINS

LOSS VARIOUSLY ESTIMATED AT FROM $50,000,000 TO $80,000,000

BLAZE STILL SPREADING EASTWARD AND SOUTHWARD AT 3.30 A. M.

Starting In John E. Hurst Building The Fire Sweeps South To Lombard, East To Holliday And North To Lexington, Destroying Wholesale Business Houses, Banks

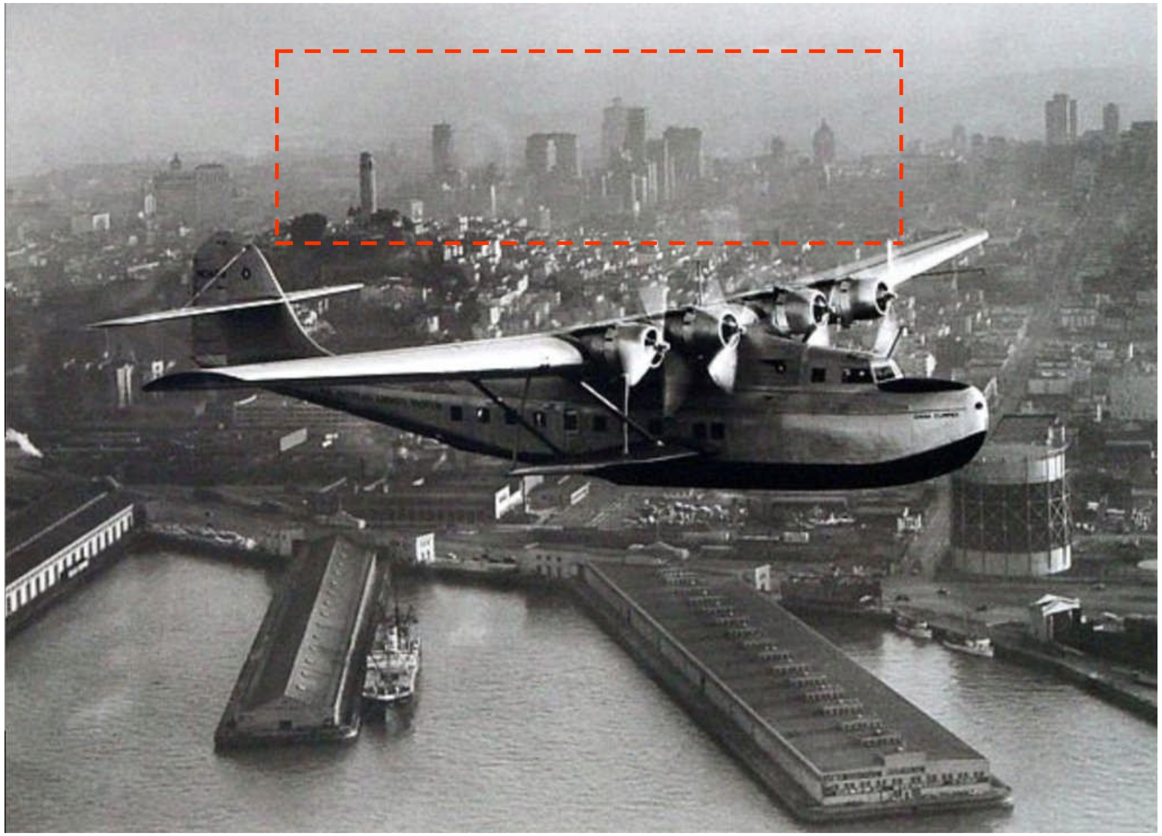
Part 5

How Safe?

Bad Vibrations

"…Just what happens to a building in an earthquake? W.E. Hart, structural engineer for the Portland Cement Association, answers: 'The action may well be described as a sudden powerful hammer blow delivered at the base of the building, followed by another blow from the opposite side, when the earth movement ceases as suddenly as it began. These blows coming in rapid succession set up vibrations that apply unusual stresses to various parts of the building. Sometimes the damage begins with the first blow and increases with each vibration. Other times, some seconds pass before the structure begins to give way…"

***Popular Mechanics,* July 1933**



“Shivers and shocks in the earth’s crust thirty years ago sent San Francisco tumbling into ruins. The behavior of tall buildings during the quake did not auger well for the future of the skyscraper. But today San Francisco boasts a good many skyscrapers and people pay substantial sums to live in them…”

Popular Mechanics, **March 1936**

<u>Left</u>: caption: “PAA China Clipper outbound from the rebuilt City of San Francisco, 1936”

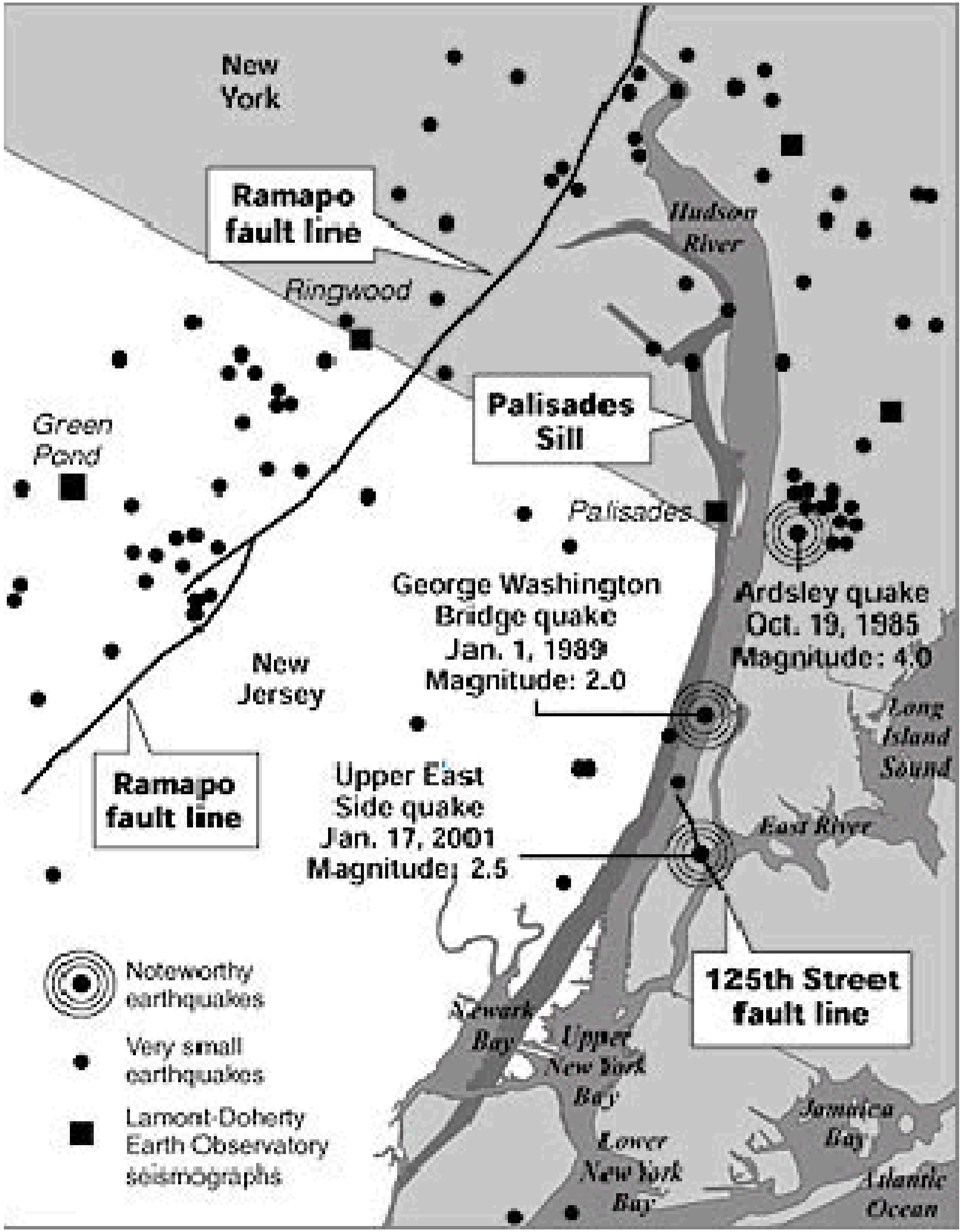
"…Recently the northeastern section of the country experienced a quake which came dangerously near the little island of Manhattan, which is sown thicker with skyscrapers than any similar area in the world…"

***Popular Mechanics,* March 1936**

The RFZ

“…One side of another well-known geological fault extends approximately along the line of the Hudson river. There is the possibility that some time during the Ice Age the New York side slipped under the strain of a terrific tremor. However, today the geological position of Manhattan island and the surrounding territory is such that about the only danger of even a slight quake comes from the fact that Mother Earth may decide to do a mild ‘black bottom’ in the vicinity of northern New England, just as she did in February, 1925…”

***Popular Mechanics,* June 1928**



Left: caption: “The Ramapo Fault Zone and faults underlying New York City.” The *Ramapo Fault Zone* (RFZ) strikes northeast from Peapack, New Jersey, for about 60 miles into and across the *Hudson River Highlands* gorge. The RFZ lies adjacent to New York City. Another fault, the *New York Bight Fault* lies beneath the *Atlantic Ocean* east of NYC, about twenty-five miles distant at its closest point (it may extend north beneath *Long Island*). Past motion on this near vertically dipping fault plane is downward to the west, suggesting that the crust to the west, under NYC, may be subjected to downward motion.

“…the RFZ is an active fault zone with a recurrence interval of from a few hundred to 2,000 years...Indeed, our data suggest that the RFZ will sustain a damaging movement within the next few decades…”

***Popular Mechanics,* June 1928**

RE: in a study involving radiocarbon dating of basal peats underlying tidal marshes, scientists found indications of both the sinking and rotating of crustal blocks within the RFZ. If a “damaging movement” were significant enough to involve the sinking and rotating of the crustal blocks beneath NYC, the city would be no more.

Conflicting Opinions

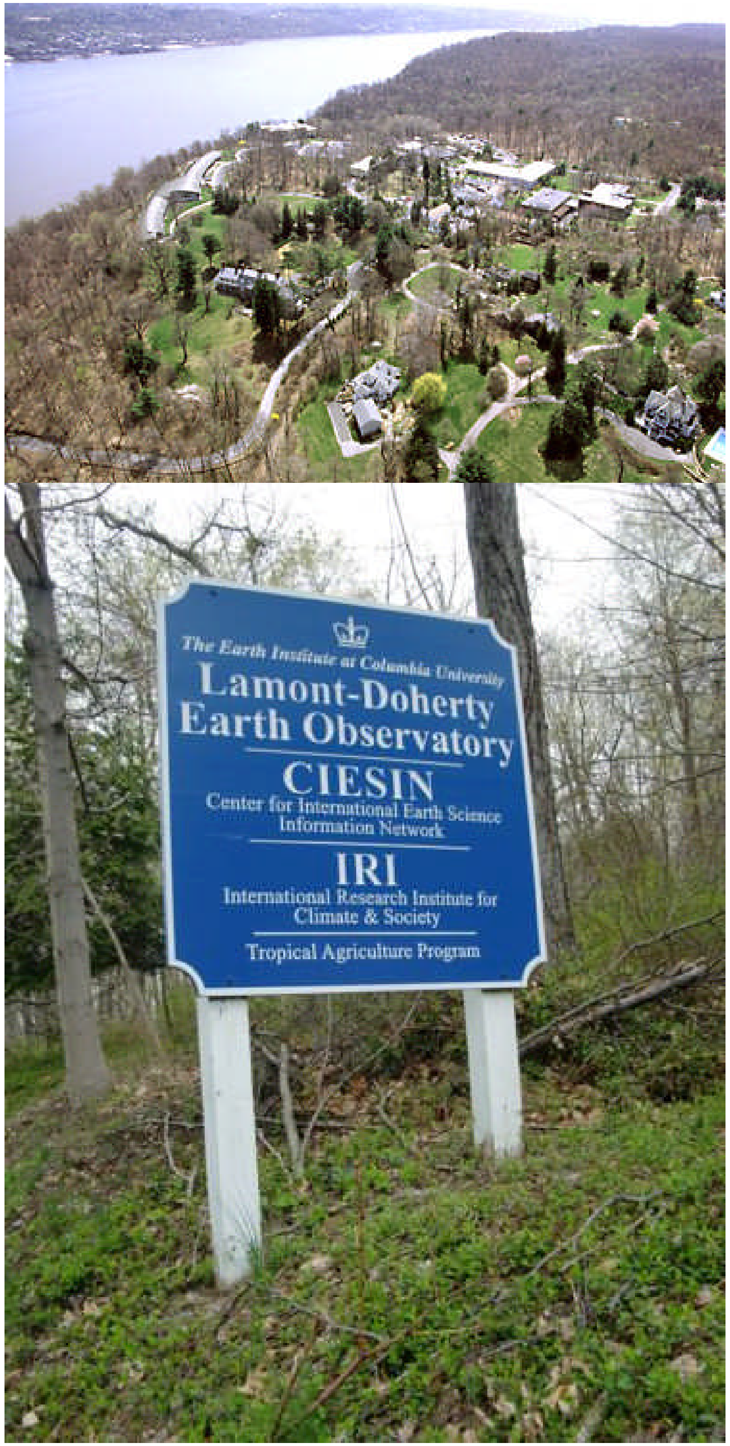
"…Consolidated Edison, the metropolitan New York utility giant, finally overcame efforts of environmental and scientific groups to prevent the construction of the three-unit nuclear generating plant, one within 3,000 feet of the Ramapo Fault. Testimony before the Nuclear Regulatory Commission centered around conflicting scientific opinions from Dr. Charles F. Richter, inventor of the Richter Scale, and Dr. Lynn R. Sykes, head of seismology at the Lamont-Doherty Geological Observatory branch of Columbia University…"

***Popular Mechanics*, January 1977**

<u>Above</u>: caption: "Indian Point Nuclear Generating Unit Nos. 2 and 3"

“…Dr. Richter and Con Ed took the position that the Ramapo Fault is not capable of generating large, damaging quakes. Dr. Richter observed, that quakes in the Ramapo region are ‘of relatively rare occurrence, of minor magnitude and relatively trivial.’ Lamont scientists, however, argue that the fault is indeed active and has the potential to release more energy than the power plant structure can withstand. Con Ed says the units were built to withstand a quake of the highest intensity reported in the region…”

***Popular Mechanics,* January 1977**

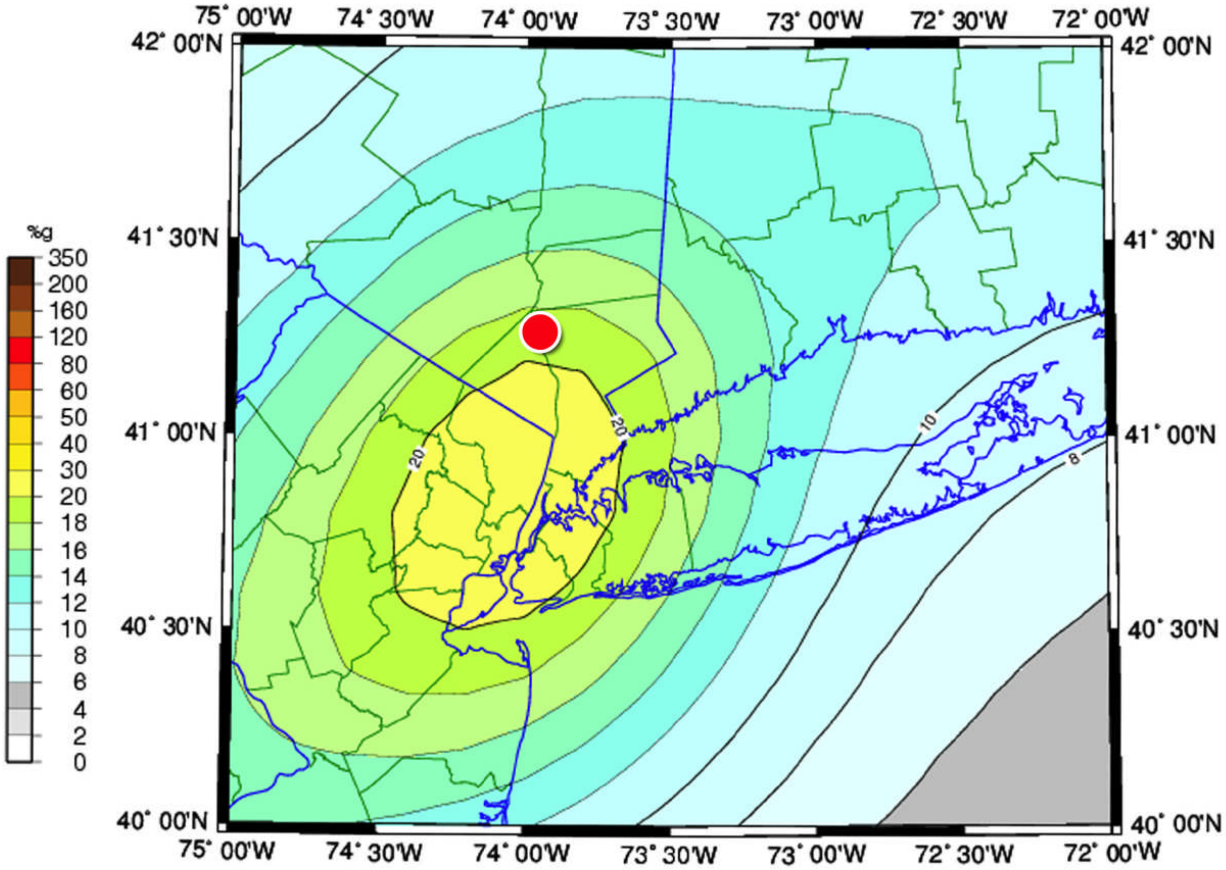


"…Dr. Yash Aggarwal, a Lamont scientist who made the first fully accurate earthquake prediction in the United States, revealed in an interview with PM that the Con Ed researchers may have been looking in the wrong place for evidence of seismic activity along the ancient fault line. He explained that the rocks along the system are so old that examining them for <u>recent</u> seismic activity would inevitably prove fruitless…"

***Popular Mechanics,* January 1977**

<u>Left T&B</u>: caption: "The Lamont-Doherty Earth Observatory in Palisades, New York"

EARTHQUAKE HAZARD IN THE AREA AROUND INDIAN POINT

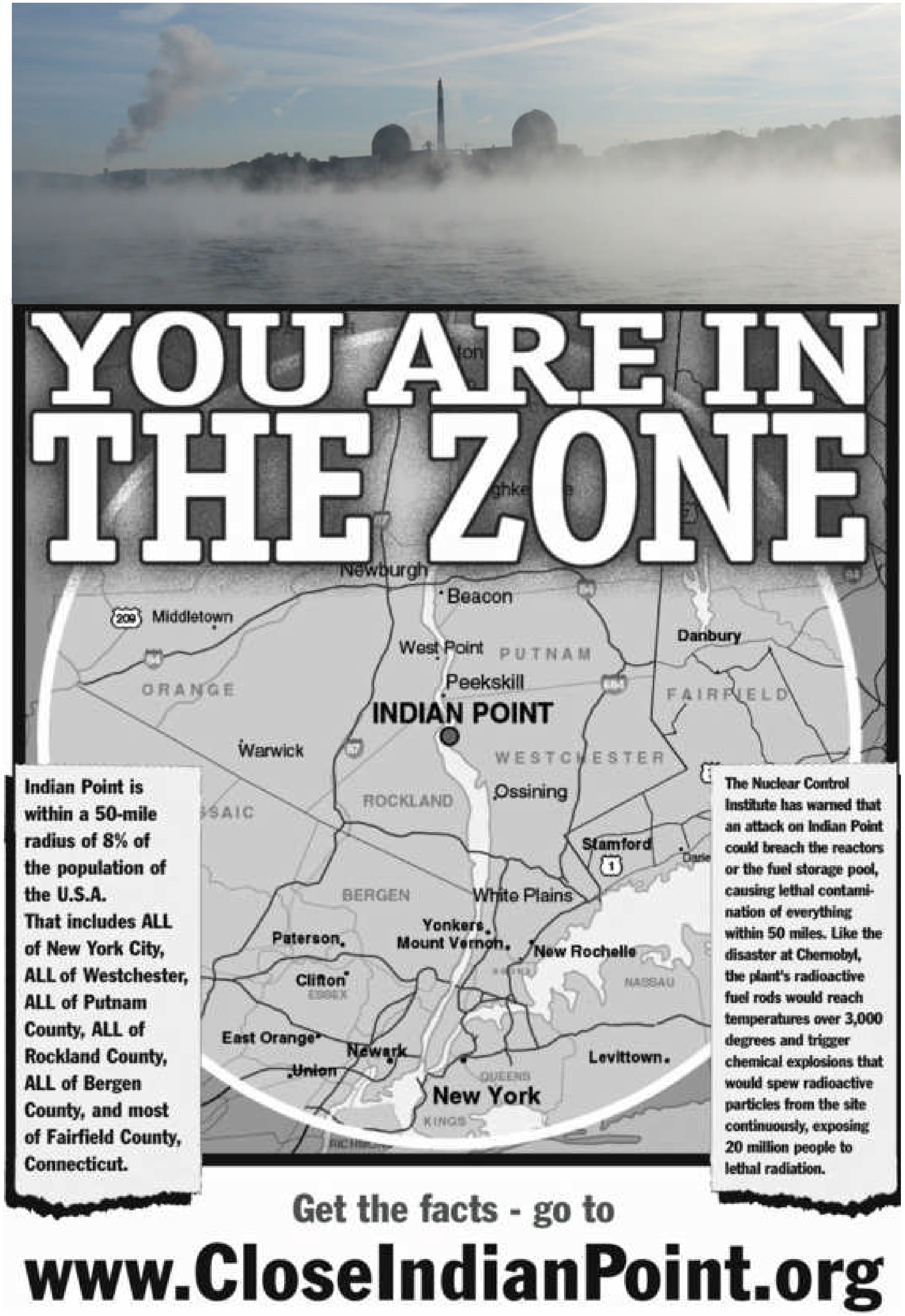


"…The size of future quakes in the area will decide which of the conflicting scientific opinions is correct."

***Popular Mechanics*, January 1977**

"We cannot continue to roll the dice with the operation of Indian Point - there is simply too much at stake. The NRC has repeatedly ignored the danger that Indian Point poses to New Yorkers - from its vulnerability to a terrorist attack, to its incapability to withstand potential earthquakes, to its lack of a plausible evacuation plan in the event of a catastrophe. We must do what is safest for New York and close Indian Point."

Andrew Cuomo, **NYS Attorney General, 2007**



YOU ARE IN THE ZONE

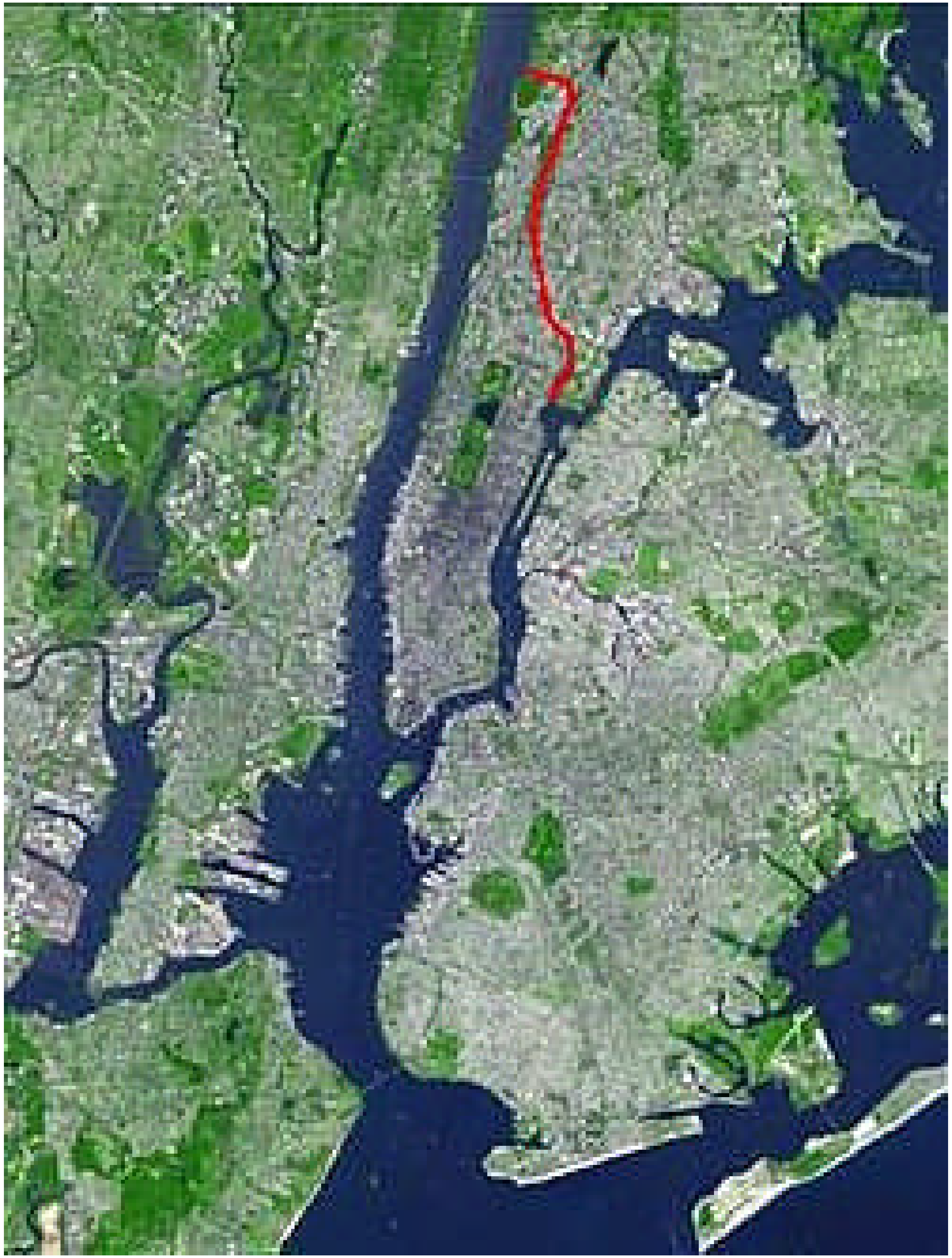
Indian Point is within a 50-mile radius of 8% of the population of the U.S.A. That includes ALL of New York City, ALL of Westchester, ALL of Putnam County, ALL of Rockland County, ALL of Bergen County, and most of Fairfield County, Connecticut.

The Nuclear Control Institute has warned that an attack on Indian Point could breach the reactors or the fuel storage pool, causing lethal contamination of everything within 50 miles. Like the disaster at Chernobyl, the plant's radioactive fuel rods would reach temperatures over 3,000 degrees and trigger chemical explosions that would spew radioactive particles from the site continuously, exposing 20 million people to lethal radiation.

Get the facts - go to

www.CloseIndianPoint.org

The Making of Manhattan Island



"…Granite, such as forms the foundation of New York City and other American centers of population, is relatively safe but not entirely immune to quakes. Geologists point to the Harlem River, connecting the Hudson and the East River and making Manhattan an island, as evidence of disturbances in the past. This river, they say, runs through a gneiss and limestone gorge formed by faulting or slipping of rock strata many years ago. The Nile and the Mississippi are said to follow similar lines of faulting…"

***Popular Science,* May 1933**

<u>Left</u>: caption: "The Harlem River, in red, separates the Bronx from Manhattan"

Skyscraper Cities

In This Number: A BAROMETER FOR THE BLUES.

The World Magazine

For the Week of SUNDAY, JANUARY 20, 1907.

How Far Can New York Climb Into the Sky?

THE FORTY-SIX STORIES for the NEWEST SKYSCRAPER WILL BE WITHIN FOUR STORIES of the LIMIT, DECLARES ARCHITECT HOPPIN, but the NEW YORK BUILDING SUPERINTENDENT Says ONE HUNDRED STORIES ARE POSSIBLE.

The 100-Story Building Possible and Probable.

By EDWARD S. MURPHY, Superintendent of Buildings.

By Architect F. L. V. Hoppin.

"FURTHEST SKYWARD" IN THE METROPOLIS.

"…Again the skyscraper is suspected of harboring danger. Can San Francisco, New York, Chicago, and other skyscraper cities survive a 'severe' temblor? Plainly, if cities in the United States were exposed to such shocks as periodically shake Japan, the answer would undoubtedly be that our skyscraper cities, as built today, are not safe. But engineers and architects have studied the severity of past earthquakes in the eastern half of the country…"

Popular Mechanics, **March 1936**

<u>Left</u>: caption: "'How Far Can New York Climb into the Sky?' *The World Magazine*, January 20th 1907." The article expressed doubt that it would ever be practical to build higher than fifty stories.

“…In Japan buildings are limited to 100 feet in height, or eight stories above street level, and the Japanese have devised a special type of construction to withstand the destructiveness of earthquakes. In the United States, the area most commonly affected by quakes is the Pacific coast, where engineers and architects have also evolved a special type of skyscraper construction. All the recent skyscrapers of San Francisco embody certain features which enable them to stand a test even as severe as that of 1906. They are, in fact, considered so safe that insurance companies do not hesitate to offer them a low rate on earthquake damage policies…”

Popular Mechanics, March 1936

On April 18th 1906, a magnitude 7.8 earthquake struck the San Francisco peninsula. It was one of the most devastating in the history of California. The earthquake and resulting fires caused an estimated 3K deaths and $524 million in property loss. Damage in San Francisco resulting only from the earthquake was estimated at $20 million; outside the city, it was estimated at $4 million. The sensible duration of the shaking in San Francisco was about one minute. The earthquake damaged buildings and structures in all parts of the City and *County of San Francisco* (although over much of the area the damage was moderate in amount and character). Most chimneys toppled or were badly broken. In the business district (which was built on ground made by filling in the cove of *Yerba Buena*) pavements were buckled, arched and fissured. Brick and frame houses of ordinary construction were damaged extensively or destroyed; sewers and water mains were broken and streetcar tracks were bent into wavelike forms.

Left T&B: SF City Hall before (top) and after (bottom) the 1906 earthquake

Weather Partly cloudy tonight and Friday. Cooler Friday.

NIGHT EDITION

Only Cincinnati Paper Having Its Own [illegible]

10 Pages

No Cincinnati paper has been able to give news of the Earthquake as quickly and accurately as The Post.

THE CINCINNATI POST

VOL. 51. NO. 92. CINCINNATI, THURSDAY. APRIL 19, 1906. PRICE ONE CENT.

The Scripps-McRae Press Association has had the first and best news of the Earthquake from the outset.

3000 DEAD; $300,000,000 LOST
SAN FRANCISCO IS OBLITERATED

THIS SHOWS THE EXTENT OF THE DEVASTATION IN SAN FRANCISCO

PHOTOGRAPHED FROM NOB HILL, RESIDENCE SECTION, NOW ON FIRE. ARTIST'S WORK SHOWS BIG BUILDINGS AND LANDMARKS AND THEIR FATE.

Thursday Sees Survivors Facing Death From Hunger and Thirst.

NO POWER ABLE TO CHECK FLAMES

EARTHQUAKE IN A NUTSHELL

SAN FRANCISCO is practically a city of the past. Almost all of what was left by the earthquake has been swept away by the fire.

Three thousand is a conservative estimate upon the total number of dead.

The property loss is estimated at from $300,000,000 to $500,000,000, 10 times larger than the entire damage done by the eruption of Vesuvius.

LATEST BULLETINS FROM FRISCO

SOLDIERS PREVENT FUGITIVES' FLIGHT

SAN FRANCISCO, VIA OAKLAND, CAL., April 19.—(Spl.)—Drunken soldiers, with drawn

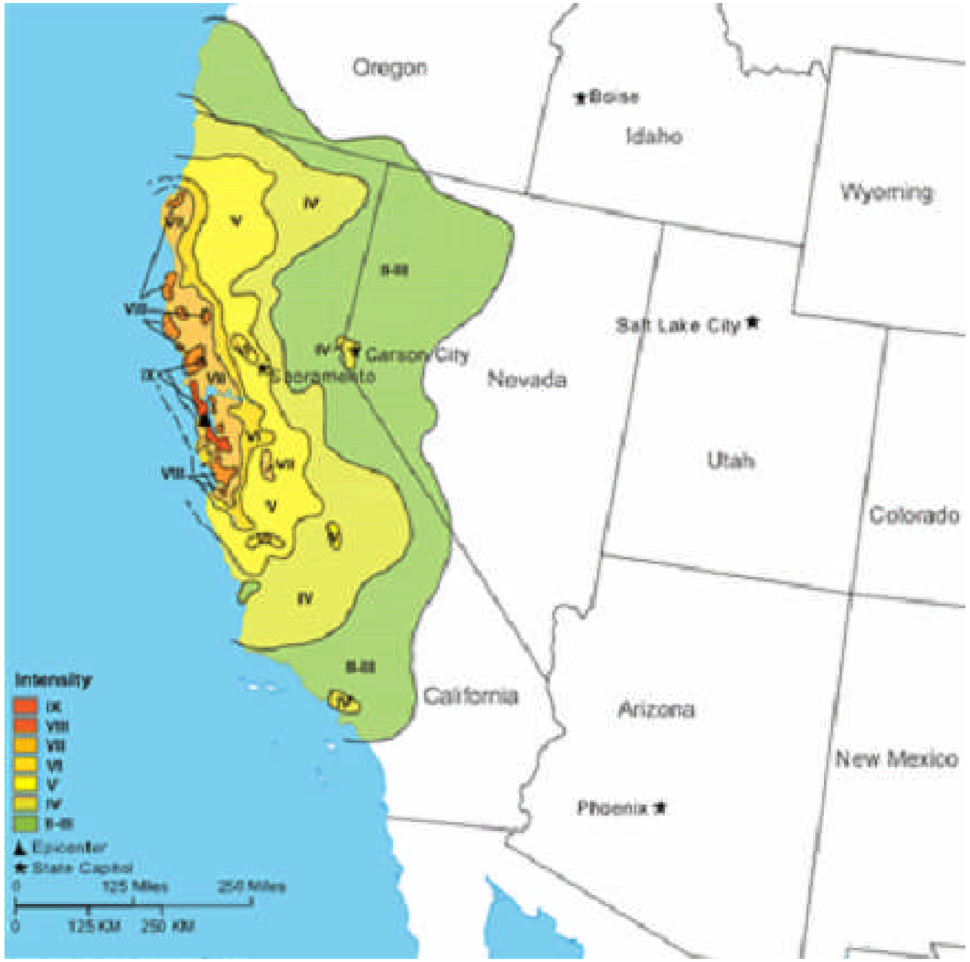
200,000 more rations from Denver and other Western supply departments to San Francisco.

GOVERNOR DECLARES A PUBLIC HOLIDAY

Frisco Transformed From a City of Joy to a Place of Death

HUNDREDS DIED IN THEIR HOMES


RUINS OF SAN FRANCISCO
HILL IN FOREGROUND
ROM LAWRENCE CAPTIVE AIRSHIP
1500 FEET ELEVATION

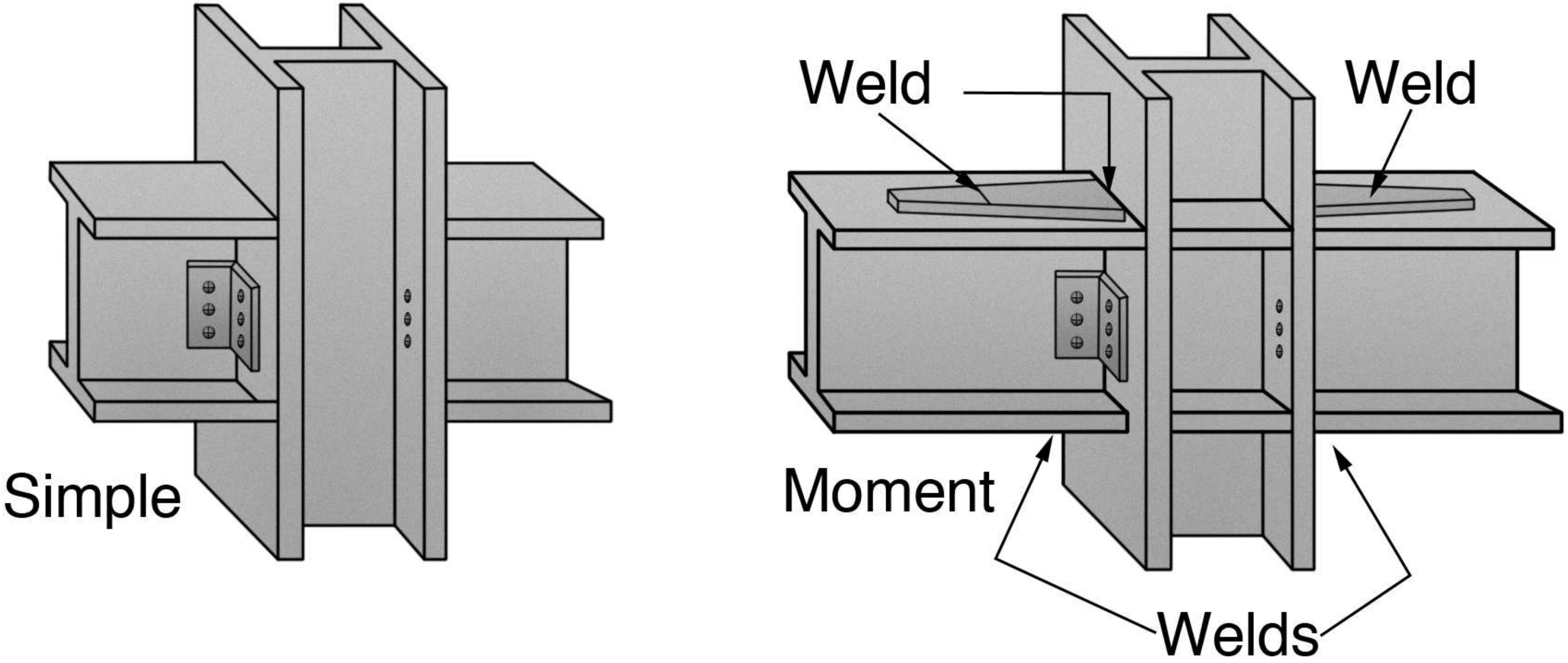


The 1906 *San Francisco Earthquake* caused the most lengthy rupture of a fault that has ever been observed in the contiguous U.S. The displacement of the *San Andreas Fault* was observed over a distance of 300 km; from San Juan Bautista to Point Arena (where it passes out to sea). Additional displacement was observed farther north. The largest horizontal displacement (6.4 meters) occurred near Point Reyes Station in *Marin County*. Trees swayed violently and some were broken-off above the ground or thrown down while water in springs and artesian wells either increased or decreased its flow. The region of destructive intensity extended over a distance of 600 km (left). Most of California, parts of western Nevada and southern Oregon felt the quake. Many aftershocks were reported, some severe.

“…Pacific coast engineers and the owners of large buildings now believe earthquake dangers can be overcome even in the largest modern buildings by taking certain precautions in the design. These engineers are now generally agreed that skyscrapers should rest on a massive foundation block of concrete; that the building’s structural steel work should be embedded in monolithic concrete; that the floors should be built of reinforced rock concrete. Both wind resistance and quake resistance are increased by the use of special cross braces in the steel frame…”

***Popular Mechanics,* March 1936**

Moment-Resistance



Moment-Resistant Frames **are steel-frame structures with rigid welded joints. These structures are more flexible than shear-wall structures and are less likely to undergo major structural damage (but more likely to have damage to interior walls, walls and ceilings). Several steel-frame buildings failed in the 1994** ***Northridge Earthquake,*** **but the failures were, in large part, due to poor welds at the joints.**

<u>Above</u>: caption: “Joint used in a moment-resistant frame”

Moment-Resisting Frames (above L&R):

- **Used for both structural steel and/or reinforced concrete construction;**
- **The horizontal beams and vertical columns provide both support for the structure’s weight and the strength and stiffness needed to resist lateral forces;**
- **Stiffness and strength are achieved through the use of rigid connections between the beams and columns that prevent these elements from rotating relative to one another, and;**
- **Moment-resisting frame systems are popular because they do not require braced frames or structural walls, therefore permitting large open spaces and facades with many unobstructed window openings.**

Connectivity

"…As second University of California study is aimed at improving beam-to-column connections in multi-story buildings. An inspection of building failures after the 1964 Alaska earthquake showed that the most common structural weakness was the connection between the horizontal and vertical components…"

Popular Mechanics, **June 1967**

"…Prof. Egor Popov has been testing beam-and-column assemblies with his own earthquake machine – a powerful double-acting hydraulic jack that alternately applies force up and down in what are called reverse-loading cycles. The jack starts with small up-and-down thrusts that gradually grow larger until the tip of a steel beam moves through a 10-inch arc. The simulated earthquake action induces a strain more than 15 times greater than the maximum elastic strength of the beam flanges. The flanges buckle and the beam eventually cracks…"

***Popular Mechanics,* June 1967**

Left: caption: "Egor P. Popov (1913-2001)." Popov was a structural/seismic engineer who helped to transform the design of buildings, structures and civil engineering in earthquake-prone regions. He was primarily famous for his work doing research for *UC Berkeley*. He is also well known for developing the steel *Moment-Resisting Frame* and *Eccentrically Braced Frame* (EBF).

“…According to Prof. Popov, steel beams and their connections can withstand a larger number of such reverse-loading cycles than might be supposed. The studies show that moderate flange buckling does not necessarily indicate a failure of the steel connection, the flange will regain its original shape when the strain is relieved…”

***Popular Mechanics,* June 1967**

Reverse Shear

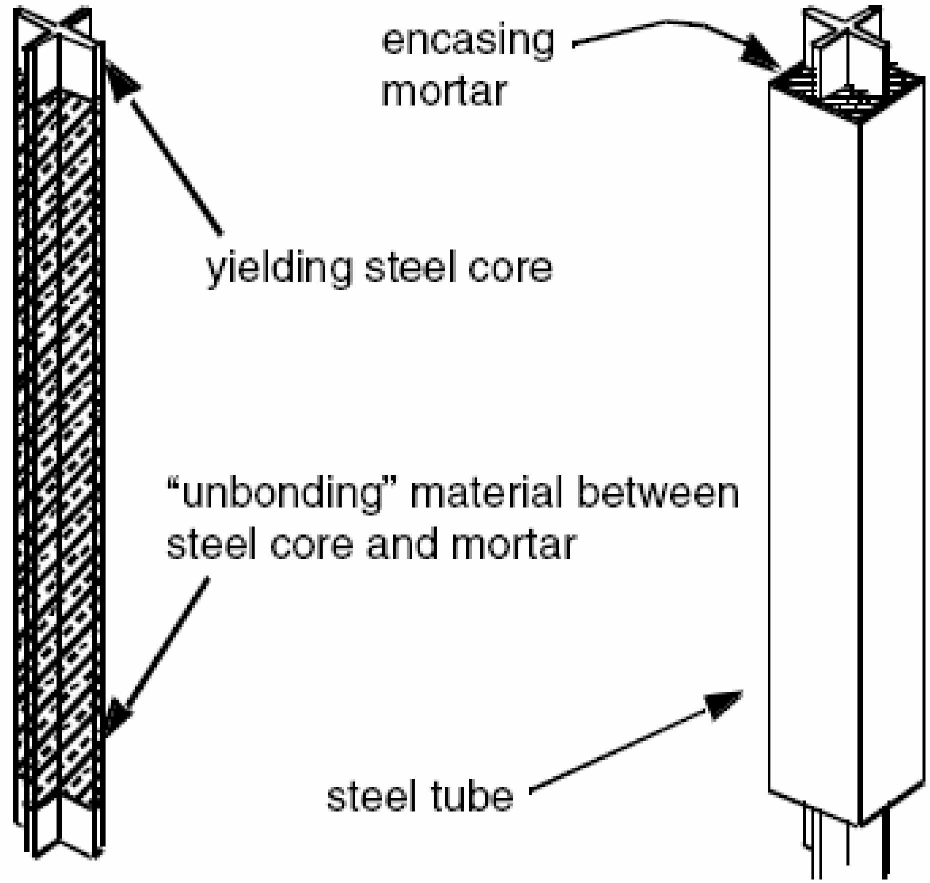
“…The structure of any building is based on the downward force of gravity. Beams and girders are supported to keep them from falling. But the gargantuan forces of an earthquake can cancel out the force of gravity with powerful upward thrusts. This special kind of stress, called reverse shear, can cause massive girders to fail as the first shock hits because they have little resistance to <u>upward</u> pressure. Quake-proof girder joints, called stirrups, which resist shear in either direction, have been developed to replace bent-up reinforcing rods…”

***Popular Mechanics,* January 1977**

Interface

“…In steel-framed buildings, the way that welded and riveted joints are made can spell the difference between a structure standing through a quake or collapsing. ‘The most critical area in steel and concrete structures,’ says Professor Clough, ‘is the interface between the two materials. We are coming up with new designs that will help make them work together for mutual support…”

Popular Mechanics, **January 1977**

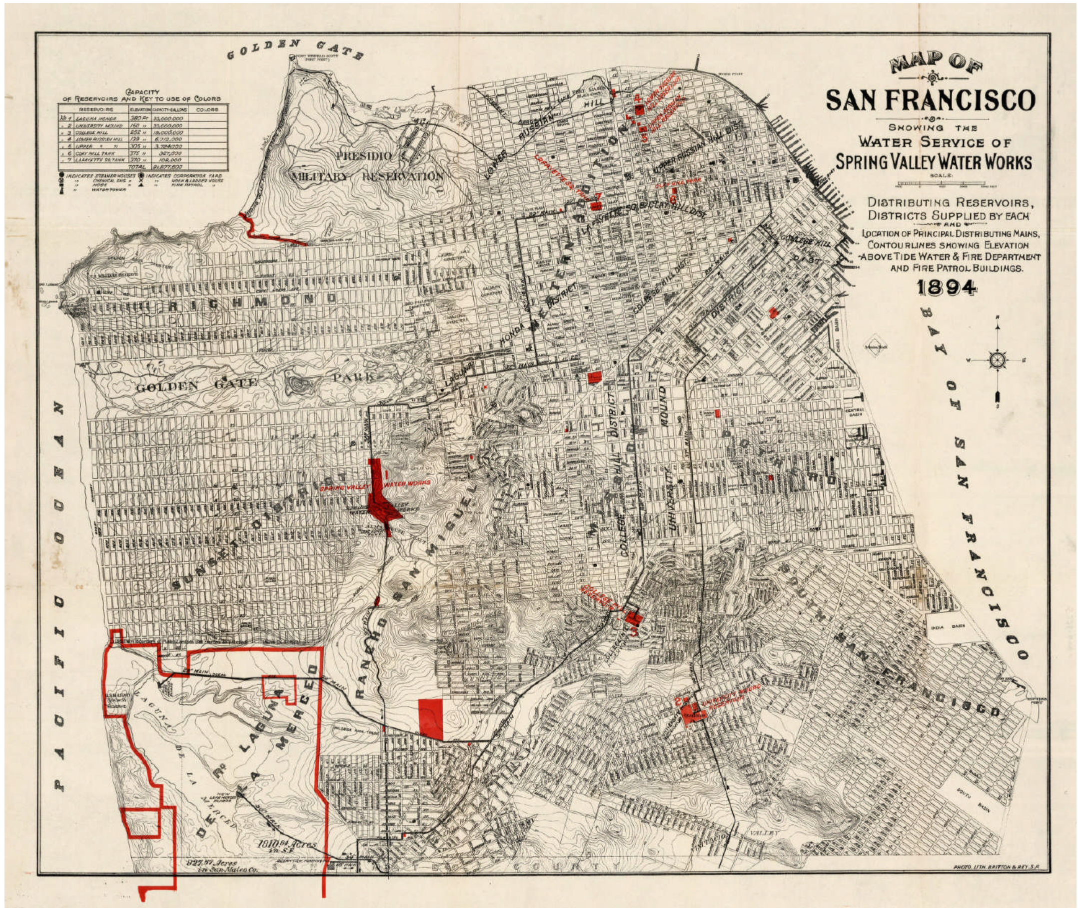


Left: a *Buckling Restrained Brace* (BRB) is a structural brace that is designed to allow a building to withstand cyclical lateral loadings (typically earthquake-induced). It consists of a slender steel core, a concrete casing designed to continuously support the core and prevent buckling under axial compression and an interface region that prevents undesired interactions between the two. Braced frames that use BRBs (known as *Buckling Restrained Braced Frames* (BRBF) have significant advantages over more typical braced frames.

Compounding the Problem

“The greatest damage done to cities by earthquakes arises from the conflagrations which almost always follow. In the earthquake of 1906, at San Francisco, it has been definitely determined that more than 90 percent of the property loss was caused by fires occasioned by the breaking of gas mains and the firing of the gas by sparks from broken electrical connections…”

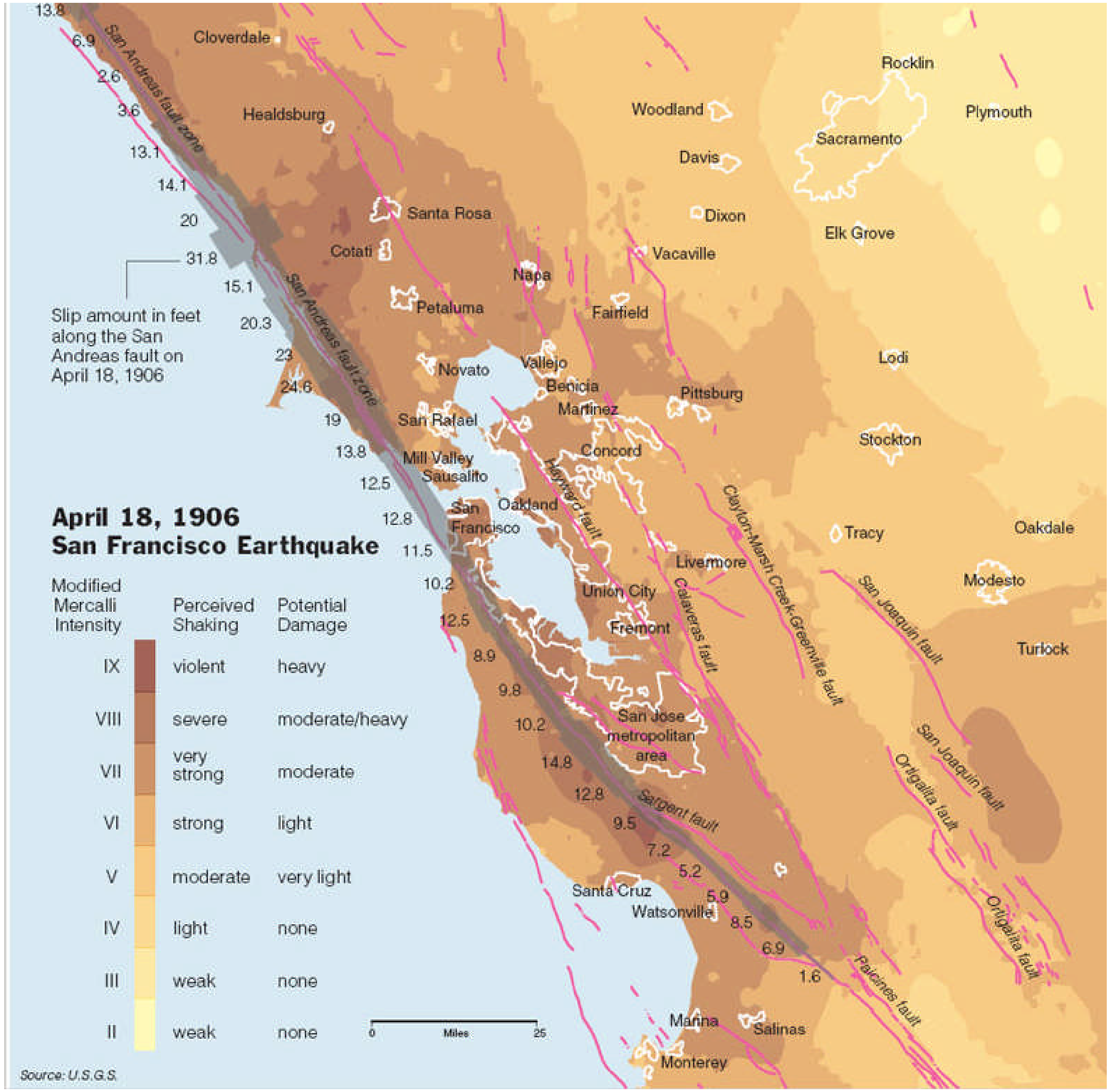
Popular Mechanics, **November 1923**



"…San Francisco is considered by waterworks engineers to be one of the most difficult cities of its size in the United States to supply with water. When the earthquake hazard is added to the other considerations, the limits of the comparison may well be increased to the area of the world…"

***Popular Mechanics*, Nov. 1923**

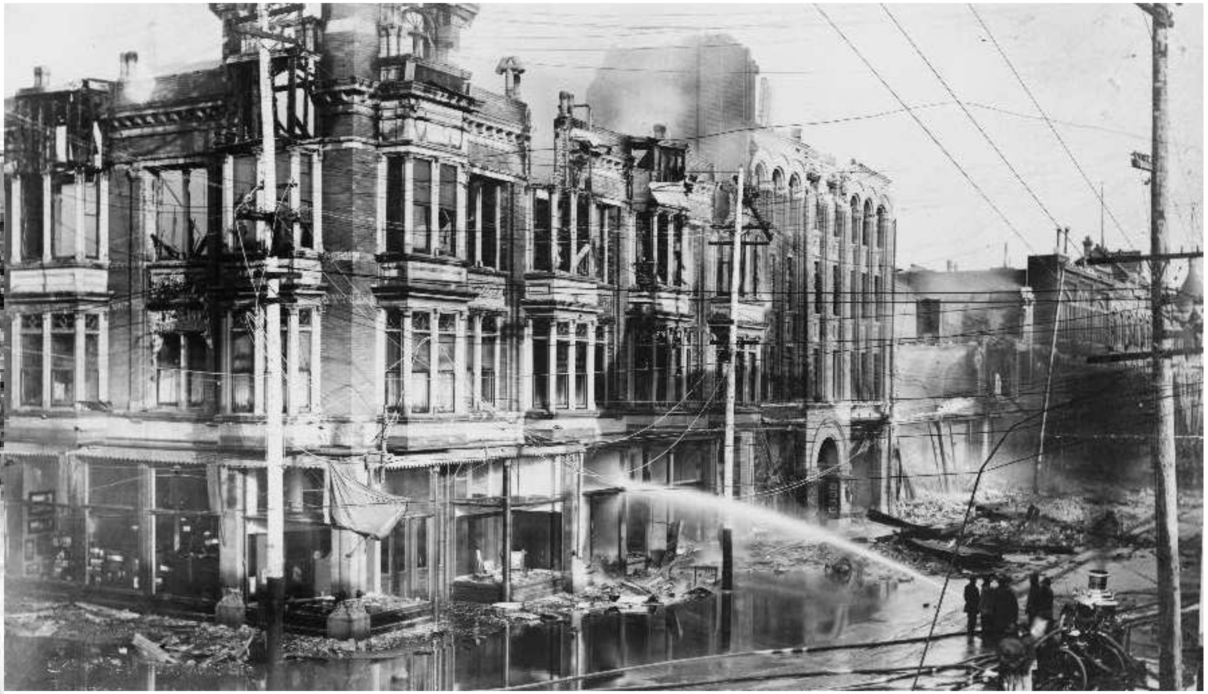
Left: caption: "Map of San Francisco Showing The Water Service of Spring Valley Water Works, 1894"



"…Situated, as it is, on the extreme tip of a peninsula which a number of earthquake faults cross, it is not hard to realize that all of the conduits carrying water to the city must of necessity be exposed to more or less interruption due to earthquakes. Another feature of importance is the fact that, the south the neck of that tongue of land is cut almost across by marshy areas, which are subject to the same jelly-like shaking…"

***Popular Mechanics*, Nov. 1923**

<u>Left</u>: caption: "Map of the Great San Francisco Earthquake." The image combines quake intensity with fault lines, urban areas and slip along the *San Andreas Fault*.



"…The principal lesson learned in 1906 in San Francisco was that if waterworks structures are located in soft or filled ground, or near a fault which moves, it is practically impossible to construct certain parts of them, such as pipe lines, in such a manner as to guarantee absolutely against earthquake damage..."

***Popular Mechanics,* November 1923**

<u>Left</u>: caption: "Tank Hill was built in 1894 by the Spring Valley Water Company to store drinking water pumped from Laguna Honda. Tank Hill became city property in 1930 when the SVWC. was acquired to establish the San Francisco Water Department."

<u>Right</u>: caption: "A fire truck sprays water on a block of burned buildings on June 8, 1906"

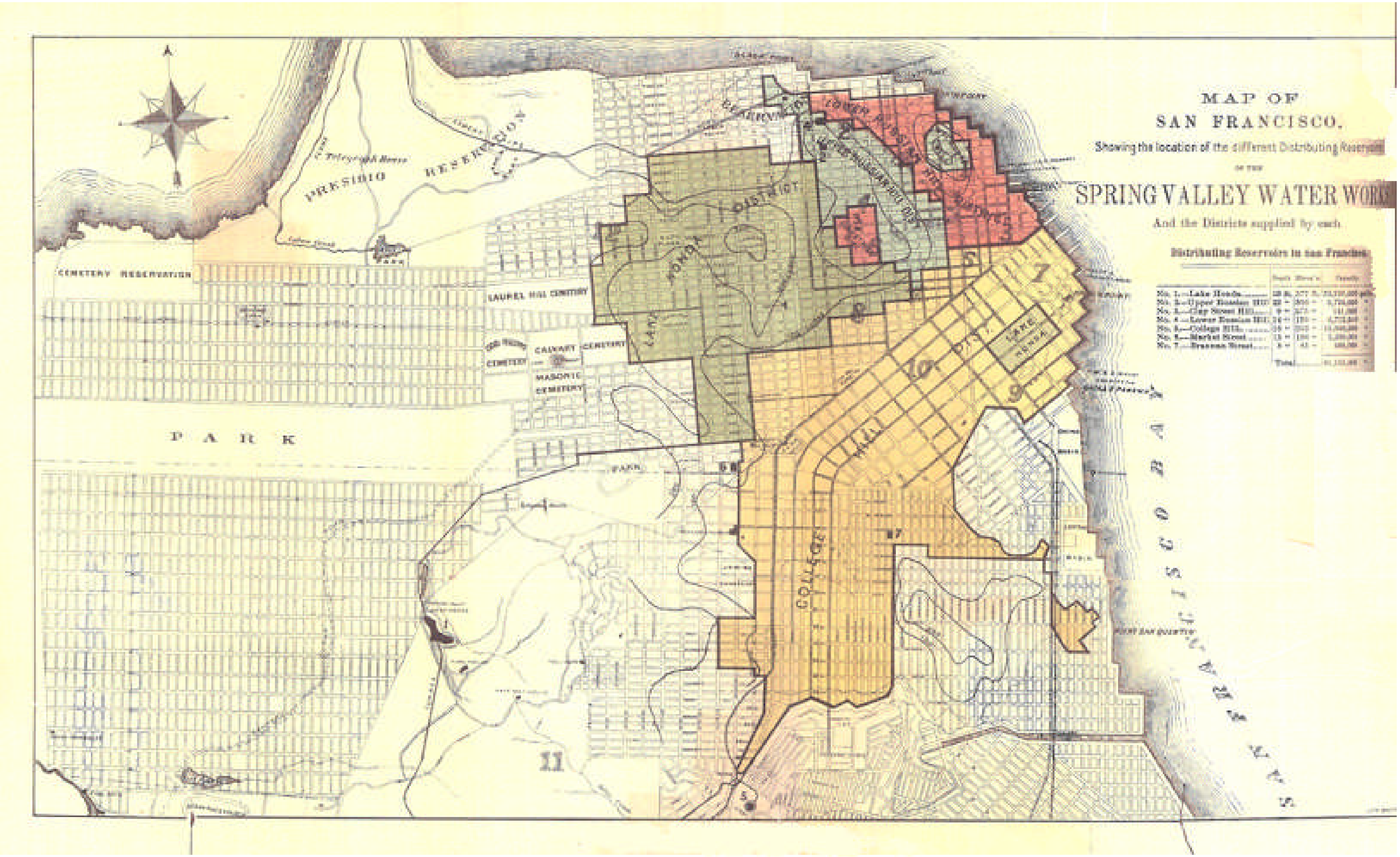
“…Three precautions may be taken, in this and in other cities in earthquake areas, to insure the water supply against damage from seismic disturbances;

<u>First</u> – Waterworks structures should be so located as to avoid known areas which are subject to excessive movement;

<u>Second</u> – The isolation of selected sections of the system by means of gate valves, placed at all points where pipes cross the boundaries of the ground subject to such seismic movement. This precaution is, of course, involved in the treatment of the local distributing system in each city;

<u>Third</u> – Perhaps most important, the carrying in storage within the city limits of a large quantity of water available for distribution. With sufficient stored water breaks in the conduits carrying the water would be relatively far less important than breaks in the distributing system…”

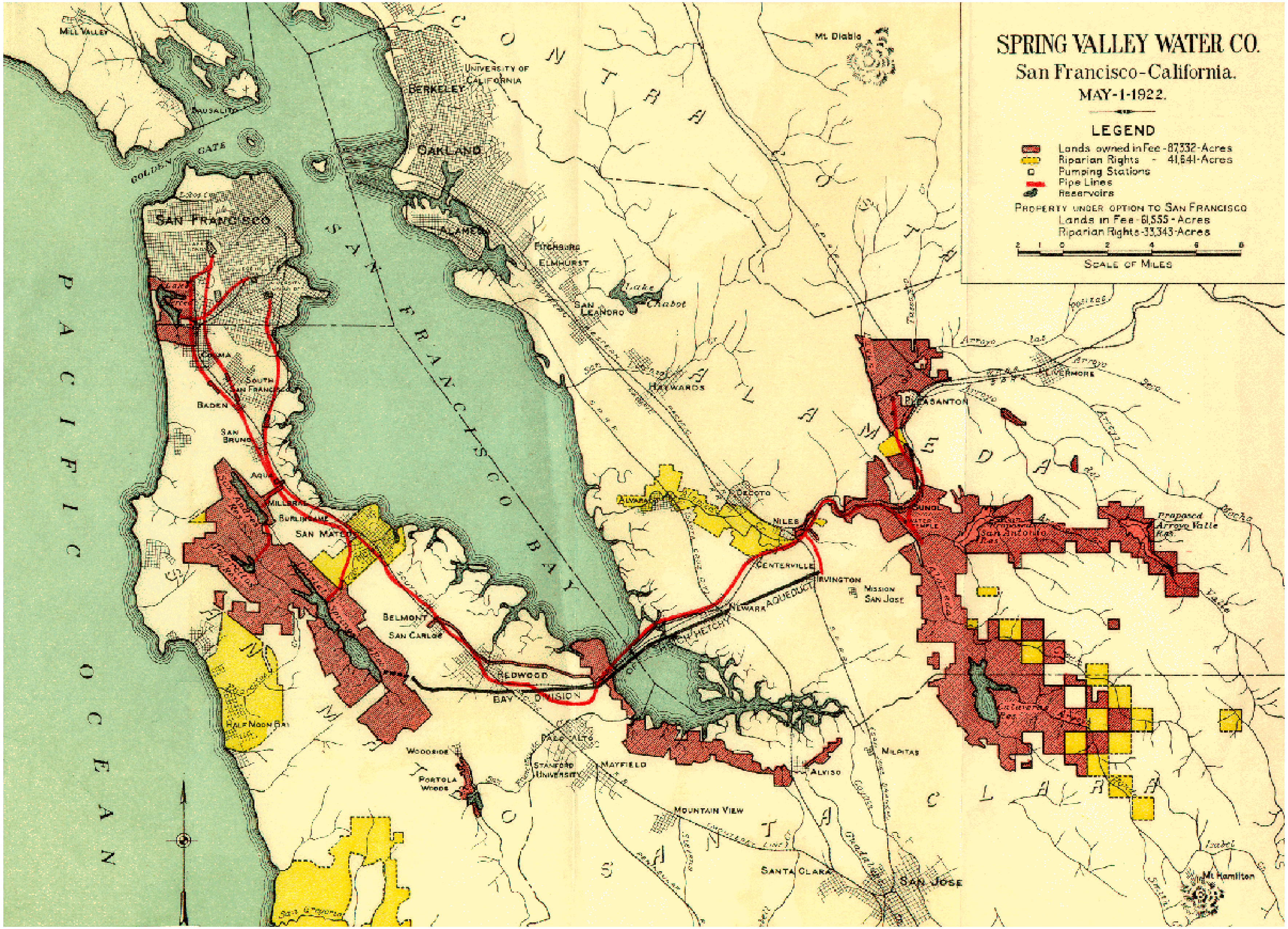
***Popular Mechanics,* November 1923**



Above: caption: "Map of San Francisco showing the location of the different Distributing Reservoirs of the Spring Valley Water Works (1876-77)"

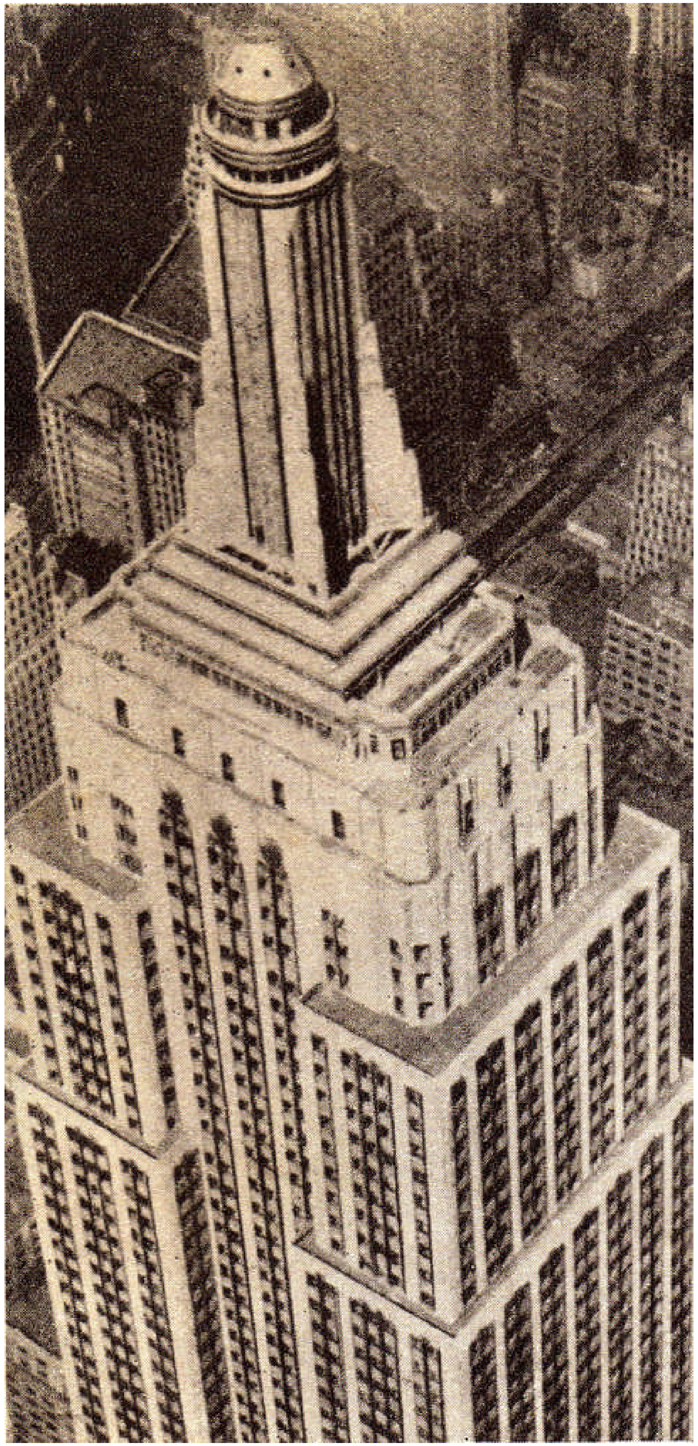
“…It developed in the San Francisco quake that water was needed more for fire fighting than for any other purpose, and, following the reconstruction of the burned district, plans were made and a system constructed that embodies all the best features of water supply for fire purposes that have been in use anywhere. Many features of this system are designed to meet earthquake conditions, such as the location of the reservoirs and pumping stations on solid foundations, the avoidance of filled ground in laying large feeders, gating of distributing mains in filled ground, duplication of pumping stations and sources of supply, and the use of special joints in connecting pipes designed to allow greater movement before rupture.”

***Popular Mechanics,* November 1923**



Above: caption: “1922 map showing the pipelines of the SVWC and the Sunol Water Temple”

Shaken, Not Stirred



"…In the world's highest man-made structure, the Empire State building, a long pendulum installed to measure the sway of the structure did not register any unusual movement in the recent quake. But strangely, the radio beam near Newark airport deviated from its course for a few seconds and then returned to normal. Reports from cities in Canada and the eastern half of the United States showed some of the skyscrapers were shaken but not one suffered damage…"

***Popular Mechanics*, March 1936**

What Ought One Do?

"…What ought one do in an earthquake? The first thought, of course, is to run. The best thing you can do, Dr. Bailey Willis, the earthquake expert, advises is, 'Stand still and count to fifty – by that time all danger will be over.' All the damage of the Japanese quake of 1923 happened in less than sixty seconds and the greatest wreckage of the San Francisco quake of 1906 occurred during the first minute…"

***Popular Mechanics,* March 1936**

Operation Shakedown

"'Householders, attention! As you know, a major earthquake has occurred. There will be more shocks for some time. It may not be wise to sleep in your house tonight. Try sleeping in the back yard or a park. If you have a barbecue in your back yard use it. If not, there may be some fallen bricks from your chimney. Build a simple cooking pit with these. Boil water before drinking. If the pipes are broken, get the water from your hot-water heater. If there is no electricity, use your car radio to receive announcements'…"

Popular Mechanics, **May 1958**

RE: according to the *National Earthquake Information Center* (NEIC) of the *U.S. Coast and Geodetic Survey*, from 1865 to 1966 over 1,500 deaths and more than $1.3 billion in property damage was caused by earthquakes in the U.S. Most deaths (935) occurred in California.

“…This is part of a message that is ready for release by radio stations in California. It was used once, though not broadcast to the public, when ‘Operation Shakedown’ was conducted by the California Disaster Office. This office, a state agency, coordinates relief activities during civil calamities. It is part of the Civil Defense organization. In California, all the resources of civil defense from block wardens up can be mobilized when a major earthquake occurs. ‘Operation Shakedown’ was a rehearsal for that event…”

***Popular Mechanics,* May 1958**

RE: in 1956, to emphasize the importance of the natural disaster aspects of the state’s disaster preparedness programs, the Legislature amended the *California Disaster Act* to authorize the Governor to proclaim a “state of disaster” (as well as a “state of extreme emergency”). The Act also changed the name of the *Office of Civil Defense* to “California Disaster Office.” It was stipulated that the office should act as the coordinator of all state disaster activities and that every state agency and officer should cooperate with the office’s director in rendering all possible assistance. A revised *Civil Defense and Disaster Plan* was issued in January 1958. This plan gave equal emphasis to civil defense and disaster aspects of the program.

“…It was assumed that an earthquake had caused death and destruction over a wide area in the state. Radio centers were manned, rescue squads and mortuary teams were set up, and emergency equipment was moved out of storage and tested. All the activities that would be necessary after a quake were practiced…”

Popular Mechanics, **May 1958**

RE: in March 1959, a *Civil Defense Operations Plan* was issued. This plan was developed under a federally-funded project supervised by the *California Disaster Office*. A complete revision of the *California Civil Defense and Disaster Plan* was issued in November 1963. In 1968, California Governor *Ronald Reagan* issued an *Emergency Resources Management Plan*, developed by the Disaster Office with the assistance of the private sector and government. In September 1970, California’s emergency management agency was formed when the *California Emergency Services Act* was passed (superseding the *California Disaster Act*). The new act re-designated the *State Disaster Council* as the *California Emergency Council*, with no major changes in composition, powers, or duties. However, it renamed the California Disaster Office: “Office of Emergency Services” (OES), The Act went into effect on November 23rd 1970.

Left: caption: “OES Administrative and Mutual Aid Regions.” In 1972-73. the *National Oceanic and Atmospheric Administration* (NOAA) prepared reports estimating earthquake losses in the San Francisco and Los Angeles areas. These reports clearly demonstrated that a major earthquake would cause damage that would devastate the current capabilities of the local, state and federal response communities. Two significant events that shaped California’s current earthquake preparedness program occurred in 1979. Then Governor *Jerry Brown* appointed the *Earthquake Task Force*, bringing together representatives of local, state and federal agencies, private industry and volunteer agencies to address planning and preparedness issues. The Task Force remained active through 1985, developing and drafting the *California Earthquake Response Plan* for the southern *San Andreas Fault* in 1983 and subsequent Northern California plan.

After the 1980 *Mount St. Helens* eruption in Washington, the USGS took a closer look at geologic hazards facing urban areas (which included re-evaluation of the estimates NOAA made in 1972-73 for earthquake hazards in California). There were concerns that a damaging earthquake would occur in Southern California and that state and local governments were unprepared to deal with the consequences. That prompted establishment of a joint state-federal effort to accelerate preparedness. The *Southern California Earthquake Preparedness Project* (SCEPP) and the *Bay Area Earthquake Preparedness Project* (BAREPP) were created as part of the *Seismic Safety Commission* and in the mid-1980s joined OES. The *California Earthquake Prediction Evaluation Council* (CEPEC), established in 1974 as an advisory committee to OES, was officially appointed in 1976. CEPEC acts as an advisory body to the Director of OES relating to earthquake predictions. It may also be activated to evaluate and assess information on seismic activity, particularly the occurrence of earthquakes that may be foreshocks. Meetings of CEPEC are held quarterly or as required to evaluate predictions. Upon review of the prediction, CEPEC advises the OES Director of the validity of the prediction and, if the prediction is considered valid, the OES Director notifies the Governor and may implement the *Short-Term Earthquake Prediction Response Plan* or take other actions as appropriate. That plan includes notification of local governments of the prediction and the public release of information. The members of CEPEC are appointed by the Governor, upon recommendation by the OES Director and the CEPEC Chairperson.

“…To make the drill as authentic as possible, ‘flash’ reports that might be typical in an actual earthquake were forwarded to information centers: ‘San Dimas-Big Dalton Dam has burst. Oil refinery fires spreading in Los Angeles harbor district. Pasadena reports main sewer line broken, sewage flowing down Arroyo Seco. Area G reports seven dead bodies picked up. Glendale has asked for 200 cots for injured or homeless. Long Beach estimates 2,300 homes destroyed, many fires’…”

***Popular Mechanics,* May 1958**

RE: earthquake simulation exercises in 1987 and 1989 (and the response to the 1989 *Loma Prieta Earthquake*) highlighted the need for a manageable and effective system for compiling disaster intelligence and resource requests. In pursuing solutions, OES identified several issues. One problem was that a number of jurisdictions were discussing the same information or resource needs. Another was the need for a high capacity, failsafe communications system. To address these issues, OES proposed expanded use of the operational area concept in emergencies and development of an alternate network of communications hardware. These proposals were the focus of the *Operational Area Satellite Information System* (OASIS). OASIS offered a systematic approach for exchanging disaster intelligence and resource requests between special districts, cities, counties, operational areas and the state. The communications hardware component included a high frequency radio system and a satellite communications network, each with one downlink per county and also downlinks to state agencies, including OES.

OES
CALIFORNIA

Governor's Office of Emergency Services

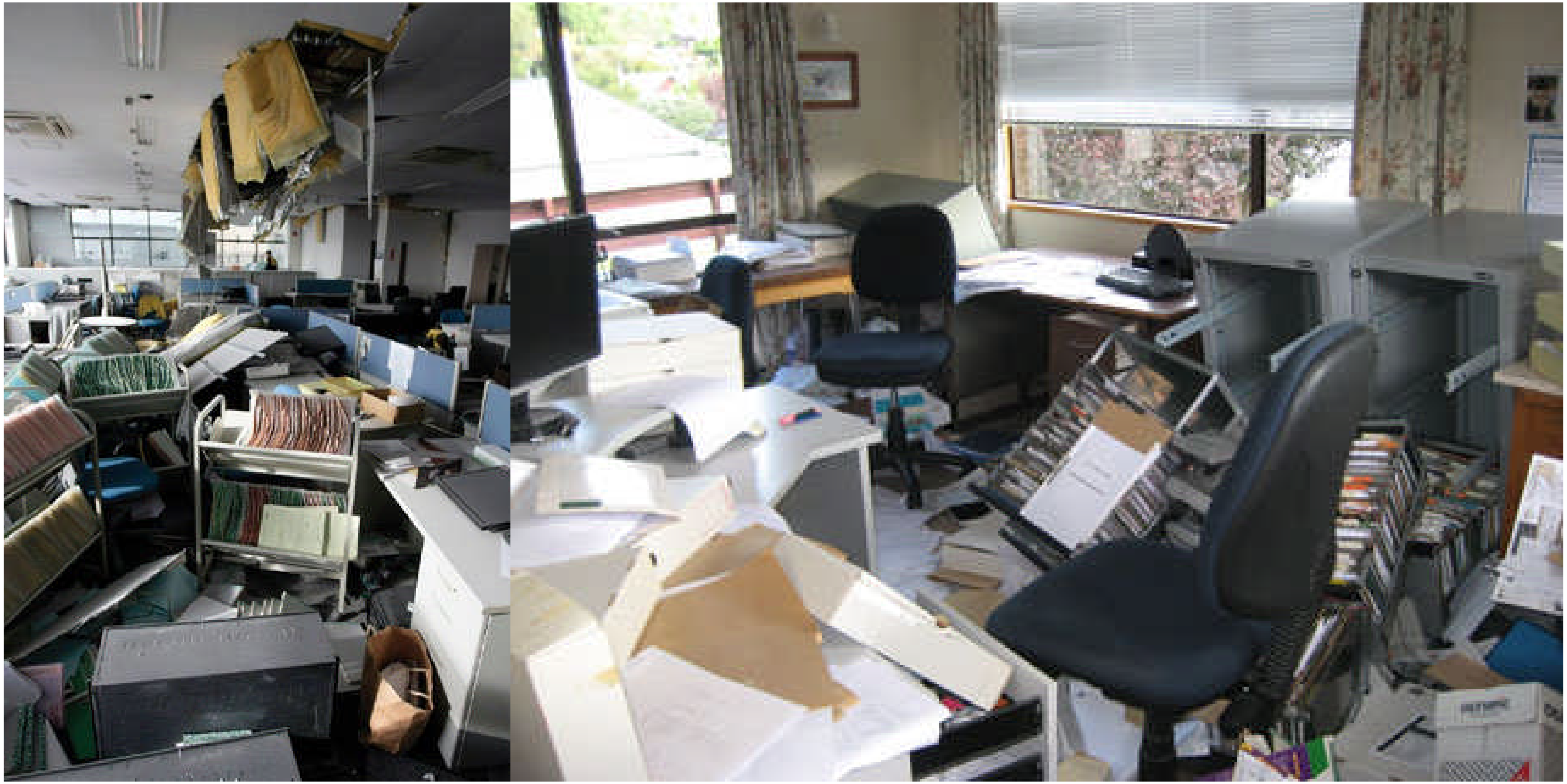
Since 1917, state level emergency organizations have existed in California. But disasters (most notably the *San Francisco Earthquake* of 1906) had a major impact on the state long before. From its earliest days, California assumed the role of leader in disaster preparedness, response and recovery. However, the original impetus for disaster preparation in the state was planning for WWI. Recognizing that the problems created by many types of disasters are similar, since 1945 the *California State Legislature* has given a single agency the responsibility for planning and preparing for war-caused emergencies, natural disasters and/or civil disturbances. Programs, equipment and emergency personnel are available for use in coping with any disaster, the main differences being in the degree and extent of damage/destruction and in the primary types of assistance required.

“…What happens to a major building during a devastating quake? Experts believe a typical scenario would go like this:

- ***People are terrified. The drama starts when the thundering of the earth is felt by everybody inside the building, particularly on the upper floors. Anyone looking out the window will see the horizon move up and down, the side to side. People inside the building become petrified and disoriented;***
- ***Too much to cope with. Things start to happen very fast – large desks start moving, chairs tip over, file cabinets spill their contents. Interior spaces become a shambles as people head for the elevators in panic;***
- ***No way out. The structural frame of the building is moving from the forces of the quake. The interior structures and systems can’t take the deformations; phone connections are ripped apart, steel doors seize against their casings, steel staircases start to separate from their landings;***
- ***Elevators are out. Some electric supply lines to the elevators are broken. In other shafts, the counterweights slip out of their guides and the elevators seize in their tracks;…”***

continued…

***Popular Mechanics*, January 1977**



“…continued;

- ***Nowhere to hide. The interiors of most floors now look as though a bomb has gone off; suspended ceilings are falling, jumbled wires are shorting out, small fires start, partition walls are collapsing and heavy pieces of furniture are tumbling across the debris-covered floor;***
- ***Destruction from above. As the ceilings fall, large sections of heating and air-conditioning ducts begin to pull apart, sending boxlike chunks of sheet metal crashing down on the people below. As the lights go out, water and sewage lines break at their welds and smoke starts to filter through the hallways;***
- ***No rescue in sight. Many people have given up, but some cling to the hope of rescue. It may not be coming. In many cases, masonry firehouses have collapsed on the emergency equipment inside them. Police communications have been disrupted;***
- ***The structure survives but not the people. Curtain walls have been thrown from the exterior of the building to the streets below. Glass windows have shattered. As the shuddering stops (it may last only 20 or 30 seconds), the building is still standing but the inhabitants are not…”***

***Popular Mechanics,* January 1977**







“…Dr. Charles Richter, Professor of Seismology at the California Institute of Technology, says, ‘There are several well-recognized possibilities for the location of this expected great earthquake. My own preference is, first, the southern California sector centering somewhere near Fort Tejon; second, the central California sector extending north and south from San Francisco; third, the intermediate sector extending from Hollister to a point northeast of Paso Robles. There are still other possibilities; no part of California is exempt from earthquake risk…”

***Popular Mechanics,* May 1958**

Good Vibrations

“…John Ripley Freeman, former president of the American Society of Civil Engineers, who has made an exhaustive study of skyscraper behavior, said, recently: ‘The public is afraid of earthquake forces because they have been measured by weak structures; but these forces can nearly always be resisted by intelligent and not over-expensive construction. The motion of a great building on a massive concrete foundation bears some relation to the mass of a great steamship among ocean waves. The insurance risk on a building on soft ground with extra-deep foundations of concrete tied by reinforcing steel is probably much less than on a smaller building with shallow non-rigid foundations. Since a great earthquake is supposed to have a vibration period of one or one and a half seconds, it is advisable to make a skyscraper frame nearly rigid, so its vibration period will be as small as possible, thus preventing a synchronism with the larger vibration period of the earthquake’…”

***Popular Mechanics,* March 1936**

“…In Japan engineers determine the vibration period of a building by attaching a cable to a top corner and exerting a pull. When the cable is suddenly released, the building experiences a tremor. In this way, the vibration period of concrete buildings was found to be from 0.50 to 0.65 of a second, as against one to one and one-half seconds for an earthquake of considerable violence. Mr. Freeman stated that the best construction for a skyscraper is monolithic reinforced concrete deposited around a well-designed steel skeleton…”

***Popular Mechanics,* March 1936**

“…‘The extra cost of quakeproof structures,’ declared Mr. Freeman, ‘involves competent engineering advice, good mortar sand, proper mixture of lime and cement, strong girders for floors and roofs, ties of steel rods for resisting the arch thrust and the use of reinforced concrete’…”

***Popular Mechanics,* March 1936**

<u>Above</u>: aftermath of the 1906 *San Francisco Earthquake*. Many buildings were completely destroyed while others were irreparably damaged and/or had minor or no damage. On or near the *San Andreas Fault*, buildings were destroyed and trees were knocked to the ground. One pipeline that carried water from *San Andreas Lake* to San Francisco was broken, shutting off the water supply to the city. The fires that ignited soon after the onset of the earthquake quickly raged through the city because of the lack of water to control them. They destroyed a large part of San Francisco and intensified the loss at Fort Bragg and Santa Rosa.

A Classic Example

“…Since there is no indication that quakes will ever cease, architects and engineers are developing types of construction that would be damaged least when earthquakes do occur. Generally speaking, damage is greatest to buildings erected on ‘made’ ground or loose natural alluvium, and the same quake exerts less force in areas having firm, rocky foundations. Water-soaked ground seems to intensify the force. On the whole, rigid units of construction that have little if any ‘give’ appear to receive less damage than loosely built buildings that weave in moderate tremors. In case of a tremendous shaking a rigid building probably would suffer more.”

***Popular Mechanics*, July 1935**

<u>Top</u>: some houses were severely damaged (left) while others were hardly affected (right) after the 1906 SF quake

<u>Left</u>: the undamaged *Ferry Building* after the 1906 SF earthquake

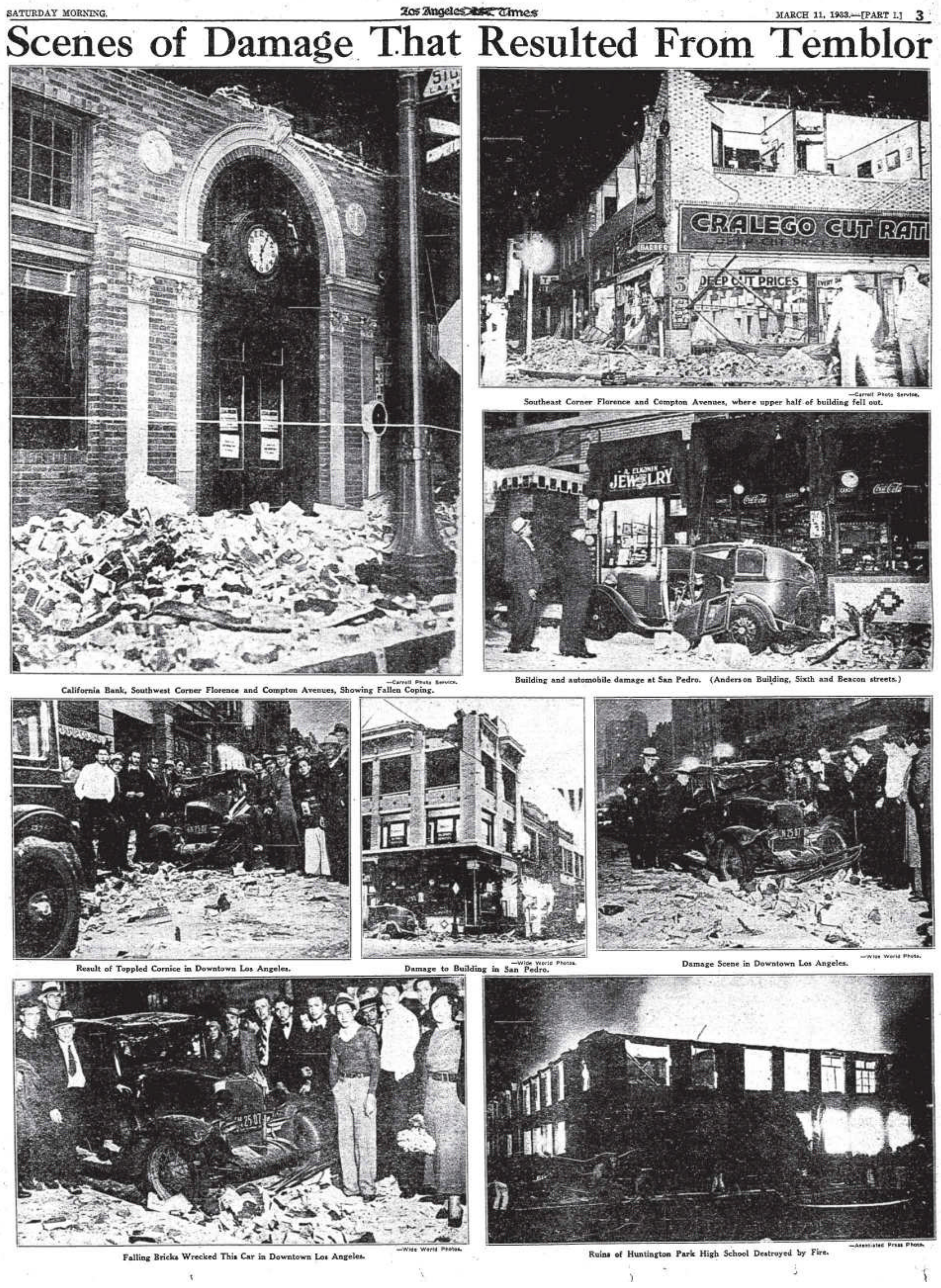
“…Since there is nothing man can do to prevent earthquakes, he must learn to live with the problem and avoid hazardous building practices. Although the San Francisco earthquake of 1906 has been used many times as a classic example of the kind of destruction that can be caused by a tremor of major magnitude, the Geological Survey contends that much of the damage of that quake could have been avoided. With a little Monday morning quarterbacking, the survey points out that earthquakes had occurred in the San Francisco area previously and that one had been of about the same magnitude as the 1906 quake. And the buildings suffering the most damage were erected on filled or ‘made’ land near the foot of Market St., whereas buildings on solid rock suffered little or no damage…”

***Popular Mechanics,* June 1967**

Practically Earthquake-Proof

“…Buildings of medium height can be constructed so that they will be practically quake-proof, claim noted engineers who have studied earthquake effects for years. These authorities say that a building with a substantial framework solidly tied together by strong walls and floors, made of good materials, should be reasonably safe…”

***Popular Mechanics,* July 1933**



SATURDAY MORNING. Los Angeles Times MARCH 11, 1933.—[PART I.] 3

Scenes of Damage That Resulted From Temblor

—Carroll Photo Service.
California Bank, Southwest Corner Florence and Compton Avenues, Showing Fallen Coping.

—Carroll Photo Service.
Southeast Corner Florence and Compton Avenues, where upper half of building fell out.

Building and automobile damage at San Pedro. (Anderson Building, Sixth and Beacon streets.)

Result of Toppled Cornice in Downtown Los Angeles.

—Wide World Photos.
Damage to Building in San Pedro.

—Wide World Photo.
Damage Scene in Downtown Los Angeles.

—Wide World Photos.
Falling Bricks Wrecked This Car in Downtown Los Angeles.

—Associated Press Photo.
Ruins of Huntington Park High School Destroyed by Fire.

"…E.M. Scofield, contractor, who was a member of the coroner's jury which investigated the recent California disturbance, says that by an added cost of three to seven percent, any building can be made shock-resistant. Engineer Hart recommends reduction of the danger of falling walls, cornices and copings, which caused much of the damage at Long Beach, by making these parts integral parts of the building. Overhanging decorations and cornices would be eliminated…"

***Popular Mechanics,* July 1933**

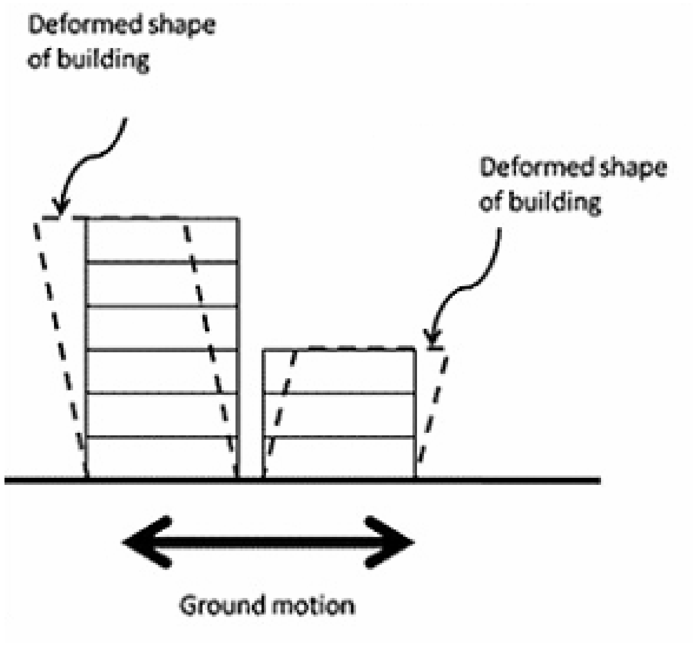
Left: caption: "Los Angeles Times, March 11, 1933. Scenes of the damage wrought by the Temblor."

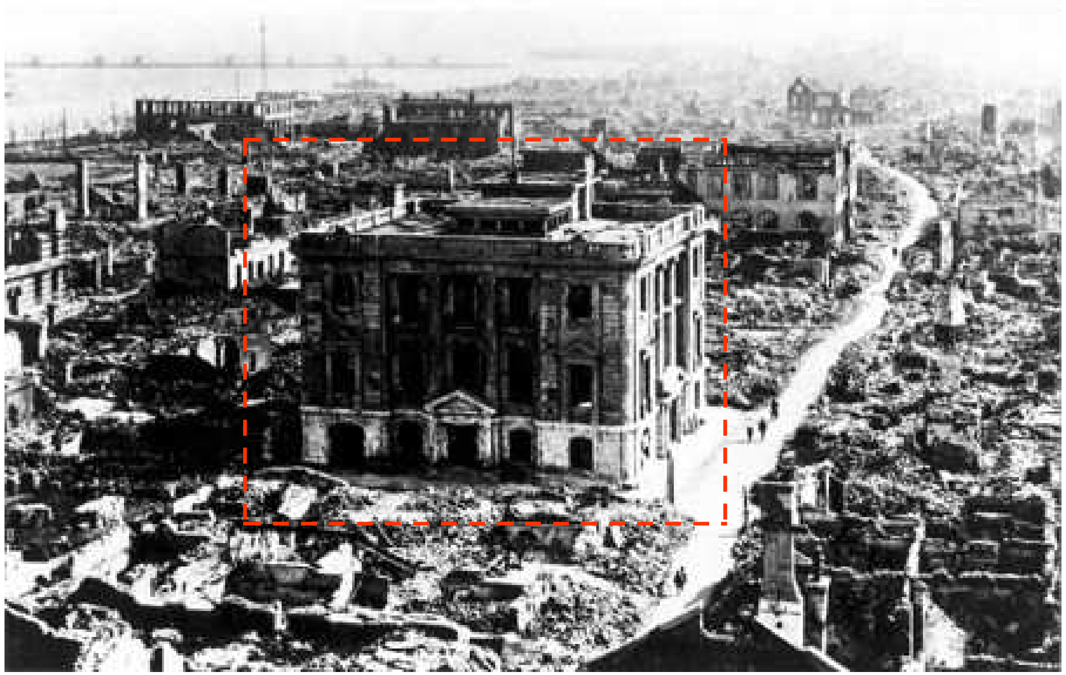
"…Dr. Baily Willis, geological engineer of Stanford University, says: 'Reinforced-concrete walls and reinforced-concrete filler wall in reinforced concrete frames exhibited the highest degree of resistance among structures tested by the Long Beach shock. Good brick laid in cement offers good resistance but is stronger if reinforced. Wood frames with wire or metal lath and good stucco gave the best satisfaction in light buildings'…"

Popular Mechanics, **July 1933**

Above L&R: The *Brayton Theatre* before (left) and after (right) the '33 quake

Long Beach Mar. 10 - 1933





"…Steel-skeleton skyscrapers escaped damage, probably due to the fact that such structures are elastic. When the earthquake jerks the sky-scraper's basement to the left, steel a few stories above is pulling the other way and absorbing part of the energy. As the wave climbs, it loses a little energy at each floor and actually is 'tired out' before it reaches the top. A thirty-story steel-frame building capable of withstanding wind pressure of thirty pounds per square foot at the top is considered by many experts to be safe against any shock that might be reasonably expected…"

***Popular Mechanics*, July 1933**

Left: caption: Building deformation due to ground movement"

Right: caption: "steel-framed building left standing in wake of the '33 earthquake"

The Three “Goods”

“…After careful study, technical men have concluded that good design, good workmanship and the proper use of good materials are the requirements for buildings that can be expected to resist earthquakes. Reinforcement with steel or metal laths is generally recommended…”

***Popular Mechanics,* July 1933**

A House Vibrated Cannot Stand

By the mid-1930s, earthquake tests became more sophisticated. Researchers at the USGS hauled portable “earthquake machines” to various buildings so that they could measure the “pitch” of a structure (the frequency at which it would collapse). This data not only helped them locate the weak areas of buildings, but it helped them understand how buildings behaved during an earthquake. Why did some buildings fail while others stayed upright? Generally, the better “tied-together” all elements were, the more likely it was that a building could/would stay up. One engineer suggested that taller structures be built with a diagonal bracing that could collapse during an earthquake, throwing the building out of sync with the tremors. Others recommended building the lower floors with elastic material, which would absorb the energy released by a quake. At any rate, the availability of new lightweight materials such as concrete made of pumice (instead of gravel) meant that engineers were better equipped to construct earthquake-resistant buildings.

A Miracle of Physics

"Looking like an oversize, three-wheeled grind-stone, a weird machine recently whirred atop bridges, dams, and office buildings of the West in a strange series of tests. Through its use, a crew of two or three men can cause a giant dam or a huge skyscraper to vibrate infinitesimally throughout its mass, showing exactly how it would act under stress and shock…"

***Popular Mechanics,* May 1935**

Left: caption: "Experts of the U.S. Coast and Geodetic Survey using the vibrator which finds the vibrating pitch of buildings"

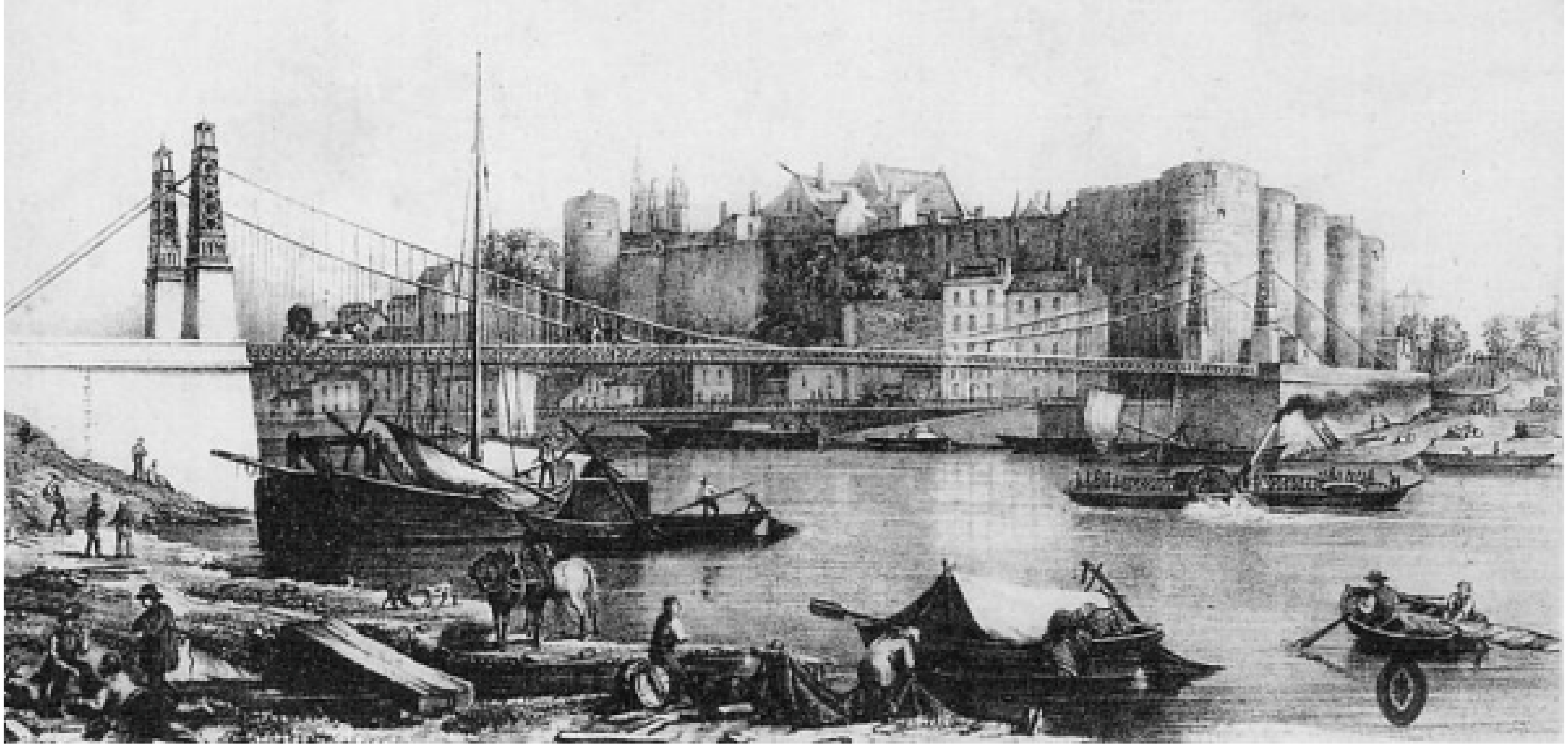
“…Just how a machine no larger than a light roadster can sway a giant mass of steel and concrete, is a miracle of physics. Army leaders long have known that a company of soldiers should break step when crossing a bridge. If the tread of marching feet should fall in tune with the structure’s natural ‘pitch,’ powerful vibrations would be set up that might cause the bridge literally to tear itself to pieces. That principle, used in miniature, forms the basis of the ‘earthquake machine’…”

Popular Mechanics, **May 1935**

Resonance Disaster

Mechanical Resonance **is the tendency of a mechanical system to respond at greater amplitude when the frequency of its oscillations matches the system's natural frequency of vibration (its *Resonance Frequency* or *Resonant Frequency*) than it does at other frequencies. It may cause violent swaying motions and even catastrophic failure in improperly constructed structures including bridges, buildings and/or airplanes. This phenomenon is known as "Resonance Disaster." Avoiding resonance disasters is a major concern in every building, tower and bridge construction project. Buildings in seismic zones are often constructed to take into account the oscillating frequencies of expected ground motion. Many resonant objects have more than one resonance frequency; it will vibrate easily at those frequencies and less so at others. Many clocks keep time by mechanical resonance in a balance wheel, pendulum or quartz crystal.**

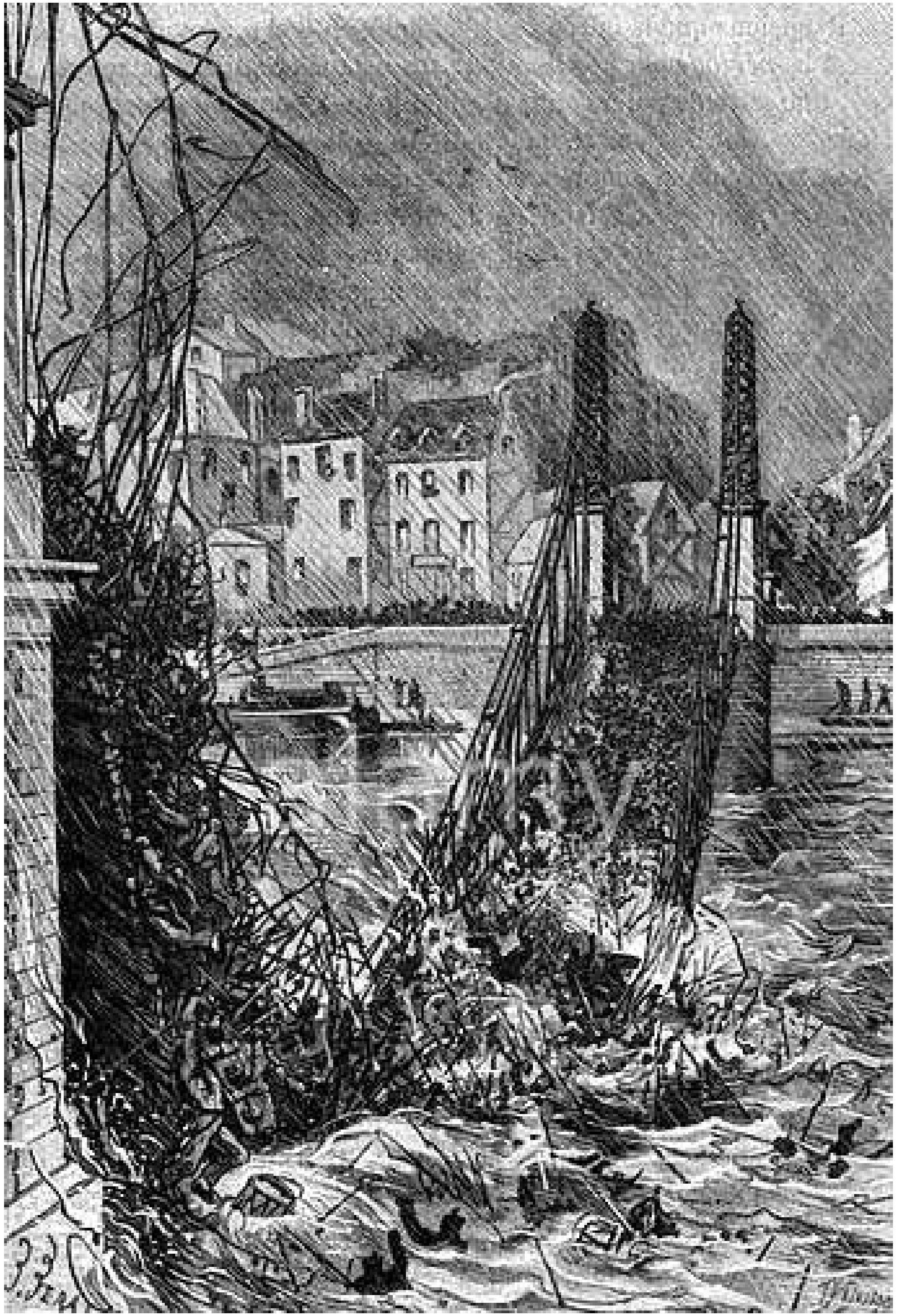
On November 7th, 1940, the *Tacoma Narrows Bridge* collapsed due to *wind induced resonance*. In this case, the resonance (identical frequency) was caused by strong wind gusts blowing across the bridge, creating regions of high and low pressure above and below the bridge. This produced violent oscillations, or waves, in the bridge; tensing or relaxing the supporting cables (which acted much like rubber bands) and increasing the intensity of the waves in the bridge deck, causing the deck to be moved up and down violently, leading to its catastrophic collapse.



The *Basse-Chaine Suspension Bridge* (above) over the *River Maine* in Angers, France, was completed on July 16th 1839. Its 335-foot span served pedestrians and wagons well. The bridge had been built by two of the most experienced contractors in France who had conscientiously adhered to all the rules then known of the art/science of suspension bridge-building. Today, we would call it "state-of-the-art" bridge engineering. In the early 19th Century, France was the acknowledged world leader in suspension bridge design and construction.

<u>Above</u>: caption: "Collapse of the Basse-Chaine Suspension Bridge over the River Maine in Angers." Suspension bridges were known to oscillate in the wind and failures were not unknown, but on April 16th 1850, the unthinkable happened. It was a stormy day and the bridge was oscillating. This would not have been regarded as unusual as 478 marching soldiers approached the bridge. As they crossed, an anchorage tore loose and the deck disappeared beneath their feet; 226 soldiers fell to their deaths. It was the deadliest bridge collapse in history.

An inquiry was launched immediately; its initial findings were disturbing. The bridge had been designed according to the best and most well-proven theories of the day, constructed to the highest standards and there had been no visible signs of weakness before the collapse. Cables carrying the weight of a suspension bridge must be anchored firmly. At the time, there were two methods for building suspension bridges. The British used massive eye-bar chains made of heavy plate-iron links. Each bridge was held firm by these giant iron links, which were secured in deep underground anchorages. By contrast, the French and Swiss pioneered a method of supporting suspension bridges with wire strands or cables, based on the work of engineer *Louis Joseph Vicat*. The wire cables were split into strands beneath the ground and grouted in place in the anchorages with hydraulic lime mortar. In theory, the mortar would protect the strands from water, rust (oxidation) and any subsequent loss of strength. This had been the approved and near-universal method of building suspension bridges in France. However, there was no way to inspect the anchored-ends of the cables. It turned out that the hidden mortar did not always cling securely to the cable and water leakage was a problem. The cables were rusting and the mortar was failing, weakening the entire structure. The harmonic vibrations set-up by the troops marching in lock-step cadence across the bridge that fateful day had triggered the failure of the anchorage.



“Oxidation did not originate in a structural error particular only to the Basse Chaine Bridge, but rather to a structural fault in the system itself, so that it is to be feared that the same result will occur wherever it has been applied”

Commission of Inquiry

Left: caption: “Angers Bridge collapse, France, 16.4.1850, wood engraving” Beginning in 1831, hundreds of suspension bridges had been built using a system now shown to be dangerously flawed. Immediately, all suspension bridges were suspect. The inquiry’s findings led to an immediate halt to the construction of further French suspension bridges. During the next twenty years, there was an official moratorium on suspension bridge construction in France and many existing bridges were demolished. The moratorium was finally lifted in May 1870 by a French government decree. By this time, the French lead in iron cable suspension bridges had passed to North America, primarily through the work of a German immigrant, *John A. Roebling.*

Built in 1837 and named for a French military victory in Algeria that same year, the *Pont de Constantine* was impressive for its time. It linked the Ile St-Louis and the Quai St-Bernard on the left bank of Paris. The main span of 333-feet was complemented by two smaller spans of 85-feet. With a width of just under 10-feet, it was a *passerelle* (pedestrian bridge). In November 1850 (in the wake of the *Basse Chaine Bridge* dis-aster), it was reported that a commission of engineers had examined the bridge and recommended that the cables and deck be "tested to insure solidity." Eventually, it was demolished and replaced by a fixed (arch) bridge in 1863. Today, not one of the many 19th Century suspension bridges over the *Seine River* in Paris remains.

"…Three rotating steel disks, each having a variable weight attached to its circumference, create artificial earthquakes which thrill through the structure under test to betray its natural period of vibration. As the off-balance wheels gradually come to rest after being spun at high speed, they produce back-and-forth impulses slowly dropping from twelve a second, to zero. When they happen to strike the natural 'pitch' of the structure, strong pulses are built up, which in turn are detected by a recorder attached to the building. This recorder is really a little seismograph in which a needle beam of light stabs a moving photographic film to make a complete record of vibration…"

***Popular Mechanics,* May 1935**

<u>Left</u>: caption: "Another view of the earthquake machine, showing the motor that drives the off-balance wheels to set up small vibrations in buildings"

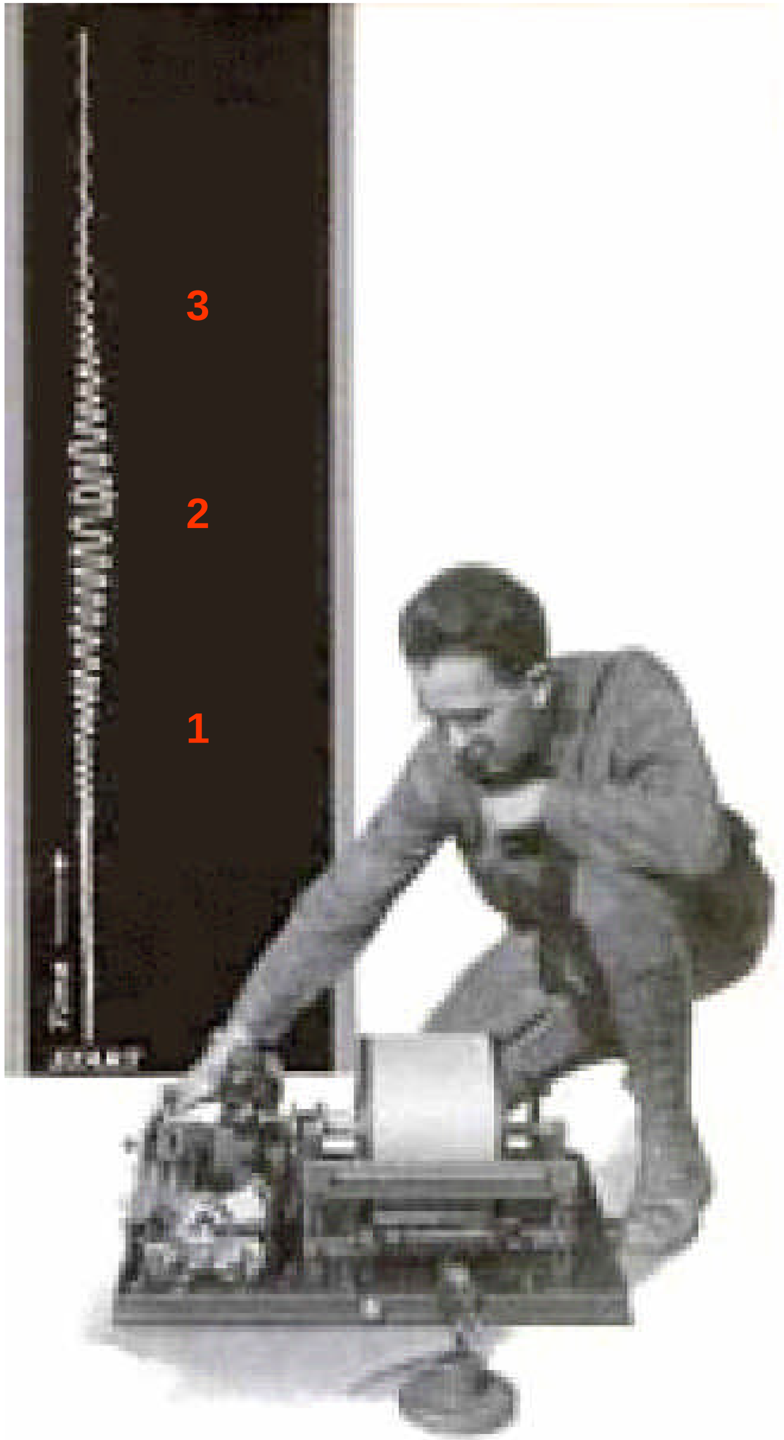
"…Knowing the pitch of a building is important to engineers and architects because it enables them to estimate a structure's ability to resist the shock of earthquakes or cyclones and sudden bursts of wind. To get this information, experts of the United States Coast and Geodetic Survey for months carried portable instruments to various large buildings in the west and made records of their natural movements…"

Popular Mechanics, **May 1935**

Like Trees in the Wind

“…Setting up sensitive recorders like small seismographs, they found that every large structure is constantly in motion. Wind pressure and the jar of passing traffic cause tall office buildings to vibrate and sway like trees in the wind. Of course, the movement is very slight – perhaps only a few ten thousandths of an inch at the top of a tall building; but it is enough to register upon delicate instruments…”

***Popular Mechanics,* May 1935**



“…That fact made it possible to measure the pitch of the structures, for analysis of the minute ripples traced upon sensitive photographic film always showed a predominant wave, the natural frequency…”

Popular Mechanics, **May 1935**

Left: caption: “When the impulses produced by the earthquake machine strike the natural pitch of the building, the strong vibrations resulting are recorded as in the strip at left:

1) As speed of wheel is decreased the vibrations become slower;

2) Intense sympathetic vibrations as the machine strikes the natural ‘period’ or ‘pitch’ of the building;

3) Dies down as natural period is passed and vibrations fall out of step with the structure.

Below, the recording instrument, resembling a seismograph.”

“…More than 140 buildings, thirty large tanks, and dozens of bridges, dams, and piers thus gave their records to science, and the Survey man in charge of the work hopes to add 500 more to the list before the end of the year…”

***Popular Mechanics,* May 1935**

“…In correlating their results, experts soon found a better way than merely to depend upon the chance impulses of wind and traffic. Why not create small artificial earthquakes that would search out the natural pitch, setting up spontaneous vibrations that would probe more deeply into these mysteries? That is what the three-wheeled vibrator does…”

Popular Mechanics, **May 1935**

"…The work will be further aided by a new instrument which makes records on four floors of a building at once. By keeping one instrument in place as a key recorder, and testing the other floors, three at a time, scientists will learn exactly what takes place at each floor, and locate the zones of weakness…"

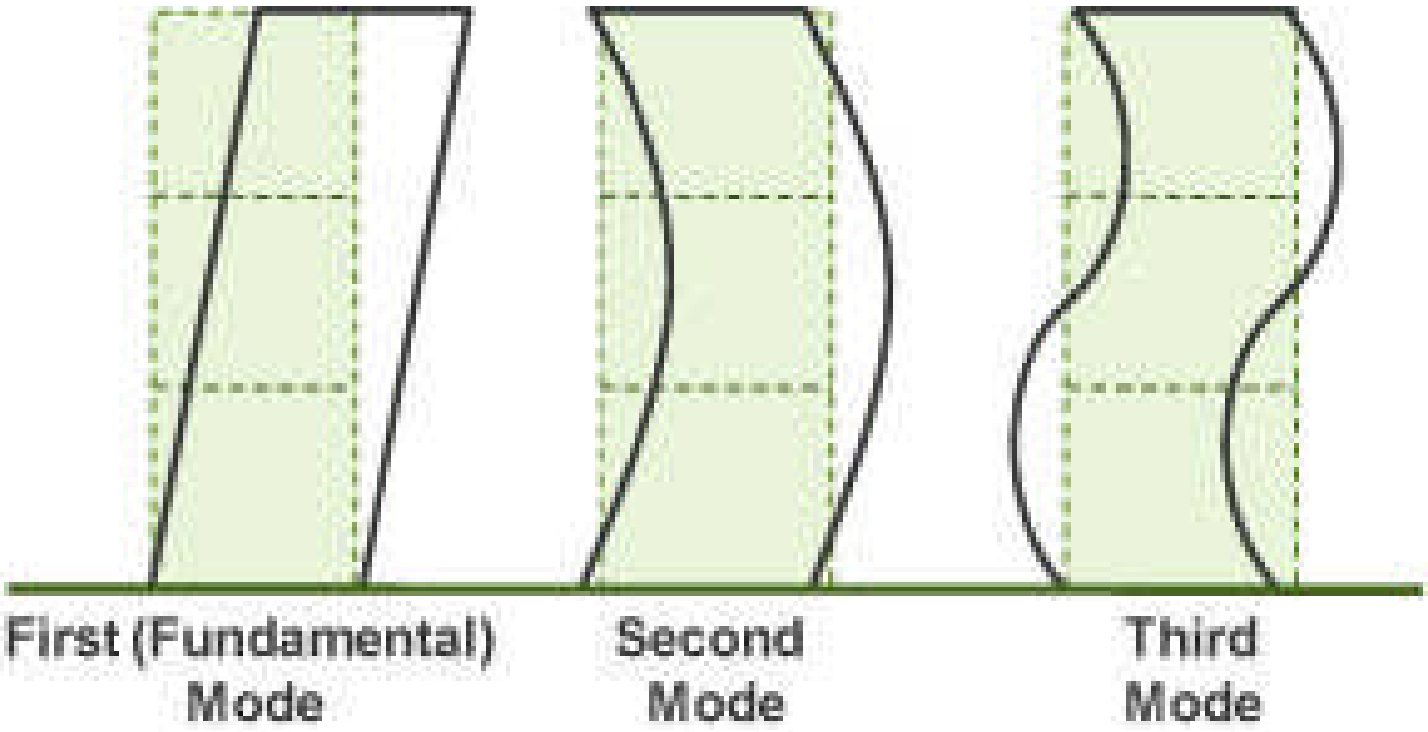
***Popular Mechanics*, May 1935**

Most Feared

“…Earthquakes usually have a predominant frequency that is most to be feared. For example, Japanese scientists found that the quakes which shook their island had an average period between three-tenths and four-tenths of a second on rock. If a building can be ‘tuned’ to some remote pitch, it will respond but feebly, if at all, to earth shocks…”

***Popular Mechanics,* May 1935**

RE: the natural period of a building is related to its mass and stiffness, which is in turn related to height, construction type, layout and lateral-force resisting system (among other characteristics). These attributes determine the pattern of inertial force generated within the elastic building, which strains its structural components and causes it to move in response to the force generated by the ground movement. When the building is set in motion, these forces can combine with each other or cancel each other out, depending on their respective frequency and phase. If the ground motion is rich in waves of a period close to the natural period of the building, the building response can become amplified, resulting in larger deformation and therefore greater damage. In other words, different buildings with differing natural periods will respond differently to the same ground motion.

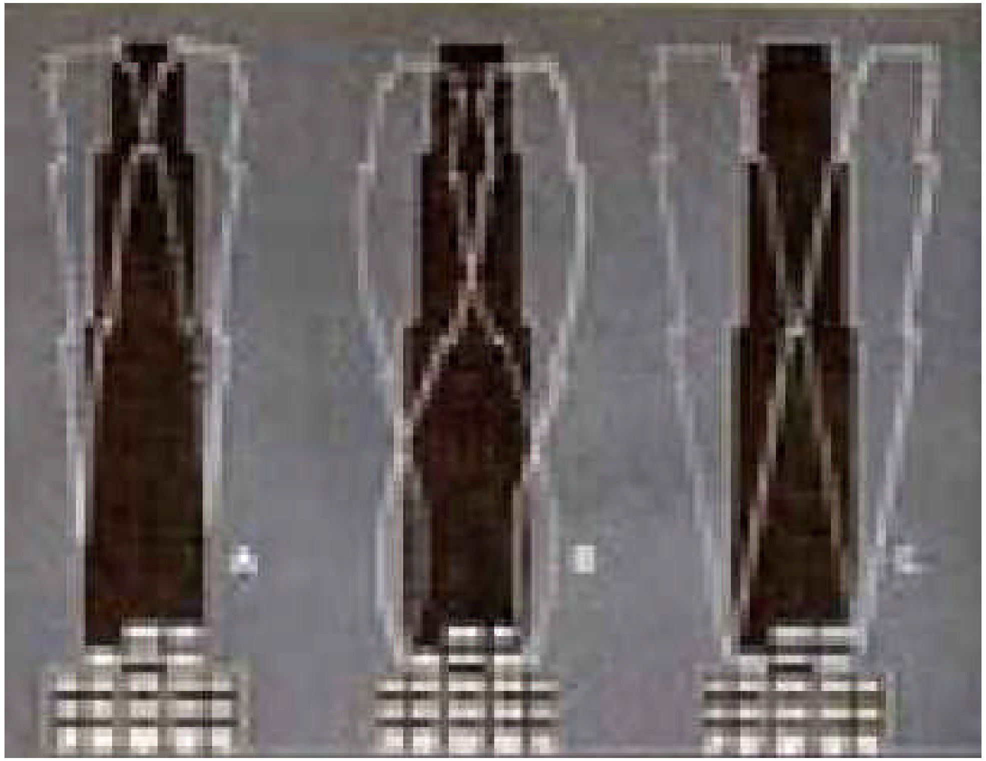


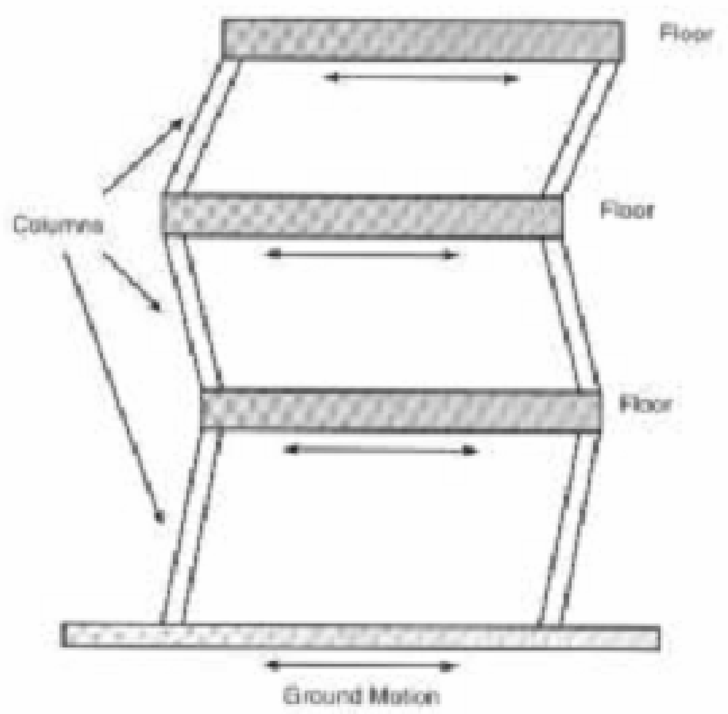
Above: caption: “The first three modes of vibration.” Ground motion causes a building to oscillate in a manner that depends both on the characteristics of the incoming seismic waves (such as amplitude, frequency, and time of arrival) and on the configuration and natural period of the building itself (the time it takes for the building to complete a single cycle of oscillation in free vibration). A building modeled as an elastic system in free vibration can adopt a number of shapes, or modes. Earthquake ground motions usually cause buildings to vibrate primarily in their fundamental mode, but for certain building types, such as tall and flexible ones, higher modes are also important.

A Great Laboratory

“…Experts at the U.S. Coast and Geodetic Survey have converted the whole state of California into a great laboratory where the principles of construction are being studied in an effort to answer many questions now puzzling science. How does a building behave when it is racked by an earthquake? Does it vibrate stiffly, like a rod, or sinuously, like a snake? Do the floors tilt, or remain level? Does a granite foundation help?...”

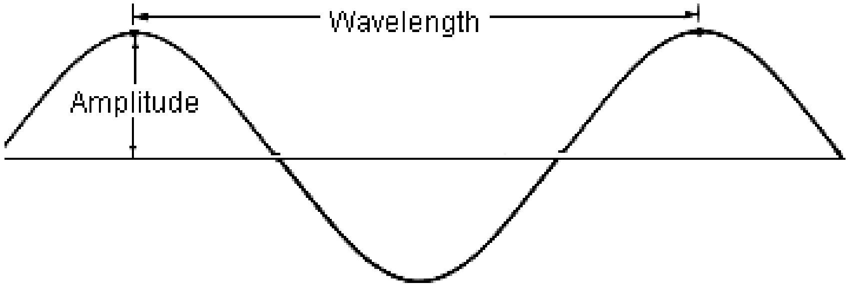
Popular Mechanics, **May 1935**





<u>Left</u>: caption: “How does a building behave when it is rocked by an earthquake? Does it vibrate stiffly, like a rod (A), or sinuously, like a snake (B)? Or does it sway, with the floors remaining level (C)? Science is now seeking the answer.”

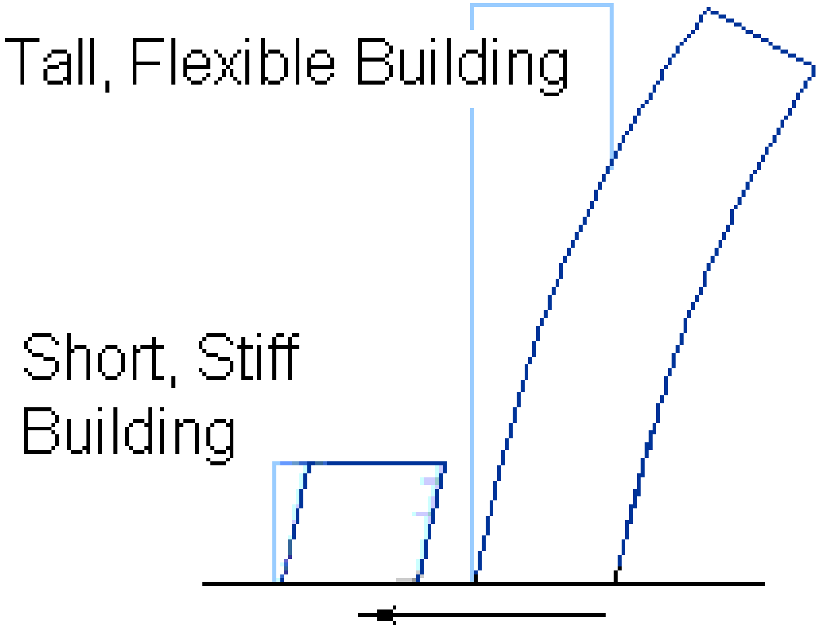
<u>Right</u>: caption: “Simple vibration model of a building subjected to ground motion. The natural frequencies of vibration of a structure are the frequencies at which the structure ‘likes’ to oscillate. If the ground moves at a building’s natural frequency, it will tend to oscillate strongly and possibly collapse. Thus, a building should never be exposed to ground movement at any of its natural frequencies.”



"…So far, engineers have learned that the higher a building is, the more slowly it vibrates; that its pitch also decreases with its width and stiffness; and that a building that is well tied together so as to move as a unit, best resists injury…"

***Popular Mechanics,* May 1935**

RE: the most important characteristics of earthquake ground motions for buildings are the duration, amplitude (of displacement, velocity and acceleration) and frequency of the ground motion. Frequency is the number of complete cycles of vibration made by the wave per second. A complete vibration can be considered to be the same as the distance between one crest of the wave and the next, or one full wavelength (above). Frequency is often measured in units called *Hertz*. If two full waves pass in one second, the frequency is 2 hertz (2 Hz). Response of the building to ground motion is as complicated as the ground motion itself, yet typically quite different. It also begins to vibrate in a complex manner and, because it is now a vibratory system, it also possesses a frequency content. However, the building's vibrations tend to center around one particular frequency, which is known as its *natural* or *fundamental frequency*. Thus, the shorter a building is, the higher its natural frequency. The taller the building is, the lower its natural frequency.



The building period is the inverse of its frequency:

- **The frequency is the number of times per second that the building will vibrate back and forth;**
- **The period is the time it takes for the building to make one complete vibration. The relationship between frequency (f) and the period (T) can be expressed as the formula:**

$$T = 1 / f$$

Thus, a short building with a high natural frequency also has short natural period. A very tall building with a low frequency has a long period. For example, it takes the *Empire State Building* a comparatively long time to sway back and forth during a strong gust of wind.

“…Out of the welter of wreckage left by the disastrous earthquake of March, 1933, have come facts that will be of direct aid to engineers everywhere in planning new buildings; for many of the principles of good construction apply equally well to safeguarding structures against storms. Strangely, it was not the tall buildings that suffered most, but those from one to three stories high. Frame houses were but slightly damaged, possibly because of their flexibility…”

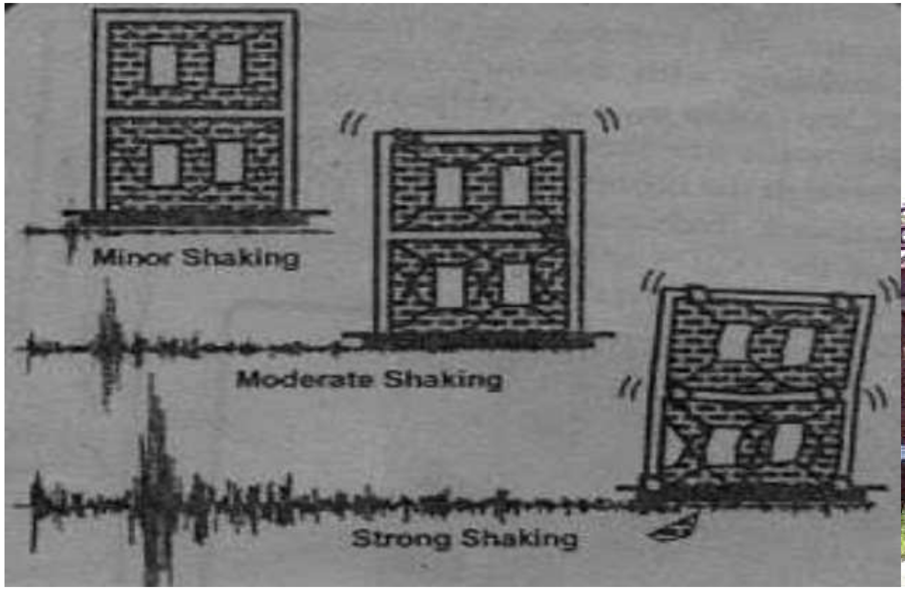
***Popular Mechanics,* May 1935**

"…In addition to its sidewise, lunging thrust, the big earthquake had two major vertical movements – one a slow rise and fall to the ground, the other a very rapid up-and-down tremor. Probably the fast tremors crumbled the mortar between bricks of buildings and made them easy prey for the later shocks…"

***Popular Mechanics,* May 1935**

<u>Above</u>: caption: "Long Beach Upholstery, private apartments, and Lincoln Dry Cleaners on E. 4th Street, Long Beach. This kind of damage is typical of that sustained by un-reinforced masonry buildings, and shows the hazard of falling debris around such buildings."

On the Other Hand…

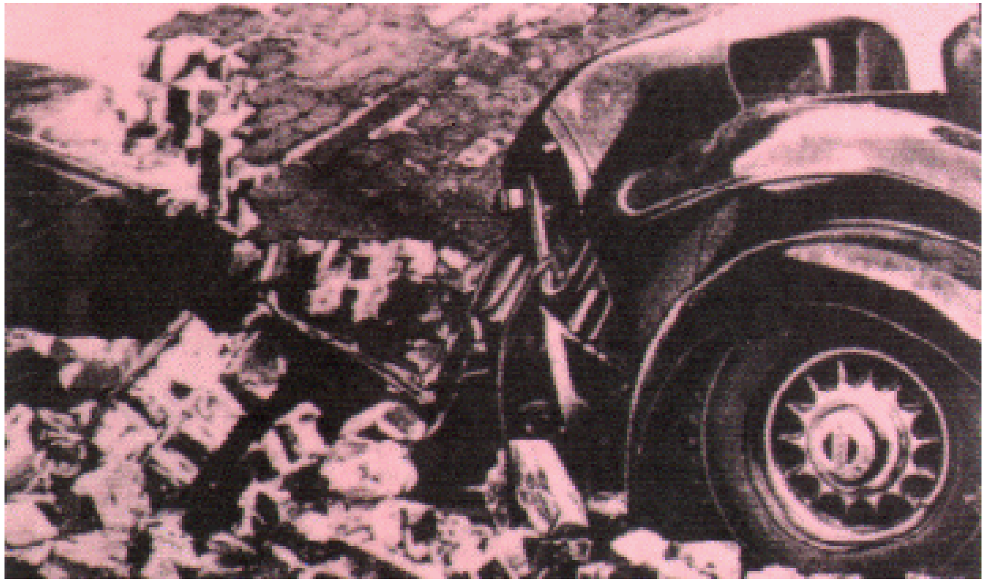


“…On the other hand, properly designed brick buildings came through without great damage. Brick construction has been approved as a safe method of building, provided it is properly tied together. One brick building survived a very bad earthquake because discarded cables from an old mine had been embedded in the mortar joints to lend strength. The same principle is being applied in modern reinforced brick construction…”

Popular Mechanics, **May 1935**

<u>Left</u>: caption: “Grid of reinforcement can be built into each masonry element without the requirement of any extra shuttering and it reduces the scope of corrosion of the reinforcement. As the reinforcement bars in both vertical and horizontal directions can be continued into the roof slab and lateral walls respectively, the structural integrity in all three dimensions is achieved.”

<u>Right</u>: caption: “Experimental study of reinforced concrete frame in-filled with masonry wall was conducted under Indonesian Earthquake Study, 1981”



"…Many lives were lost simply because unnecessary parapets, decorated corners, projecting cornices, and superfluous ornamentation came crashing down into streets with fatal effect…"

***Popular Mechanics*, May 1935**

A Bright Idea

“…Safeguarding against severe stresses now is possible through concrete, made with pumice instead of gravel, to reduce dead weight sharply; and through lightweight materials in the framework to make structures more flexible and lighter. Use of such materials, plus proper bracing in the frame, may produce structures with a vibration wave safely out of range of shocks…”

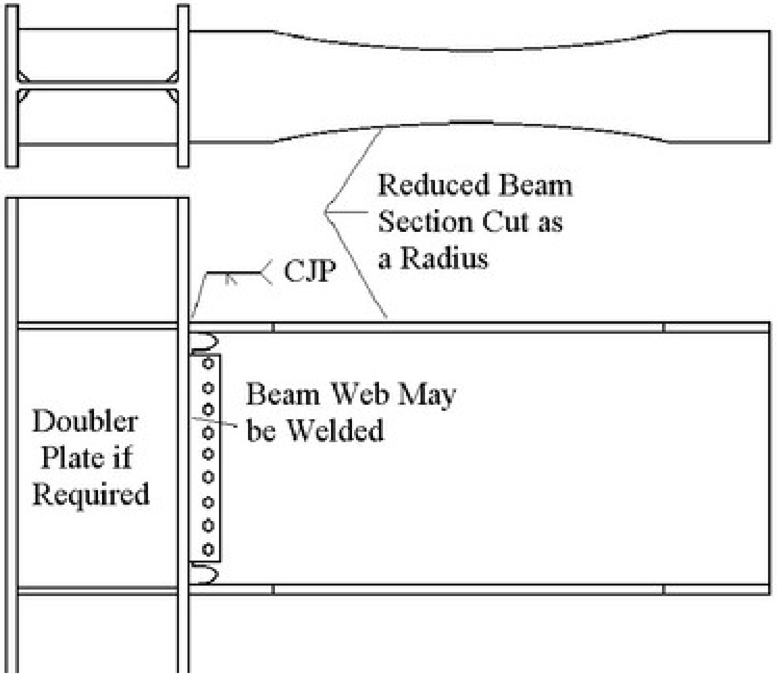
***Popular Mechanics,* May 1935**

"…One expert has suggested that tall buildings be made with diagonal bracing much weaker than that of the framework. If a severe earth shock came, it would break this bracing, throwing the building entirely out of tune with the tremors…"

***Popular Mechanics,* May 1935**

<u>Top Left & Above</u>: caption: "I-shaped beam with dogbone connection to column"

<u>Bottom Left</u>: caption: "Ductile behavior of steel moment frame structures can be achieved using Reduced Beam Section (a/k/a 'dogbone' connection). The dogbone connection consists of trimming a portion of the steel beam flange in the region adjacent to the beam-to-column connection; this type of connection acts as a ductile fuse, and it forces yielding to occur within the reduced section of the beam."



“…Another authority recommends that engineers make the first floors of large buildings more ‘elastic,’ allowing easy relative motion between the structure and the ground – a sort of buffer floor to absorb the shock of quakes. Others recommend greater protection against lateral forces…”

***Popular Mechanics,* May 1935**

Far Greater

"…If the weaknesses in building construction are corrected, the structures will be much safer for the occupants. One new plan for a business block calls for shatterproof windows and reinforced concrete construction with encircling beams like barrel hoops to make the whole building a unit. Another structure, the Edison Building in Los Angeles, has been designed to withstand a horizontal force equal to one-tenth the total dead weight of the building. This amounts to a sidewise thrust of more than 8,000,000 pounds at the first-floor line. Both riveting and welding strengthen the frame, and the structure will withstand forces far greater than those of past earthquakes."

Popular Mechanics, **May 1935**

<u>Above L&R</u>: caption: "Southern California Edison Building under construction"

Until Recently

"…Until recently, skyscrapers were prohibited in earthquake-prone areas like California and Japan because it was thought that tall buildings could not be made safe from quake damage. Buildings were restricted to 13 stories in Los Angeles, for instance, and even less in Japan. Today, restrictions on building height are being lifted, and modern skyscrapers are shooting up all over California and Japan…"

***Popular Mechanics,* June 1967**

<u>Left</u>: caption: "Southern California Edison Building"

"…The tallest of the new structures boast 40 stories or more, with promises of 50-story giants to come. Structurally, say experts, there's no reason buildings can't go to 100 stories or more…At the moment, the practical limit is thought to be around 50-stories. Tall buildings actually give more in a strong wind than during an earthquake…A 30-story building may sway as much as 10 or 12 inches during a strong wind gust…"

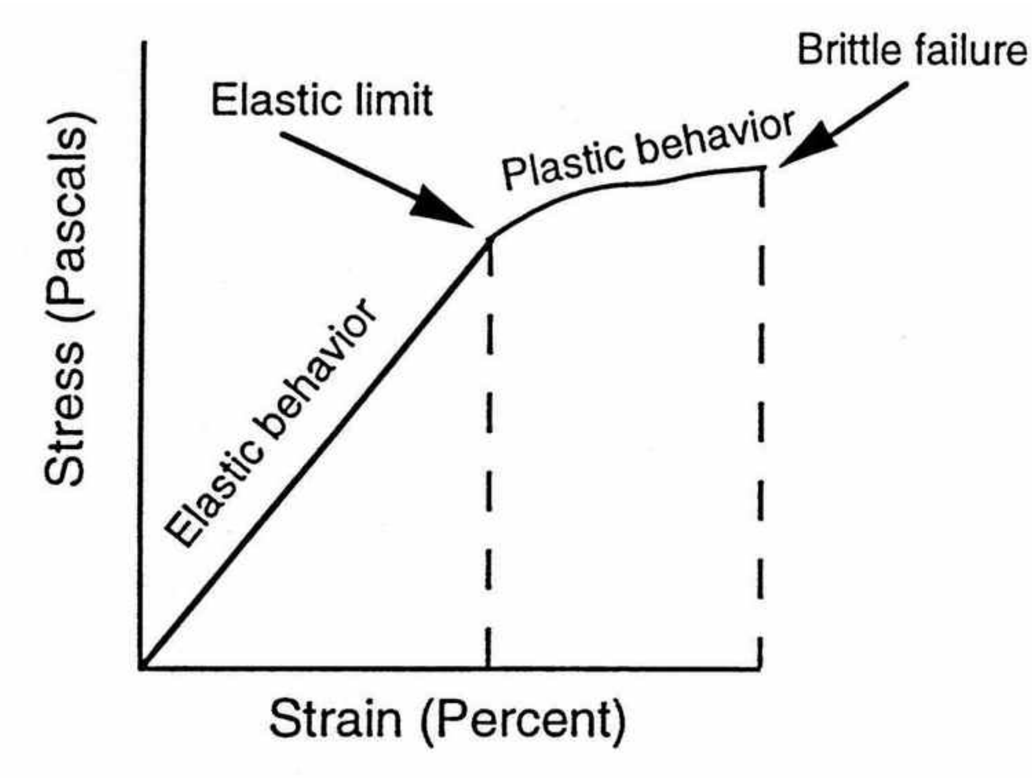
***Popular Mechanics,* June 1967**

Left: caption: "The 36-story Kasumigaseki Building - Tokyo's first skyscraper, opened its doors in 1968." Strict regulations had prohibited tall buildings due to the ever-present danger of earthquakes. The building is widely regarded as the first modern office building skyscraper in post-WWII Japan. Japan's *Building Standard Law* set an absolute height limit of 31-meters (102-feet) until 1963.

Elastic vs. Plastic

“…One of the newest approaches to the design of earthquake-proof high-rise buildings is called ‘plastic’ design – an improved technique that takes advantage of the reserve strength of steel beyond its yield point. Structural engineers used to design beams and columns so that stresses were kept below specified limits in the elastic range of the material. But, beyond the elastic range, steel has a substantial reserve capacity, and the new knowledge of this reserve strength is used in high-rise designs…”

***Popular Mechanics*, June 1967**



Left: caption: "Material properties of steel. When subjected to moderate stresses, the strain is proportional to stress, and the steel deforms elastically. At higher stresses, where the elastic limit is exceeded, the steel deforms plastically (ductile behavior). At even higher stresses, the yield strength is exceeded, and the steel breaks by brittle failure."

"…Much of the research in the plastic design field has come from Lehigh University in Pennsylvania. It was applied originally to steel-frame one and two-story buildings, but now the lessons are being applied to taller structures. At the same time, newer knowledge of metals has enabled engineers to use steel in ways that simply were not possible before World War II. As a result, plastic design structures up to 20 or 30 stories high are in the offing, with no sacrifice of safety."

***Popular Mechanics,* June 1967**

<u>Above</u>: caption: "Preparing to test steel beam connection rotation capacity. Structural Behavior Laboratory, Lehigh University"

Part 6

The Jesuit Science

A Year to Remember

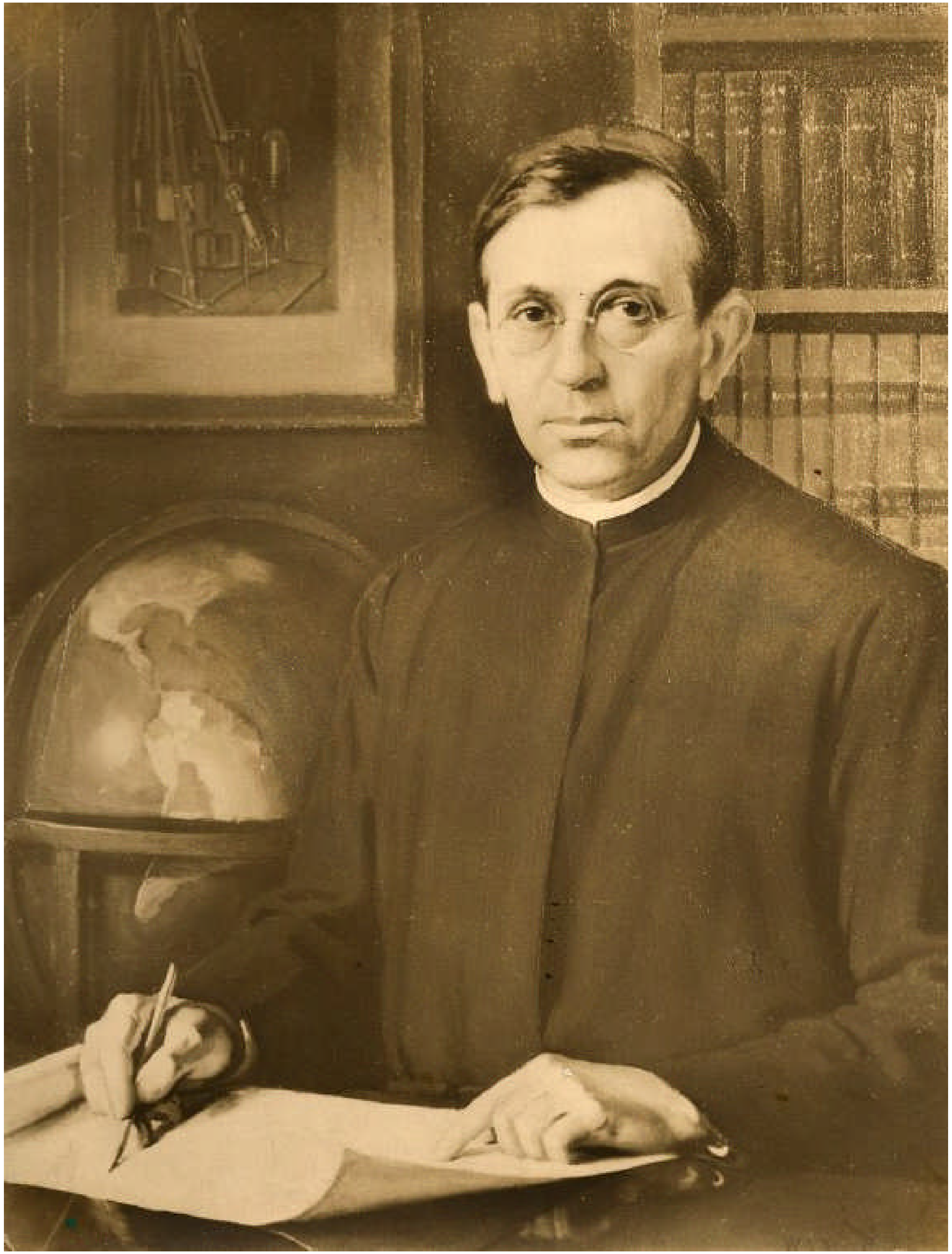
"…The year 1925 was notable for a number of fairly strong shocks in the United States and Canada, as well as another destructive quake in Japan, and out of that year's activities grew the present earthquake survey being made by the Carnegie Institution, the Coast and Geodetic Survey and the Engineering-Economic Foundation. The same year saw earthquake insurance established in the United States with the Woolworth building insured for $5,000,000…"

***Popular Mechanics*, June 1928**

<u>Left</u>: caption: "Woolworth Building"

“…The survey has been carried out mainly in California, with both state and federal governments cooperating. Another survey has been started in the Mississippi valley, where Dr. James B. McElwane, S.J., president of the Seismological Association of America, has opened a new recording station at Florisant, Mo., near the New Madrid ‘fault’…”

***Popular Mechanics,* June 1928**



“…The Jesuit fathers are the most numerous earthquake observers in the United States, and probably in the world. Their universities have seismographs scattered all over the country, with the center of activity in Washington, where Father Tondorf, of Georgetown University, is usually the first to announce each successive quake…”

Popular Mechanics, **June 1928**

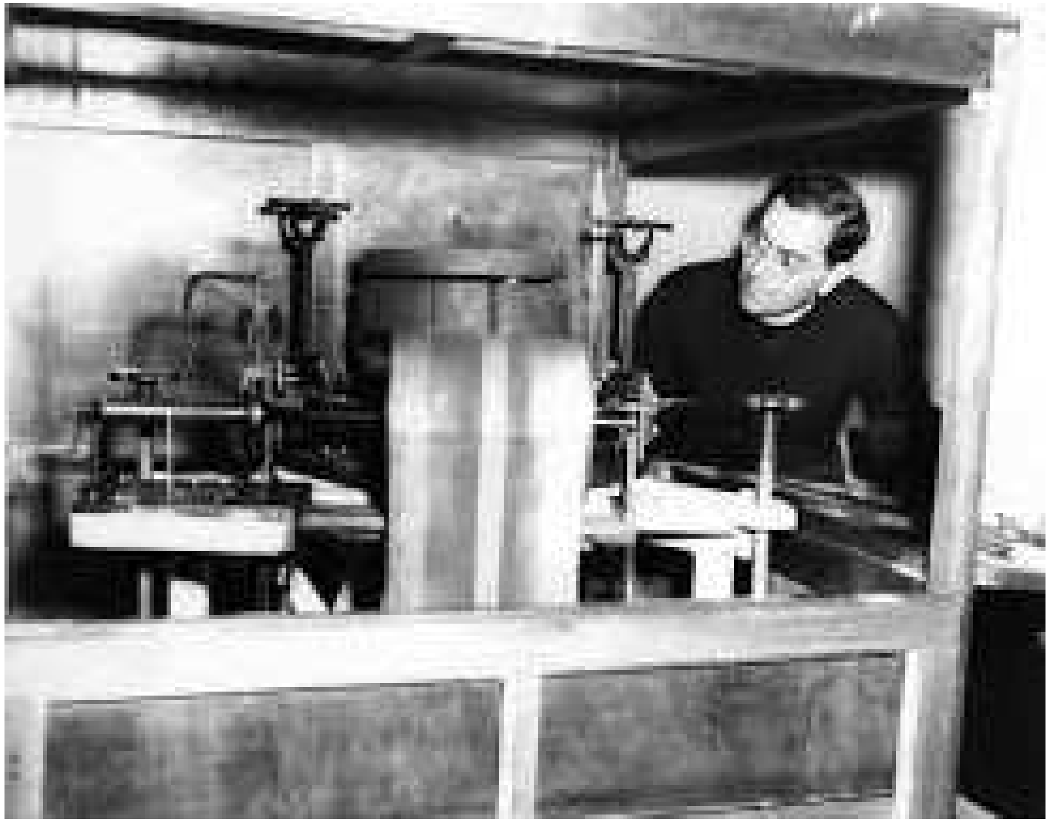
RE: *Seismology* – the science that studies earthquakes, their cause/s and the propagation of seismic waves in the interior of the earth has held a special interest among Jesuit scientists since the 16th Century. So much so, it has been called “The Jesuit Science.”

<u>Left</u>: caption: “Reverend Francis A. Tondorf S.J.”

GEO

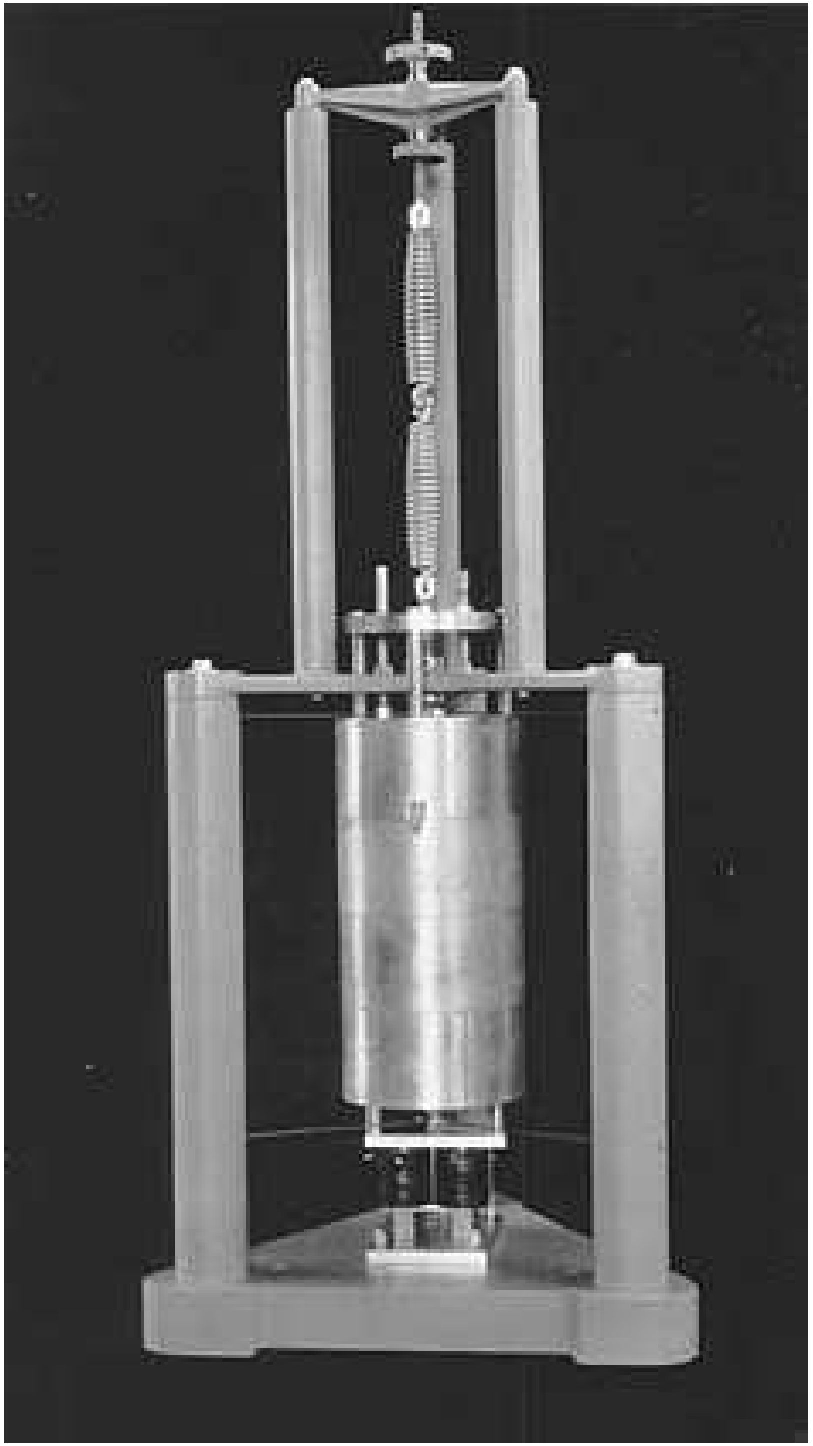
“Georgetown (GEO) is the name used by seismologists to designate the Seismological Observatory at Georgetown University. Six seismographs now operate continually day and night in the vault beneath the College quadrangle. Set on piers imbedded in the Hilltop rock, these instruments are ready at any moment to record earth vibrations caused by distant earthquakes…”

Georgetown University Alumni Magazine, **March 1959**



"…The photographic records are processed twice daily at 7 a.m. and 7 p.m., E.S.T., and register major earthquakes occurring in any part of the world. Because the liquid core of the earth hampers the transmission of earthquake vibrations from the far side of the globe, the best-registered earthquakes occur in this hemisphere…"

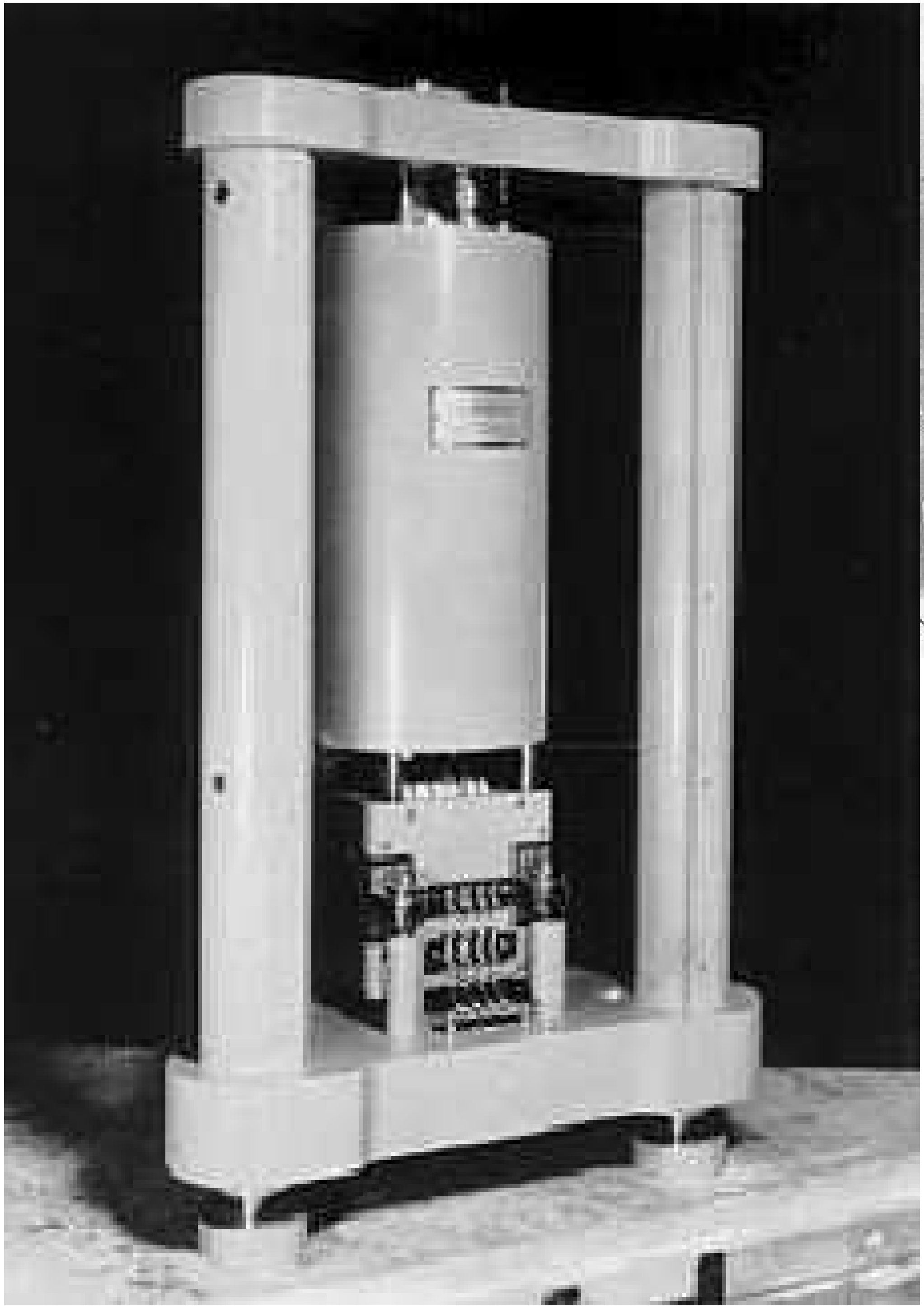
***Georgetown University Alumni Magazine,* March 1959**

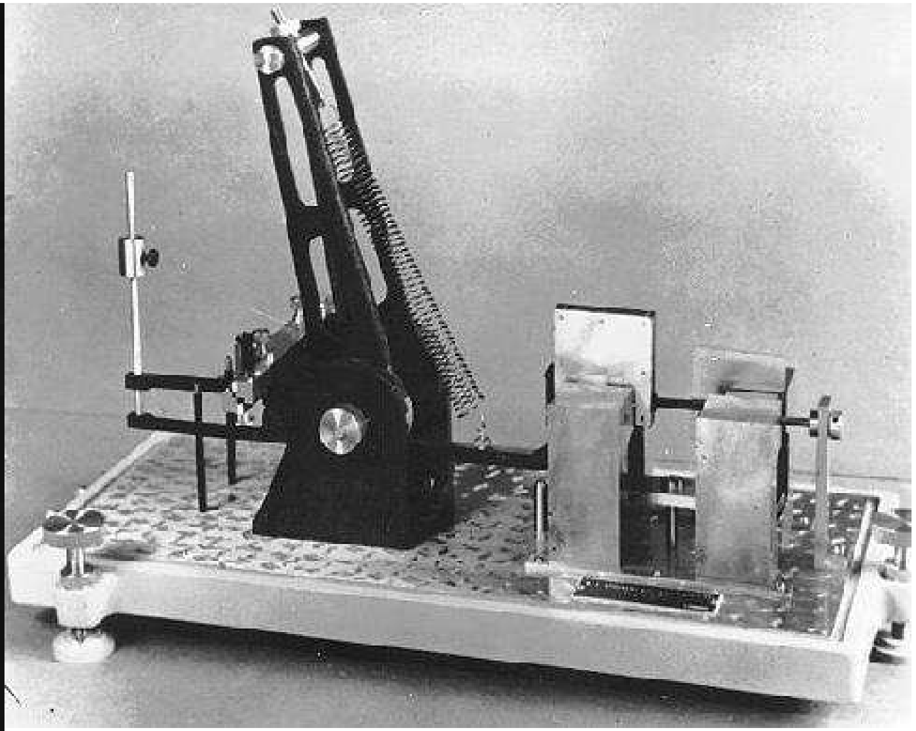


"…With a modern short-period vertical seismograph, purchased last year, a minor earthquake is recorded about every fourth day somewhere within 6,000 miles of Georgetown. The arrival time of the very first wave together with other identifying phases is reported immediately to the Preliminary Determination of Epicenter Office of the United States Coast and Geodetic Survey here in Washington…"

Georgetown University Alumni Magazine, **March 1959**

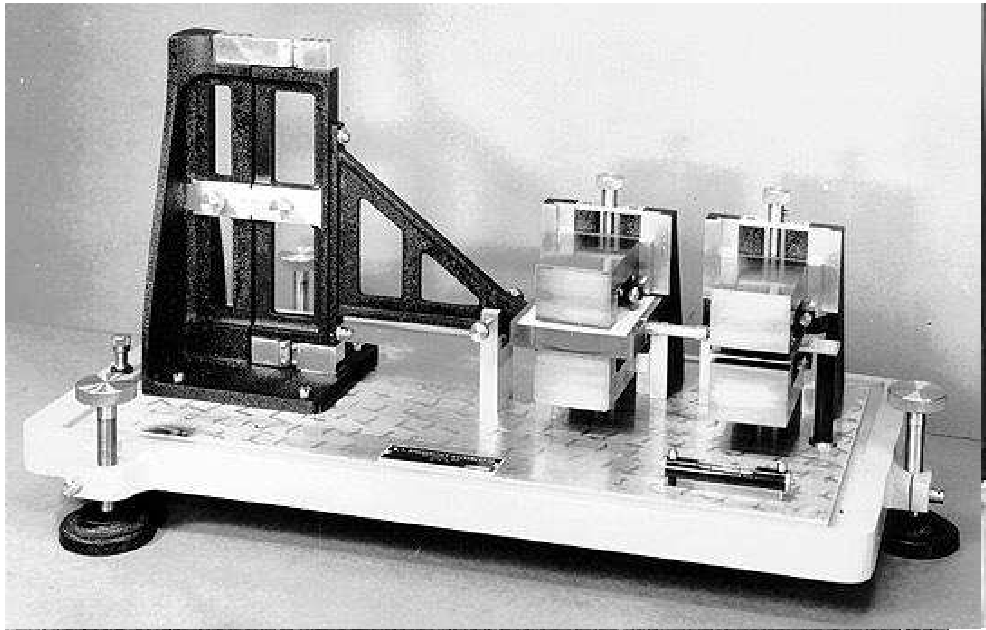
Left: caption: "The Benioff vertical component sesimometer. A variable reluctance instrument electromagnetically damped."

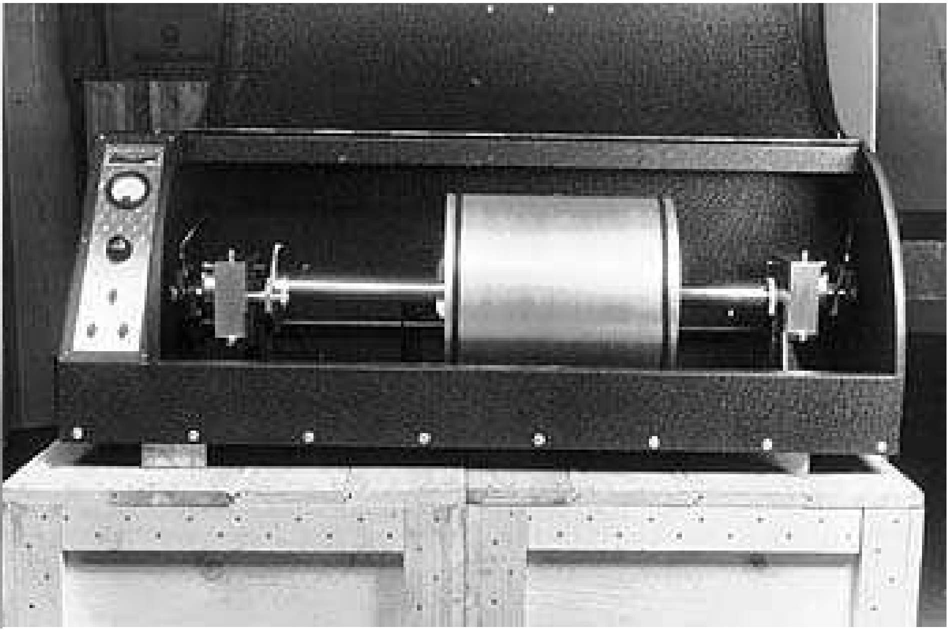


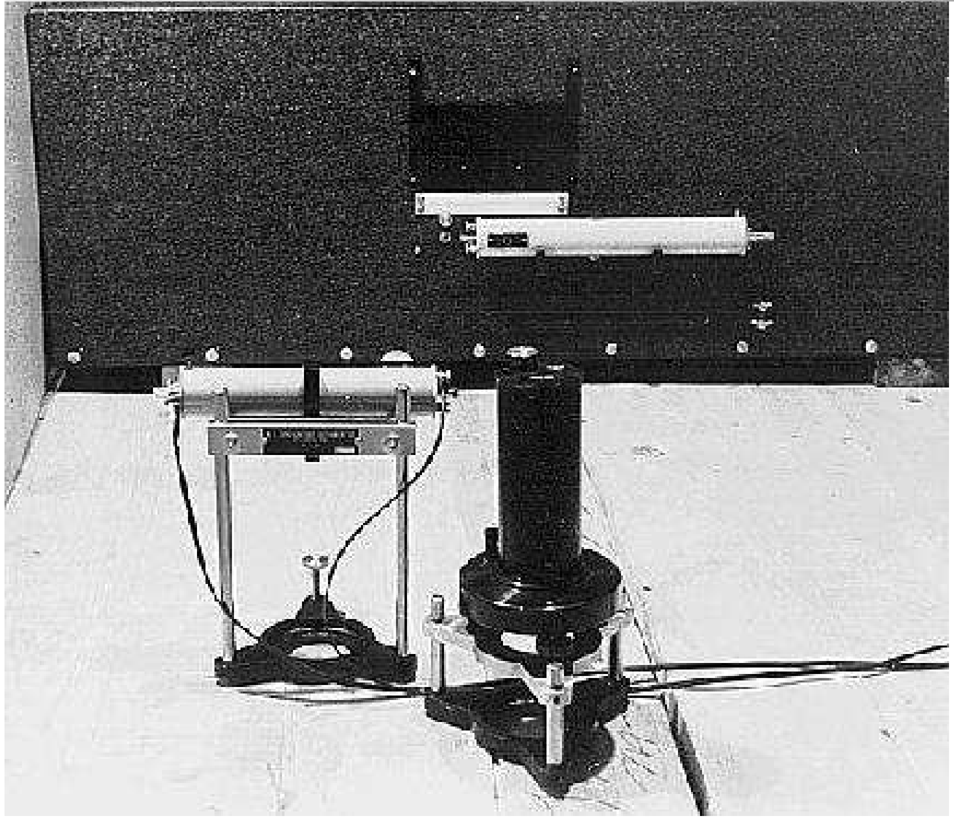


<u>Above</u>: caption: "Sprengneter vertical component seismometer with electromagnetic recording and damping"

<u>Left</u>: caption: "An early prototype of a Benioff vertical component seismometer"







<u>Top Left</u>: caption: “Sprengnether horizontal component seismometer with electromagnetic recording and damping”

<u>Top Right</u>: caption: “Sprengnether Instrument Company recording drum”

<u>Left</u>: caption: “Sprengnether galvonometer”

“…Similar reports are received by the P.D.E. Office over cable, by telephone, and by postal card from other seismograph stations throughout the world. At times Georgetown is the first station reporting since it is so close. From the reported arrival times of the first waves the Government scientists then determine the exact time and place of the earthquake. Within several days the precise conclusions of P.D.E., together with the names of the stations reporting, are mailed to seismologists in all parts of the world…”

***Georgetown University Alumni Magazine,* March 1959**

"…A typical list of reporting stations might include: COL, FORD, CEO, GUAM, HARV, PAL, WEST, etc. Frequently, the only indication of an earthquake on the Georgetown records is found on the short-period seismograph and closely resembles in size and shape this printed 'W'…"

***Georgetown University Alumni Magazine,* March 1959**

“…Approximately once a month the Galitzin seismographs record a major earthquake. Earth waves may be recorded for as long as six or eight hours. Rev. Frederick W. Sohon, S.J., Observatory Director, recalls a day when eight earthquakes were recorded within twenty-four hours. The record of each earthquake overlapped the next so that the whole day’s record was filled with vibrations. In the record of each major earthquake are good indications of where the quake occurred, for the direction from which the underground vibrations and the surface waves arrive in addition to the time interval between vibration groups show the direction and the distance of the epicenter. This is the kind of information which the news services and the public desire. Major earthquakes are quickly reported by telephone to the Washington Star or Post, to the Associated Press, and to United Press International. Thus the Georgetown reports may be seen in newspapers or heard on radio and television news programs, coast to coast…”

***Georgetown University Alumni Magazine,* March 1959**

"…After the P.D.E. card is received, a careful restudy of the earthquake record is made. New phases are identified; uncertainties are resolved; errors are corrected. Revised readings are listed in the Station Bulletin and forwarded to the Central Station of the Jesuit Seismological Association at St. Louis University. For every major earthquake the Central Station publishes data from Georgetown and the other Jesuit seismograph stations in the United States. Several years later this data will be included in the International Seismological Summary published at the Kew Observatory, England…"

***Georgetown University Alumni Magazine*, March 1959**

“…The Georgetown Seismological Observatory was founded by Rev. Francis A. Tondorf, S.J., in 1909 as the College Journal testifies, although Father Tondorf preferred to give 1911 as the opening date of the observatory. Through a generous gift from a Georgetown alumnus, Patrick H. O’Donnell, A.B. ‘92, A.M. ‘93, LL. B. ‘94, Father Tondorf purchased a horizontal and a vertical Wiechert seismograph-each of 80 kg. pendulum mass. He first operated these instruments at the base of the South Tower, but the wind caused even this massive 212 ft. bastion to sway and tilt the earth…”

***Georgetown University Alumni Magazine,* March 1959**

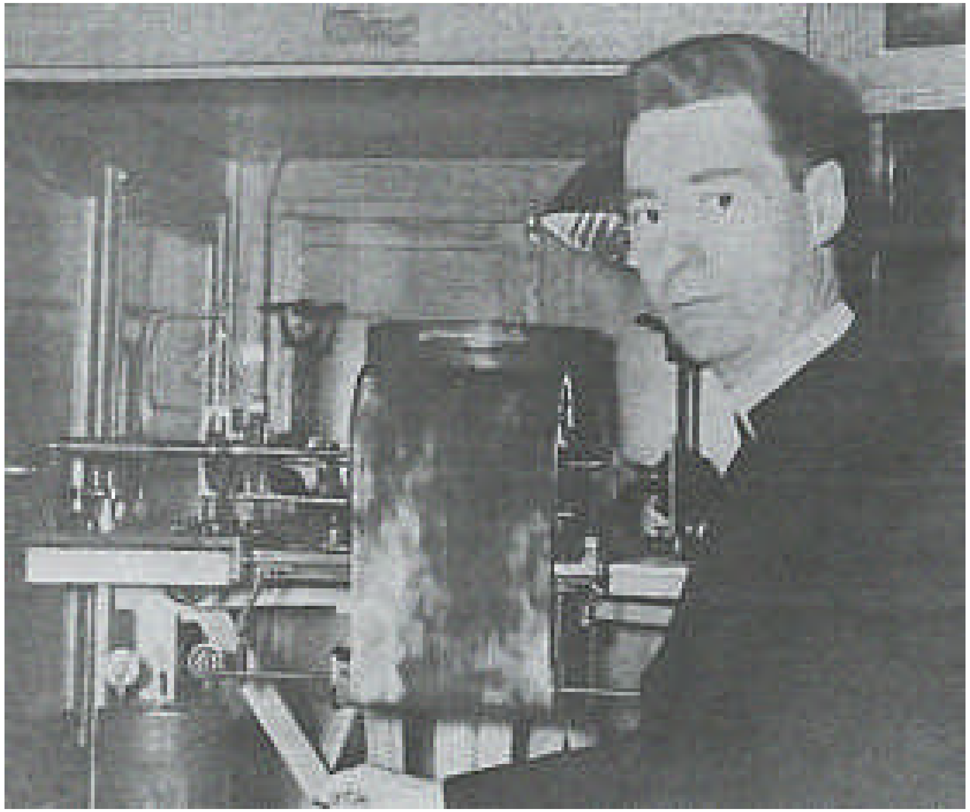
"…Searching for a more stable base, Father Tondorf was forced to move the instruments to the more sheltered vault beneath the quadrangle. In 1912 a pair of Bosch photographic seismographs of 200 grams pendulum mass were installed in a separate concrete building on top of Observatory Hill…"
Georgetown University Alumni Magazine, **March 1959**

“…Father Tondorf wanted nothing but German-made instruments. He imported two Bosch-Omori mechanically recording seismographs of 25 kg. each and a Mainka two-component conical pendulum seismograph of 145 kg., each of which were installed in the narrowing quadrangle vault. Then a 200 kg. Wiechert was added. The older 80 kg. Wiechert was sent to Guatemala City; the Bosch-Omori seismographs were donated to Weston College. Later when the electro-magnetic photo-recording Galitzin instruments were purchased, the Bosch photographic instruments and the 200 kg. Wiechert were loaned to Woodstock College…”

Georgetown University Alumni Magazine, **March 1959**

“…For many years Father Tondorf was aided by Brother Charles J. Ramage, S.J. The devoted brother kept the instruments in perfect condition and changed the records faithfully every day. He assisted Father Tondorf when he placed a Cambridge-type vertical Galitzin seismograph in a corner of the vault in 1923. Three years later two Cambridge-type Galitzins were placed in a crypt under Dahlgren Chapel. With the acquisition of these electromagnetic instruments the Georgetown station operated at the highest practicable degree of magnification. Further improvements could be made only by acquiring additional seismographs of longer and shorter periods than the Galitzins, then Father Tondorf died on November 29, 1929…”

Georgetown University Alumni Magazine, **March 1959**



"…Father Sohon was appointed to succeed Father Tondorf as Director of the Seismological Observatory. During the summers of 1930, 1931, and 1932 and during the scholastic year of 1931-32, Rev. John S. O'Connor, S.J., now Head of the Department of Physics at St. Joseph's College, was in charge during the temporary absence of Father Sobon. In December of 1930, Father Sobon, and Rev. William J. Tynan, S.J., moved the horizontal Galitzins from the Dahlgren crypt to Observatory Hill. Later Father O'Connor transferred them to the quadrangle vault where they are operating today…"

Georgetown University Alumni Magazine, **March 1959**

Above: caption: "Father O'Connor computes results of earthquake vibrations, received through one of Georgetown's six seismograph machines"

"…Father Sohon published the Georgetown Seismological Dispatches from 1929 to 1941. These were summaries of news wire accounts written by reporters at the scene of earthquakes. Father Sohon also published the 'Georgetown Seismological Bulletin' from 1929 through 1935. His volume entitled 'Introduction to Theoretical Seismology' has been studied carefully by seismologists everywhere. He also has done excellent research on the effect of tropical cyclones in generating microseisms…"

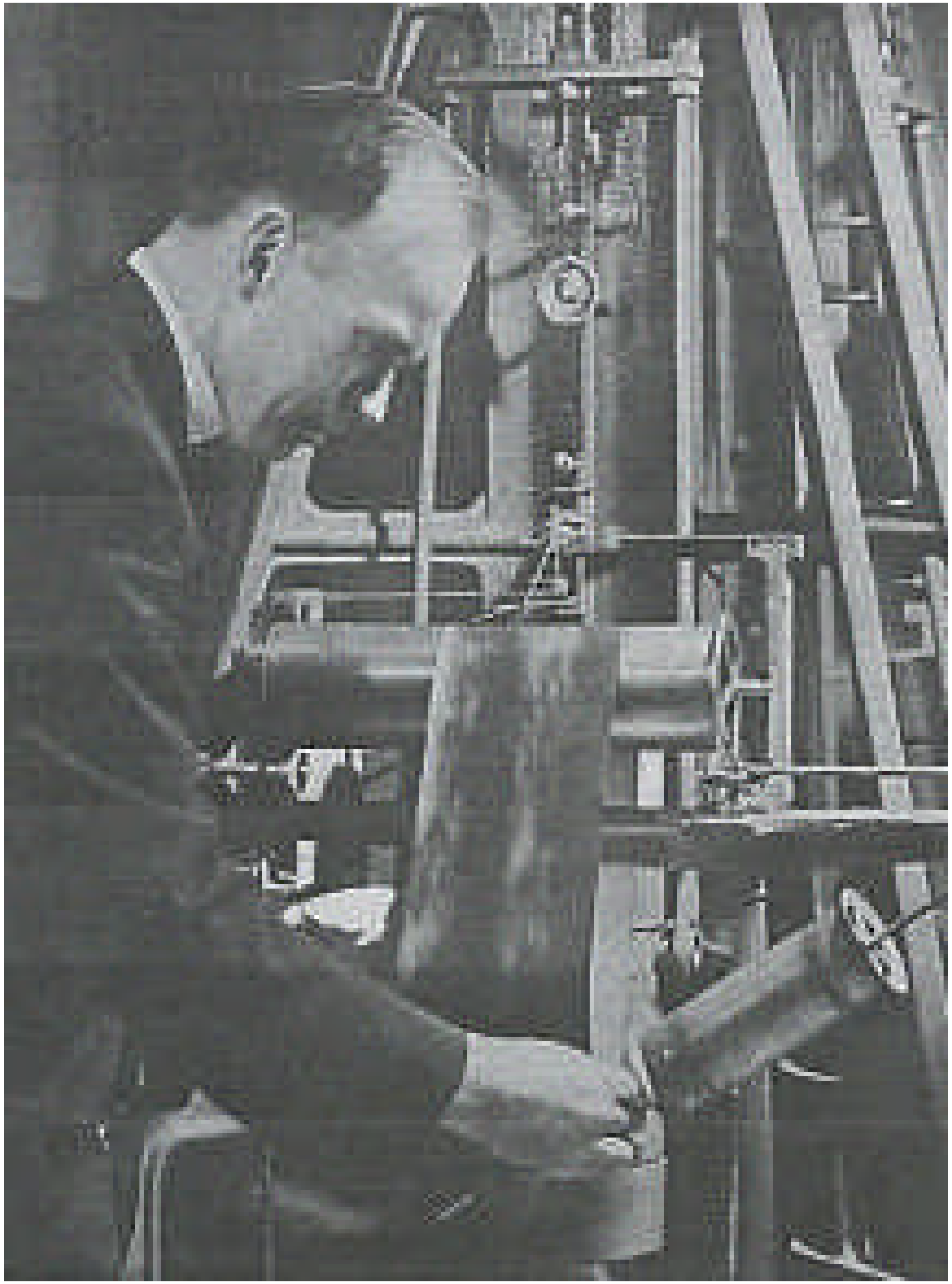
Georgetown University Alumni Magazine, **March 1959**

<u>Left</u>: caption: "Earthquake tremors from California are interpreted by the Rev. Frederick W. Sohon, S.J.,

from Georgetown seismograph"

"…During World War II, he assisted the Navy Department in its effort to develop a seismic method of tracking hurricanes. This was the only feasible method when radio silence was mandatory and enemy submarines were prowling the Atlantic. In 1952 Father Sohon became seriously ill. After several heroic attempts he found that he was no longer able to run the seismographs, but there was no one to assist him and no one to take his place…"

Georgetown University Alumni Magazine, **March 1959**



"…In the summer of 1957 Father Rector asked Rev. Bernard McConnell, S.J., a teacher of freshman mathematics, to reactivate the seismograph station. Rev. Henry Miller, S.J., who had just finished Theology at Woodstock was interested in seismology and seismic prospecting, but he was destined to study Geophysics with a Seismology Major at Columbia University - Father Sohon's own alma mater. It could be as much as five years until he finished his studies and there was no sense in letting the seismographs deteriorate in idleness…"

Georgetown University Alumni Magazine, March 1959

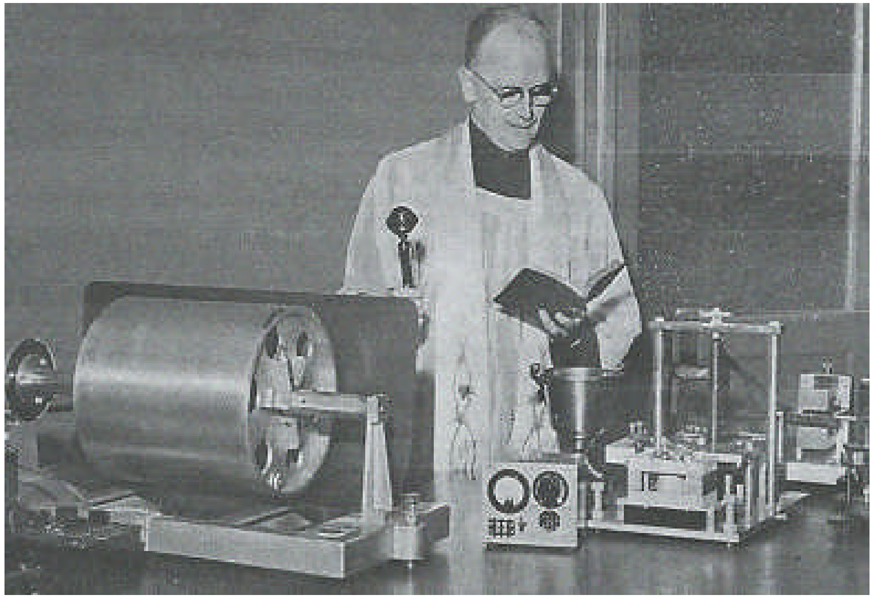
Left: caption: "In vault beneath the Georgetown University quadrangle, Father McConnell reads to see if distant earthquakes have occurred"

“…The coils of the North-South Galitzin by this time were so badly corroded that their resistance to the electric current generated by incoming earthquakes was almost infinite. Acid from the celluloid cover had eaten away the tiny wire. Fortunately, replacement coils from the U.S. Bureau of Standards were available so that immediate repairs could be made. The three components of the Galitzin seismograph and the two components of the Mainka were operating regularly by September 1, 1957. Reports were sent regularly to the P.D.E. Office of the U.S. Coast and Geodetic Survey. Because the Galitzin seismographs had to be recalibrated, reports to the news services were withheld for one year, until September of 1958…”

***Georgetown University Alumni Magazine,* March 1959**

"…Beginning in March of 1958 and through the following summer, the U. S. Coast and Geodetic Survey assisted in a series of tests to improve the Georgetown instrumentation. Mr. Leonard Murphy, a Fordham alumnus, was Director of the Preliminary Determination of Epicenter. He requested Mr. Frank Werner, his chief instrument man, to set up the tests. A short-period vertical Wilson-Lamison seismograph was placed in the quadrangle vault. Another was operated simultaneously in the seismic vault that overhangs the gymnasium. These instruments recorded four times as many earthquakes as the Galitzins. They worked well at both sites, although the quadrangle instrument showed unusual vibrations when the students took their meals in the Maguire and Ryan dining rooms. The six-hundred-pound gong named 'Sancta Maria, 'Sedes Sapientiae,' thumping the hours on top of the Healy Tower, left her marks on the record. The precise sixty-per-minute beat of the R.O.T.C. drum and bugle corps appeared faithfully once or twice each Tuesday afternoon. Thus, it was decided that the site on top of Observatory Hill was a better location for the Wilson-Lamison seismograph…"

***Georgetown University Alumni Magazine,* March 1959**

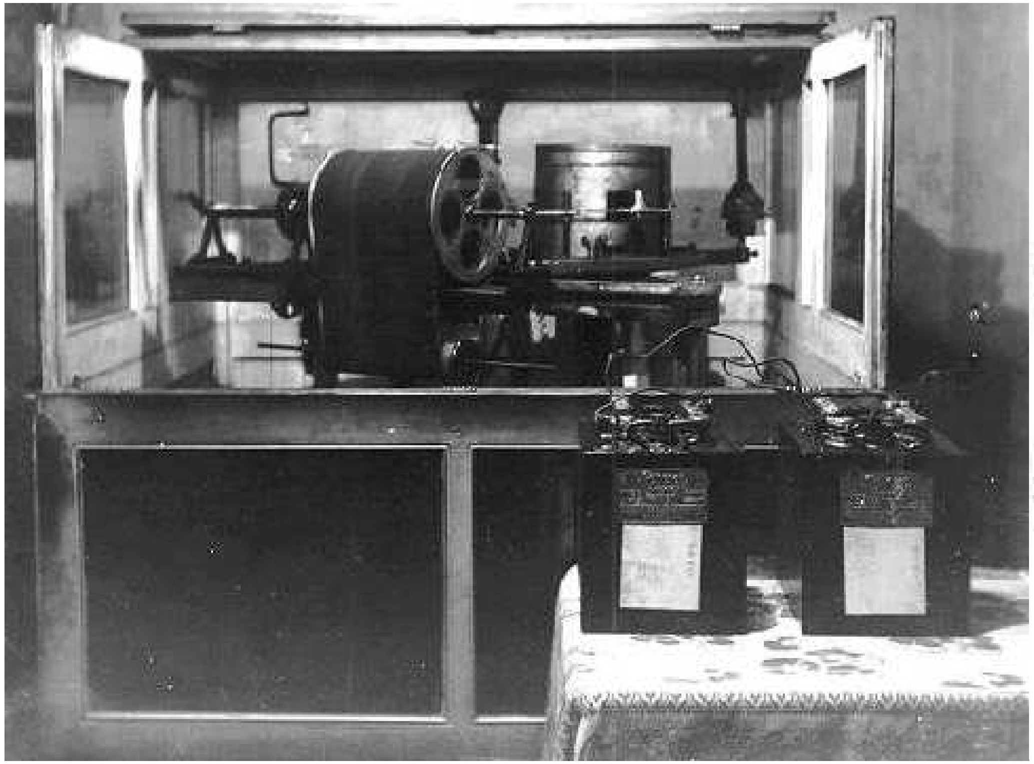


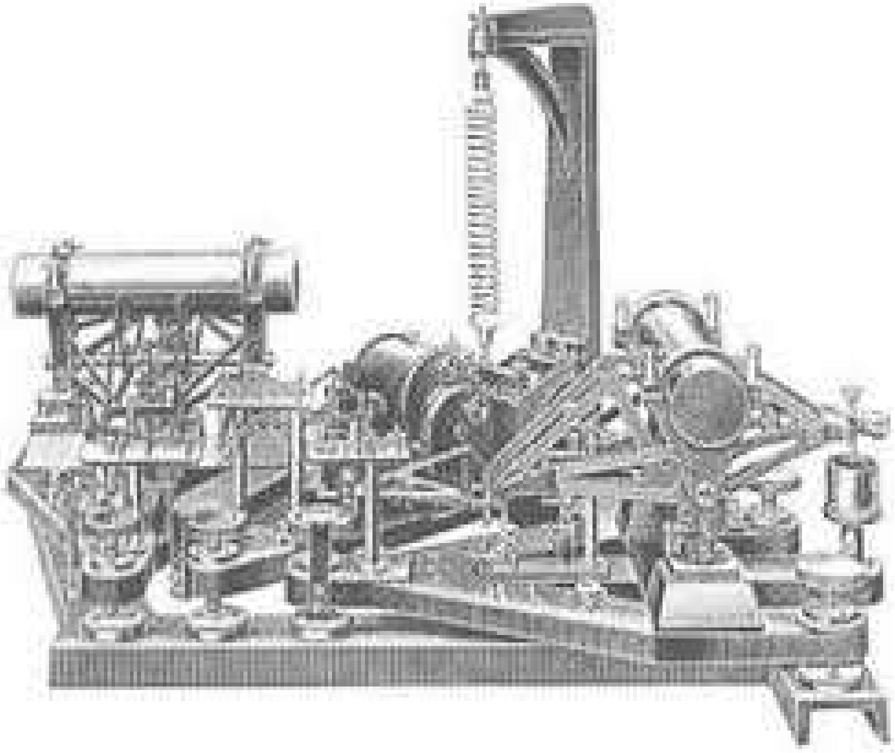
Left: caption: “Reverend John M. Daley, S.J., Dean of the Graduate School at Georgetown University, uses the Roman Ritual as he reads the special blessing for a new seismograph for Georgetown’s Seismological Observatory”

“…Because of the excellent performance of these test instruments a Wilson-Lamison seismograph and recorder were made for Georgetown by the Times Instrument Co. of Washington, D. C., according to specifications of the U.S. Coast and Geodetic Survey. Rev. Joseph J. Lynch, S.J., of Fordham University, supplied the needed galvanometer. The instrument was placed in the vault by the end of the summer and remains there today.”

***Georgetown University Alumni Magazine,* March 1959**

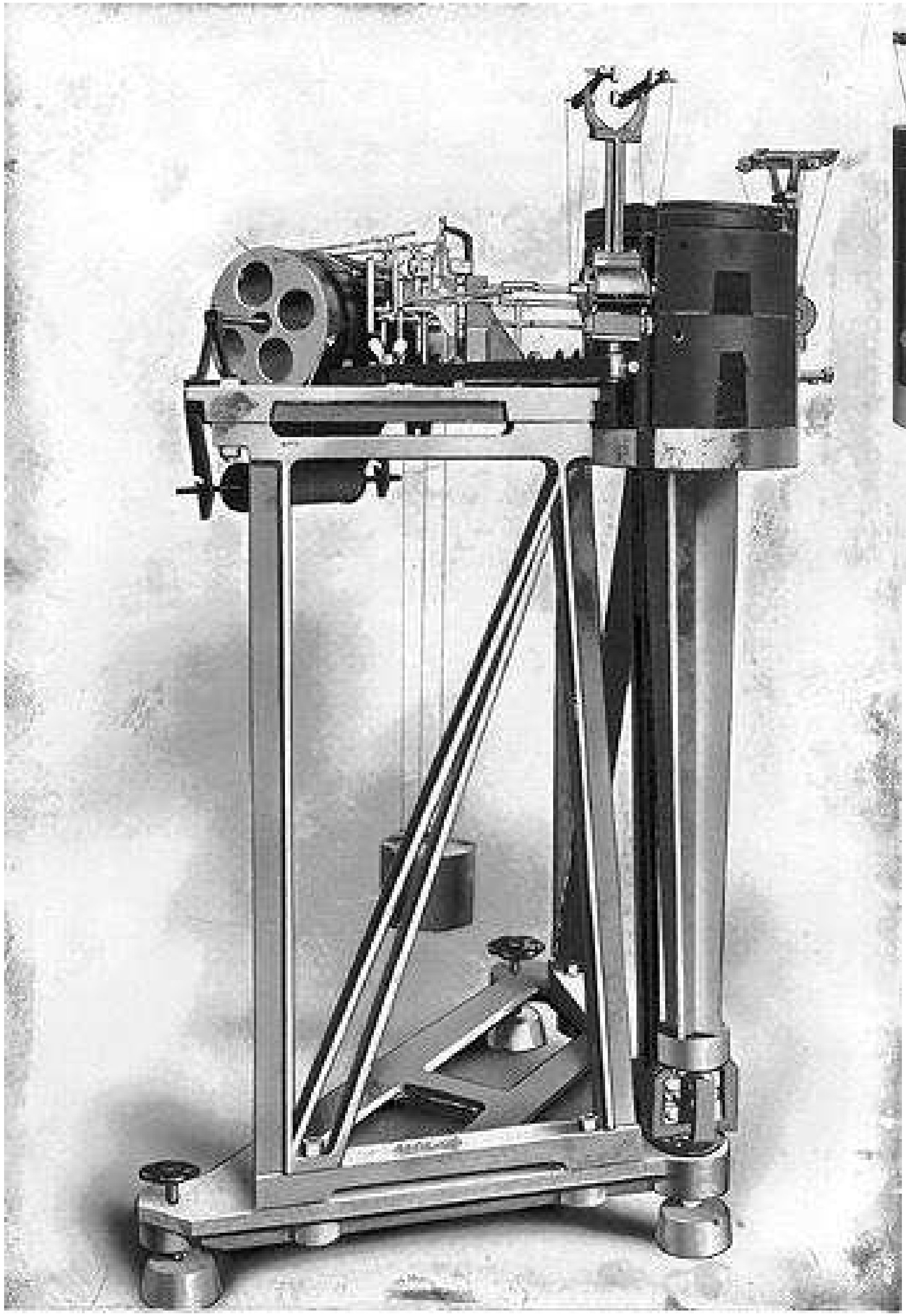
The Jesuit order made some of the most important early studies of earthquakes in the seventeenth and eighteenth centuries. Today, their modern observatories a true global network of seismic stations. In Central and South America, the Jesuits established two important seismological centers; in Bogota, Colombia and La Paz, Bolivia. They also operate seismological stations in Asia, Africa and Australia. Jesuit seismologists studied "microseisms" (a faint earth tremor caused by natural phenomena, sometimes referred to as "hum"). Jesuits also played an important role in regional and international seismological organizations. In North America, the *Jesuit Seismological Association* established the first continental network of stations with uniform instrumentation. Its central station was located at *Saint Louis University*.

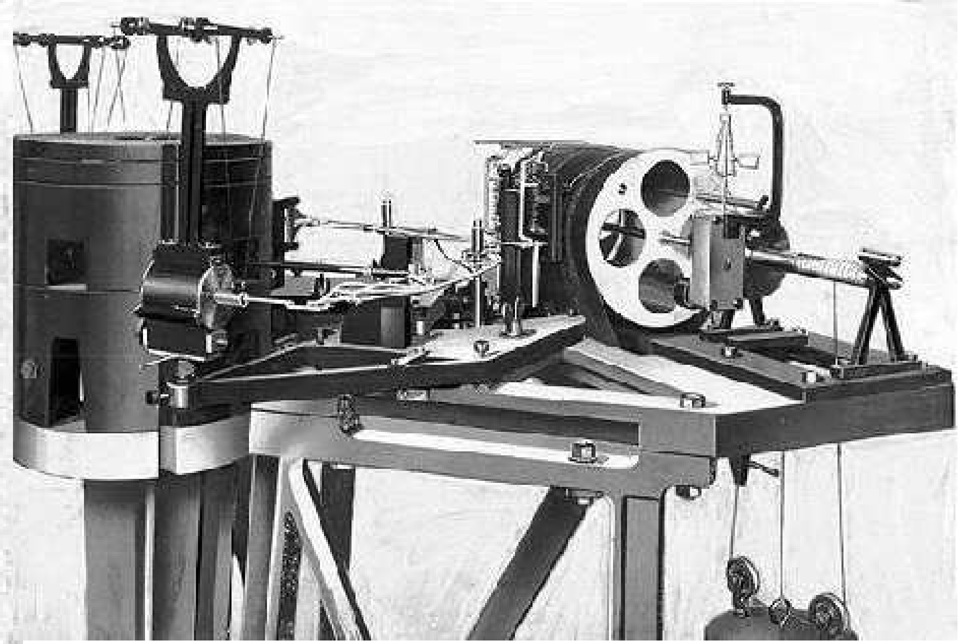




Left: caption: “The Wiechert 80 Kg. Horizontal Component Seismograph. Located in the basement of DuBourg Hall at Saint Louis University, the seismograph was installed in 1909 and recorded it’s first earthquake on October 9th of that year.”

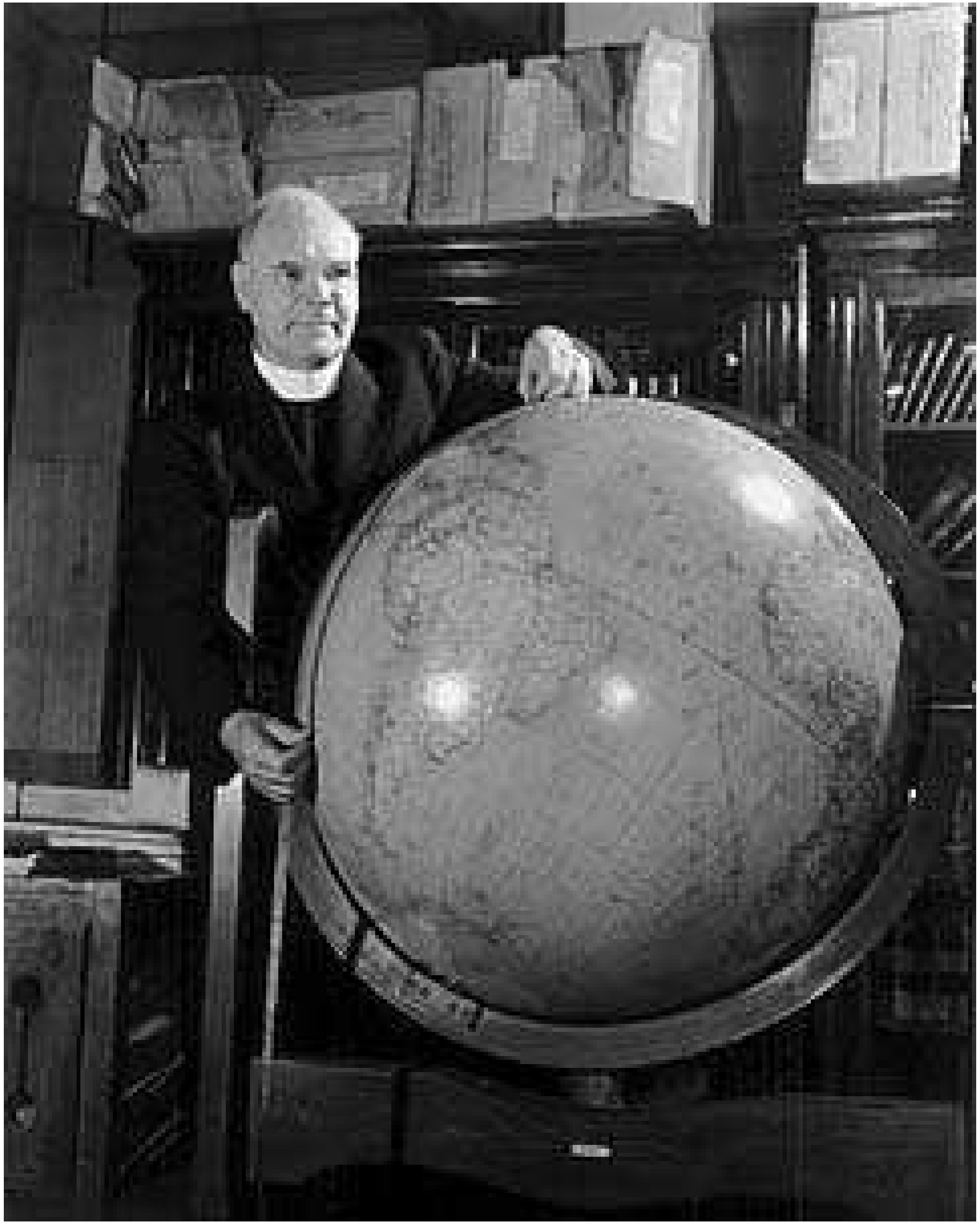
Right: caption: “Drawing of Mintrop/Wiechert mobile seismometers built to observe higher frequencies in all three components”





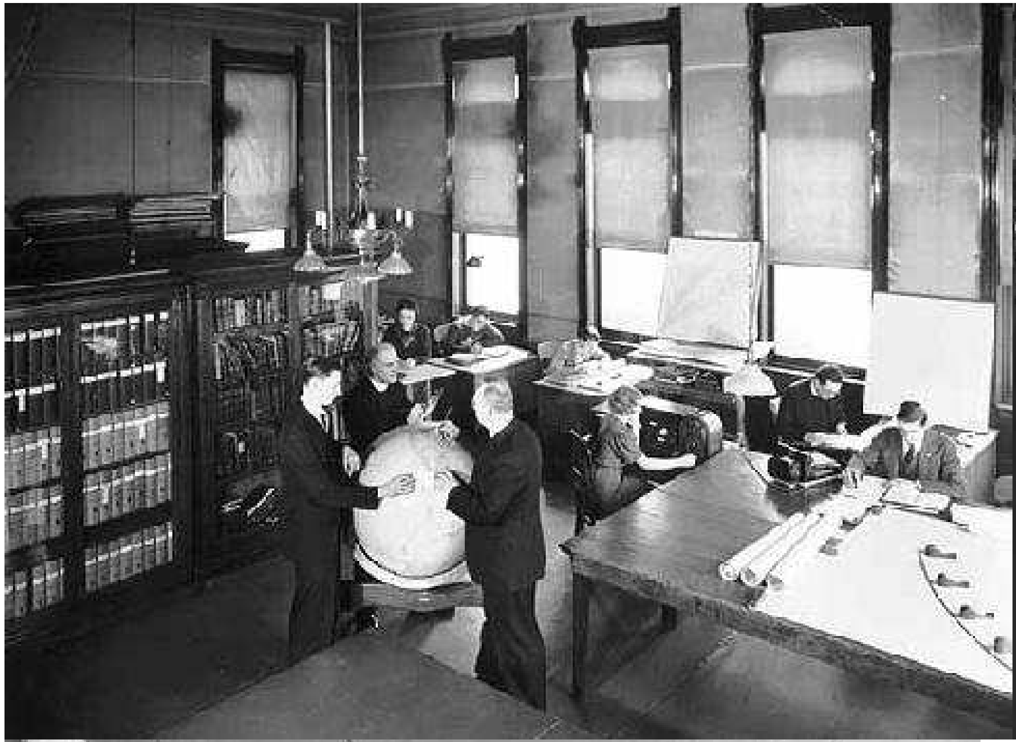
Above: caption: “Detailed illustration of small Wiechert horizontal component seismograph”

Left: caption: “Detailed illustration; side view of small Wiechert horizontal component seismograph”



In 1925, the Department of Geophysics at *Saint Louis University* was founded.

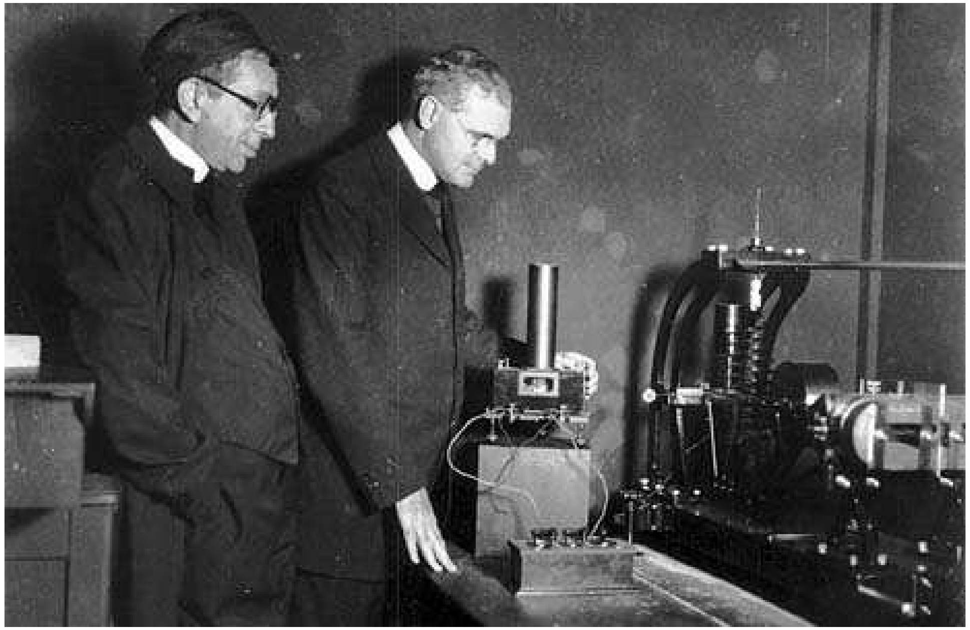
Left: caption: “The Rev. James B. Macelwane with the thirty-inch Dietrich Reimer globe, the then state-of-the art tool for true longitudes and geocentric latitudes. Otto Nuttli related that one of his first functions as a new Ph.D. was to calibrate the globe, because the map on the globe was not exactly positioned in terms of latitude and longitude.”



Top Left: caption: “The office of the Central Station of the Jesuit Seismological Association - Saint Louis University’s Geophysics Department, Sodality Hall, 1940”

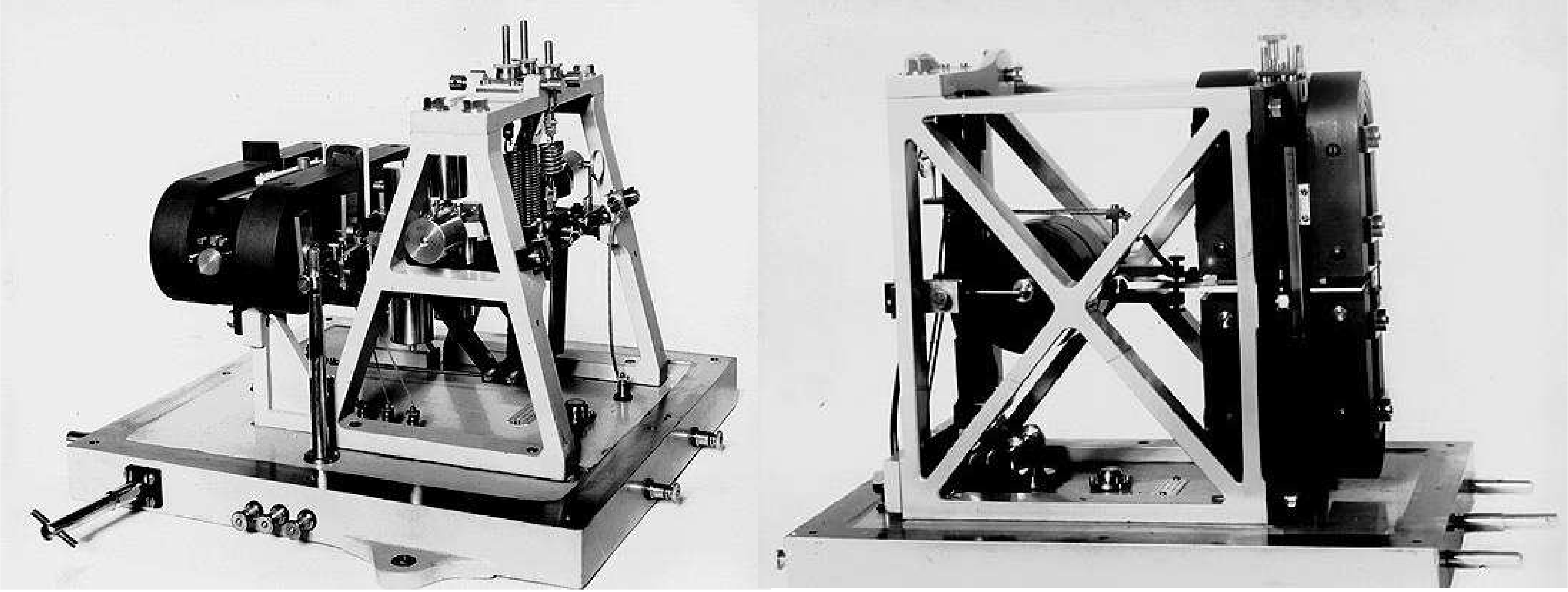
Top Right: caption: “Earthquake research, Sodality Hall - Fathers Macelwane, Blum and Doctors Heinrich and Walter”

Left: caption: “A Vibration Recording Apparatus, Father Macelwane and Dr. Edward J. Walter”



In 1926, Galatzin-Wilip instruments were installed at Florissant, MO.

Left: caption: “Rev. Francis A. Tondorf, S.J., and Rev. James B. Macelwane, S.J., examining a Cambridge-type vertical component Galitzen electromagnetic seismograph installed in 1923 at Georgetown University. Wilip improved the Galitzen design in terms of temperature and pressure stability to make the Galitzen-Wilip.”



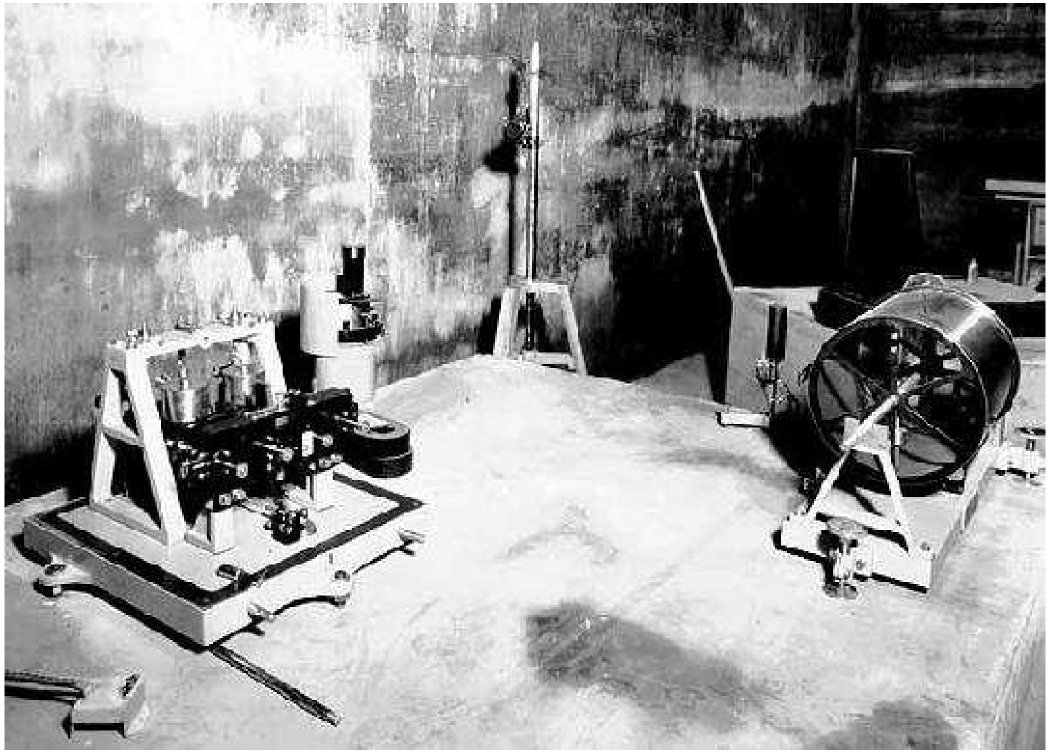
Left: caption: “Aperiodical Vertical Sesimograph with compensation of temperature and galvanometric registration. Named for Prince B. Galitzin and Professor J. Wilip. (Galitzin-Wilip Vertical Seismometer). Made by Hugo Masing, Factory for Precision Mechanics in Tartu, Estonia.”

Right: caption: “Aperiodical Horizontal Seismograph with galvanometric registration. (Galitzin-Wilip Horizontal Seismometer). Made by Hugo Masing, Factory for Precision Mechanics in Tartu, Estonia.”

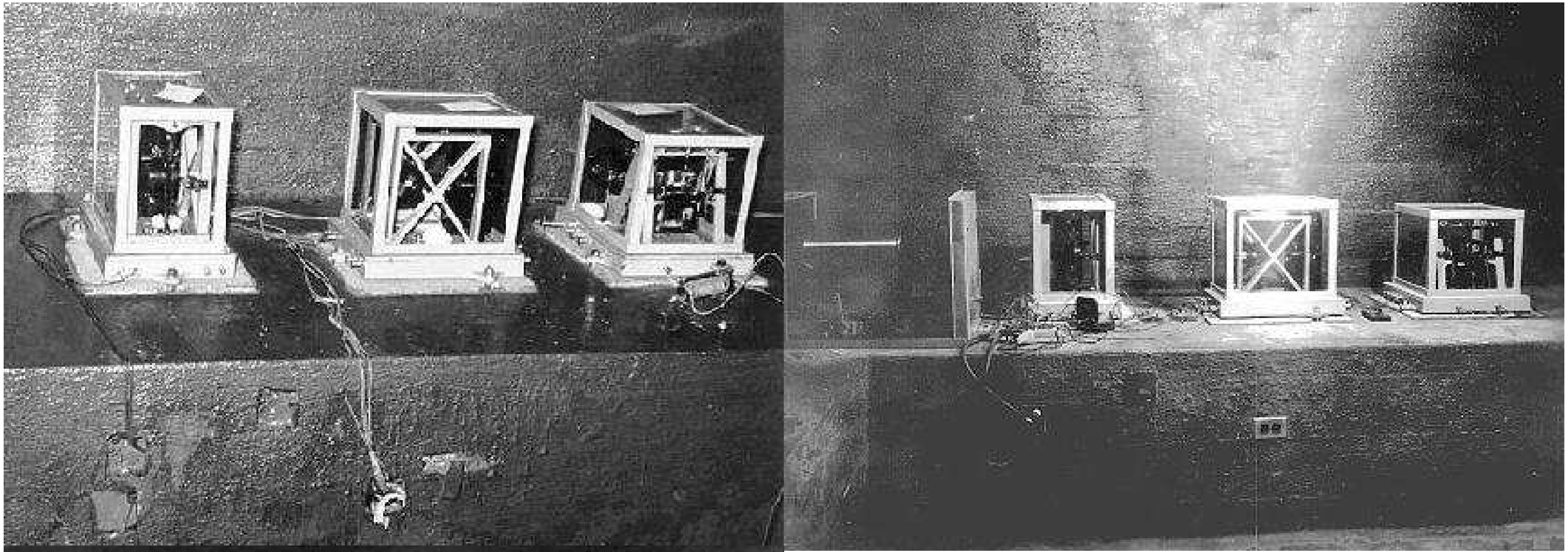
“…A seismological observatory looks like a small one-car garage. The basement houses the recording instruments. In a larger station like the Harvard University Oak Ridge, there is a lower level for the sensitive parts of the seismographs. They rest on a concrete pier anchored to bedrock. The pier is insulated from the building so that the house vibrations do not affect it. Observatory walls and roof are banked and insulated so that atmospheric conditions do not affect the instruments. Since earth waves are mostly directional, the standard station has seismographs arranged at right angles to each other. In this manner, no tremor passes the station without etching its records on the graph…”

***Popular Mechanics,* August 1946**

RE: the *Florissant Station* was established in 1928 at the *Saint Stanislaus Seminary*. The site was outside the city limits, far from any source of vibrations due to traffic in and around the *Saint Louis University* campus. The recording drum worked from a wind-up spring, in the manner of an old alarm clock. A rotating spherical pendulum acted as a governor. This was necessary before the advent of stabilized 60 Hz AC mains in the U.S. and the use of synchronous motors. The Florissant station was upgraded in 1961 and continued operations through 1971.



__Left__: caption: “Vertical Galitzin-Wilup seismometer and recording drum at the Florissant, MO vault. The galvanometer is to the right and behind the seismometer. The light source is on the pier in front of the recording drum. The photographic paper was removed when this picture was taken. The tripod in the rear could hold a scale, used for sensor calibration.”



<u>Above L&R</u>: caption: "Vertical, North-South, and East-West Galitzin-Wilip Seismometers at the Florissant, MO vault. Recording drum pictured in bottom photo, left of seismometers."

<u>Left</u>: caption: "Instrument room looking southwest; left to right: Brother Ellis W. Haworth, Father James B. Maclewane, Father George J. Brunner, Dr. Cornelius G. Dahm and Father Anthony J. Westland"

The seismic station at St. Louis University was Inaugurated in 1927, in the basement of the Gymnasium, with the installation of Wood-Anderson seismographs.

<u>Left</u>: caption: “Layout on the Gymnasium Pier, 1940”

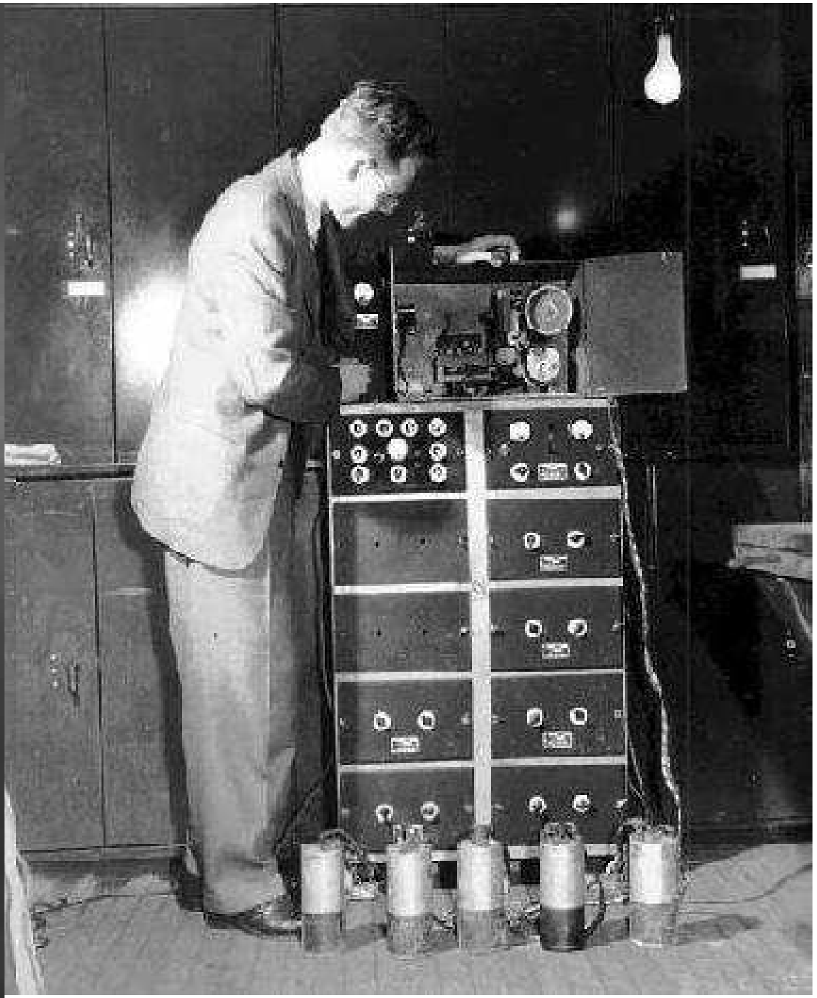
<u>Right</u>: caption: “Layout of the gymnasium pier, Saint Louis Station, circa 1940. Pictured left-to-right: Dr. Albert Frank, Dr. Florence Robertson and Fr. Macelwane.”

"I believe that Humble was doing exploration in the Libyan desert and had to clear out fast as the German army swept eastward. As I recall Fr. Macelwane's account, a pilot was about to take off when he saw the instrument, didn't know what it was, but it looked valuable. He put it in his plane and got out. I do not know the path by which it got to SLU, but Fr. Mac was well-known to the oil industry and I assume somebody at Humble decided to make it a gift."

Dr. Carl Kisslinger*, SLU Chair of the *Department of Earth and Atmospheric Sciences

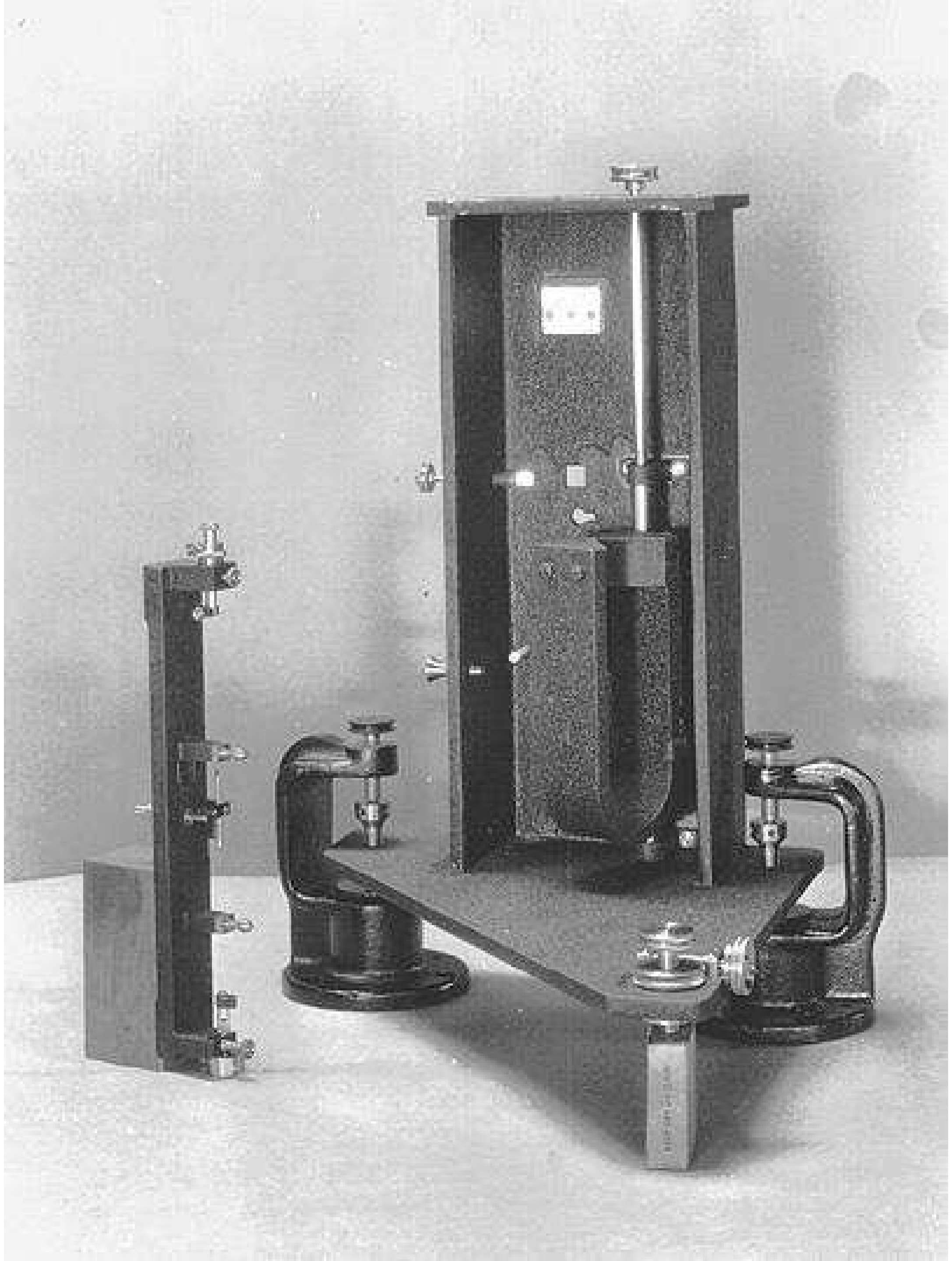
RE: the instrument saved from capture by the Germans in North Africa during WWII was a *Truman Gravimeter*, used by the *Humble Oil Company* (usually referred to as a "Humble-Truman Gravimeter"). The instrument probably got to SLU through Father Macelwane's close ties with the oil industry.

<u>Left</u>: caption: "Dr. Florence Robertson, checking a Humble-Truman Gravimeter "



Above: caption: “Seismograph Service Corporation Type Reflection Seismometers, Amplifiers, and Camera”

Left: caption: “Refraction seismograph system”



In 1930, seismographs were installed in *Saint John's Seminary* in Pulaski Heights, Little Rock, AK. In 1938, seismographs were installed at Southeast Missouri State University in Cape Girardeau, MO.

<u>Left</u>: caption: "The short-period Wood-Anderson torsion seismometer in use at Cape Girardeau Seismological Observatory, part of the Saint Louis University group of Stations, under the direction of the Jesuit Seismological Association."

In 1961, instruments were installed at Rolla, Missouri, Manhattan, Kansas, Dubuque, Iowa and Bloomington, Indiana as part of U.S. Air Force's *Vela Uniform Research* on nuclear explosions. In 1985, the *Regional Seismic Network* was installed to monitor *New Madrid* and *Wabash Valley* (Illinois) earthquake activity. By 1985, the *Jesuit Seismological Association* had grown to include fifty stations. In 1990, modern broadband digital seismographs were installed as part of BILLIKEN (*Broadband Intracratonic Large-aperature Low-noise Informational Kooperative Earth-observing Network*). In 1997, in cooperation with the *United States Geological Survey* (USGS) and as a component of the *Advanced National Seismic System* (ANSS), the *Cooperative New Madrid Seismic Network* (CNMSN) was established. The Network (including *St. Louis University* and the *University of Memphis*) consists of fourteen broadband digital instruments and ninety three-component analog systems. The seismic network uses two types of sensors; acceleration and broadband. The difference is that the former is a low sensitivity instrument (designed to capture very large earthquake motions on scale) while the latter provides on-scale recordings of small local and large distance earthquakes. The St. Louis University component of the ANSS monitors a broad region of the central U.S. where significant earthquakes have occurred in the past. In addition, accelerometers operate in urban areas to record any/all motions of engineering significance. All seismic networks supported by the USGS monitoring earthquakes in the U.S. operate according to the high standards of the ANSS.

Part 7

The Waiting Game

Where Next?

“Where will America’s next great earthquake hit, and what will the damage be? In seismological laboratories scattered from coast to coast, patient observers are recording on smoked paper the earth temblors of all the world in an effort to find an answer to those two problems…”

Popular Mechanics, **June 1928**

The Riddle of Why and When

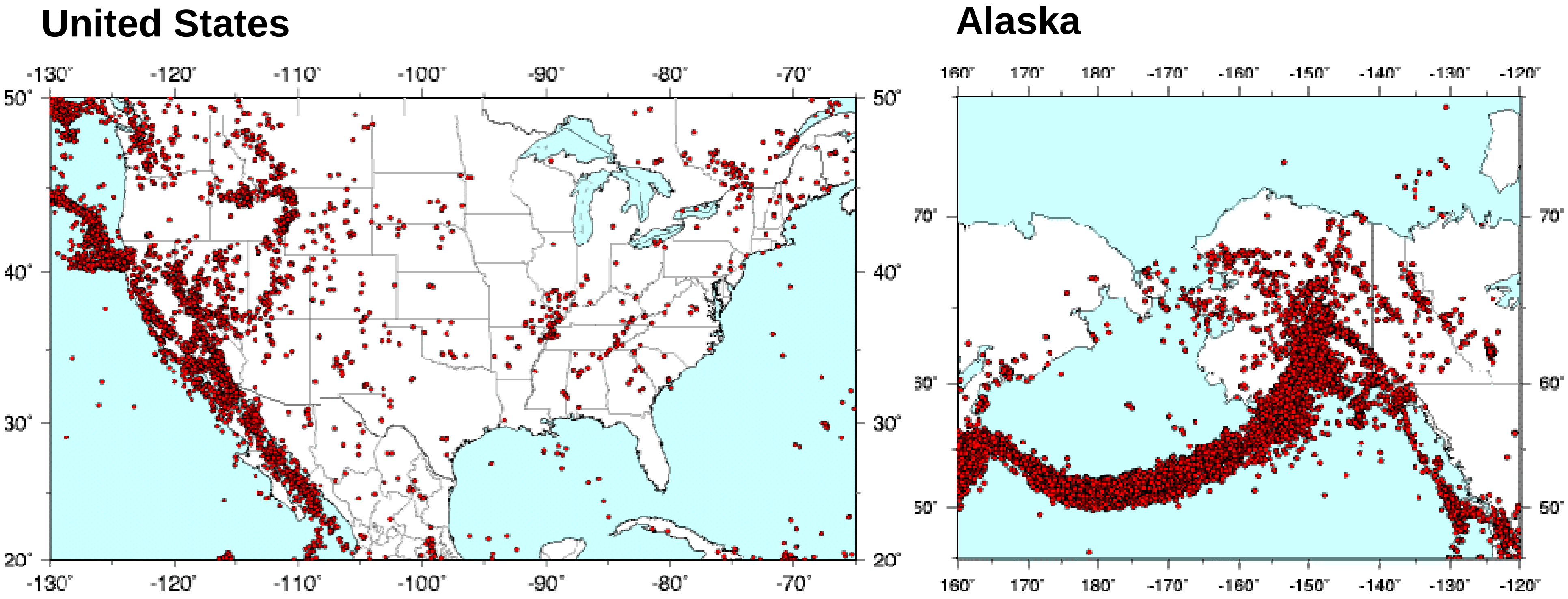
“…The answer to the first is slowly being pieced together from the study of each year’s quakes, their probable causes, and other data which may eventually solve the riddle of why and when an earthquake is to occur...”

***Popular Mechanics,* June 1928**

"…The answer to the second will depend largely on the use to which the country puts the solution of the first, for damage will be lessened in direct proportion to the precautions taken in earthquake zones to build shake-proof houses and offices…"

***Popular Mechanics*, June 1928**

Early Warning



"…There are about thirty-five earthquake observation stations in the United States which regularly publish their results. Many are located at universities, but several are operated by amateurs who have made a hobby of earthquakes…"

***Popular Mechanics,* March 1936**

<u>Above L&R</u>: caption: "Earthquakes, Magnitude 3.5 and Greater, 1974 – 2003"

“…In California, there is a system for gathering quake information from some 20,000 persons who do not operate seismographs. These observers are provided with printed cards on which they record information concerning any quake that happens to occur in the region. Information obtained with these cards has proved extremely valuable in analyzing local earthquakes…”

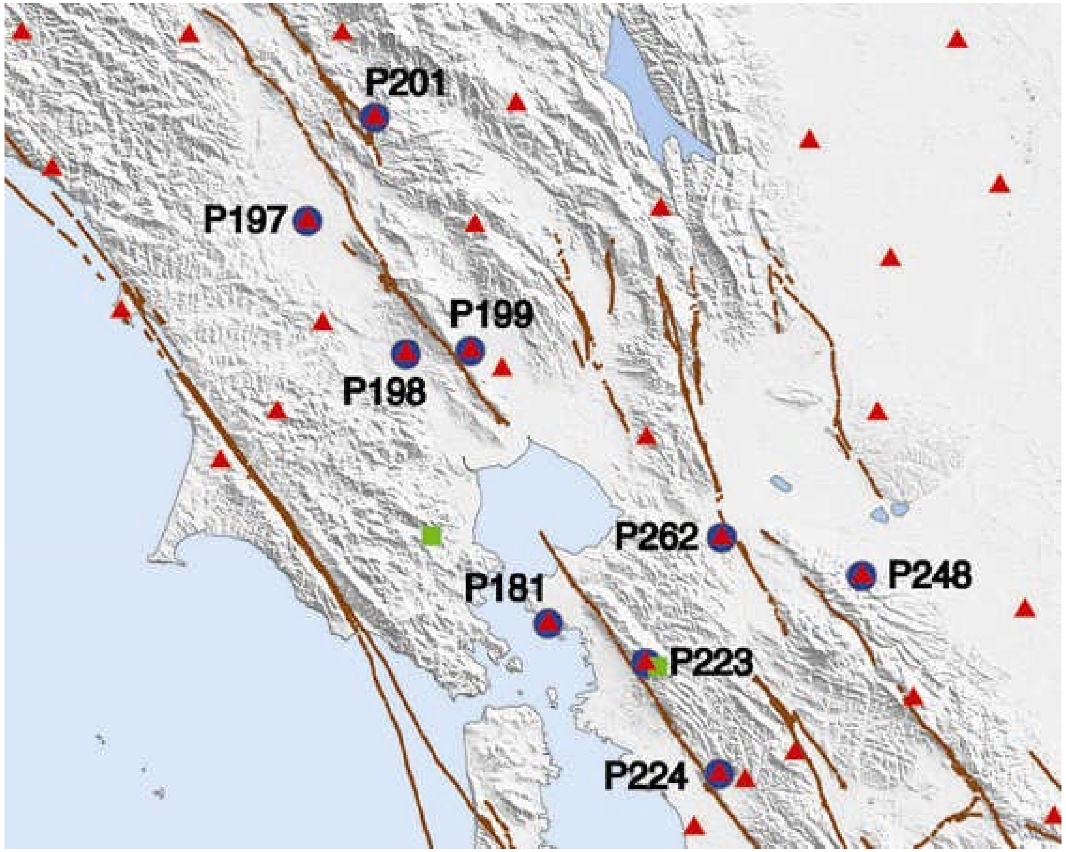
***Popular Mechanics,* March 1936**

"…a system being developed at MIT raises the hope that seismology may become something more than a waiting game…the technology should make it possible to sound a warning anywhere from 10 to 100 seconds in advance – enough time to run for safety, or at least dive under the nearest desk…"

***Popular Mechanics*, January 1990**

“…The technology is based on an artificial intelligence program in a computer linked to a series of accelerometers placed along a fault line. In a quake, the computer would quickly process information from the sensors to determine the magnitude of the quake and areas likely to sustain damage. Then, warnings would automatically be issued by radio or telephone to businesses and perhaps civil defense authorities in the regions at risk, and sirens would sound…”

***Popular Mechanics,* January 1990**



"…Accelerometers that feed data to the computer are spaced about 3.5 miles apart along the fault line. Measuring about 1 cu. ft. in size, they are mounted on concrete pads, which in turn are set into the ground, ideally in bedrock to provide the most accurate data…"

Popular Mechanics, **January 1990**

Left: caption: "Location of ten sites with newly installed accelerometers in the San Francisco Bay area (blue circles)"

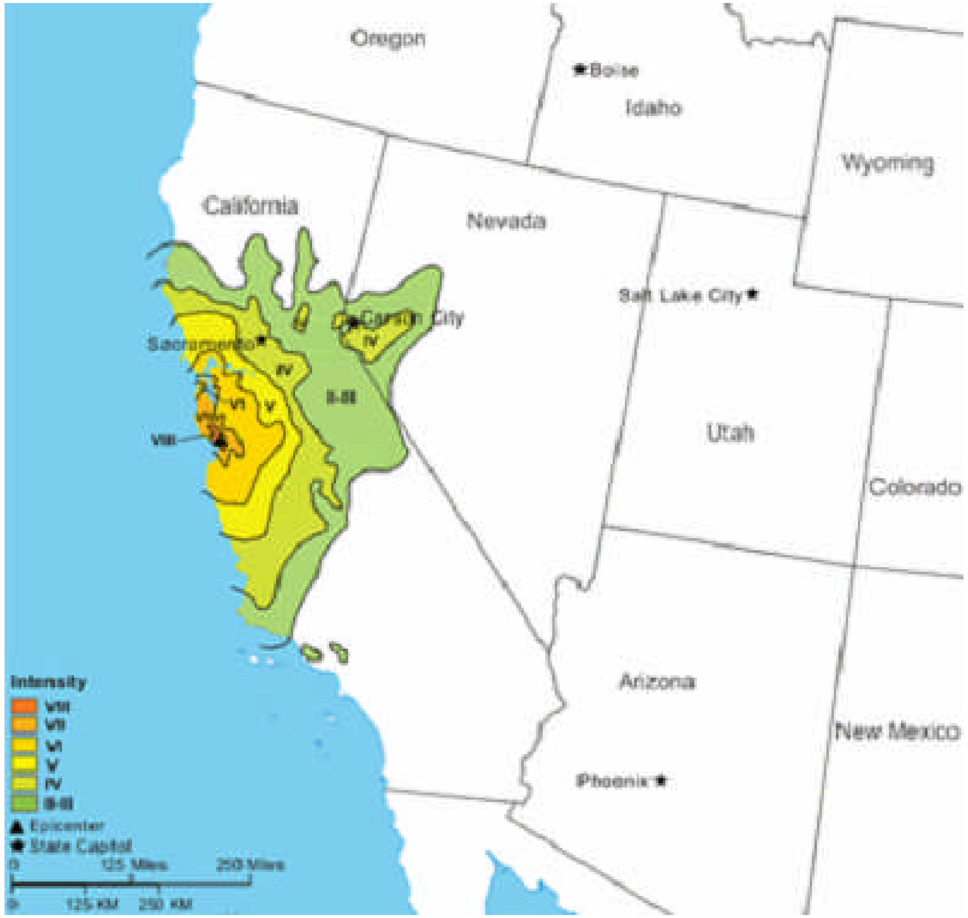
“…The ability of the system to provide early warning depends on the fact that the most damaging seismic waves propagate out from a fault rupture at a rate of about 3 kilometers per second. The ruptures occur in such a way that after they’ve gone on for 10 to 15 seconds, it is possible to know that the resulting quake will exceed 6 on the Richter scale, the point at which serious destruction begins. Thus, some degree of advance warning can reach any area farther than about 30 to 45 kilometers from the epicenter…”

***Popular Mechanics,* January 1990**

"…The current version of the program is tailored specifically to work along the San Andreas fault, the 600-mile meeting of tectonic plates that grind past each other at a steady rate of ½ in. a year, and last October broke loose with the lurch that knocked San Francisco off its feet. The program could, however, be adapted to work in a variety of locations…"

***Popular Mechanics,* January 1990**

RE: on October 17th 1989, a magnitude 6.9 earthquake struck the *Santa Cruz Mountains*. This major earthquake (a/k/a "Loma Prieta") caused 63 deaths, 3,757 injuries and an estimated $6 billion in property damage. It was the largest earthquake to occur on the San Andreas fault since the great *San Francisco Earthquake* in April 1906. The most severe property damage occurred in Oakland and San Francisco, about 100 km north of the fault segment that slipped on the *San Andreas Fault*. In Oakland and San Francisco, reinforced-concrete viaducts collapsed: *Nimitz Freeway* (Interstate 880) in Oakland; *Embarcadero Freeway*; *Highway 101* and *Interstate 280* (in San Francisco). Communities sustaining heavy damage in the epicentral area included Los Gatos, Santa Cruz and Watsonville.



__Left__: caption: “Santa Cruz Mountains Earthquake - 6.9 - October 17, 1989.” Liquefaction, as evidenced by sand boils, lateral spreading, settling and slumping, occurred as far as 110 km from the epicenter. It caused severe damage to buildings in San Francisco’s *Marina District* as well as along the coastal areas of Oakland and Alameda in the east *San Francisco Bay* shore area. Structures damaged by liquefaction include buildings, bridges, highways, pipelines, port facilities, airport runways and levees. Subsurface soil conditions, which amplified accelerations in the San Francisco Bay area, strongly influenced structural damage patterns and probably contributed to liquefaction problems in loose, sandy fills underlain by deep, cohesive soil deposits.

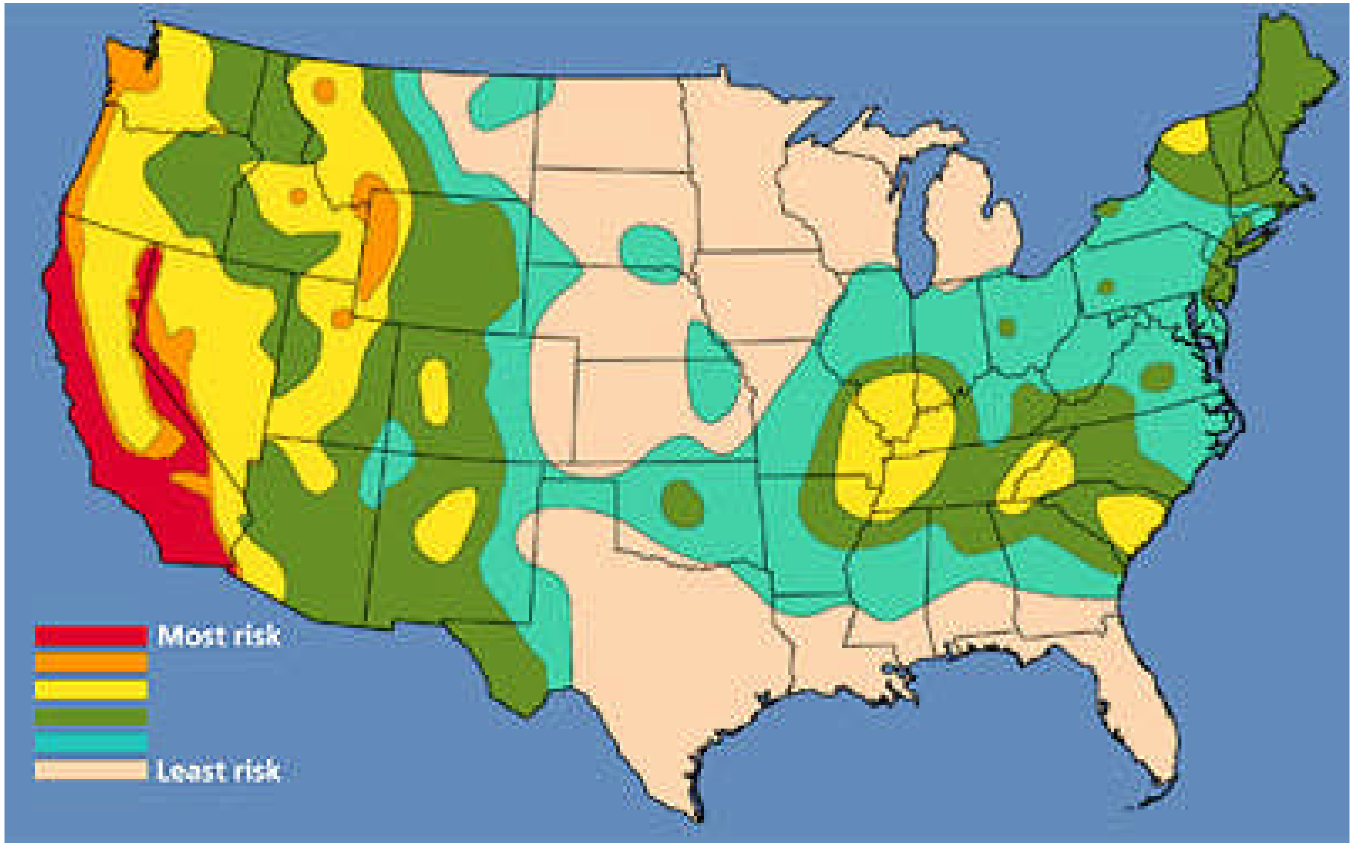
“…So far, it has been tested only in theoretical simulations, Seismic data from previous quakes were fed into the computer, showing its ability to interpret and respond. Questions remain, however, about whether the system would be able to avoid triggering false alarms when monitoring a steady stream of real seismic data 24 hours a day…”

Popular Mechanics, **January 1990**

Eyes and Ears

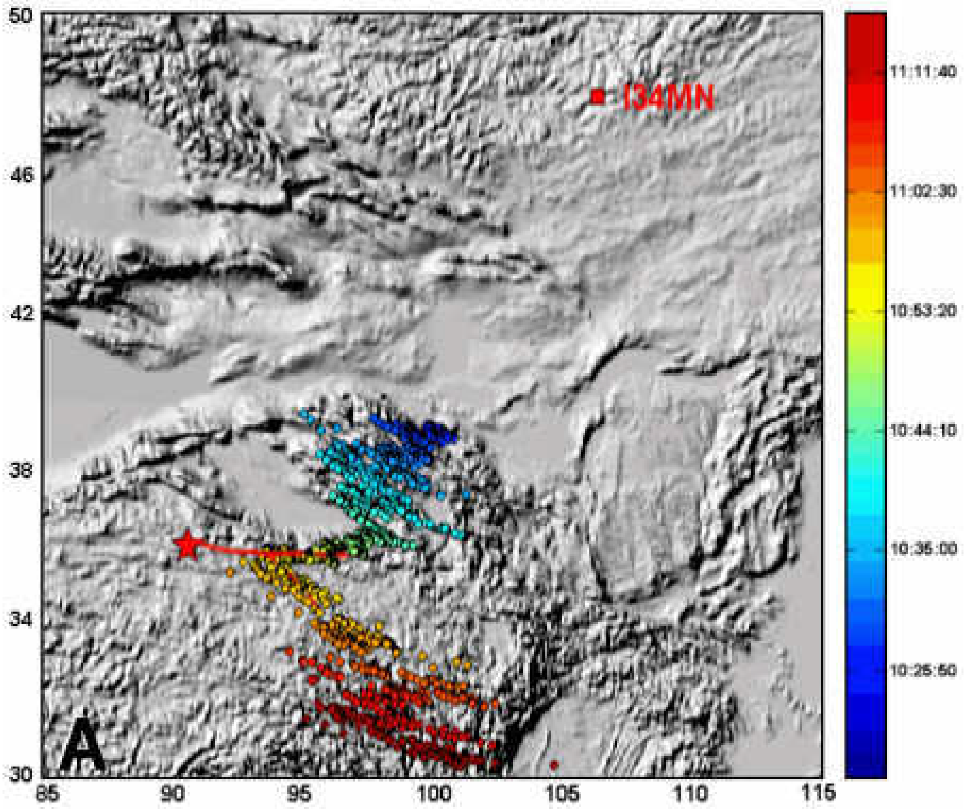
“…In addition, in regions of strong earthquakes, Uncle Sam’s quake experts have enlisted the help of postmasters and others who canvass the region and obtain information that will be helpful in determining the distribution and intensity of the quake…”

***Popular Mechanics,* March 1936**


Most risk
Least risk

“…In California, state engineers want to drill a mile-deep hole into the San Andreas fault zone, and install at the bottom a sensitive rock microphone that picks up the snapping and popping of rocks under strain. The device is used now in tunnels and mines to warn of impending rock falls. The engineers think the rock in the fault zone may become noisier as the strain approaches the breaking point, and that with experience they might judge when an earthquake is imminent. The Coast and Geodetic Survey plans to establish a string of such laboratories running the length of the San Andreas fault. The first would be located near Hollister. Recordings of the noise at various sound levels would be made on megatape for about 15 seconds out of every 15 minutes. Analysis might lead to methods of listening for earthquakes…”

***Popular Mechanics,* July 1964**



<u>Left</u>: caption: “Location of the secondary sources of infrasound generated by the earthquake in China.” On September 14th 2001, a magnitude 7.8 earthquake occurred in northern China. For over an hour, the Mongolian IS24 station, located approximately 2K km from the epicenter, recorded infrasonic signals with an azimuth variation of 20 to 30-degrees. A detailed analysis of the speed of the first coherent waves detected showed values that were characteristic of seismic waves. These recordings confirmed that mountains can act as secondary acoustic sources when vibrating just after an earthquake.

Weeks in Advance (?)

"…In California also, Sheldon Breiner, geophysicist with Varian Associates of Palo Alta, is using recently-developed supersentive magnetometers to study local changes in magnetic fields that are caused by rocks under stress. Breiner's studies confirm in a general way the belief that there is a relationship between changes in the magnetic fields of rocks below the surface and the occurrence of quakes. He and his group have detected abrupt shifts in magnetic intensity a few hours and a few minutes before actual earth movements. Although the geophysicist says that earthquake prediction is not one of his immediate goals, some of his associates think the method may lead within 10 years to an accurate way of foretelling the location and intensity of a quake weeks in advance…"

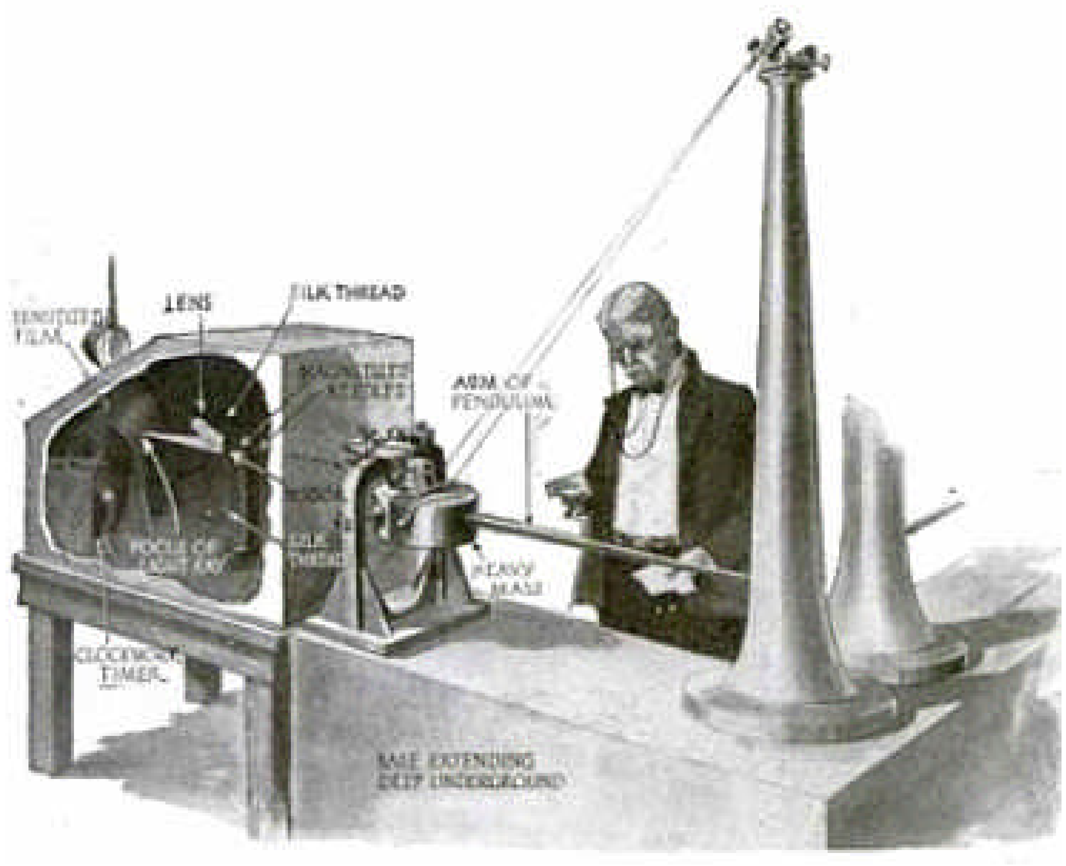
***Popular Mechanics,* July 1964**

Susceptible of Improvement

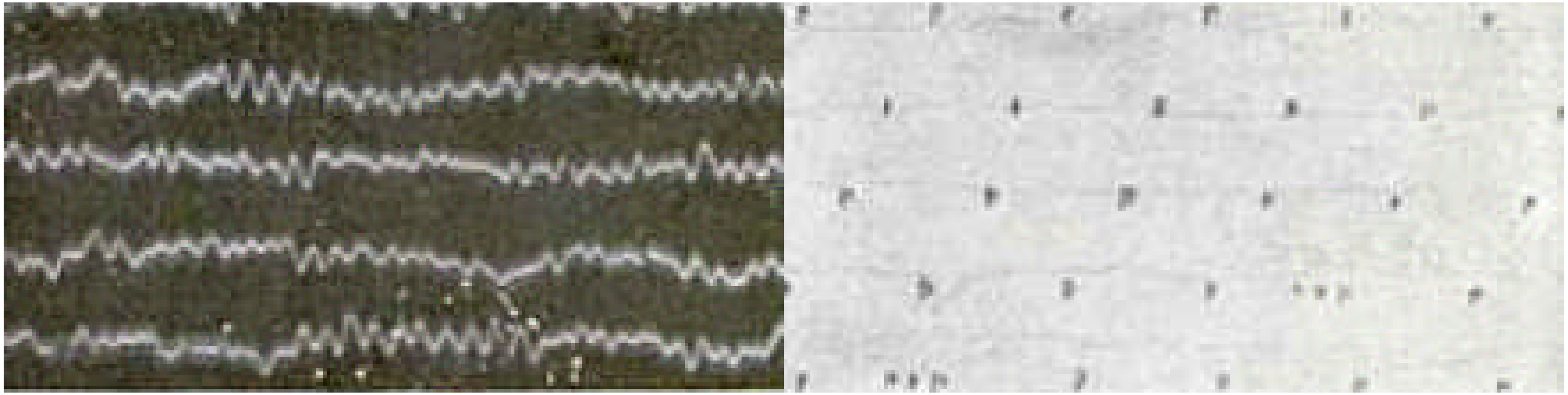
“…The lamp was set up at a distance of 150 centimeters from the end of, and in line with, though slightly above, the arm of an Omori 100-kilogram horizontal pendulum, the tip of the arm being fitted with a magnetized horizontal needle. An ordinary light mirror, with a diameter of twelve millimeters, was then firmly fastened to a vertical taut silk fiber, held on a post standing on a concrete table: while a second magnet was attached to the back of the mirror in such a manner that it lay at right angles, with its north pole adjacent to the south pole of the arm magnet…”

***Popular Science,* October 1919**

RE: modern-day seismometers employ electronic sensors, amplifiers and a recording device (most commonly a computer). However, in the early 20th Century, seismologists relied on a *seismograph* – a device that used a stylus to trace patterns on drum covered in smoked paper. *Dr. A.T. Jaggar* and *Dr. Arnold Romberg,* of the *Kilauea Observatory* in Hawaii, proposed updating the system by using a machine that registered seismic movement photographically; a *Seismograph Camera*. Instead of showing jagged lines, the new seismograph’s recordings showed continuous lines with small breaks to indicate unusual movements.



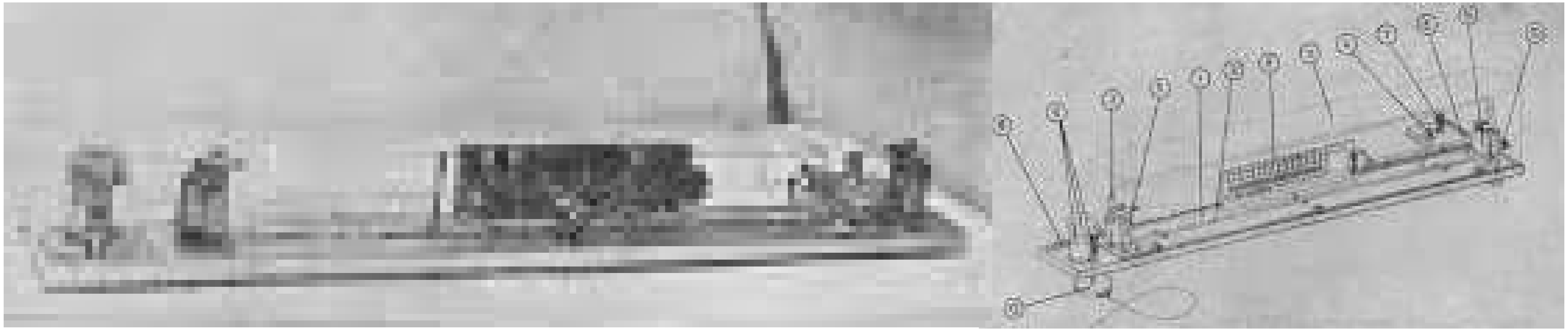
Left: caption: “in this instrument devised by Dr. A.T. Jaggar and Dr. Arnold Romberg, of the Kilauea Observatory in Hawaii, earth tremors are recorded by a system of photographic registration. Remarkably accurate records have been made, although the machine is still susceptible of improvement”



<u>Left</u>: caption: “A record by the old method, made by a writing-pen on a drum covered with smoked paper. The perpendicular marks show intervals of one minute. The magnification is small, the phases of tremors indistinct.”

<u>Right</u>: caption: “In the new method by photography the time marks are indicated by small breaks in a continuous line. A study of this record of a normal period of usual earth tremor is of great interest.”

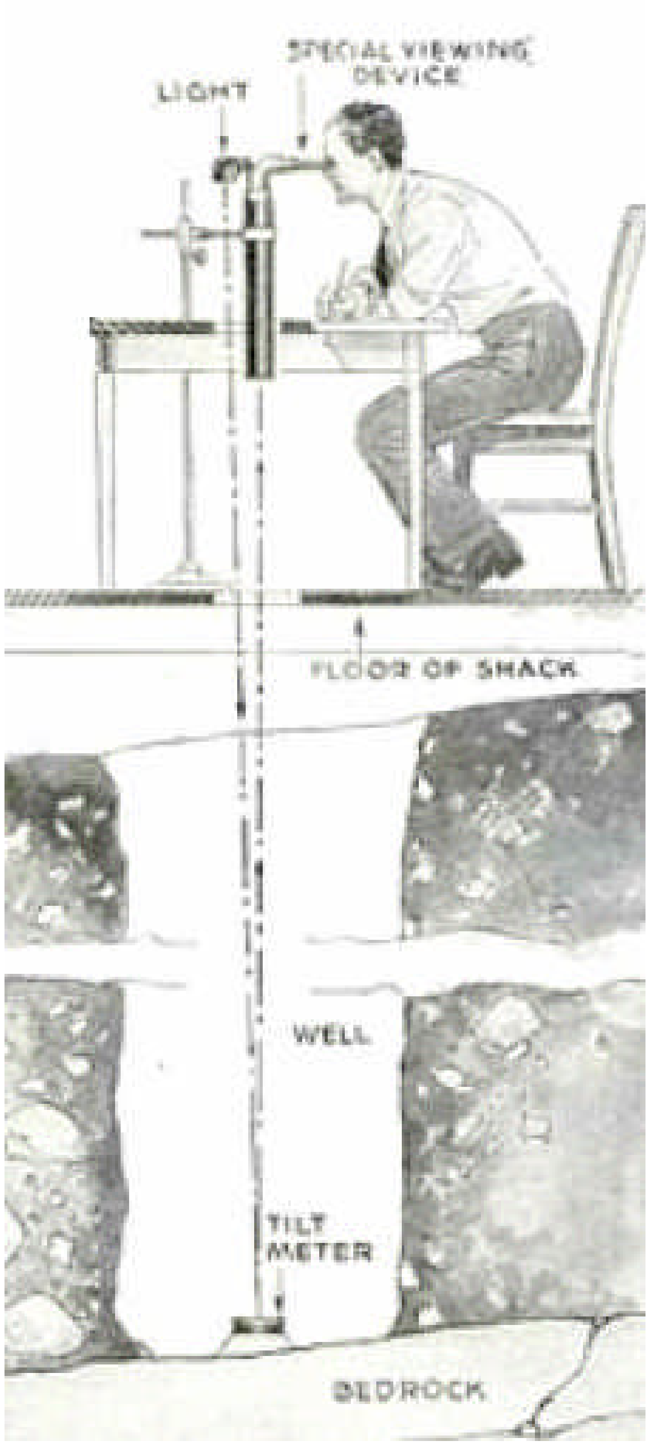
The Tilt Will Tell



“…Also last fall, Prof. Akitune Imamura of the Tokyo Imperial University, announced that Prof. Ishimoto, one of his colleagues, had developed an instrument called the clinograph, which was capable of producing an earthquake warning prior to the shock itself. Prof. Imamura pointed out that a short time before an earth tremor occurs, a slight tilting of the earth’s surface takes place. The clinograph’s function is to detect this…”

***Popular Mechanics,* June 1928**

<u>Above L&R</u>: caption: “Figs. 5A & B - Ferrofluid clinograph realized in fact a tilt transducer able to furnish the information concerning the relative level variations of the ferrofluid located in two communicating vessels, has been experimented in the frame of the laboratory of calibrating and ageing geodynamical apparatus. Analogical or digital information storage. Sensitivity: 10 mV/sec for a signal/noise ratio 40 dB for length of 1 m order.”



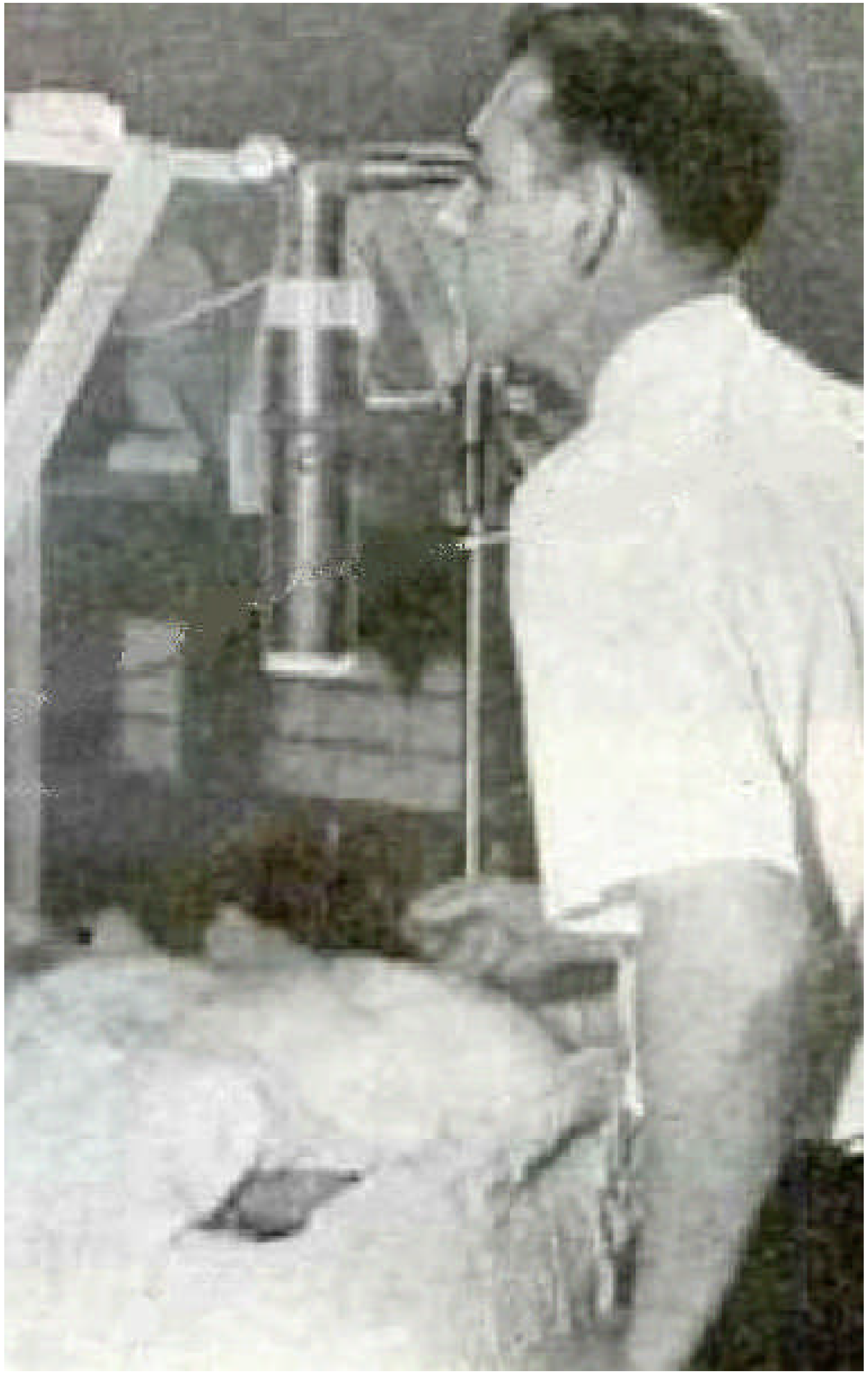
George E. Merritt, **of the** ***U.S. Bureau of Standards*** **in Washington, D.C., surmised that he could predict earthquakes by peering deep within the earth's crust. Several years earlier, Japanese scientists claimed that a tilt took place within the earth's crust months before an earthquake occurred. Using that study, Merritt created his "Tiltmeter," which could note any changes in the earth's crust within one-tenth of a second. Parallel reflecting surfaces (a tray of oil upon a quartz plate) were placed deep within a pit. Light from a helium lamp would reflect the fluid and transmit a beam of light, which would change if/when the earth tilted. Then, the** ***Angle of Misalignment*** **(tilt) could be measured thus determining if it was severe enough to cause an earthquake.**

Left: caption: "Drawing shows tiltmeter in operation. Light from helium lamp hits fluid surface and quartz plate resting on bedrock. Tilt in earth's crust changes angle of light suggest approaching quake."

"…It is known as a tiltmeter and resulted from a discovery made several years ago by Japanese scientists. A short time before the actual quake occurs, they announced, a tilt takes place in the earth's crust. This suggested to Merritt the possibility of developing a machine that would record slight tilting of the earth's crust and warn of an approaching quake…"

***Popular Science,* September 1932**

Left: caption: "Tiltmeter from which light is reflected to warn of an earthquake"



"…Embedded in the earth at the bottom of a pit or well are two parallel reflecting surfaces, a quartz plate and a tray of oil resting upon it. They reflect a ray of light to an operator above who watches through a special device. Any tilting of the earth's crust throws the two reflecting beams out of alignment and produces an effect known as 'interference fringes' by which the angle of tilt can be measured with the optical instrument through which the operator is looking…"

Popular Science, **September 1932**

Left: caption: "George E. Merritt, of the U.S. Bureau of Standards, peering through a special device at light of helium lamp reflected from the tiltmeter"

“…According to the inventor, several of these instruments located at different points in a section of land would give data that would record any warning movements in the entire countryside. In addition to giving warnings of approaching earthquakes, the tiltmeter, Merritt points out, could be employed by engineers in constructing large buildings, dams and bridges to determine earth shifts so structures can be specially designed to resist them.”

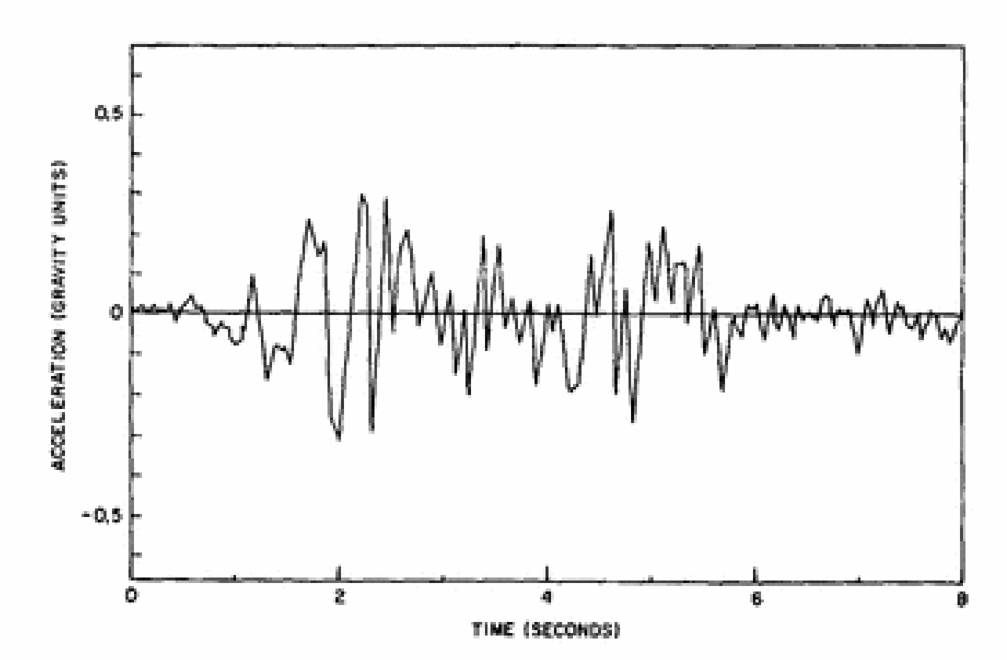
Popular Science, **September 1932**

Similar, But Different

“…Also precise measurements of any earth movement would be accomplished more accurately than ever by using lasers. A laser would be set up on one side of the fault line. A beam of high-intensity light from it would be focused on a line parallel with the fault to a mirror 3,000-4,000 feet away and reflected back into a measuring device. Another beam from the laser would be aimed at another mirror exactly the same distance away, but across the fault line and perpendicular to the first beam. The slightest movement of the earth on either side of the fault could then be detected instantly and analyzed…”

***Popular Mechanics,* July 1964**

Three-Part Trap



“…Meanwhile, science continues to seek the earthquake’s secrets. Captain N.H. Heck, of the United States Coast and Geodetic Survey, lists the accelerograph, the displacement meter and the Weed strong-motion instrument as three parts of the ‘trap’ which the survey is using to detect the strange movements of the earth’s crust. The accelerograph measures violence of shocks, the displacement meter records the distance and speed of the earth’s sway from side-to-side and the Weed instrument traces two components of horizontal earthquake movement with a single pendulum on a moving plate of smoked glass…”

***Popular Mechanics,* July 1933**

<u>Above</u>: caption: “Accelerogram for El Centro, Ca earthquake of May 18, 1940, N-S component”

Seismologists and structural engineers have long been interested in the design of structures that can resist the strong horizontal shaking of the ground during potentially damaging earthquakes. Recordings of this ground motion have successfully provided the data by which building codes, design procedures and strong ground motion research were/are based. Strong ground motion accelerographs (left) recorded on photographic paper, waxed paper and film.

Old Mother Earth

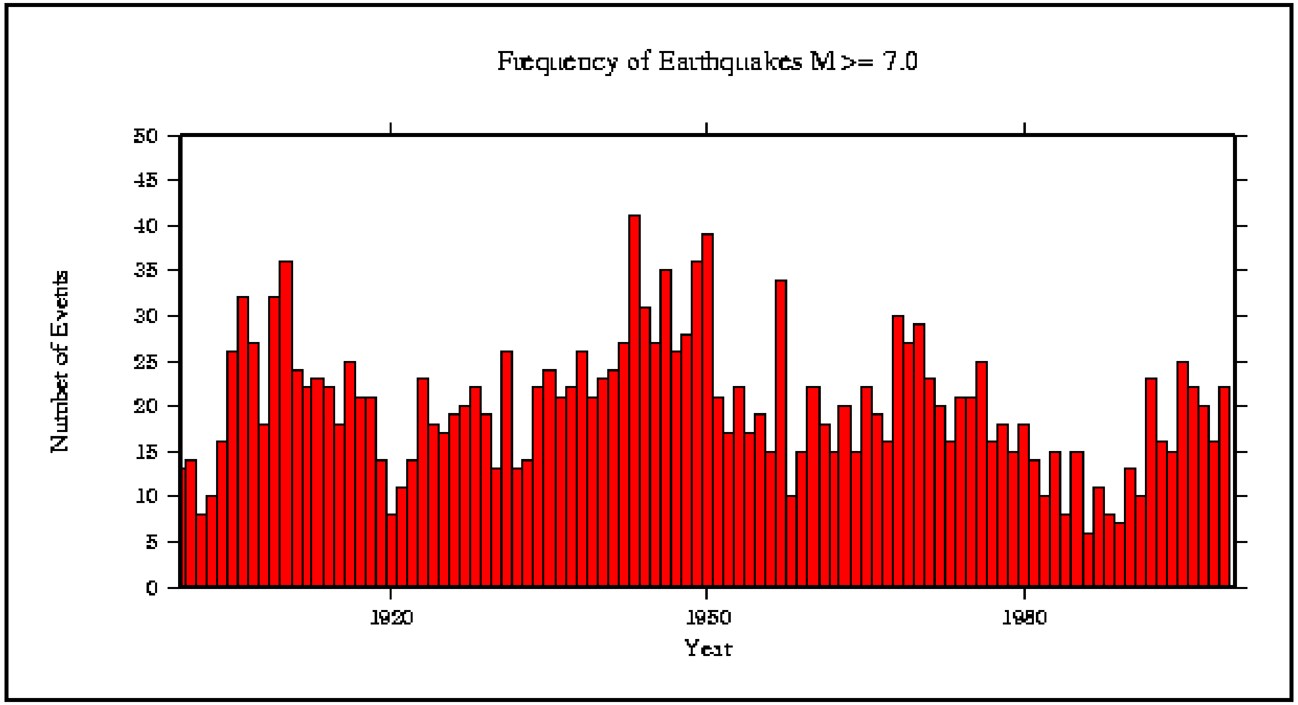
"…Old Mother Earth is never at rest. It is estimated that 30,000 temblors are felt each year, and the delicate scientific instruments record thousands more. Major quakes rock the globe every six or seven days…"

***Popular Mechanics,* October 1939**

“…Because our great cities cover only a fraction of the land surface, major earthquake disasters occur only once or twice a year. The majority of violent shocks occur in mountains, jungles, polar regions, or under seas where they do little damage. When a sharp quake jolts a metropolitan area, however, it may destroy millions of dollars worth of property and take hundreds of lives…”

***Popular Mechanics,* October 1939**

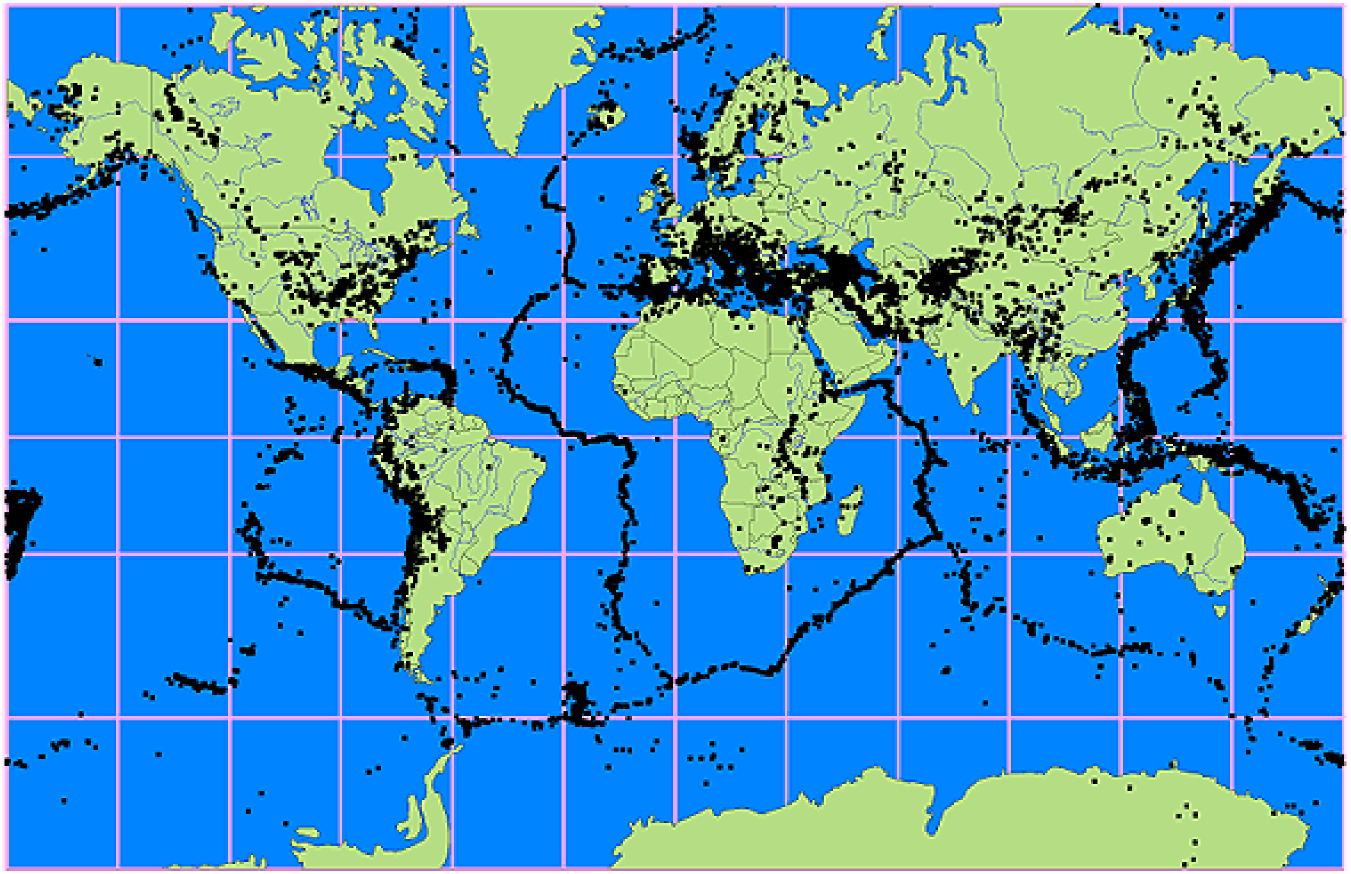
All Earthquakes, Great and Small



"…In all, about twenty-five earthquakes, big and little, take place every day. In a year there about fifty of a destructive nature, but most of them occur beneath the sea. Every time an earthquake of a size worth noticing occurs, about twenty separate reports, from as many seismological stations scattered throughout the United States, speed into Washington in telegraphic code messages. From such reports, the location and intensity of the shock are calculated, and from the studies of the record valuable facts about the interior structure of the earth are obtained…"

***Popular Mechanics*, March 1936**

<u>Above</u>: caption: "U.C. Berkeley - Magnitude 7.0 and greater earthquake events per year, 1899-1999"



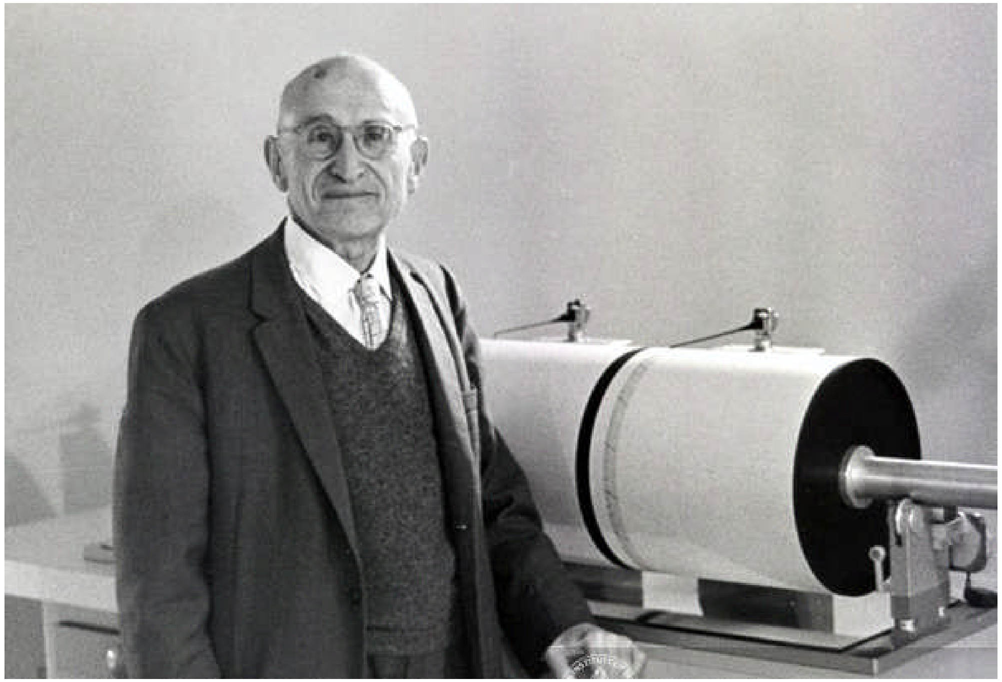
A Concerted Effort

“…In a concerted effort to learn where earthquakes will strike and how to prepare for them, science has established more than 350 seismological stations around the world. About fifty are located in the United States, principally on the Pacific coast and in New England. Two of the best-equipped stations are in California; one on the Berkeley campus of the University of California, the other at Pasadena under the joint sponsorship of the Carnegie Institution of Washington and California Institute of Technology. At Berkeley there are thirteen seismographs under the watchful eye of Prof. Perry Byerly…”

***Popular Mechanics*, October 1939**

SEISMOLOGICAL LABORATORY

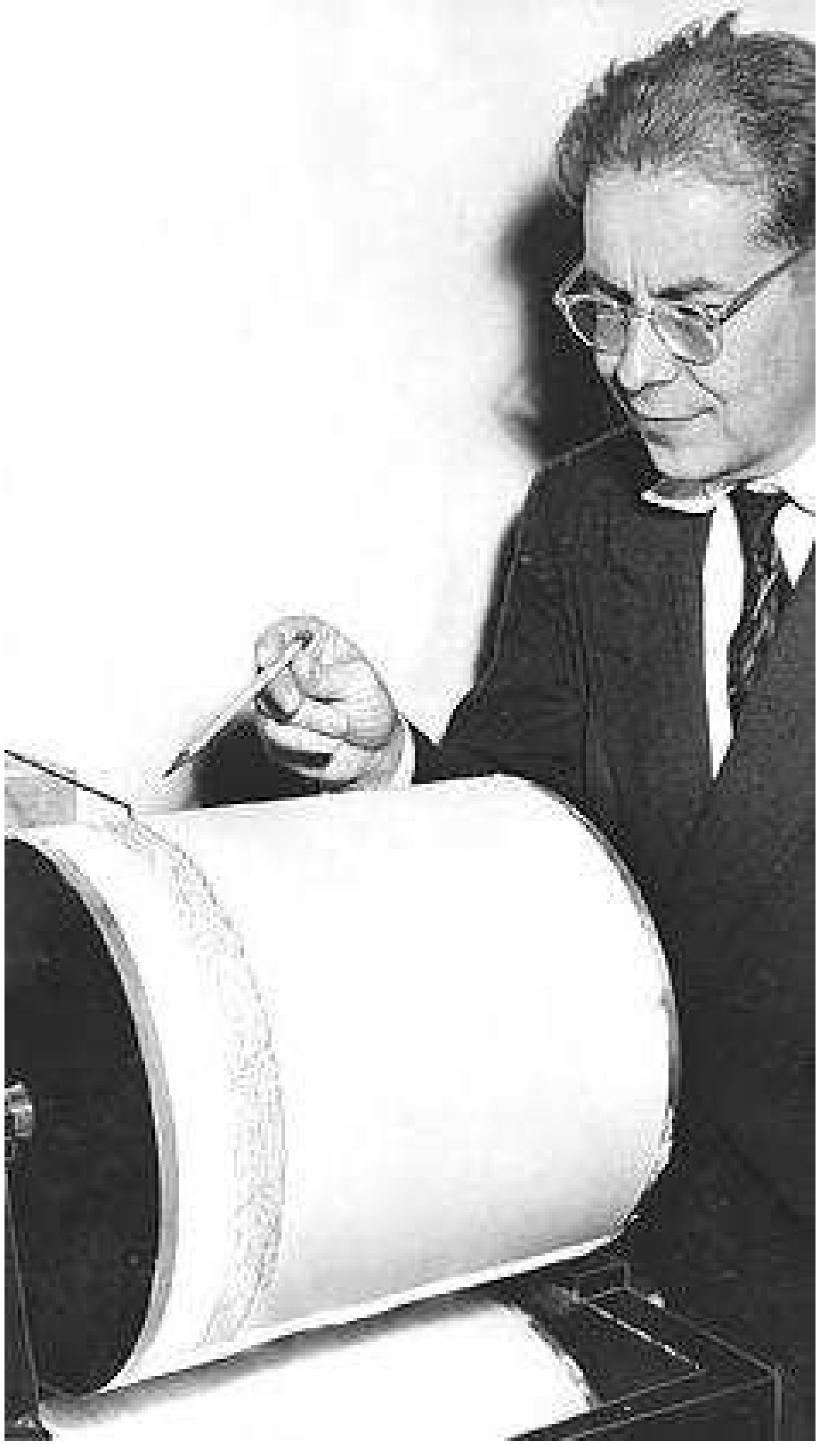
California Institute of Technology



"…The Seismological Laboratory of California Institute of Technology is directed by Prof. Beno Gutenberg. A number of associated stations make daily records and send them to Berkeley or Pasadena. These centers exchange records. Seismologists study the seismograms under the microscope, interpret their zigzag lines, and file the records. The University of California has a library of more than 80,000 seismograms…"

***Popular Mechanics*, October 1939**

<u>Right</u>: caption: "Beno Gutenberg with Seismograph"

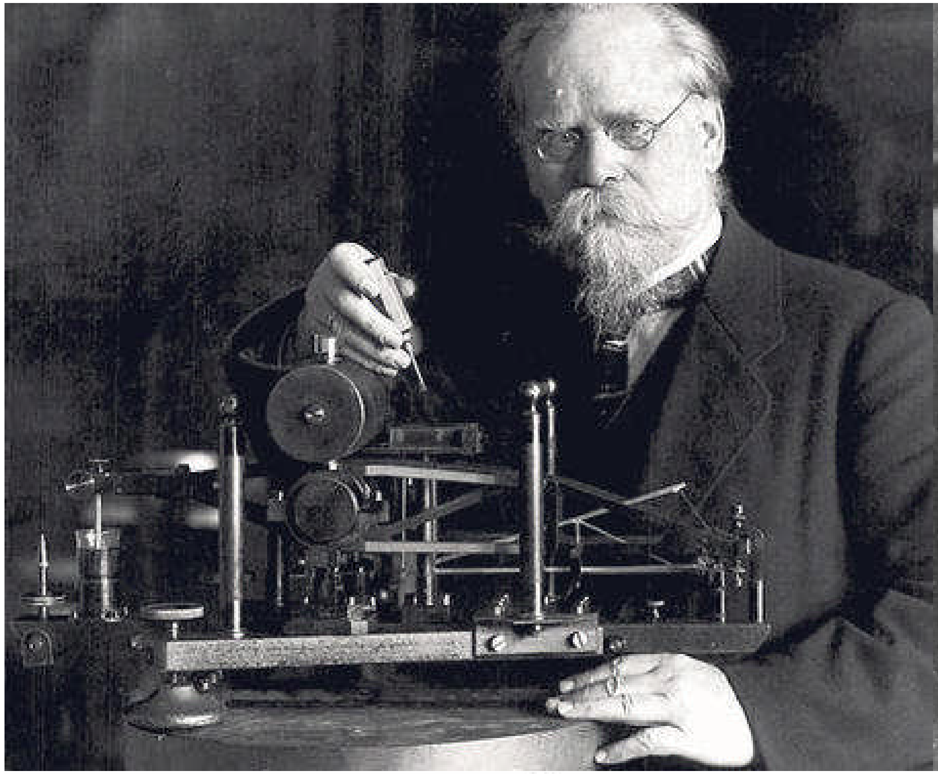


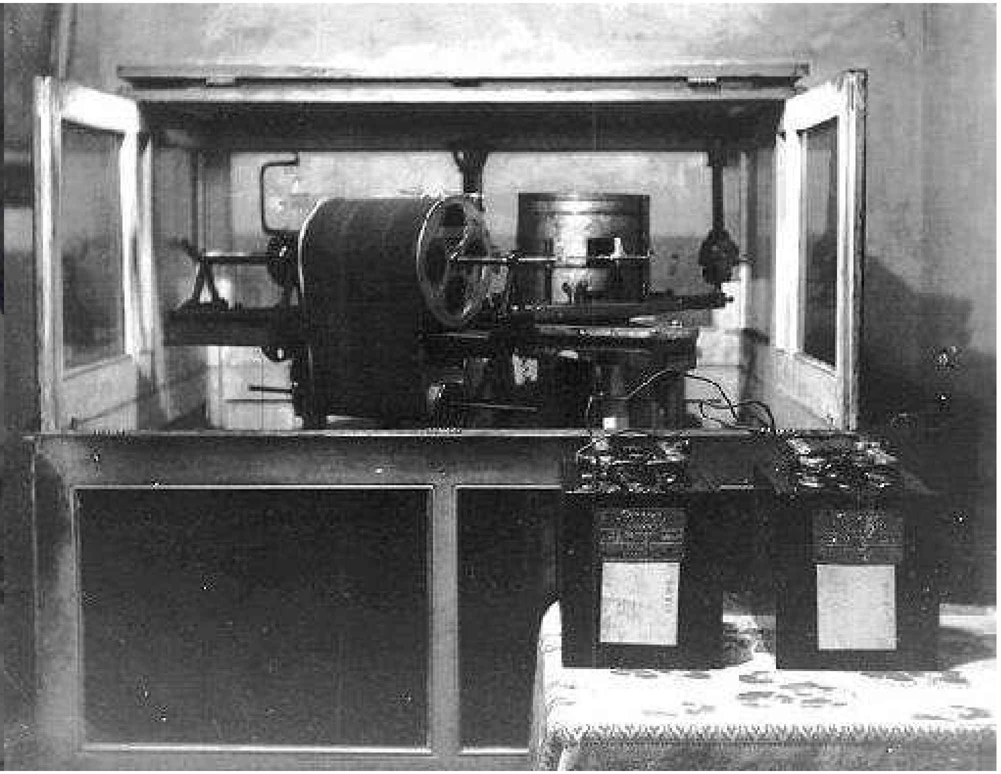
"…Only during the past ten or twelve years have precision instruments been in general use. Seismographs record the time, direction, amplitude, duration, and other characteristics of the tiniest temblor. Some instruments are so delicate that they record traffic vibrations, and footsteps…"

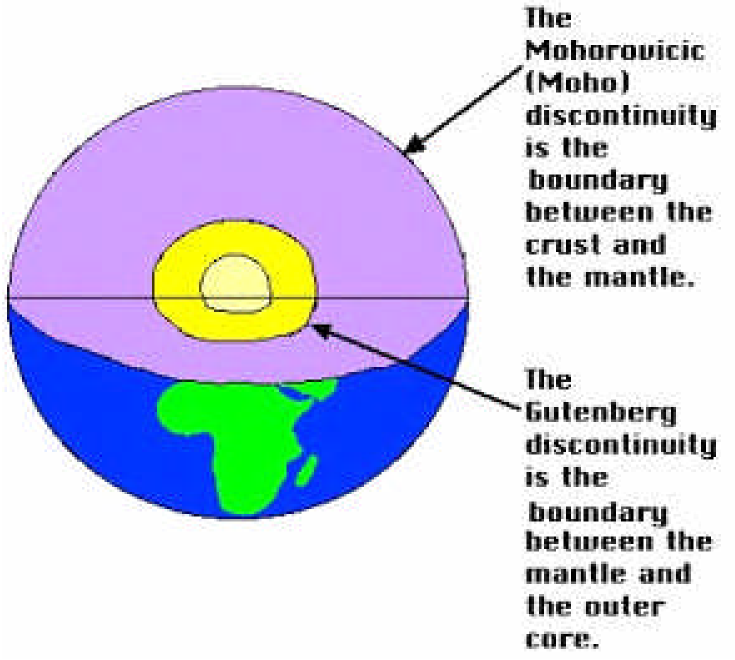
Popular Mechanics, **October 1939**

<u>Left</u>: caption: "Charles F. Richter, Seismologist." ***Charles Francis Richter*** **(along with** ***Beno Gutenberg*****) developed the** ***Richter Scale*****. For many years it was the standard used to measure earthquake intensity and remains synonymous with earth-quakes. However, since the early 1990s, seismologists have preferred the** ***Moment Magnitude Scale*** **to measure earthquake intensity.**

Prussian-born Seismologist *Emil Weichert* (1861-1928) was a founder of one of the world's most distinguished schools of geophysics: the *Geophysical Institute* in Gottingen, Germany. In 1897, after accepting a position at the *Institute for Theoretical Physics* in Gottingen under a former professor, within one year he went on to be named "Extraordinary Professor of Geophysics and Director" of the new Geophysical Institute. There he taught *Beno Gutenberg*, who went on to teach at the *California Institute of Technology* from 1930-1960. Gutenberg determined the "Gutenberg Discontinuity" - a boundary between the lower mantle and upper core of the Earth. Weichert also taught geologist *Karl Bernhard Zoppritz,* who went on to make early charts of earthquake wave travel times (he made charts that included all the different types of waves produced by an earthquake). Weichert's own work included producing a new model of Earth's interior which included a core 1,500-meters thick with a rocky shell (later revised to include an intermediate layer between the mantle and the core). He also invented the improved form of the inverted-pendulum seismograph in 1900 that is still in use today. Wiechert wrote several scholarly papers on various topics throughout his lifetime (one, in 1907, was on the "Propagation of Seismic Waves through Earth"). Weichert also developed a method of geophysical prospecting by means of artificially producing "mini-earthquakes." Not only was Weichert part of the group that founded the *International Association of Seismology* in 1905, he also set up *Geophysical Observation Centers* in German Colonies prior to WWI, which aided in the development of Seismology as a quantitative science.







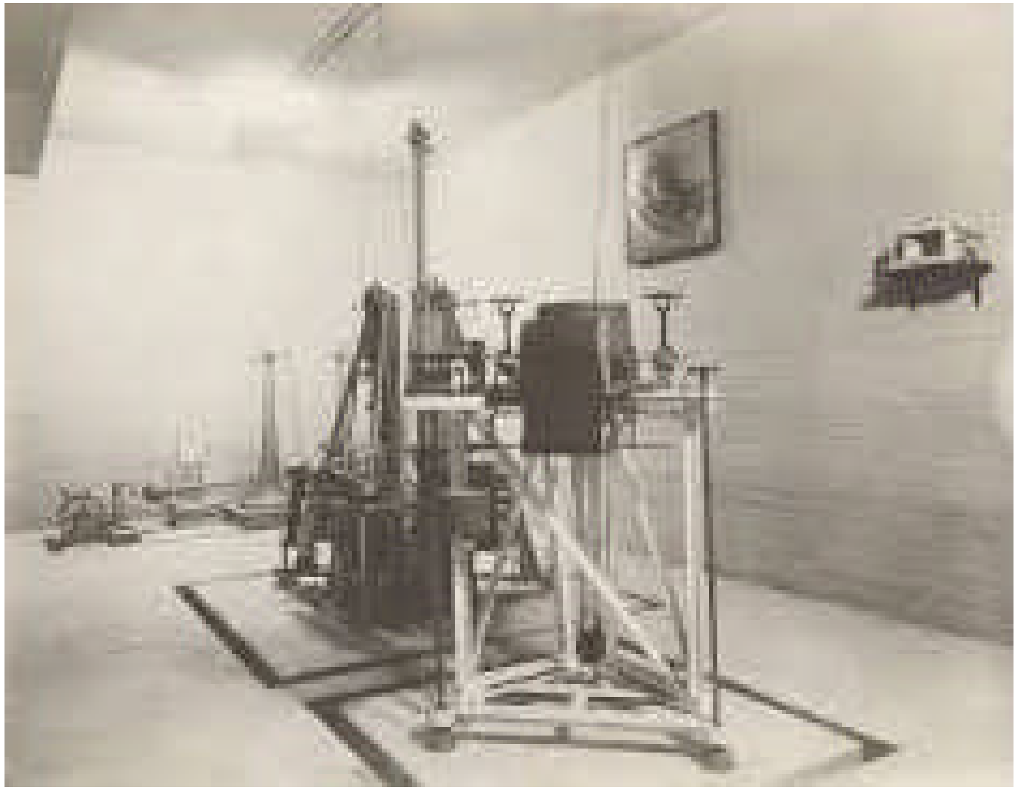
<u>Top Left</u>: caption: “Prof. Emil Weichert, Seismologist
<u>Top Right</u>: caption: “Inverted-Pendulum Seismograph
<u>Left</u>: collaborating with Richter, Gutenberg developed a relationship between seismic magnitude and energy, represented by the equation: log $E(s) = 11.8 + 1.5M$. This gives the energy $E(s)$ given from earthquakes from seismic waves in ergs. Another famous result known as “Gutenberg-Richter Law” provides probability distribution of earthquakes for given energy. He also worked on determining the depth of the core-mantle boundary (a/k/a “Gutenberg Discontinuity,” left) as well as other properties of the interior of the earth.

“…The principal feature of all seismographs is a suspended pendulum which tends to remain motionless even though the frame the frame from which it hangs is severely jarred. Fastened to this pendulum is a delicate pencil, or a mirror which throws a needle-like beam of light. The pen or beam traces the earth vibrations on paper or film, which may be on a revolving drum. When there are no temblors, the pen or beam of light traces a straight line; during an earthquake, the drum jiggles and a zigzag line results…”

Popular Mechanics, **October 1939**

Left: caption: “Seismograph used for recording on film”

Every Which Way



"…Most seismological stations are equipped with three instruments, one oriented to pick up east-west vibrations; another responds to north-south vibrations, and a third, vertical vibrations. These instruments are mounted on concrete piers anchored to bedrock. Most seismological stations also have strong-motion instruments for recording major quakes…"

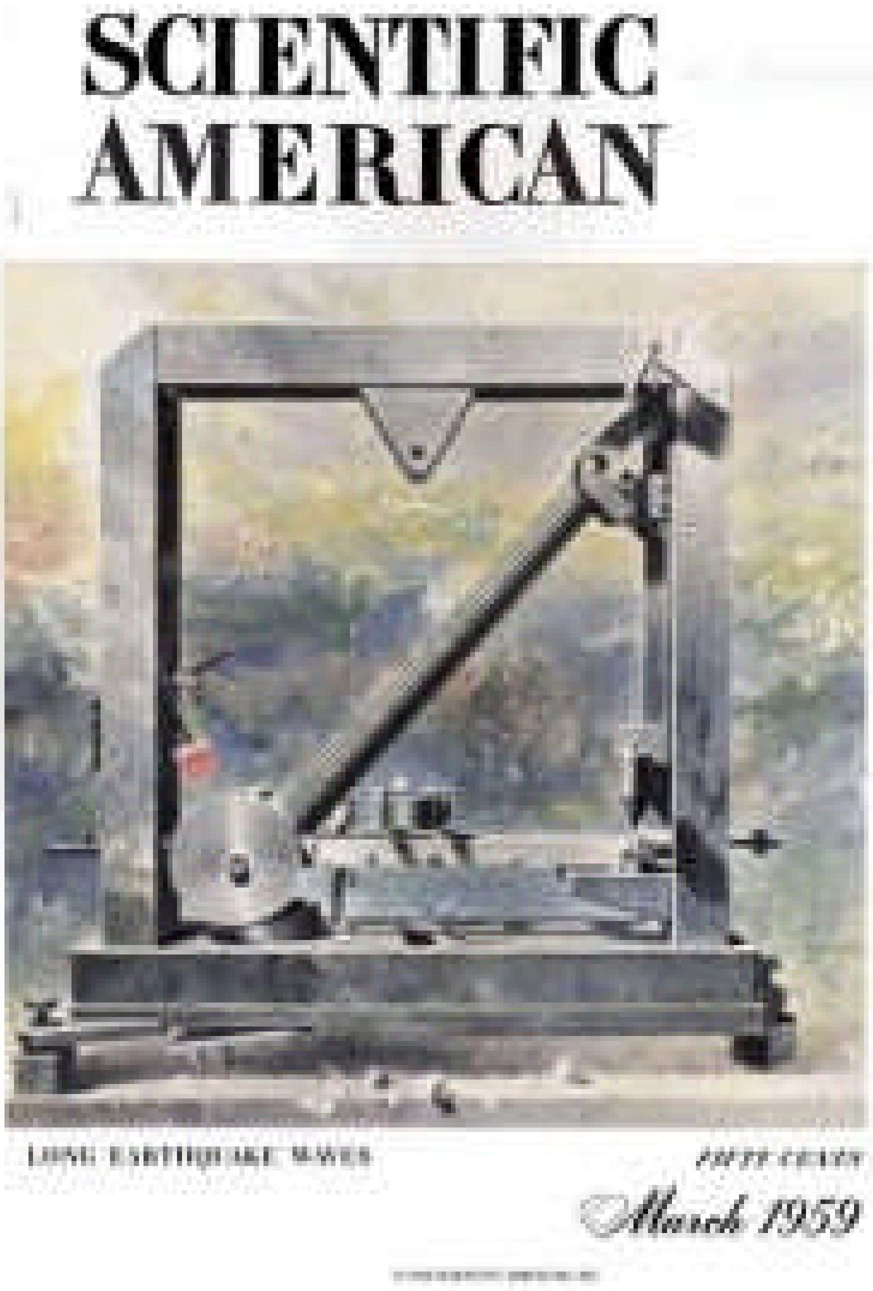
***Popular Mechanics,* October 1939**

<u>Left</u>: caption: "Seismological station at Maguire Hall, Georgetown Univ. Equipment shown (from front-to-back): Wiechert seismograph; Mainka seismograph; Bosch Omori seismographs"

The Long and Short of It

“…Surface shocks arrive at the incredible speed of 7,200 miles an hour and other vibrations may travel three times as fast. Magnetic controls keep the drums turning at constant speed in spite of power fluctuations and earth shocks…”

Popular Mechanics, **October 1939**



In March 1959, a watercolor rendering of the *Press-Ewing Seismograph* appeared on the cover of *Scientific American* magazine (left). *Frank Press* designed the instrument in the late 1940s while he was a Lamont graduate student under Lamont’s founding director, *Maurice* “Doc” *Ewing*. It became the first mass-produced seismograph to accurately record an earthquake’s so-called “long-period” (slow-moving energy waves rippling across the Earth’s surface). Most seismographs until that time were best at measuring high-frequency body waves rocketing through the Earth’s interior. Surface wave recordings by the Press-Ewing helped confirm that oceanic crust was uniformly thin, three to four miles in depth, compared to continental crust, which could be up to twenty-five miles thick.

The *Press-Ewing Seismograph* (top, *Frank Press* at right) was the prototype for the *Sprengnether Seismograph* (bottom), used in the *World-Wide Standardized Seismographic Network* - the first global seismic network, built to detect *Cold War* nuclear explosions. The Press-Ewing owed its basic design to the 1904 electromagnetic seismograph invented by Russian Prince *Boris Galitzen*. A magnet and wire coil allowed Galitzen’s instrument to record a friction-free electric signal on photographic paper, improving on its mechanical predecessors. In 1934, a *University of Texas* undergraduate, *Lucien Lacoste,* invented the *Zero-Length Spring* that made the detection of ultra-slow earthquake waves possible. The spring had to be soft yet extremely stable. Thus, the triumph of the Press-Ewing may have been its use of a special alloy that gave this critical part those properties.

“Before the Press-Ewing, seismographs were not standardized and more difficult to run. As a standardized network grew up, you could see the earthquakes lining up in clear patterns. Any school kid could look at a map of the world’s earthquakes and see the plate boundaries.”

***John Armbruster*, Lamont-Doherty Seismologist**

RE: the Press-Ewing’s unique glass sphere was designed to eliminate the influence of atmospheric pressure but it was dropped from its successor, the Sprengnether (essentially a simplified and slightly smaller version of the Press-Ewing) because it did not work particularly well. By 1953, the instrument was recording earthquakes from stations in Bermuda, Pennsylvania and Western Australia. By the 1960s, earthquake data coming from the *Press-Ewing Seismograph* would help prove the theory of plate tectonics; that slow-moving plates at the Earth’s surface generated earthquakes in the process of building mountains, ocean basins and continents. *Erhard Wielandt*, inventor of the *Broadband Seismometer* stated: *“The design of the Press-Ewing set the standard for long-period seismometers until electronic feedback seismometers came up.” Frank Press* went on to become a leading Earth Science researcher, science adviser to POTUS *Jimmy Carter* and author of a popular Geology textbook.

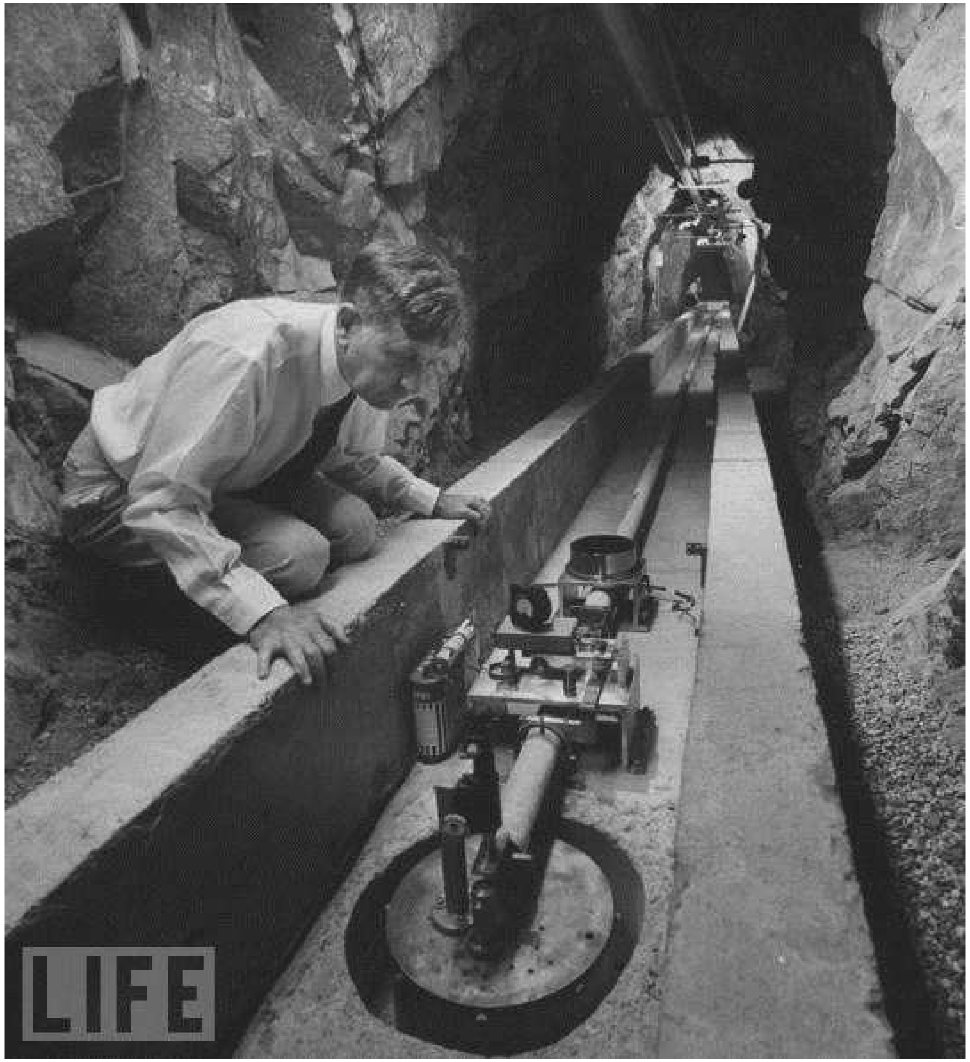
A Knack for Invention

“…No one has yet found a way of accurately predicting when an earthquake will occur, though Caltech seismologists hope a new instrument they are using may eventually lead to accurate forecasts. The new device is so sensitive that it can record a strain of one part in 100 million – equal to a one-inch squeeze between the two coasts of the United States. The instrument consists of a 79-foot length of two-inch fused quartz tubing that is installed in a tunnel in a granite mountain near Glendora, about 25 miles from the San Andreas fault…”

***Popular Mechanics*, May 1958**

"…The tubing is held in the tunnel by a number of flexible supports, with one end rigidly fixed to a pier sunk in the rock. The other is free to move, and any movements are amplified and recorded by electronic apparatus. Any such movements, of course, represent contractions or expansions in the granite itself. The instrument is called a secular linear-strain seismograph. Among other things, it is able to measure the tidal strains in the crust produced by the sun and the moon, and measure and record long-period seismic waves that are not detected by other types of seismographs. Over a period of time it will indicate the strains accumulating in the rock at its location. Eventually, with a network of such machines and with new knowledge gained from operating them, the time and place of a future earthquake may be predicted with accuracy…"

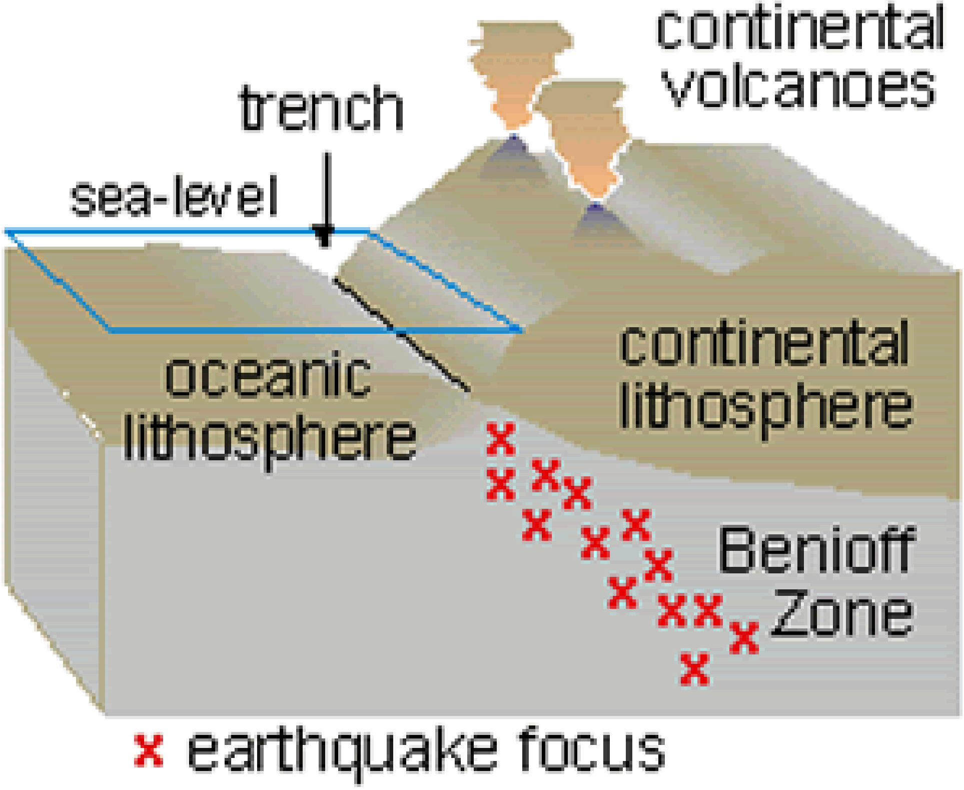
***Popular Mechanics,* May 1958**



***Hugo Benioff* had a knack for inventing and solving problems with instrumentation. Born in Los Angeles, CA in 1899, at 14yo Hugo decided he wanted to be an astronomer. Benioff graduated AB from Pomona College in 1921, after which he worked as summer assistant at *Mount Wilson Observatory* during his undergraduate years. He worked for one year as an astronomer at the *Lick Observatory*, but didn't like the nights and the cold. In 1924 he began working as an assistant physicist with the Carnegie Institute's seismological program. He earned his Ph.D. from the *California Institute of Technology* in 1935. Benioff, along with colleagues *Beno Gutenberg* and *Charles Richter* made the Caltech's *Seismological Laboratory of Pasedena* the epicenter of world geophysical research.**

Left: caption: "Benioff measuring strain on one of his instruments in 1957"

Hugo Benioff **built a working vertical seismometer and helped get many others to work properly. The *Benioff Seismometer* (1932) is now used worldwide. He started placement of seismometers that eventually became the *Caltech Seismic Network*. However, Benioff is most famous for his study of earthquake-focus depth in the *Pacific Ocean*. Deep-focus earthquakes associated with subduction zones bear the names of Benioff and *Kiyoo Wadati* (a Japanese seismologist who wrote several papers before 1936 on earthquake travel-time, deep-focus earthquakes and the planar zone of these earthquakes near trenches beneath volcanic island arcs). Wadati was the first to recognize the relationship, but it was Benioff who proposed that it was due to subduction of the seafloor (thus, the favored term for these zones is: "Wadati-Benioff Zones"). Normally, the mantle is not brittle enough to allow sufficient strain to accumulate for an earthquake. Therefore, most of the world's earthquakes are confined to the region of the upper earth known as the *Lithosphere*. The Lithosppere varies in thickness, but is generally about 100 km thick. The Lithosphere consists of crust and rigid upper mantle (chemically the same as the deeper mantle, but it behaves like the brittle crust above due to lower temperature and pressure). Continental crust averages about 35 km thick, while ocean crust is only about 5 km thick.**



In the diagram above, *Lithosphere* is represented in brown. This is where almost all earthquake foci are found. The exceptions occur beneath volcanic island arcs and volcanic mountain chains and near trenches. Therefore, Benioff concluded that the ocean crust, still rigid, is being subducted and is responsible for the deep focus earthquakes down to about 700 km.

“…Since a simplified design and a greatly reduced cost of a linear strain meter (Benioff, 1959, 1963) would make possible the proliferation of such instruments over many active regions, the Seismological Laboratory of the California Institute of Technology has placed in operation a strain-measuring instrument of semi-portable design. Through the generous co-operation of the U.S. Coast and Geodetic Survey, space was made available for this installation in the Kipapa tunnel, site of the World Wide Standard Seismograph Station in Hawaii. This tunnel, driven into the side of Kipapa Gulch I00 feet below the rim, is located on the island of Oahu in a region of weathered basalt. The strain tube is 24.4 meters long, in a direction 61.1-degrees west of north and is placed toward the far end of the 220 foot tunnel. In addition to observations of long waves and free oscillations, measurements of mid-oceanic earth tides and a possible cor-relation between secular strain on Oahu and movements of the magma beneath the island of Hawaii will be of particular interest….”

Bulletin of the Seismological Society of America, **December 1965**

Above: caption: "General view of Kipapa strain meter, excluding free end termination and pier. Device at center, below quartz, is test signal apparatus."

Left: caption: "Hinge and clamp structure carrying sample of quartz tubing. Weight of quartz produces pinching action of flexible strap by forcing wedge-shaped terminations against adjusting screws. Position of quartz may be shifted vertically or laterally by these screws before final clamping (single bolt, upper center)."

Multi-Faceted

“…A presidential commission headed by Frank Press of the Massachusetts Institute of Technology has recommended a 10-year program costing $137 million to achieve an earthquake-predicting system that would approach the accuracy of weather forecasting…”

***Popular Mechanics,* June 1967**

“…Other earthquake-research projects presently directed toward improved forecasting and reporting include:

- ***Use of the Earth Resources Observation Satellite equipped with remote sensing devices and telemetry to analyze faults and other surface features associated with changes in the structure of the earth’s crust;***
- ***New instrumentation including lasers that can detect a change in land elevation of as much as a quarter of an inch over a 10-mile span, tiltmeters, and gravity and strain gauges to record bending and compressing of sub-surface rock;***
- ***A supercluster of 525 instruments distributed over a 150-square-mile area of Montana sensitive enough to detect an explosion of 200 tons of chemicals in the Atlantic Ocean;***
- ***Establishment of a National Earthquake Information Center at Rockville, MD., on the northwestern outskirts of Washington, D.C., with an early-reporting system linked with reporting stations in many parts of the world…”***

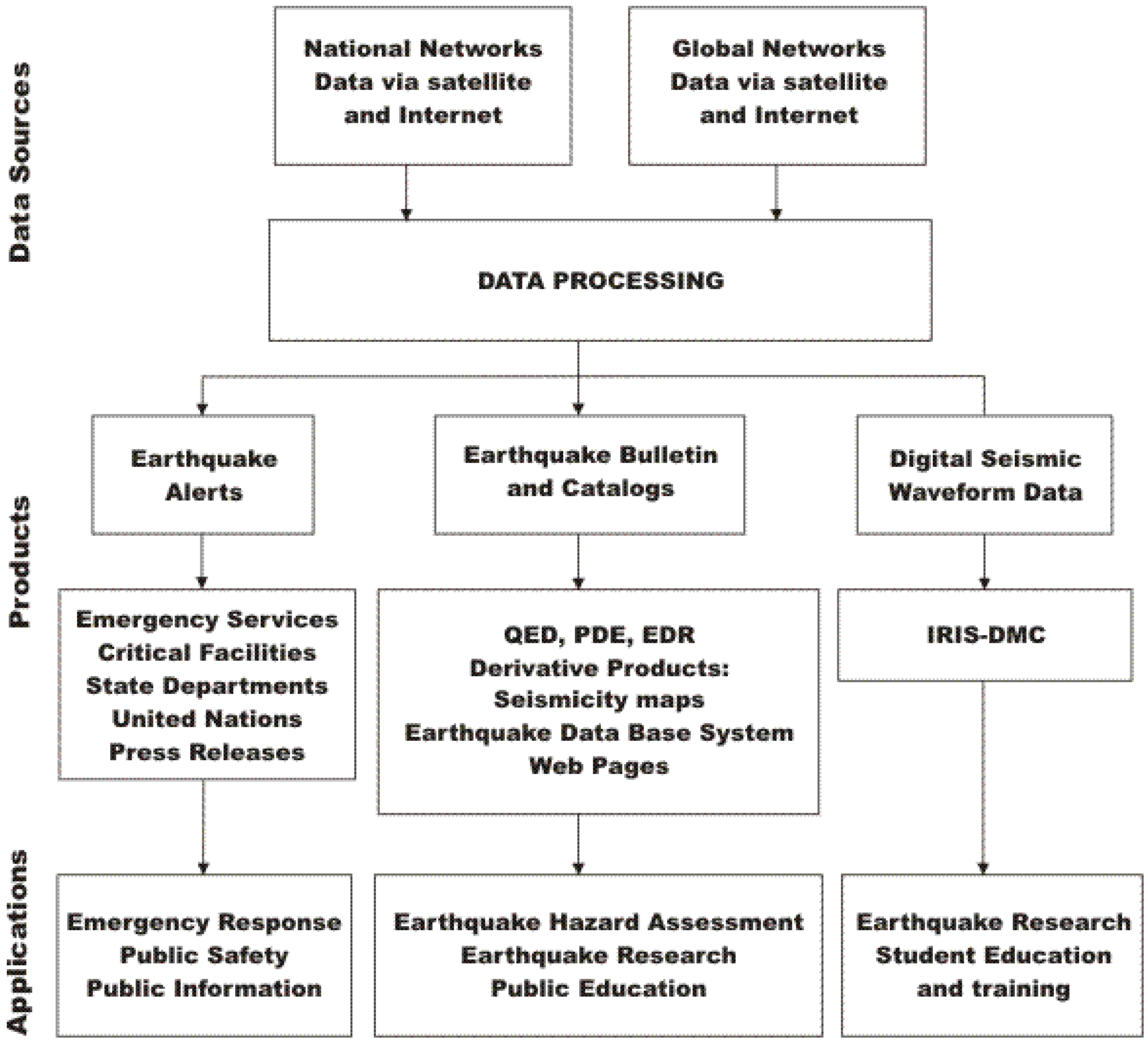
***Popular Mechanics,* June 1967**

RE: the *National Earthquake Information Center* (NEIC), was established in Rockville, MD., in 1966 as part of the *National Ocean Survey* (NOS) - Dept. of Commerce. The *U.S. Coast and Geodetic Survey*, a forerunner of the NOS, had coordinated the collection of seismological data in the U.S. for many years. The NEIC was transferred to Boulder, CO., in 1972 and made part of the USGS in 1973. In 1974, the NEIC was moved to its present location in Golden, CO.

The NEIC, a part of the *Department of the Interior*, USGS, is located in Golden, CO (10 miles west of Denver). The NEIC has three main missions:

- **First, the NEIC determines, as rapidly and as accurately as possible, the location and size of all significant earthquakes that occur worldwide. The NEIC disseminates this information immediately to concerned national and international agencies, scientists, critical facilities and the general public;**
- **Second, the NEIC collects and provides to scientists and to the public an extensive seismic database that serves as a solid foundation for scientific research, principally through the operation of modern digital national and global seismograph networks and through cooperative international agreements. The NEIC is *the* national data center and archive for earthquake information;**
- **Third, the NEIC pursues an active research program to improve its ability to locate earthquakes and to understand the earthquake mechanism. These efforts are all aimed at mitigating the risks of earthquakes to mankind. They are made possible by international cooperation that has long characterized the science of seismology.**

National Earthquake Information Center



Data Sources

National Networks Data via satellite and Internet

Global Networks Data via satellite and Internet

DATA PROCESSING

Products

Earthquake Alerts

Earthquake Bulletin and Catalogs

Digital Seismic Waveform Data

Emergency Services
Critical Facilities
State Departments
United Nations
Press Releases

QED, PDE, EDR
Derivative Products:
Seismicity maps
Earthquake Data Base System
Web Pages

IRIS-DMC

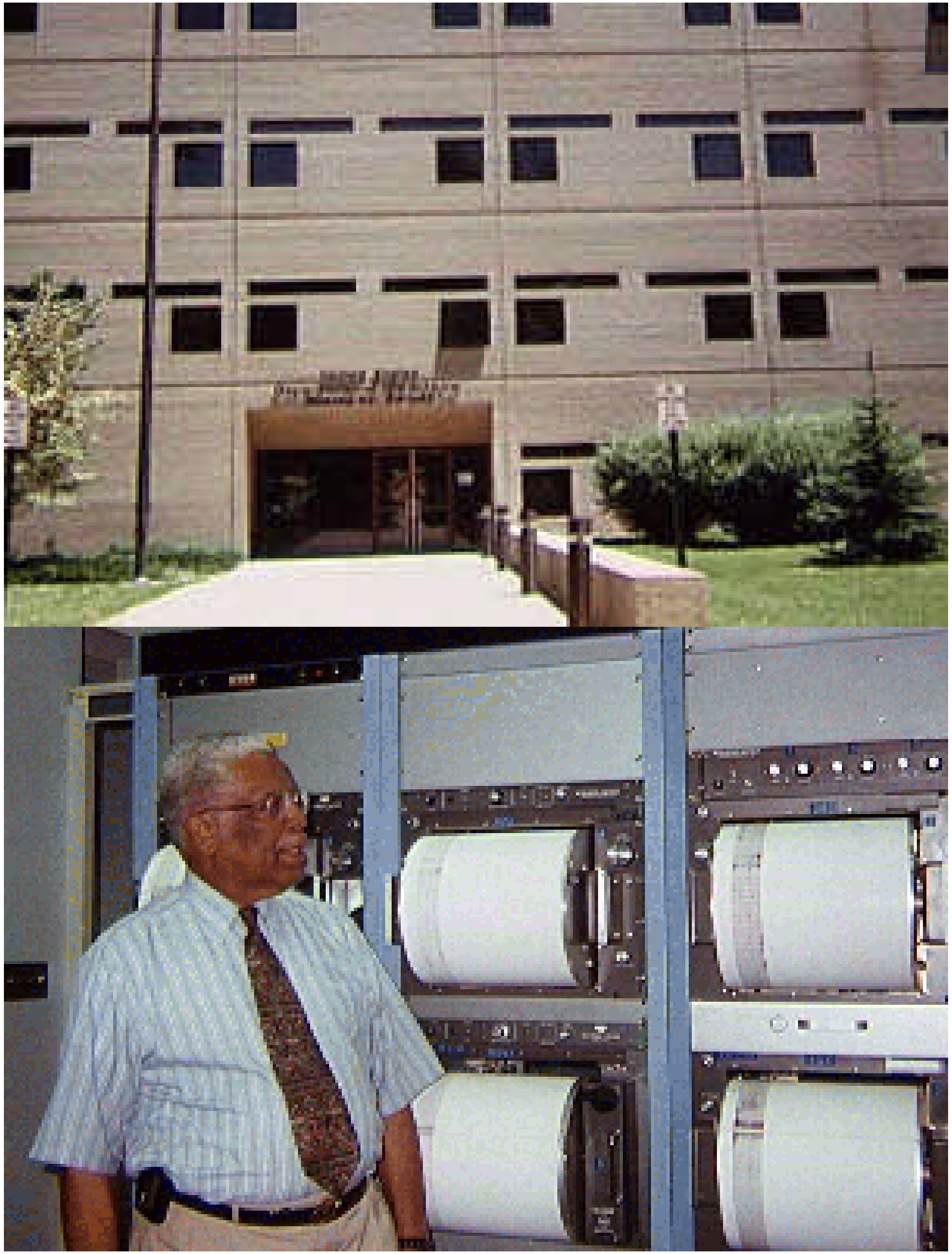
Applications

Emergency Response
Public Safety
Public Information

Earthquake Hazard Assessment
Earthquake Research
Public Education

Earthquake Research
Student Education
and training

The NEIC collects data through the operation of national and global networks and through cooperative agreements. To enable the detection and location of all felt earthquakes with the U.S., the NEIC acts as the *National Operations Center* of the *A̲dvanced N̲ational S̲eismic S̲ystem* (ANSS), a cooperative venture between the NEIC and the operators of the regional seismic networks across the U.S. The NEIC also relies on the cooperation of a variety of seismic reporting networks throughout the world to gather data and collects non-instrumental reports of the effects of earthquakes on people and man-made structures and prepares isoseismal maps showing the distribution of intensities in widely felt or damaging shocks. The data that is collected by the NEIC is published in a variety of formats and publications and are available electronically via the Internet. The *Q̲uick E̲picenter D̲eterminations* (QED) - a very preliminary list of earthquakes, is computed daily. The *P̲reliminary D̲etermination of E̲picenters* (PDE) is published weekly and monthly. The *E̲arthquake D̲ata R̲eport* (EDR), also a monthly publication, provides additional and more detailed information, mainly for the use of seismologists.



The NEIC operates a 24-hour-a-day service to determine the location and magnitude of significant earthquakes in the U.S. and around the world as rapidly and accurately as possible. This information is communicated to federal and state government agencies who are responsible for emergency response, to government public information channels, to national and international news media, to scientific groups (including groups planning after-shock studies) and to private citizens who request information. As well, a wide range of research is also conducted at the NEIC. Investigations range from resolving the internal structure of the Earth and understanding the mechanics of earthquake rupture through rapid assessment of an earthquake's impact. These research efforts are intended to improve the data service provided by the NEIC to the scientific community and the general public and, ultimately, to aid in earthquake hazard mitigation.

A Worthwhile Endeavor

“…Even though earthquakes cannot be predicted, science feels that it is not wasting its time by watching the pulse of old Mother Earth. Fault lines may be located and avoided by builders. The effect of quakes on different types of soil has been discovered. Field observations and laboratory tests determine the best way to fortify skyscrapers and apartment houses against the sudden attack of temblors.”

***Popular Mechanics,* October 1939**

A Centuries-Old Menace

"…While earthquakes are sure and inevitable as the daily rise of the sun, it is beginning to look as if man, with his ever-increasing knowledge about them, may one day win his battle with the centuries-old menace."

***Popular Mechanics,* June 1928**

Part 8

Quake-Proof Construction

Ever Since the World Began

"…The movement in America in recent years urging the serious study of the art of earthquake-proof construction is, after all, an echo from the ancients. The earthquake menace has been present ever since the world began cooling off. Pharoah Cheops, who achieved the famous pyramid at Gizeh, without a doubt built it because he wanted a final resting place that withstand the ravages of earth tremors. For a similar reason, the Mayas of Central America built pyramid-shaped temples of unusually thick walls…"

***Popular Mechanics*, June 1928**

The Blame Game

“…Results of the recent disaster and of many previous occurrences like it, have proved that fires, gaining rapid headway in crumbled buildings, have frequently caused more damage than the actual vibrations of the earth. A type of construction that will be immune in heavy shocks is sought by builders in countries where such disturbances are likely to occur.”

***Popular Mechanics,* March 1924**

“…Following the Japanese shock, Dr. Bailey Willis, emeritus professor of geology at Stanford University, asserted unequivocally that man and not nature is to blame for the disastrous consequences of earthquakes in localities like Japan, Chile, where he had been investigating causes of earthquakes for the Carnegie Institution of Washington, D.C. He pointed out that it is not the earthquakes themselves – the actual ground tremors – that cause the frightful loss of life, but the events that follow the quakes – the falling of masonry, the fires, the floods from reservoirs and similar things…”

***Popular Science*, December 1923**

“…‘To construct a house that will withstand an earthquake is not difficult if you can command the right materials and good carpenters,’ says Doctor Willis. ‘A point that has not been recognized generally by architects or engineers is that it is the earth that moves, while the house tries to stand still. If you could put a ball bearing between your house and its foundations, it would be safe in time of earthquake. This idea is embodied in every instrument for recording earthquakes and was applied many years ago by Sir John Milne to the construction of a lighthouse in Japan. I believe it can be introduced successfully in some combination of bearings, springs, or shock absorbers. For the ordinary house a broad ditch packed with cobblestones on which there rests a well braced frame of heavy beams would not be a bad substitute. It would allow the ground to slide around under the house, which could be jacked back into position with reference to such unstable things as trees, garden walks, and roads at your convenience’…”

***Popular Science*, December 1923**

Upon Weak and Shifting Sands

“It is said that San Francisco is a city built on sand. It has also been predicted that some day an earthquake will sink it below the sea. The first statement may be modified to one-half of the city being built on sand; but as to the second, practical observation of our great recent earthquake has given us greater and wider scientific ideas as well as more confidence in building on the sand…”

***Popular Mechanics,* June 1906**

“…Long experience in San Francisco has proved that sand may be cultivated, irrigated, excavated and built upon much cheaper, and with as good and in some cases better, results than building on other materials…It is by far more satisfactory to build on sand where it is stationary, than any other material…”

***Popular Mechanics,* June 1906**

"…In places like San Francisco, where we have frequent earthquakes, it is very advisable to build on sand. This statement may sound somewhat absurd, but here is the reason for it: In the great San Francisco earthquake that destroyed much of the city, April 18 last, it was found that the greatest destruction to buildings was in places where the foundations were on solid materials. The western section of the city, which was almost entirely built on sand, suffered very little loss. Why?..."

***Popular Mechanics,* June 1906**

<u>Above</u>: caption: "San Francisco set ablaze as a result of the April 1906 earthquake"

THE CITY OF SAN FRANCISCO, PARTIALLY DESTROYED BY EARTHQUAKE AND FIRE

PANORAMIC VIEW OF THE CITY AND HARBOUR FROM NOB HILL

The Palace Hotel, which stood at the [illegible] corner of Market Street and Montgomery Street, was destroyed by fire. [illegible] Lotta's Fountain, shown in the foreground, was at the corner of [illegible] Street and Market Street.

THE PALACE HOTEL AND LOTTA'S FOUNTAIN

THE COURT OF THE PALACE HOTEL

This building, one of the finest in America, which cost £1,500,000, was wrecked. The dome is the largest in the world, with the exception of St. Peter's, Rome. It fell like a pack of cards.

THE CITY HALL

One feature of the disaster is causing satisfaction, and that is that the modern buildings withstood the earthquake shock almost perfectly. The interiors were wrecked but the walls stood. A notable example is the "Call" newspaper building, shown on the right of our picture, twenty stories high, which remains [illegible] intact. This is the tallest building in San Francisco, and in practically every instance the steel framework of the big buildings successfully withstood the shock. To the left is the "Chronicle" newspaper building, which escaped [illegible], and the newspaper proprietors have agreed to combine forces and to issue a joint newspaper from the "Chronicle" offices.

THE "CALL" AND "CHRONICLE" BUILDINGS

The old Mission Dolores, at the corner of Dolores and 16th Streets, is an adobe edifice built by the Spaniards in 1776.

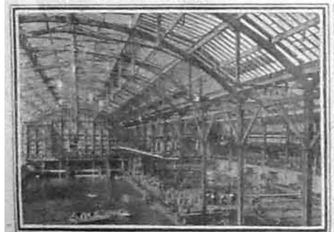
THE MISSION DOLORES

This house, which cost 300,000 dols., stood in Van Ness Avenue. This residential quarter, to the north of Market Street, was swept by fire, and little was left untouched.

MR. CLAUS SPRECKELS'S HOUSE

This museum, which is one of the most conspicuous features of the famous Golden Gate Park, escaped injury.

AN ART MUSEUM UNINJURED



The Sutro Heights, overlooking the Golden Gate, are famous as a pleasure resort. The Sutro Baths are very large and handsome, and though the structure is iron and glass, it escaped damage.

THE INTERIOR OF THE SUTRO BATHS

Market Street is a great thoroughfare [illegible] the whole city diagonally from the sea to the heights. On both sides of the street enormous damage has been done by fire.

VIEW OF MARKET STREET, LOOKING EAST

These mansions, from left to right, Crocker, Huntington and Flood, are situated in California Street, a cable road running up Nob Hill. How much damage has been done here is not yet known.

THE RESIDENCES OF RAILWAY AND BONANZA KINGS

This large open space extends from the middle of the city to the sea. It is now being used as a camping ground for the refugees.

GOLDEN GATE PARK

The destruction of China Town was accompanied by scenes of indescribable terror. After the first earthquake shocks the whole population—numbering some [illegible]—rushed into the street beating gongs, and when the fire approached from the harbour district they fled [illegible]. Some of the wealthy Chinese, who refused to leave their shops, were burned to death, and many other lives were lost in the rickety tenements occupied by the poorer class of Chinese and their families. In the lower quarters of the town the Chinese and Italians fought with each other madly till the Federal Infantry charged them with fixed bayonets, killing a number of them.

A GLIMPSE OF CHINA TOWN

[illegible] California, the population of San Francisco was [illegible]. In [illegible] it was [illegible].

SAN FRANCISCO IN 1849

The population last year was approximately [illegible], and the area of the city had extended to some fifty square miles.

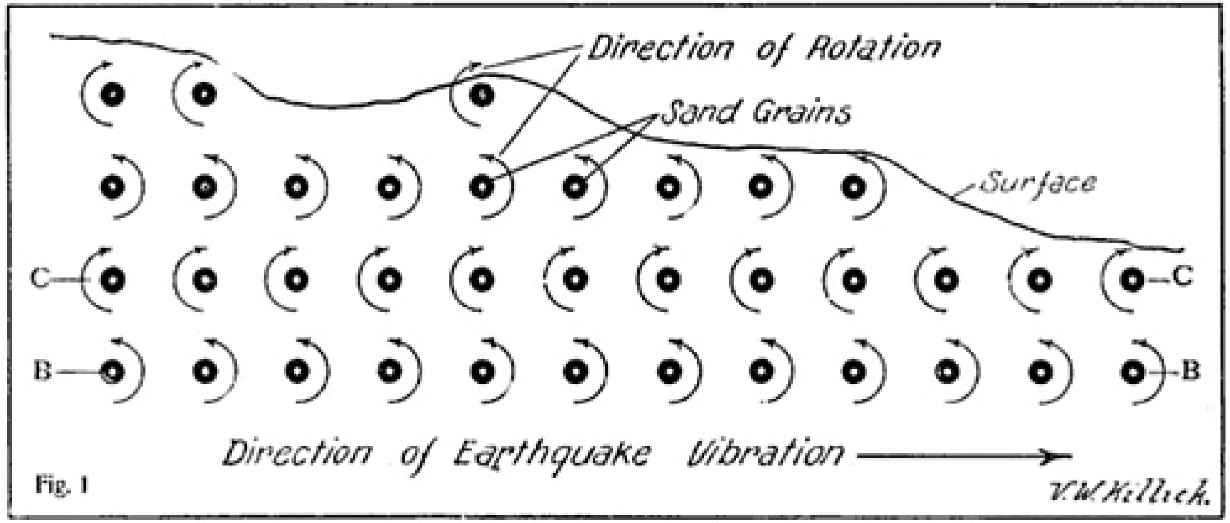
SAN FRANCISCO IN 1906

Union Square lies to the north of the Market Street, to the west of the [illegible], and immediately south of Nob Hill and China Town. It forms practically the centre of the burnt-out quarter. The view here shown is from Geary Street.

UNION SQUARE, NOW A SCENE OF HAVOC

The popular seaside resort was situated on the extreme western limits of the city on a cliff at the entrance of the Golden Gate [illegible] feet above the sea. It lies just below the famous Sutro Heights. This handsome building escaped serious damage, and was offered for the use of the homeless people.

THE FAMOUS CLIFF HOUSE



Showing Effect of Earthquake on Sand

“…Look at the diagram (Fig. 1). The large arrow indicates the direction of an earthquake vibration. Now, in the case of solid material this vibration affects the mass as a whole, but in sand the vibration affects the mass in layers. As the vibration moves forward a small belt or layer of sand, represented by the dotted line, B, separates, as it were, from the main body and the grains of sand in the layer commence a rotary motion, the direction of which is represented by the small arrows. By this motion the whole layer moves slightly forward. The next strata or layer above, see dotted line, C, is in its turn disturbed by the movement of the layer of sand beneath it. A rotary motion is caused in the grains of sand, but the rotations are in a direction opposite to that of the layer beneath…”

***Popular Mechanics*, June 1906**

<u>Above</u>: caption: “Fig. 1 – Showing Effect of Earthquake on Sand”

“…By this method the whole mass of sand is disturbed on much the same principle of ball-bearings, and hence the destructive force of an earthquake is greatly diminished on the surface of a sand hill…”

***Popular Mechanics,* June 1906**

Not So

“…By the above mentioned procedure one would conclude that the sand would quickly shift its position and allow a house foundation to sink. This is not so. Every earthquake vibration has its forward and return motion the same as any other vibration. In the diagram is shown only the forward motion of the vibration. The return motion has exactly the same effect upon the mass as the forward motion of the vibration, except that the direction of all rotations is reversed. So we see that where the sand in the first place is moved, it is also returned to its original position unless the forward motion of the sand mass is sufficiently strong to force it over a bank or precipice, when its position cannot be controlled…”

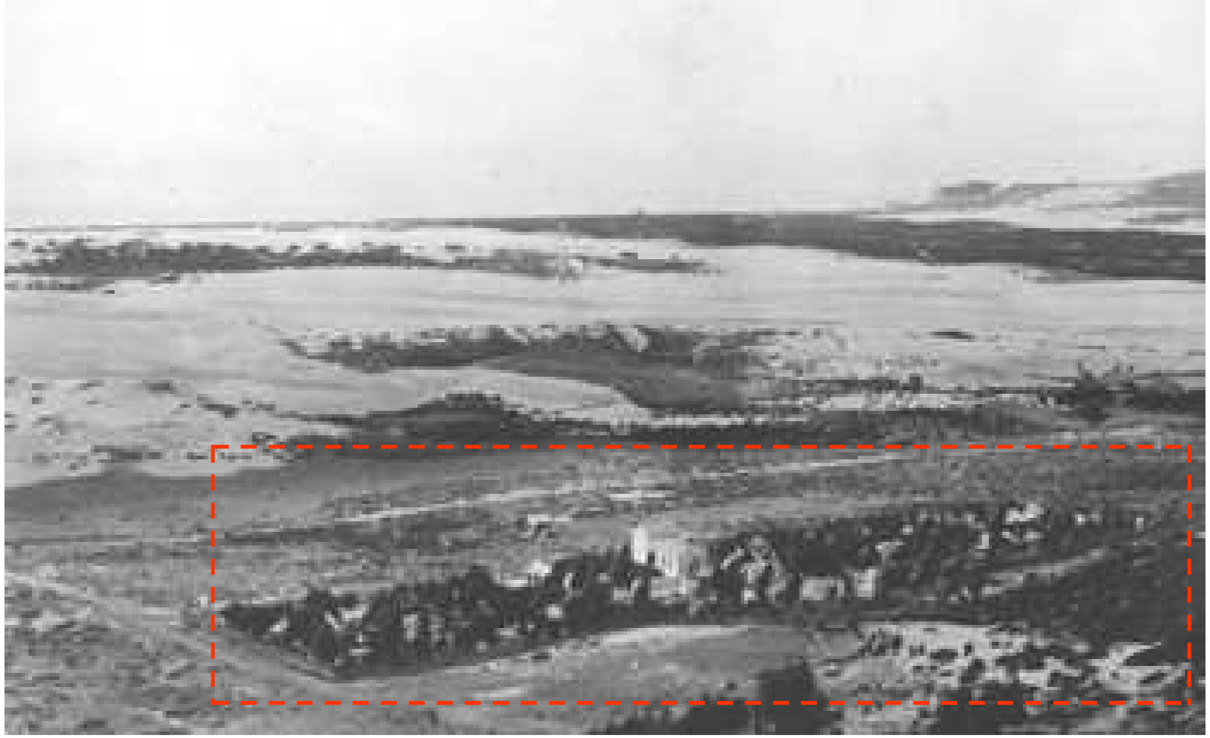
***Popular Mechanics,* June 1906**

Streetcar Suburb

"…In the western portion of San Francisco there is an area of many square miles which was nothing but a sandy waste, with no vegetation whatever. It seemed a shame such a large portion of the western metropolis should not be turned to account…"

Popular Mechanics, **June 1906**

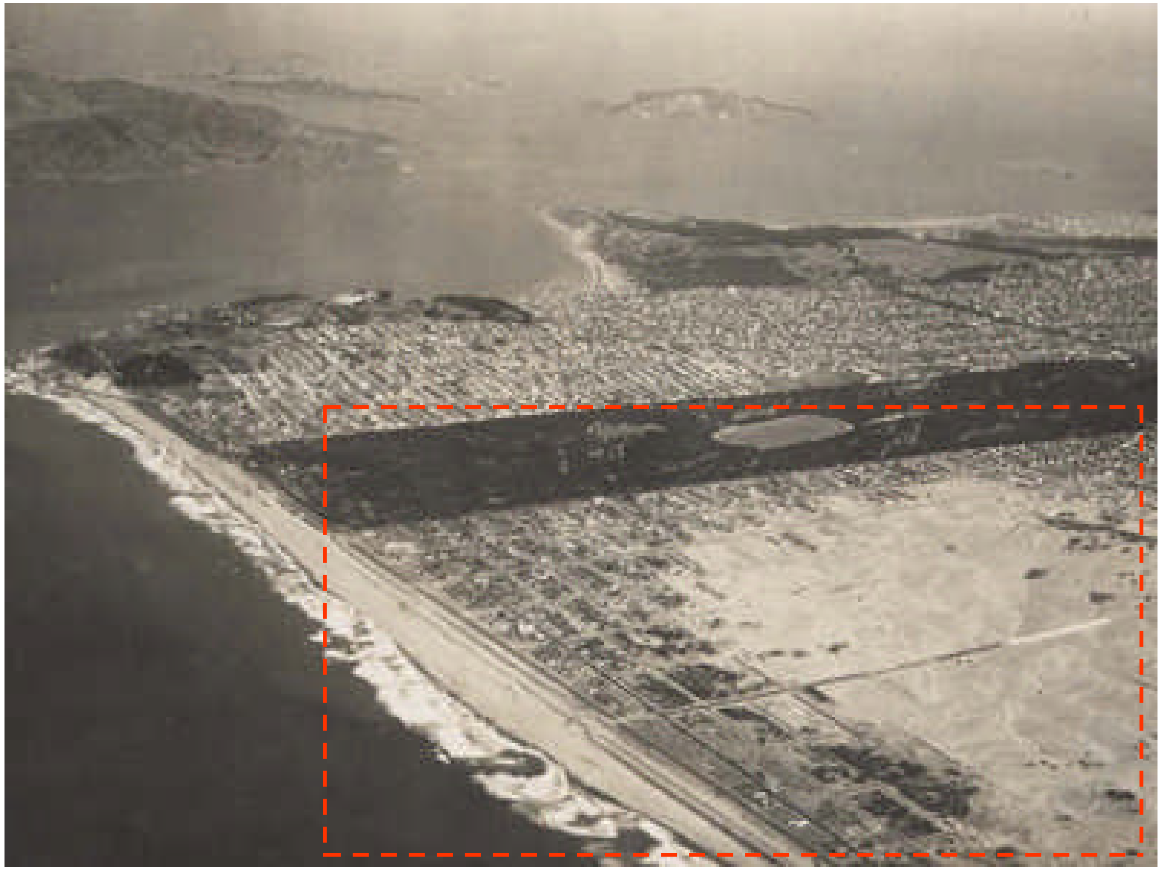
RE: at the end of the 19th Century, the *City of San Francisco* began replacing horse-drawn streetcars with electric streetcars. Dumped out near the beach in the *Sunset District* (western San Francisco), many derelict streetcars were sold to individuals who paid $10 (if it had no seats) or $20 (if it did have seats). People set up these streetcars along the sand at the *Great Highway* and turned them into homes. Some stacked two or three cars on top of one another for a multi-story home while others placed cars in a u-shape to create a courtyard protected from the wind. The area became known as "Carville-by-the-Sea" or simply "Carville." By 1901, fifty families lived in this unusual community that included a two-story church and a cafe. By the 1930s and 1940s, as development increased and property became more valuable, these streetcars disappeared. Today, only two surviving houses are known to be built around streetcars, though there may be others.

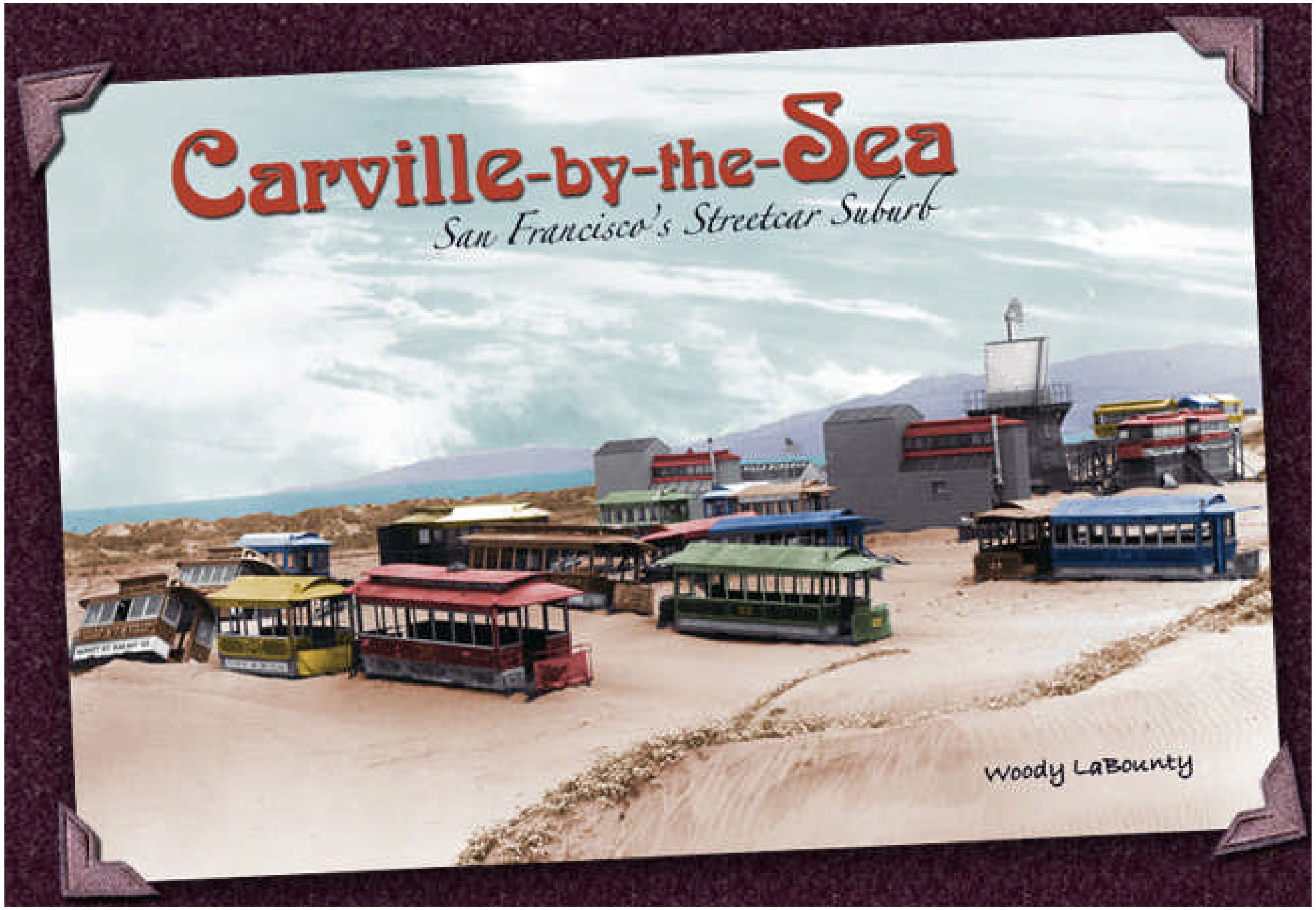


<u>Top Left</u>: caption: “Sunset dunes, ca. 1900 (at upper right is Golden Gate Park windmill)

<u>Top Right</u>: caption: “The Sunset District ca. 1900”

<u>Left</u>: caption: “The Larsen Chicken Ranch on 16th-17th Avenues between M and N Streets, ca. 1898.”





Carville-by-the-Sea

San Francisco's Streetcar Suburb

Woody LaBounty

Role Model

"…One man, however, determined to experiment. He sunk a well and at a depth of 50 ft. found water in one of the most arid places on the dunes. He proceeded to build a house on a simple concrete foundation sunk 18 in. in the sand. Within six months he had fig trees bearing fruit, and vegetables and flowers growing in abundance. He hardly felt the recent terrible earthquake, and his house is as solid as ever. From this man's experience, several persons ventured to buy lots close to him and try the same scheme…"

***Popular Mechanics*, June 1906**

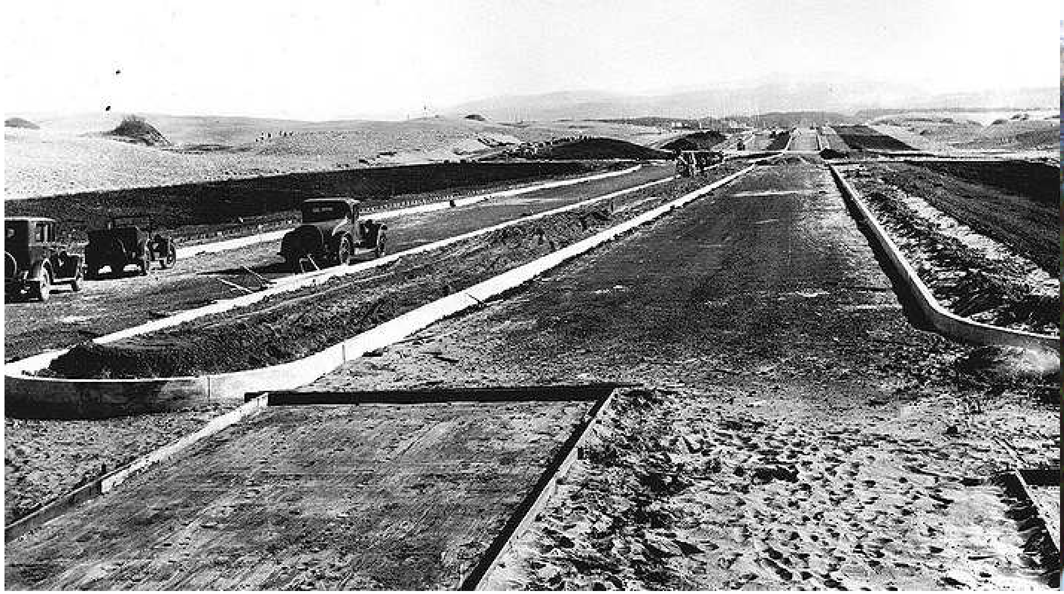
“…The city had never reckoned that the district would ever amount to anything, and so had never taken the trouble to even establish the standard grades for the streets, but as the lots were being bought up so rapidly it became necessary to do so…”

Popular Mechanics, **June 1906**

Earthquake Shacks

After the earthquake and fire of 1906, approximately two-thirds of the population of San Francisco was left homeless. In a remarkable project financed primarily by donations to a relief fund, 5,610 tiny cottages were built to house the homeless. These cottages (a/k/a “earthquake shacks”) were placed in rows in parks around the city. Rent ranged from $1 to $2 per month. By the end of 1906, the city began encouraging people to find vacant lots and remove the shacks from public land. In fact, the city agreed to refund all rents paid by people who had their shacks removed by a certain date. Some people moved their shacks to the *Sunset District*, where plenty of lots were available.

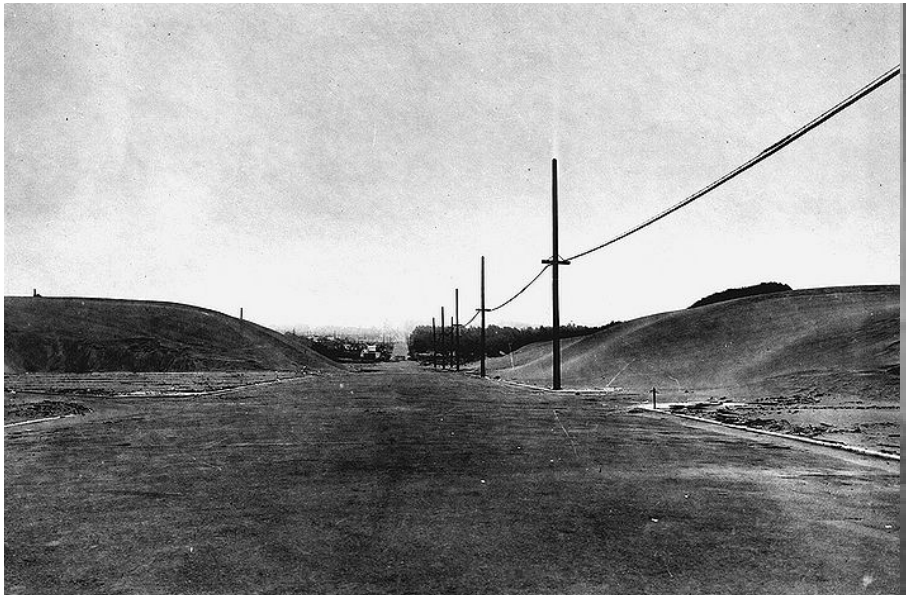
<u>Left</u>: caption: “An earthquake shack encampment in the Richmond District”
<u>Right</u>: caption: “Sunset houses start to fill the dunes, ca. 1936”



Because the shacks were so small (typically 14 by 18-feet), many people cobbled together three or four shacks to make a home. In 1982, *Sunset District* renter *Jane Cryan* discovered that she was living in a house composed of three earthquake shacks. She conducted extensive research and founded the *Society for the Preservation and Appreciation of San Francisco Refugee Shacks* (now defunct). In 1984, she convinced San Francisco to name the house at 1224 - 24th Avenue a city landmark. Another group of four earthquake shacks was discovered in the *Sunset District,* on Kirkham Street. The *Western Neighborhoods Project* works to preserve these shacks and make them available for public viewing.

Left: caption: "Sunset Boulevard under construction, April 1931"

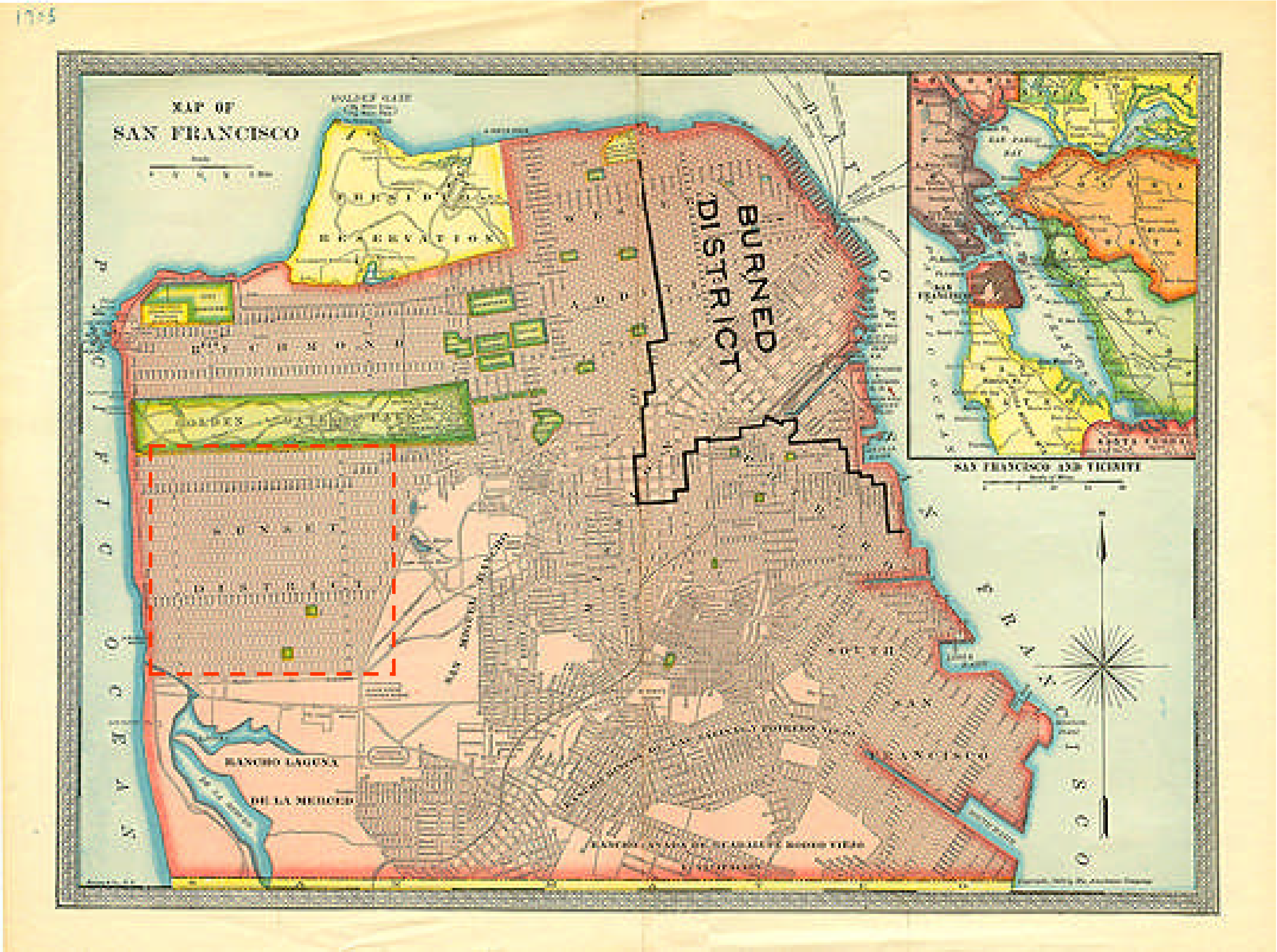
Right: caption: "This house on 24th Avenue is made up of several 1906 earthquake shacks"

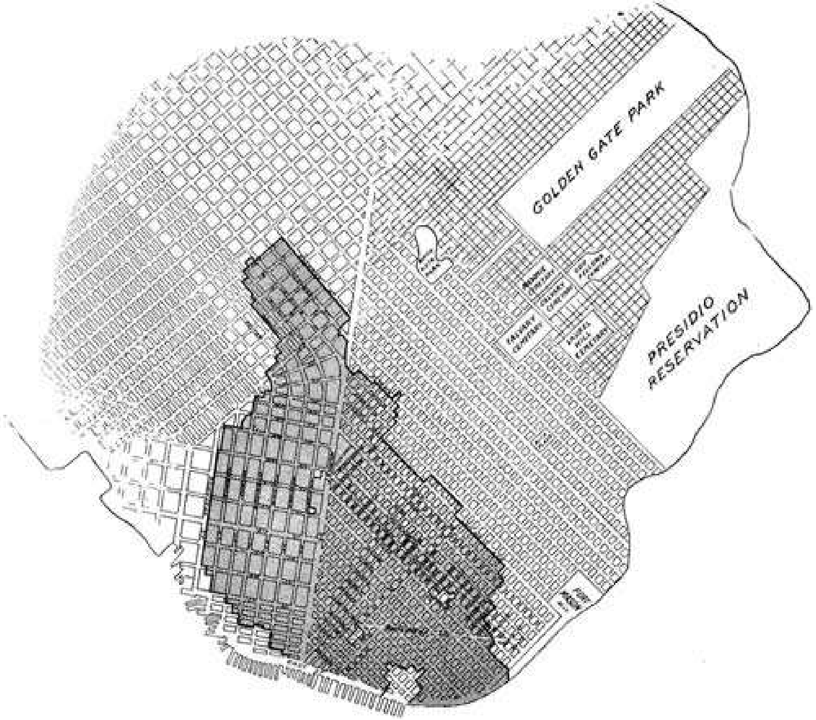


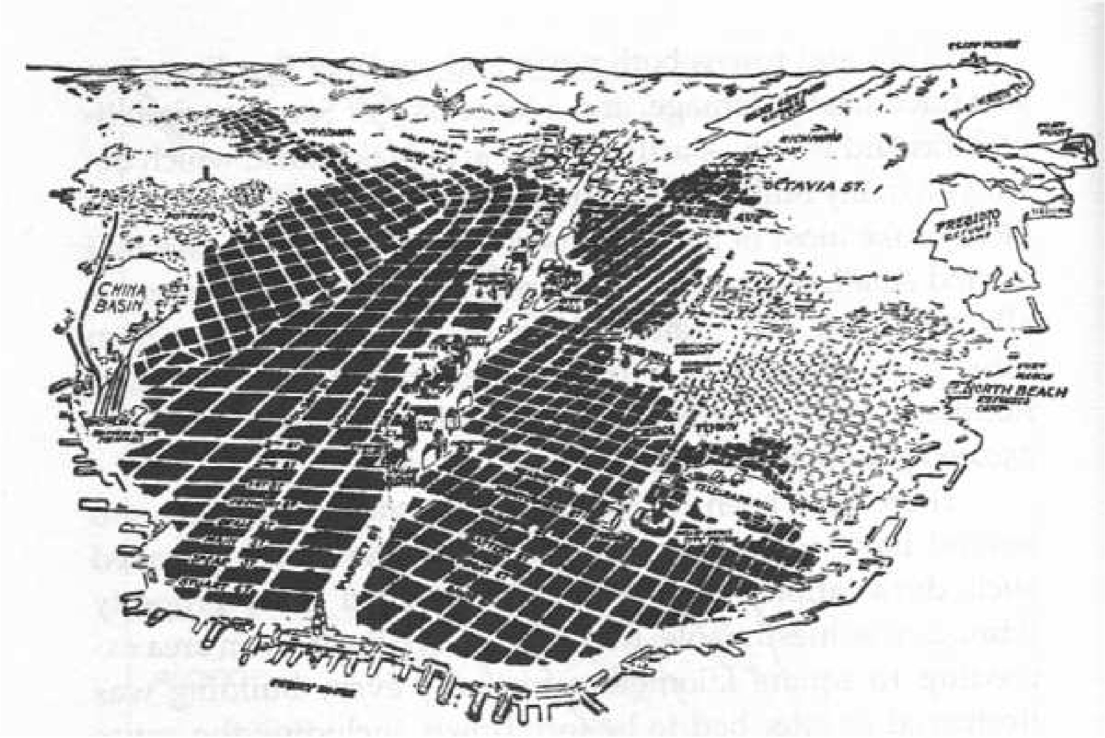
The *Sunset District* is a largely single family residential area built during the 1920s and ‘30s as an early San Francisco suburb. Sand dunes covered the land stretching from the west side of *Twin Peaks* to the ocean (prior to the completion of the *Twin Peaks Tunnel* in 1917). Initial building began at the foot of the *Haight* area and spread west to the dunes. After the opening of the *Cliff House*, rails were laid through the district to connect the beach and Cliff House with other parts of the City. The incorporation of *Golden Gate Park* clearly defined the northern border of the Sunset District and, as a result, development worked its way south from the park’s border. The 1920s saw the perfection of mass housing techniques and the Sunset District best exemplified this type of building with rows of neatly identical (a/k/a “cookie cutter”) housing stretching for blocks.

Left: caption: “A street plowed and paved through the sand dunes, ca. 1920s

Right: caption: “The L Taraval line ran through the sand dunes in the 1940s”


MAP OF SAN FRANCISCO
GOLDEN GATE
PRESIDIO RESERVATION
RICHMOND
GOLDEN GATE PARK
SUNSET DISTRICT
BURNED DISTRICT
SOUTH SAN FRANCISCO
RANCHO LAGUNA DE LA MERCED
PACIFIC OCEAN
SAN FRANCISCO
SAN FRANCISCO AND VICINITY
SAN PABLO BAY
SANTA CLARA





In the late 1800s, at most only a few hundred people lived in the *Sunset District*. By 1930, about 35K residents were in the area and by 1940, 48K people called it home. By the 1960s, almost all the land in the Sunset was covered with homes, churches, schools, businesses and a few parks. In the 1970s, development eliminated the last major sand dune when *St. Ignatius College Preparatory* was built at 2001 - 37th Avenue. Today, approximately 100K people live in the Sunset District. In just fifty years, the area was transformed from "uninhabitable" sand dunes to completely developed small neighborhoods.

Left: caption: "The darker portion is the area burned, or about three-fifths of the residences of the city and the entire business section"

Right: caption: "The devastated area of San Francisco, shown in black – a bird's-eye view looking toward the south-west"

The Test of Time

The best-known developer of houses in the *Sunset District* was *Henry Doelger*. He and his brother Frank formed *Doelger Homes* and began building homes in the 1920s. They built their first twenty-five homes in 1926. However, Henry Doelger is best known for the houses he built in a large concentrated area often referred to as "Doelger City." San Franciscans accustomed to the ornate details of Victorian and Edwardian buildings scoffed at the "cookie-cutter" way these houses were built, but the houses were well built and have stood the test of time (including earthquakes). Most of these houses have a similar floor plan; two bedrooms and one bathroom, with living quarters upstairs from a street-level garage.

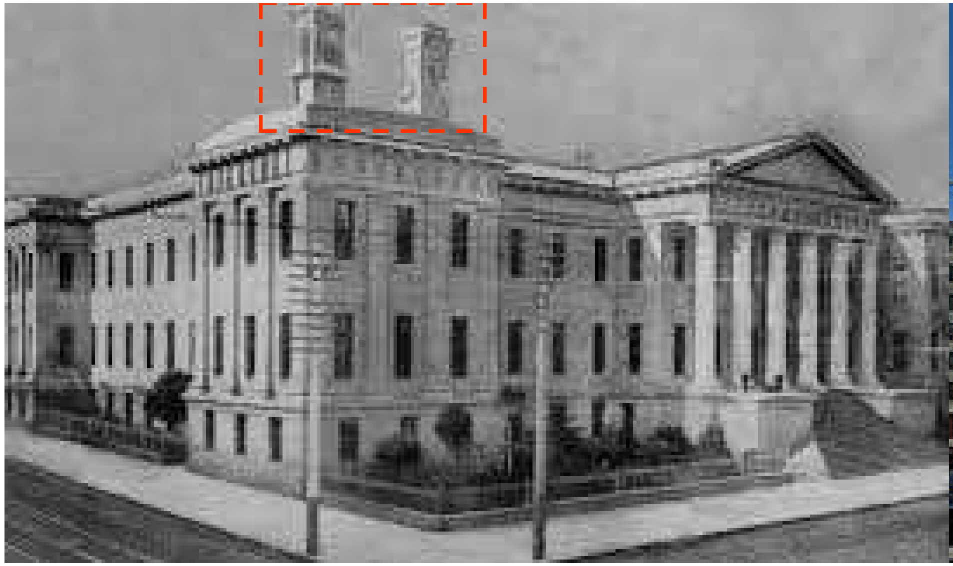
<u>Above</u>: caption: "Doelger homes featured a basic floor plan but differed only slightly on the outside"


DOELGER
HOMES

Quakeproof Chimneys (?)

“When chimneys of brick or cement blocks toppled and fell during the San Francisco earthquake, the breaks always occurred in the mortar joining them, and not in the bricks or blocks themselves. One of our readers, John W. Haynes, of San Jose, Cal., suggests a method of building quakeproof chimneys. He says: ‘I believe chimneys would be earthquake-proof if the cement blocks were made with a ¾-in. hole in each corner in which to cement iron pins, a little less than twice the thickness of a block in length, as the chimney is run up. By using two of the blocks diagonally opposite each other in setting the pins, continuous rods would be built up with the chimney. The method would be cheap and easy to use.’”

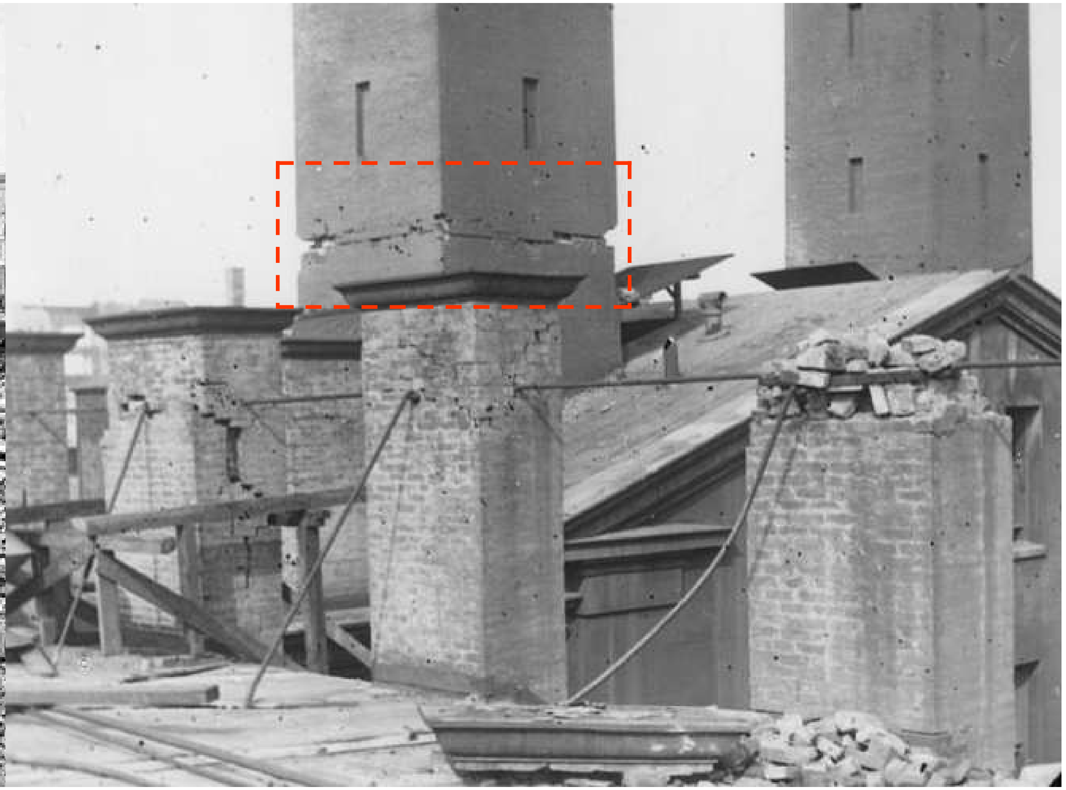
***Popular Mechanics,* September 1906**



The *San Francisco Second U.S. Mint* was begun in 1869 under the auspices of the *U.S. Treasury Department*. The Mint was designed by *A.B. Mullett*, who also produced the *Old State Building* and the *War and Navy Building* in Washington, D.C. The cornerstone was laid on May 26th 1870 and the building was finished in 1874. The building is a rectangular structure (approximately 160-feet by 217-feet) with brick masonry walls faced with a Rocklin California granite base and blue-gray sandstone upper stories. It has a narrow internal court, with four corner pavilions and a portico. It is two full stories in height with a lofty basement. In contrast, a pair of square brick chimneys,130-feet high, rise in the rear (they were used in connection with the refining of ore). The interior has cast-iron columns supporting wrought girders which, in turn, carry the floors on shallow brick arches. In the attic, iron girders support the roof, most of which is of galvanized and corrugated iron. It was the second of three *United States Mints* in San Francisico. The earliest mint was built on the waterfront in 1854 after gold began pouring into San Francisco from the *Sierra Nevada* foothills. Since the building of the third Mint in 1937, it has not functioned as a Mint. Instead, it has been used as offices for various Federal Gov't. departments/agencies.

Left: caption: "front view of U.S. Mint, San Francisco"

Right: caption: "Rear view of square brick chimneys 130 feet high"



In 1934, the *San Francisco Second U.S. Mint* housed one-third of the nation's gold reserve. The building survived the 1906 earthquake and fire aided by its iron shutters and the heroic efforts of Mint employees and soldiers who battled the flames for seven hours with a one-inch hose to protect the $200 million worth of gold stored in the vaults. Structural damage was suffered by the pair of 130-foot high freestanding chimneys as a result of the 1906 earthquake.

Left: caption: "Old United States Mint After 1906 Earthquake and Fire"

Right: caption: "Photograph of damage done to the San Francisco Mint chimneys during the 1906 Earthquake"

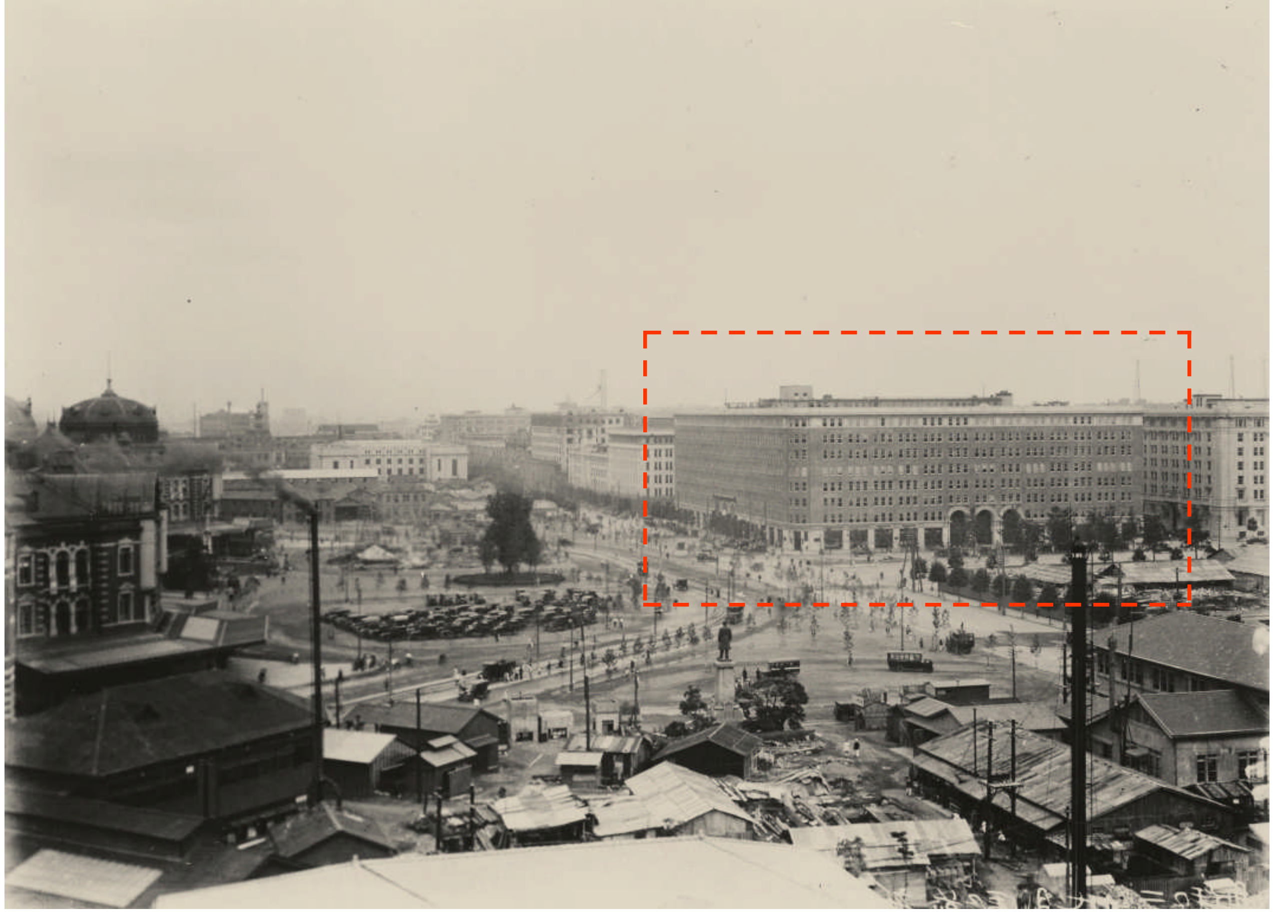
Reach for the Sky

“A business firm in Tokyo is contemplating the construction of a skyscraper building on lines similar to the plans used in the reconstruction of San Francisco, which are expected to provide against destruction from earthquake. Japan is a country of earthquakes, and the officials of the Tokyo concern believe that the new building should be earthquake-proof, since it is a skyscraper – six stories high…”

Popular Mechanics, **December 1910**

Colloquially known as “Maru-Biru,” the *Marunouchi Building* was designed by *Kotaro Sakurai* and constructed from 1923-1926 on land known as *Mitsubishi ga hara* (“Mitsubishi’s field”). It was, for over forty years, Japan’s largest (by volume) office building. The Marunouchi Building dominated the business district from which it received its name, fitting in well with the other “high-rise” buildings of the district. It survived the *Great Kanto Earthquake* with minimal damage, in large part due to its +5K pine pilings. Building restrictions that kept Tokyo buildings beneath a 100-foot height limit (until 1968) resulted in its squat, heavy-set profile that occupied an entire city block (a first for Tokyo). The building also survived intact the B-29 fire-bombing of Tokyo during WWII.

<u>Above</u>: caption: “The completed Marunouchi Building, ca. 1925”




（大東京）丸の内ビルデイング
Marunouchi Building

“…People familiar with the height of American skyscrapers may smile at the idea that a six-story building is considered a skyscraper in Japan, but such an office building, of modern American construction, would, comparatively, loom as high above a Japanese street as would be a 40-story skyscraper surrounded by 20-story skyscrapers, height being largely a matter of surroundings.”

***Popular Mechanics,* December 1910**

GINZA STREET (SHOPPING CENTER OF TOKYO)

For thirty-three years (1890-1923), *Ryounkaku* ("Cloud Surpassing Pavilion") towered 220-feet over *Asakusa Park* and the surrounding city of Tokyo. Designed by Scottish engineer *William Burton*, it was built of brick over a wood frame. The twelve-story Ryounkaku stood out among the more typical two, three and four-story buildings that were commonplace in Tokyo and is considered to be Japan's first "Skyscraper," though it lacked an iron or steel "cage" frame; one of two requirements for the title, the other being an elevator (which it did have – Japan's first). Because of its height, Ryounkaku was also known locally as *Ju-ni-kai* ("Twelve-Story Tower"). A strong tremor in 1894 weakened the tower, producing a slight lean. In its aftermath, Ryounkaku was reinforced with steel girders. Unfortunately, the reinforced tower proved to be no match for the *Great Kanto Earthquake* of 1923.

Left: caption: "Tokyo's famous Ryounkaku, before and after the 1923 Great Kanto Earthquake"

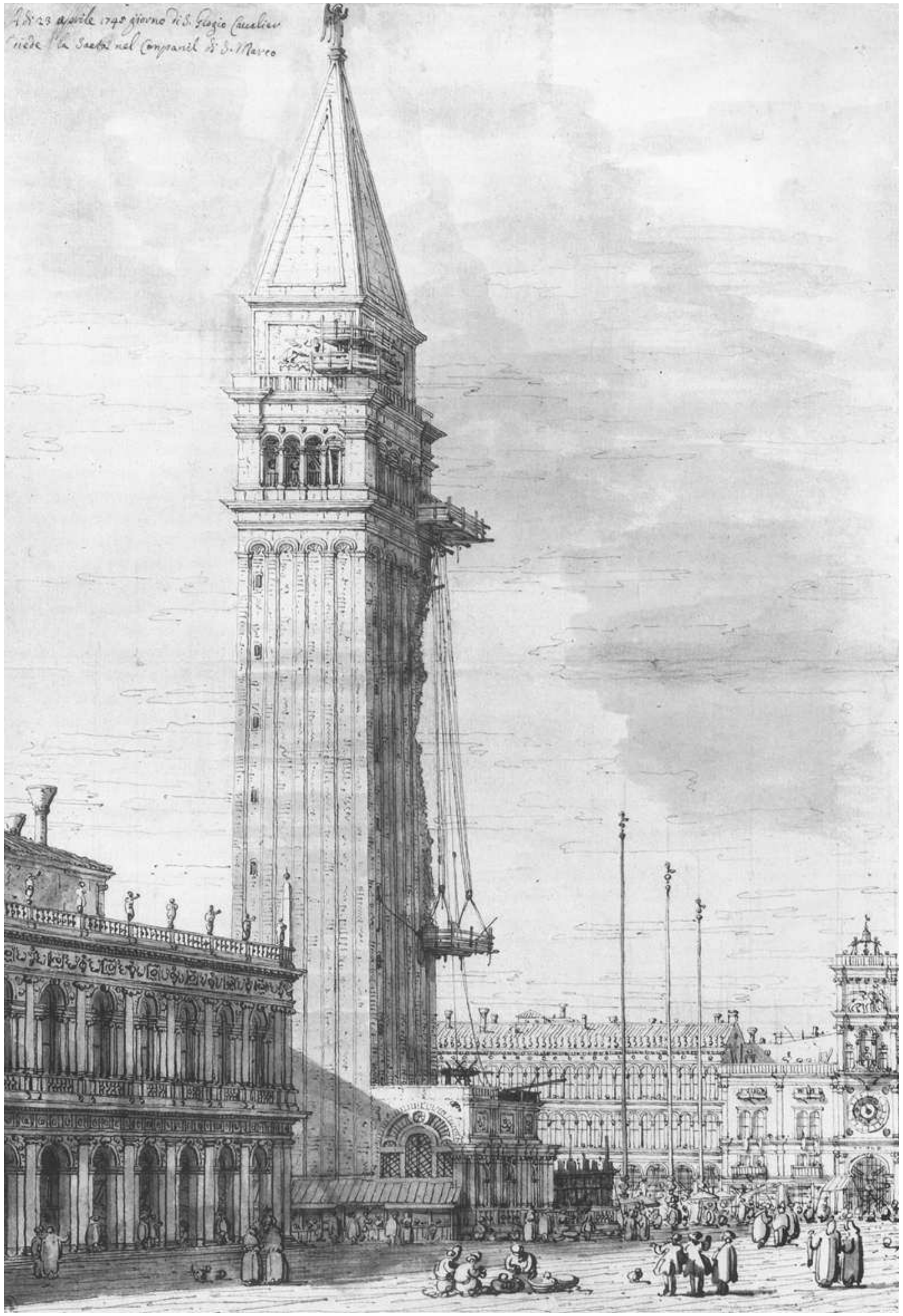

The "Jiunikai" Pagoda, Asakusa. (東京名所) 淺草十二階


大正12.9.1 東京大震災
淺草公園十二階挫折後猛火に包まる


A Part of Asakusa Park, Tokyo
Shows Twelve Story Ryounkaku
浅草公園十二階（東京）


荒物雑貨

Exceedingly Rare



"A concrete-steel campanile, 302 ft. high, now being built on the campus of the University of California, is remarkable not only for its height but for the fact that it represents a type of structure exceedingly rare in this country. The campanile had its origin in Italy as a bell tower connected with a church but detached from it, and few of the bell towers of this country or of England answer this description…"

***Popular Mechanics,* Dec. 1914**

<u>Left</u>: caption: "Campanile di San Marco Venice, under repair"

"…The California structure, known as the 'Sather Campanile,' in honor of one of the donors to the funds of the university, is said to be the highest memorial tower in the country with the exception of the Washington Monument, at Washington D.C. It is 30 ft. square at the base, which contains a room large enough to hold banquets in…"

Popular Mechanics, **Dec. 1914**

<u>Left</u>: caption: "Preliminary drawing, 1903, John Galen Howard." The campanile is UC Berkeley's most recognizable symbol.

“…The belfry is to be faced with an enormous clock which will contain 10 or 12 bells arranged as chimes. These chimes will be played by means of a keyboard much after the fashion of an organ…”

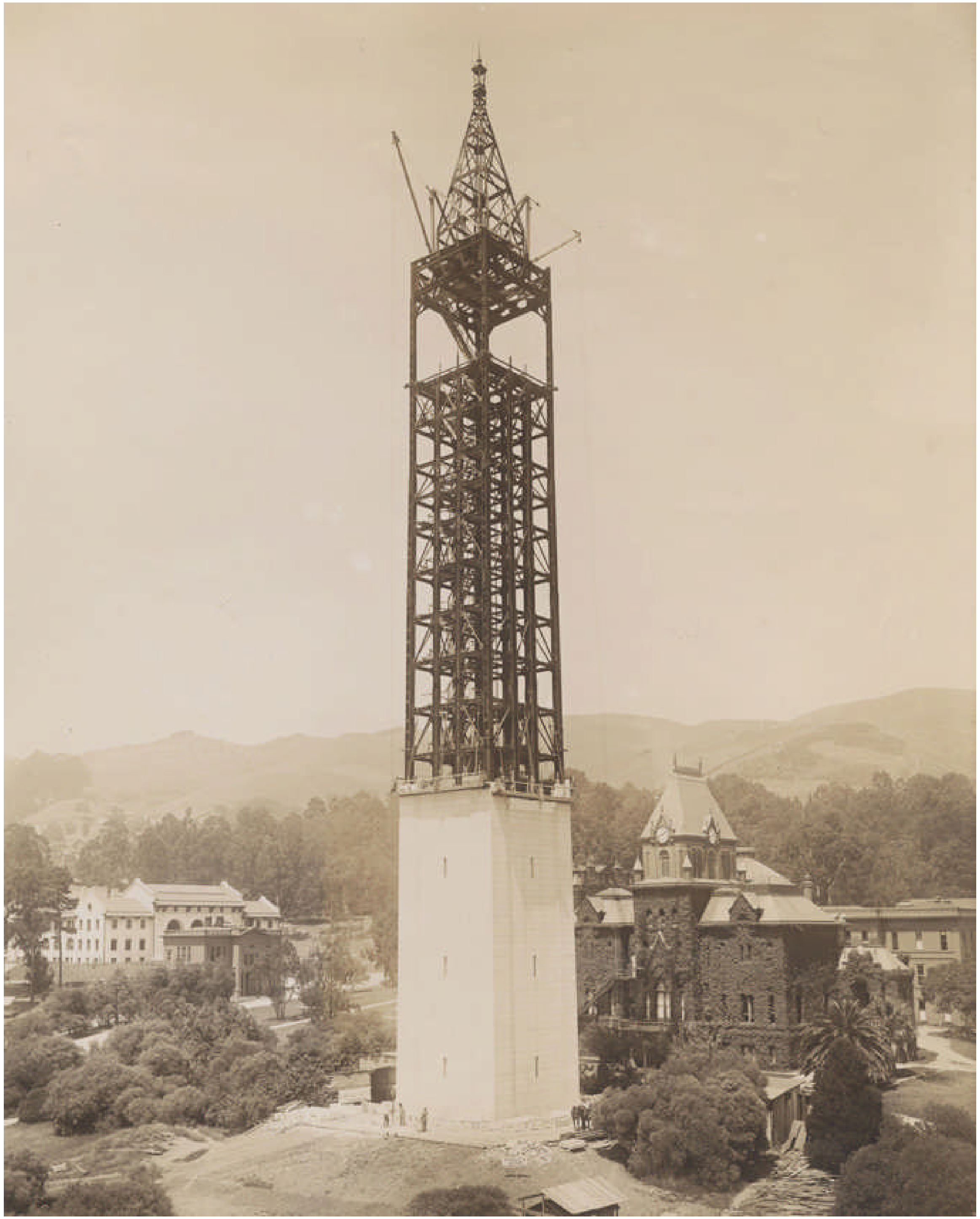
Popular Mechanics, **December 1914**

<u>Left</u>: caption: “Campanile Sather Tower UC Berkeley Carillon Bell Clock Tower.” Completed in 1914 and first opened to the public in 1917, the tower stands 307-feet tall, making it the third tallest bell and clock-tower in the world. It was designed by *John Galen Howard* and it marks a secondary axis in his original Beaux-Arts campus plan.

"…The top of the campanile is to be of white marble and will be surmounted by a light visible to ships entering the Golden Gate. An elevator will be installed for taking sight-seers to the top…"

Popular Mechanics, **December 1914**

<u>Left</u>: caption: "Campanile perspective rendering by University of California Berekely campus architect John Galen Howard, ca.1914"



"…A remarkable feature about this campanile is the method employed for minimizing the danger from earthquakes. The center of gravity is placed as low as possible and the steel frame has been planned to resist earthquake shocks. In addition to this, the period of vibration of the structure with reference to that of an earthquake has been carefully planned…"

Popular Mechanics, **December 1914**

Left: caption: "Concrete-steel campanile at University of California under construction. This campanile is 302-feet high and is ingeniously planned to resist damage from earthquakes."

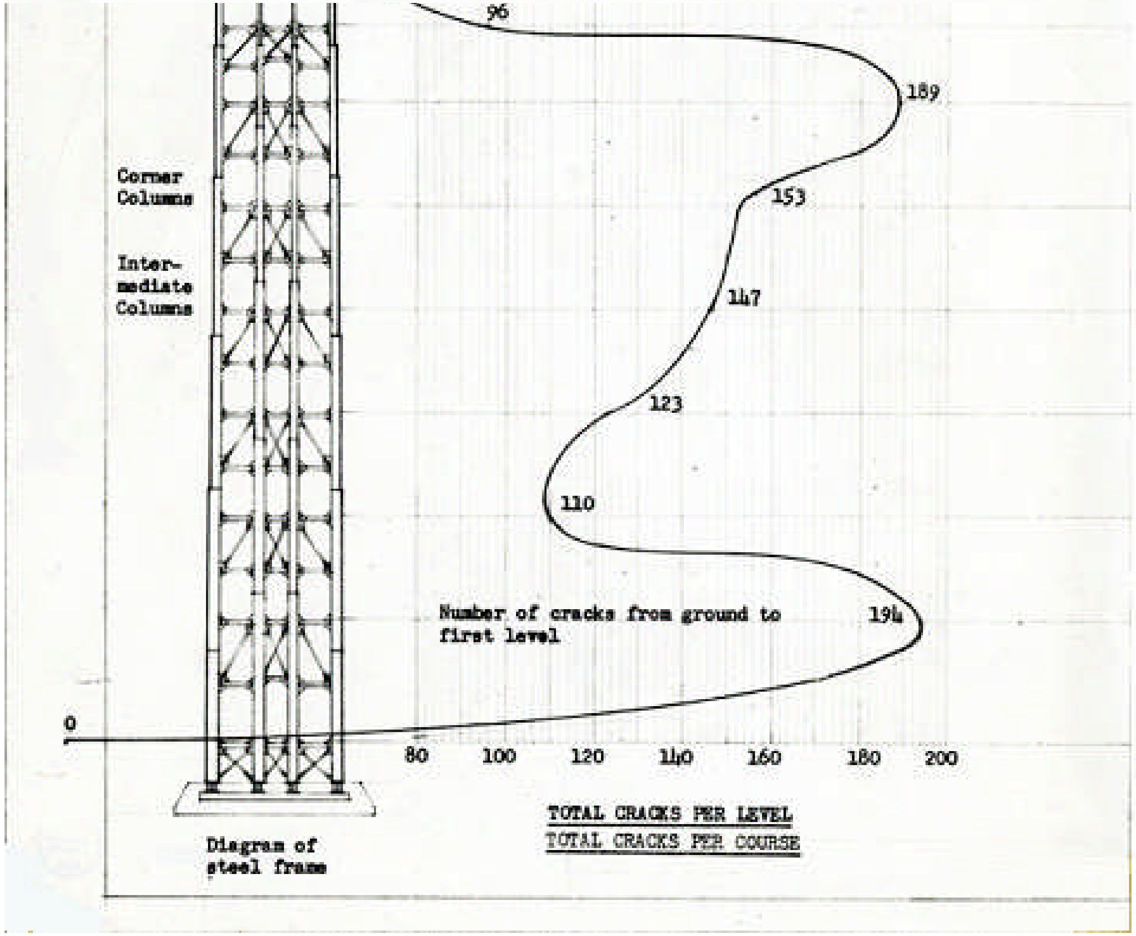
“…It has been found that an earthquake usually has a period of vibration of about one second. In order to neutralize the effect of earthquake vibration and to prevent cumulative swaying, such as would occur if the two periods were the same, and which, if severe enough, might lead to the collapse of the structure, the arrangement of the mass and framing has been planned to give the campanile a period of vibration of about two seconds, thus minimizing a possible danger.”

***Popular Mechanics,* December 1914**

***Walter T. Steilberg* (1887-1974) graduated from the *University of California, Berkeley* in 1910 with a bachelor's degree in architecture and a minor in structural engineering. Steilberg worked with *Julia Morgan* from 1910-1920 as draftsman, architect, office manager and structural engineer. In 1920, he formed his own architecture and consulting firm and collaborated with *Gardner Dailey* on many projects. Steilberg became an expert in seismic architecture and engineering issues and conducted extensive experimental research with concrete. The *Walter T. Steilberg Collection* at *UC Berkeley* documents Steilberg's engineering and architectural career/s, as well as his own research into building materials and the structural effects of earthquakes. Project records include correspondence, notes, reports, photographs and drawings documenting both his consulting and design work. A major element of the collection is Steilberg's unpublished monograph on the effects of the 1925 earthquake in Santa Barbara which includes photographs. Project files for the UC Berekeley, including the Sather Tower renovation, are well-represented.**

SATHER TOWER, UNIVERSITY OF CALIFORNIA, BERKELEY, CALIFORNIA
CRACKING OF GRANITE FACING OF SHAFT WITH REFERENCE TO HEIGHT
Graph 51-2

This graph and accompanying graphs 51-1 "Cracking of Granite Facing with Reference to Plan", 51-3 "Cracking of Granite Facing with Reference to Orientation" are based on a stone-by-stone examination of the masonry by steeplejacks. This survey revealed many very fine cracks not discerned by earlier examinations,--even when made with a 30X binocular telescope. The count of cracks on Feb. 21, 1951, was 1,017; about 680 of the facing stones are cracked (some in several places), representing about 24% of the 2,800 pieces of ashlar in this walled part of the Tower.



<u>Left</u>: caption: "'Sather Tower, University of California, Berkeley, California. Cracking of Granite Facing of Shaft with Reference to Height. Graph 51-2.' This graph and accompanying graphs 51-1 'Cracking of Granite Facing with Reference to Plan,' 51-3 'Cracking of Granite Facing with Reference to Orientation' are based on a stone-by-stone examination of the masonry by steeplejacks. This survey revealed many very fine cracks not discovered by earlier examinations, even when made with a 30X binocular telescope. The count of cracks on Feb. 21, 1951, was 1,017; about 680 of the facing stones are cracked (some in several places), representing about 24% of the 2,800 pieces of ashlar in this walled part of the tower."

Shake, Rattle & Toll

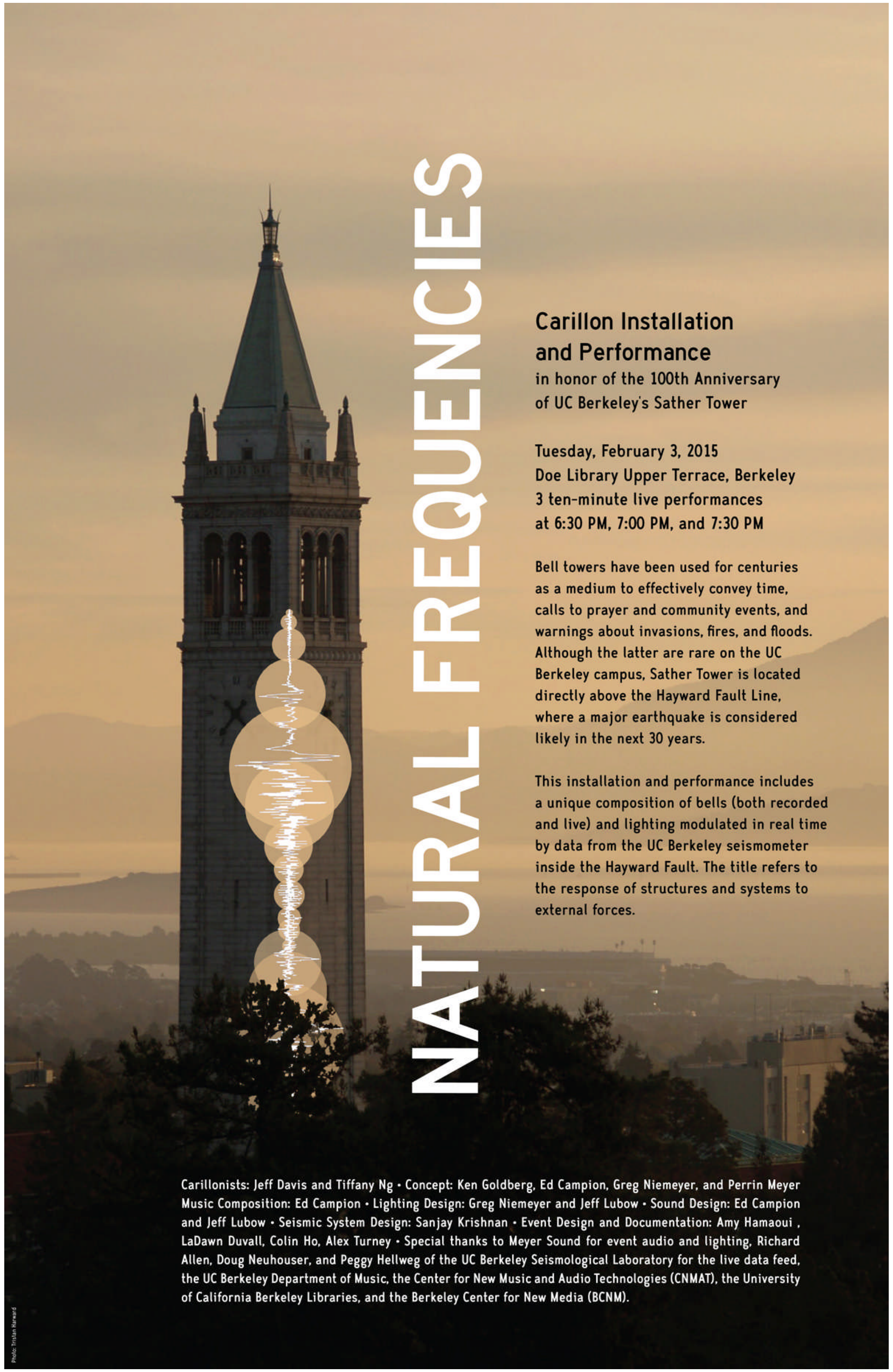
“Most residents of the San Francisco Bay area prefer to forget what scientists know to be true: One of the major faults that runs below their feet will cause a major earthquake in the next 30 years. But a recent performance on the campus of University of California, Berkeley, combined the work of engineers and artists to create a melodic reminder that the earth below us is in constant motion. In celebration of its 100th anniversary, the bells of Berkeley's Sather Tower, the world’s third-tallest bell and clock tower, were programmed to play a score composed in real time by the data from seismic shifts taking place around the Hayward Fault. The fault cuts right through the Berkeley campus. The project is called ‘Natural Frequencies,’ and it was conceived of by composer Edmund Campion, artist and roboticist Ken Goldberg and artist Greg Niemeyer; all of whom are professors at UC Berkeley. Accompanying the bells was also a light show, which was programmed to respond to the earth's movements. Campion says when he was asked to ‘have the earth play the bells at Berkeley,’ he couldn’t resist…”

***National Public Radio,* February 9th 2015**

"…The data is coming from the Berkeley Seismological Laboratory, and Campion says the Earth has 'a regular oscillating motion.' 'The Earth apparently breaths,' he says, 'and in that oscillation it's not precise, nor is it perfectly regular. And that's what I call musical.' Campion, with Jeff Lubow at the Center for New Music and Audio Technologies, created a computer program that tells the bells what to play based on the Earth's movements. Campion says the program isn't 'reading a score. It's generating a score.' The actual music was a mix of live performers in the bell tower and programmed bells…Though there was no earthquake during the performance, Niemeyer says we would have seen it and heard it if there had been. 'That's what makes it engaging,' he says…"

National Public Radio, **February 9th 2015**

<u>Left</u>: caption: "Hundreds gathered in front of the Campanile to celebrate the tower's 100th birthday, watching live performances of music and lights that harnessed real-time seismic activity from the Hayward Fault line."



NATURAL FREQUENCIES

Carillon Installation and Performance
in honor of the 100th Anniversary
of UC Berkeley's Sather Tower

Tuesday, February 3, 2015
Doe Library Upper Terrace, Berkeley
3 ten-minute live performances
at 6:30 PM, 7:00 PM, and 7:30 PM

Bell towers have been used for centuries as a medium to effectively convey time, calls to prayer and community events, and warnings about invasions, fires, and floods. Although the latter are rare on the UC Berkeley campus, Sather Tower is located directly above the Hayward Fault Line, where a major earthquake is considered likely in the next 30 years.

This installation and performance includes a unique composition of bells (both recorded and live) and lighting modulated in real time by data from the UC Berkeley seismometer inside the Hayward Fault. The title refers to the response of structures and systems to external forces.

Carillonists: Jeff Davis and Tiffany Ng • Concept: Ken Goldberg, Ed Campion, Greg Niemeyer, and Perrin Meyer Music Composition: Ed Campion • Lighting Design: Greg Niemeyer and Jeff Lubow • Sound Design: Ed Campion and Jeff Lubow • Seismic System Design: Sanjay Krishnan • Event Design and Documentation: Amy Hamaoui , LaDawn Duvall, Colin Ho, Alex Turney • Special thanks to Meyer Sound for event audio and lighting, Richard Allen, Doug Neuhouser, and Peggy Hellweg of the UC Berkeley Seismological Laboratory for the live data feed, the UC Berkeley Department of Music, the Center for New Music and Audio Technologies (CNMAT), the University of California Berkeley Libraries, and the Berkeley Center for New Media (BCNM).

Photo: Tristan Harward

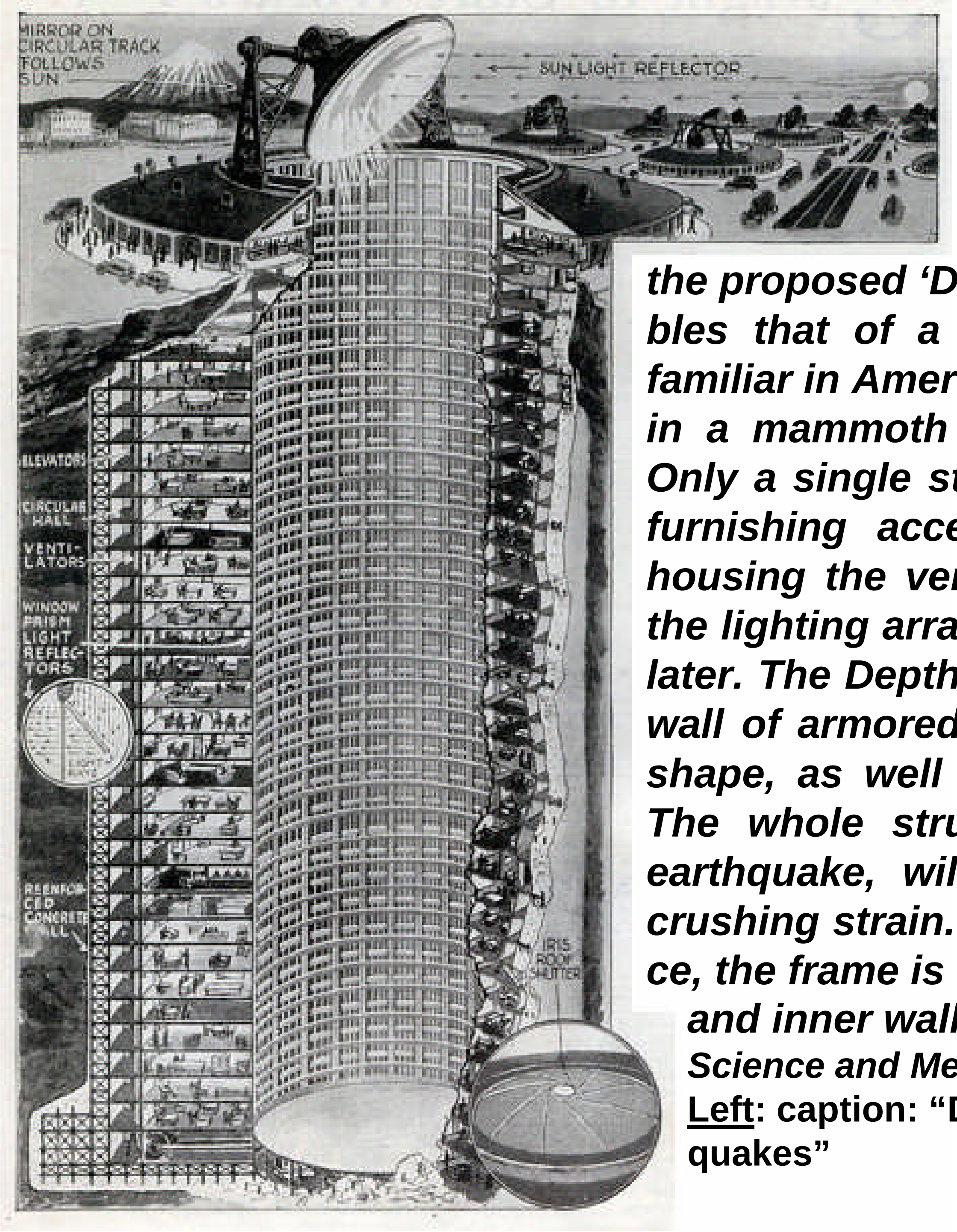
"…The project also re-imagines the purpose of the 100-year-old tower. Clock towers have been used for centuries to call people to prayer and to alert them to danger such as floods, fires or invasions. 'Natural Frequencies' builds upon that history, using modern digital tools to remind us of our connection to the powerful, vibrant and sometimes frightening Earth beneath our feet."

National Public Radio, **February 9th 2015**

Depthscrapers

“The ‘Land of the Rising Sun’ (Japan) is subject to earthquakes of distressing violence at times; and the concentration into small areas of increasing city populations invites great destruction, such as that of the Tokyo earthquake of 1923, unprecedented in magnitude of property loss, as well as life. It was natural, then, that the best engineering brains of Japan should be devoted to the solution of the problem of building earthquake-proof structures; and a clue was given them by the interesting fact that tunnels and subterranean structures suffer less in seismic tremors than edifices on the surface of the ground, where the vibration is unchecked…”

***Science and Mechanics,* November 1931**



"…The result of research, into the phenomenon has been the design of the enormous structure illustrated, in cross-section, at the left - the proposed 'Depthscraper,' whose frame resembles that of a 35-story skyscraper of the type familiar in American large cities; but which is built in a mammoth excavation beneath the ground. Only a single story protrudes above the surface; furnishing access to the numerous elevators; housing the ventilating shafts, etc; and carrying the lighting arrangements which will be explained later. The Depthscraper is cylindrical; its massive wall of armored concrete being strongest in this shape, as well as most economical of material. The whole structure, therefore, in case of an earthquake, will vibrate together, resisting any crushing strain. As in standard skyscraper practice, the frame is of steel, supporting the floors and and inner walls…"

***Science and Mechanics,* November 1931**

Left: caption: "Depthscrapers Defy Earthquakes"

“…Fresh air, pumped from the surface and properly conditioned, will maintain a regular circulation throughout the building, in which each suite will have its own ventilators. The building will be lighted, during daylight hours, from its great central shaft, or well, which is to be 75 feet in diameter. Prismatic glass in the windows, opening on the shaft, will distribute the light evenly throughout each suite, regardless of the hour…”

Science and Mechanics, **November 1931**

“…In order to intensify the degree of daylight received, a large reflecting mirror will be mounted above the open court, and direct the sunlight directly into its depths. This mirror travels on a circular track; so that it will rotate, following the course of the sun and at the same time change its angle of elevation to agree with his apparent movements. During normal daylight conditions therefore, the Depthscraper will be sufficiently illuminated without artificial lighting. When rain descends, the shaft will be quickly roofed over by a diaphragm, operating like the iris shutter of a vast camera (see the smaller detail at the lower right), which will keep the central well dry, though the rainfall would cause no detriment, other than the necessity of pumping out the water. At such times, no doubt, electric light will be resorted to, just as on dark days in buildings above the surface…”

***Science and Mechanics,* November 1931**

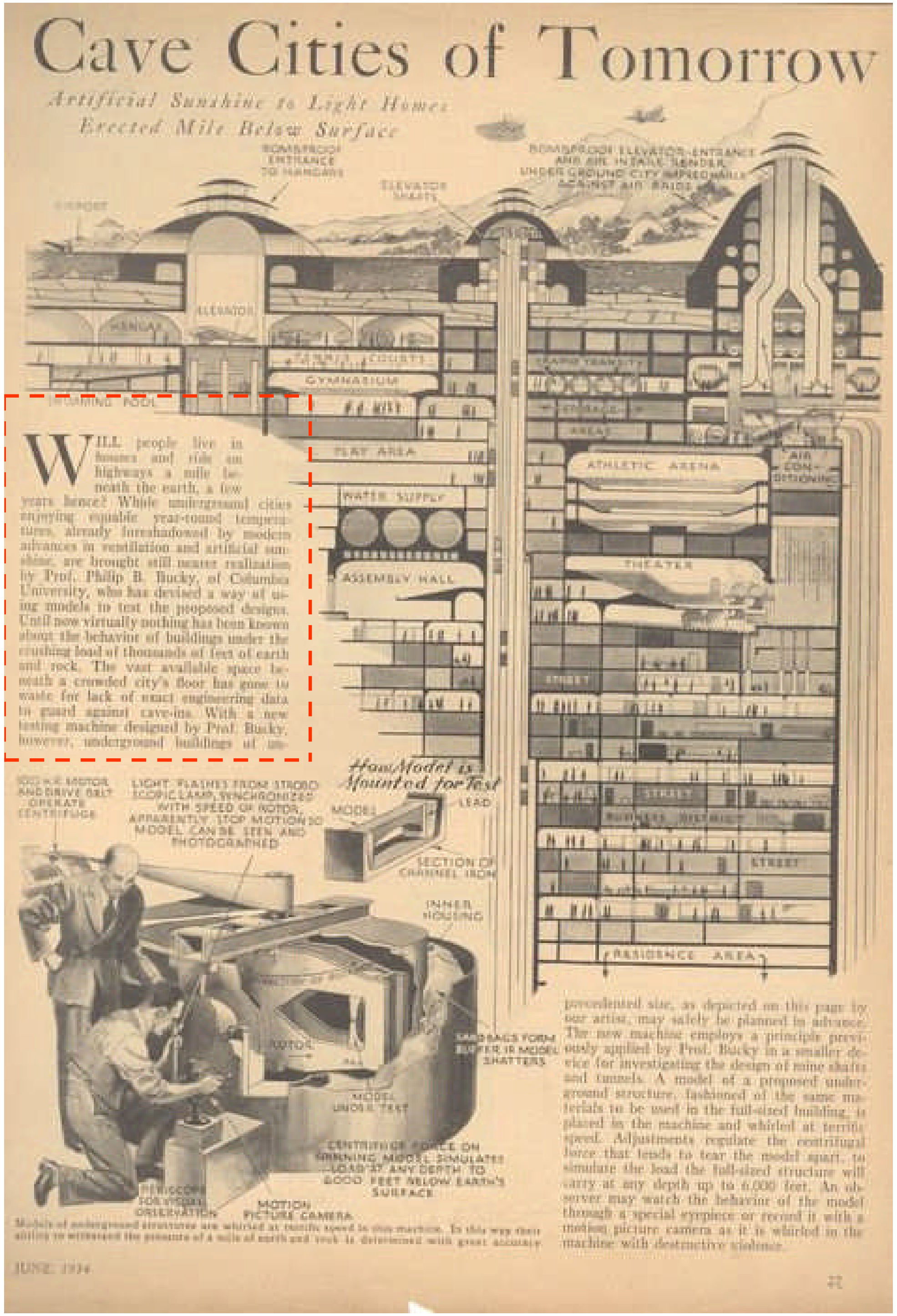
“…To the objection that living underground is unwholesome, the proponents of the Depthscraper reply that the sanitary conditions in a building of the type described will be identical with (when not superior to) those found in large buildings above the ground, where apartments and offices are lighted from interior courts. The conditioned air supply will be uniform and superior to that obtained by natural ventilation, and the inmate of such a building would not be able to detect any difference in conditions from those found in a skyscraper of similar construction, but built up instead of down…”

***Science and Mechanics,* November 1931**

“…The logic of the Depthscraper is convincing and, although such construction appears too costly for most residences in a district where land values are not excessive, for business buildings it offers a degree of safety against earthquakes (as well as hurricanes) not to be disregarded in a country which is subject to them incessantly. We understand, upon good authority, that this principle of construction is therefore to be put shortly to the practical test for construction.”

***Science and Mechanics*, November 1931**

Depthcities



Cave Cities of Tomorrow

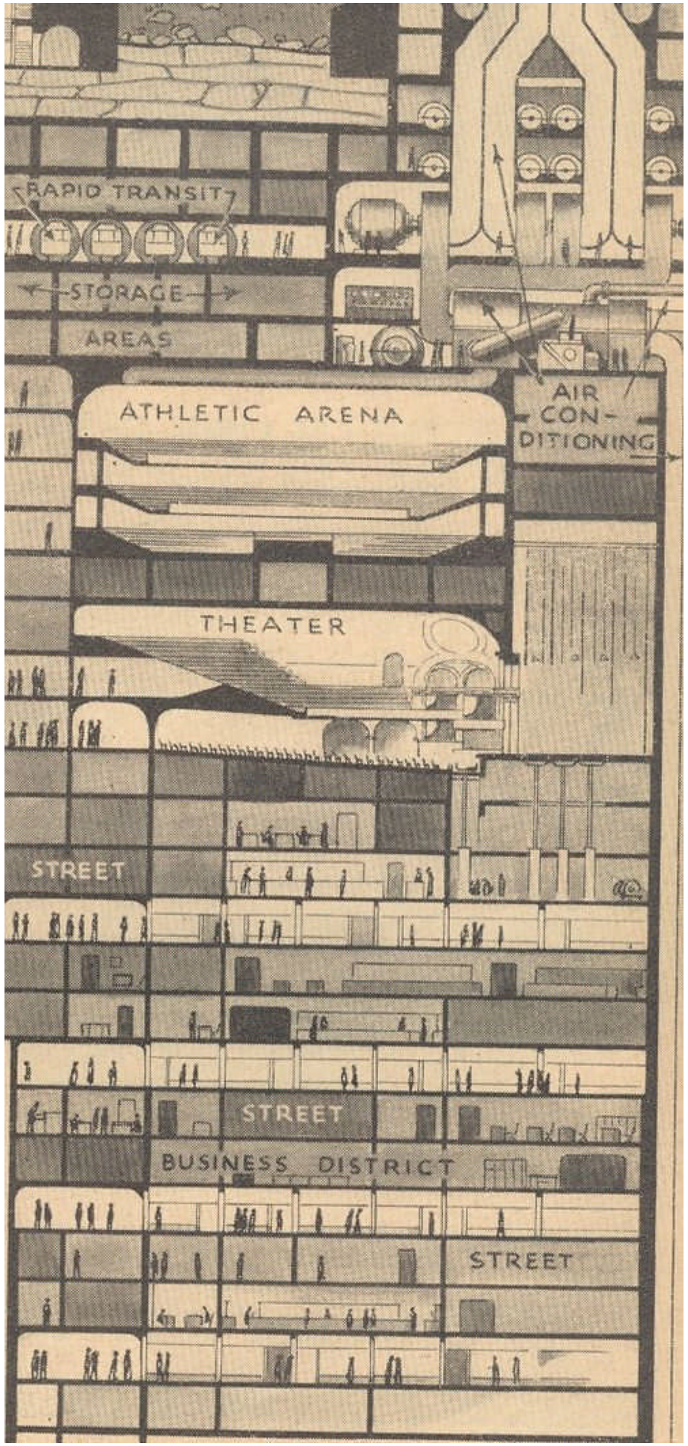
Artificial Sunshine to Light Homes Erected Mile Below Surface

WILL people live in houses and ride on highways a mile beneath the earth, a few years hence? While underground cities enjoying equable year-round temperatures, already foreshadowed by modern advances in ventilation and artificial sunshine, are brought still nearer realization by Prof. Philip B. Bucky, of Columbia University, who has devised a way of using models to test the proposed designs. Until now virtually nothing has been known about the behavior of buildings under the crushing load of thousands of feet of earth and rock. The vast available space beneath a crowded city's floor has gone to waste for lack of exact engineering data to guard against cave-ins. With a new testing machine designed by Prof. Bucky, however, underground buildings of unprecedented size, as depicted on this page by our artist, may safely be planned in advance. The new machine employs a principle previously applied by Prof. Bucky in a smaller device for investigating the design of mine shafts and tunnels. A model of a proposed underground structure, fashioned of the same materials to be used in the full-sized building, is placed in the machine and whirled at terrific speed. Adjustments regulate the centrifugal force that tends to tear the model apart, to simulate the load the full-sized structure will carry at any depth up to 6,000 feet. An observer may watch the behavior of the model through a special eyepiece or record it with a motion picture camera as it is whirled in the machine with destructive violence.

Models of underground structures are whirled at terrific speed in this machine. In this way their ability to withstand the pressure of a mile of earth and rock is determined with great accuracy.

"Will people live in houses and ride on highways a mile beneath the earth, a few years hence? Whole underground cities enjoying equable year-round temperatures, already foreshadowed by modern advances in ventilation and artificial sunshine, are brought still nearer realization by Prof. Philip B. Bucky, of Columbia University, who has devised a way of using models to test the proposed designs. Until now virtually nothing has been known about the behavior of buildings under the crushing load of thousands of feet of earth and rock. The vast available space beneath a crowded city's floor has gone to waste for lack of exact engineering data to guard against cave-ins…"

***Popular Science Monthly*, June 1934**



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***Popular Science Monthly*, June 1934**

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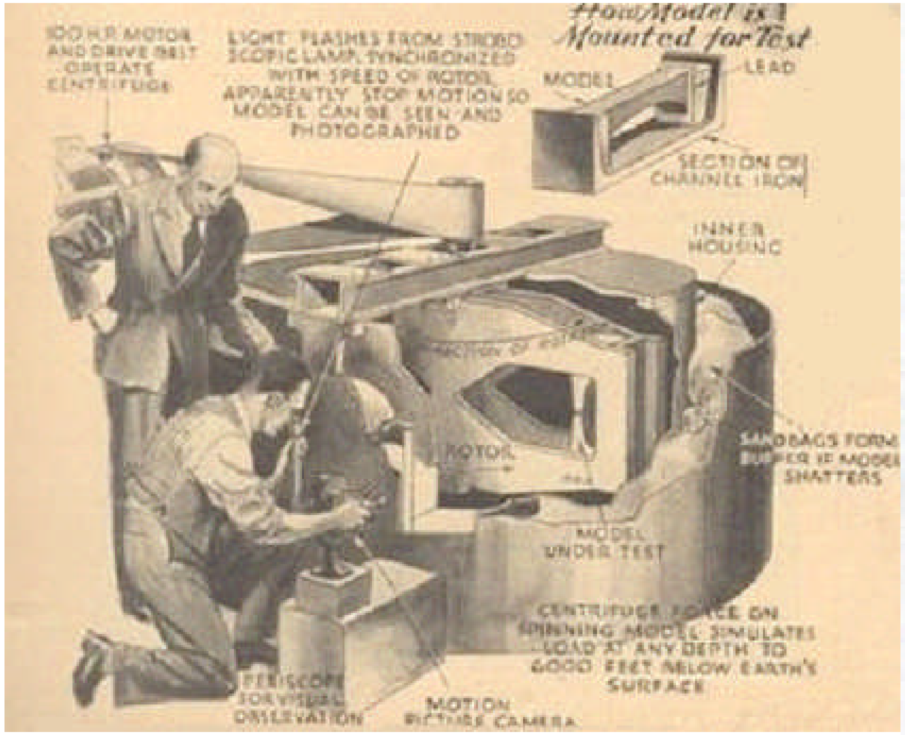
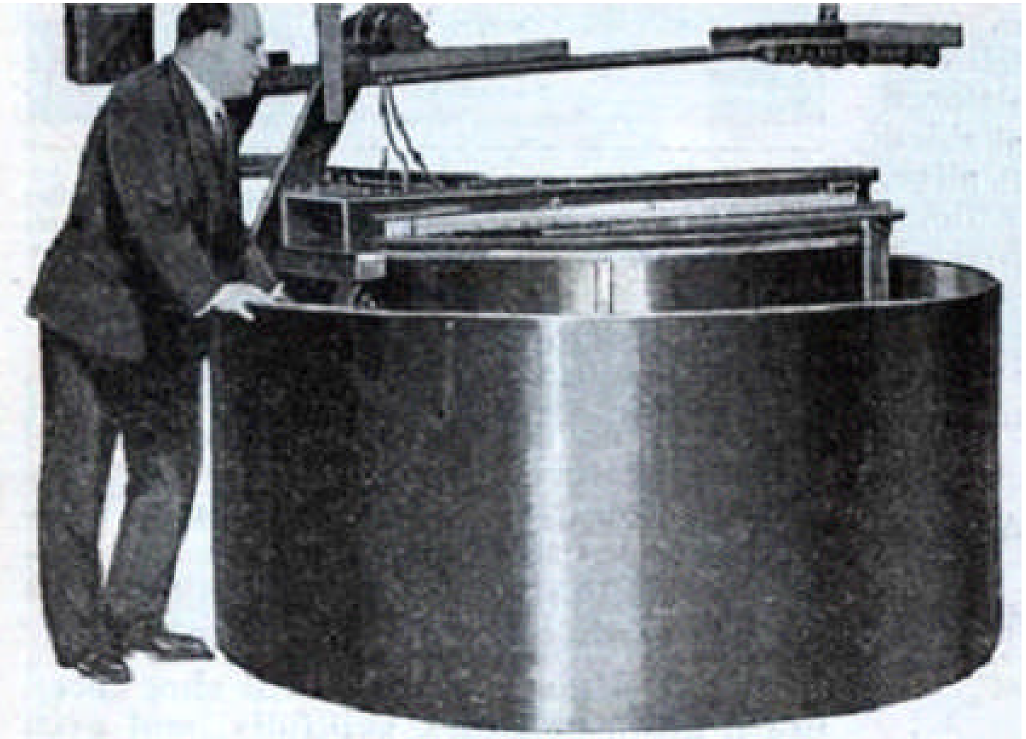
***Popular Science Monthly*, June 1934**

“…With habitable space growing more scarce every year in the crowded centers, architects and scientists freely predict that vertical cities, built from the earth’s surface downward, may eventually supplant the skyscrapers of today. The reasons for their belief in the practicability of such a plan lies in the recent successful tests of a machine known as the ‘centrifuge’ invented by Professor Philip B. Bucky, of Columbia University. Explained in its most simple terms, Professor Bucky’s machine is a device into which accurate scale models of underground structures may be placed and whirled about in such a way that the centrifugal force equals the actual earth stress to which full sized construction would be subjected…”

***Modern Mechanix*, July 1934**



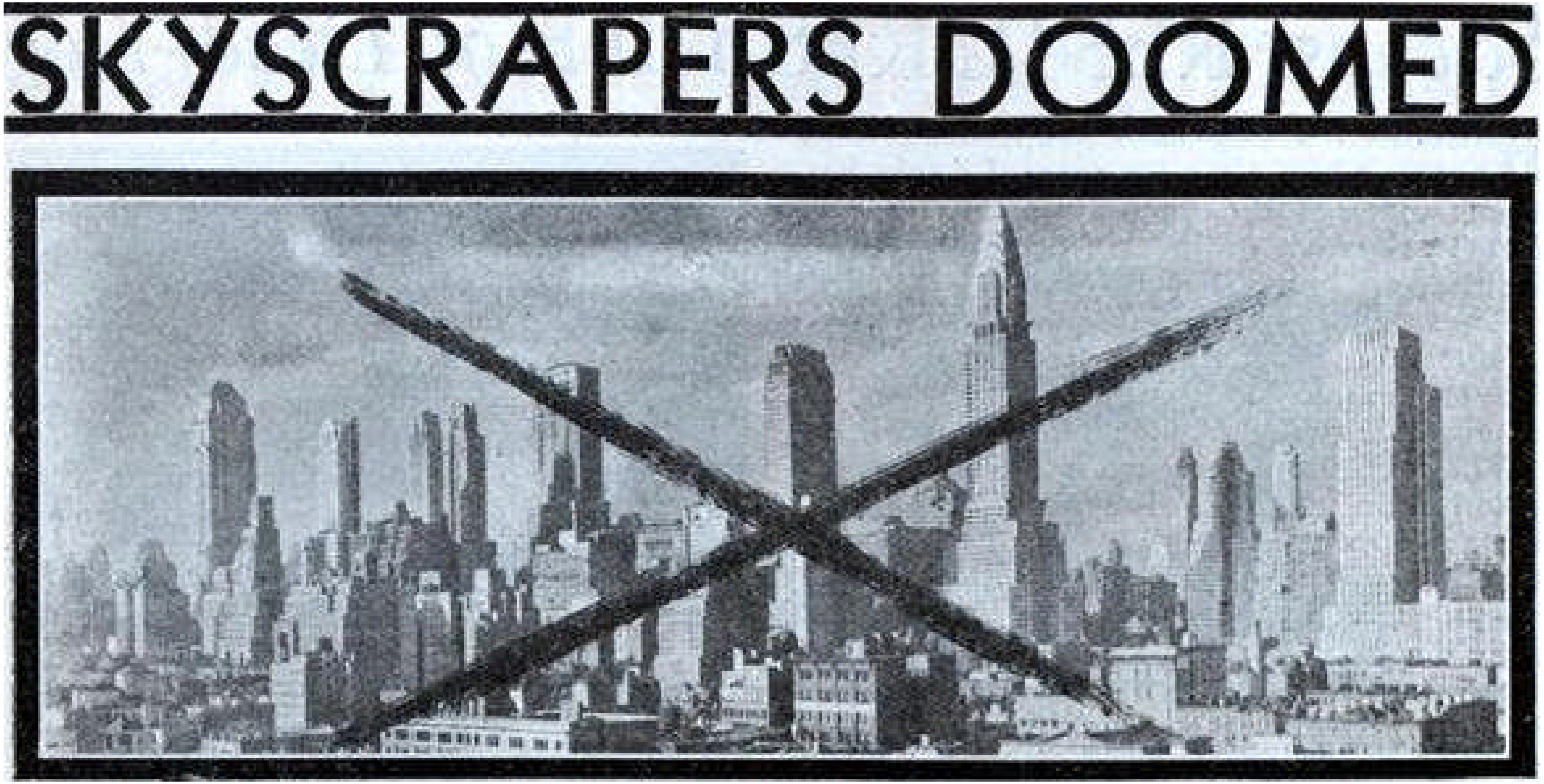


Left: caption: “Models of underground structures are whirled at terrific speed in this machine. In this way their ability to withstand the pressure of a mile of earth and rock is determined with great accuracy.”

Right: caption: “Construction models placed in this machine are whirled about until centrifugal force equals the pressure in which the full-size buildings are subjected by earth in actual sub-surface conditions”

“…Built of the same materials as the structure to be tested, the model is placed on the centrifuge and whirled at speeds up to 4,000 revolutions a minute until the centrifugal force tends to pull the model apart. A movie camera simultaneously records each revolution of the machine. When the film is run off on the screen it shows up the stress and strain under varying degrees of force up to the collapse of the model. From these technical tests a new science of foundation engineering is expected to develop. Lack of a yardstick with which to measure the stresses of the earth has hitherto kept architects from planning extensive underground projects. Testing depths up to 6,000 feet, the centrifuge opens up an amazing, vista of life in the future…”

***Modern Mechanix*, July 1934**



SKYSCRAPERS DOOMED

“Safe from bomb attacks - free from disease and changing temperatures - living in cities a mile beneath the surface of the earth - such is the dream of science for the man of the future, a not impractical dream which may doom the towers of Manhattan and every other large city to destruction…”[787]

***Modern Mechanix,* July 1934**

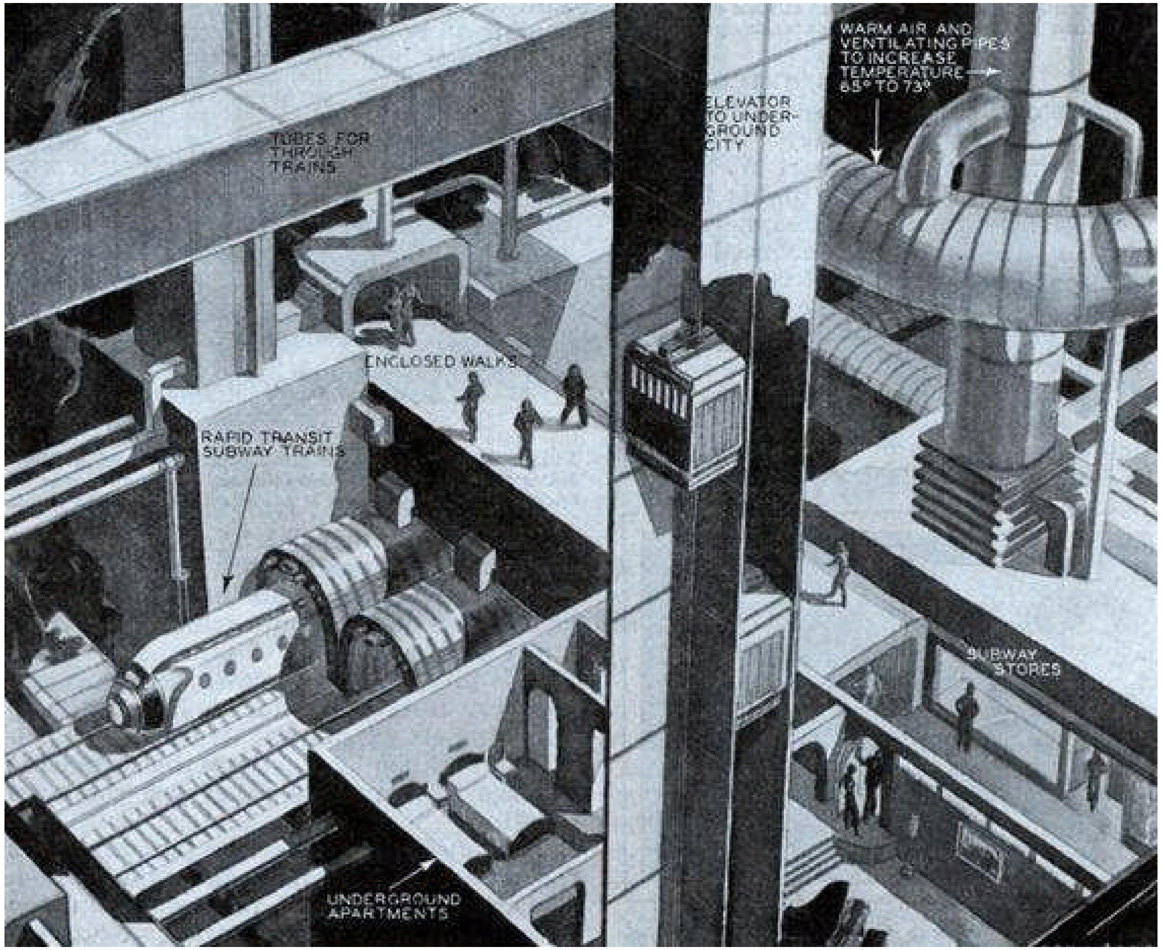
"…Despite its towering skyline, the trend of building construction in New York City has been ever downward. Today the island of Manhattan and its surroundings are honey-combed with a vast network of underground facilities. There are more than 130 tunnels and underground areas in the metropolitan district; more than 2,800 miles in the subterranean sewage system, and about 600 miles of subway trackage carrying 5,000,000 passengers every day…"

***Modern Mechanix,* July 1934**

Above: caption: "One of the three-tube subway tunnels, part of the vast network underlying New York City"

“…It will be possible to have business blocks under airports with the surface left clear for planes. Vast subterranean caverns could be constructed, capable of sheltering entire populations against enemy bomb attacks. Office buildings, factories, homes and theaters - all could be sunk into bed-rock…”

***Modern Mechanix*, July 1934**



"…Life underground would be different only in the respect that conditions, under scientific control, would be more sanitary and healthful. Conditioned air would prevail and the sun's absence compensated for by the use of ultra-violet lamps. The temperature would be constant at about 62 degrees. Coal bills would no longer worry the householder and bacteria would be killed…"

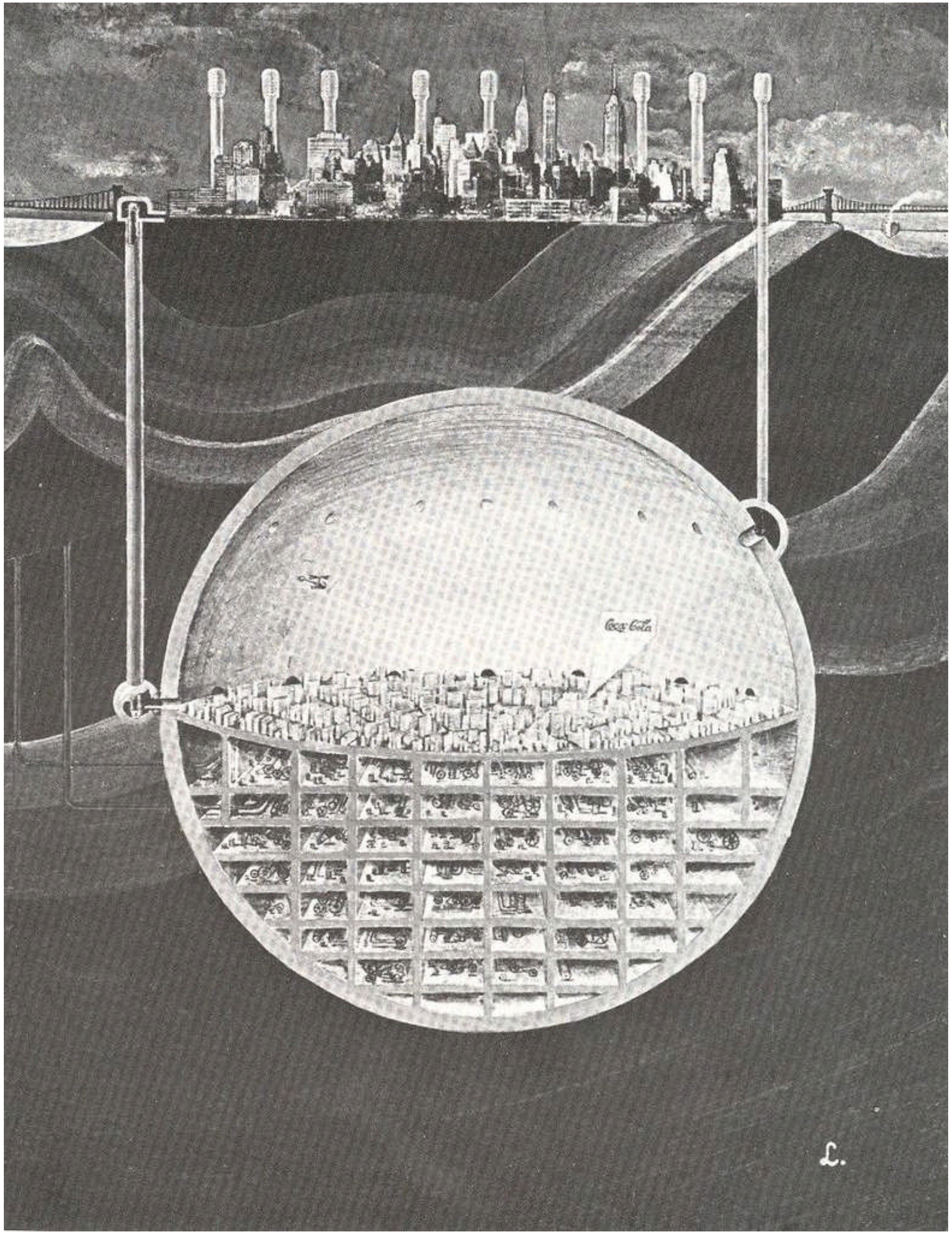
***Modern Mechanix*, July 1934**

“…Professor Bucky does not venture to make extravagant predictions. His centrifuge does not construct; it merely tests. The advantage of the machine lies in the fact that the safety of underground buildings may be absolutely proven by testing miniature models.”

***Modern Mechanix*, July 1934**

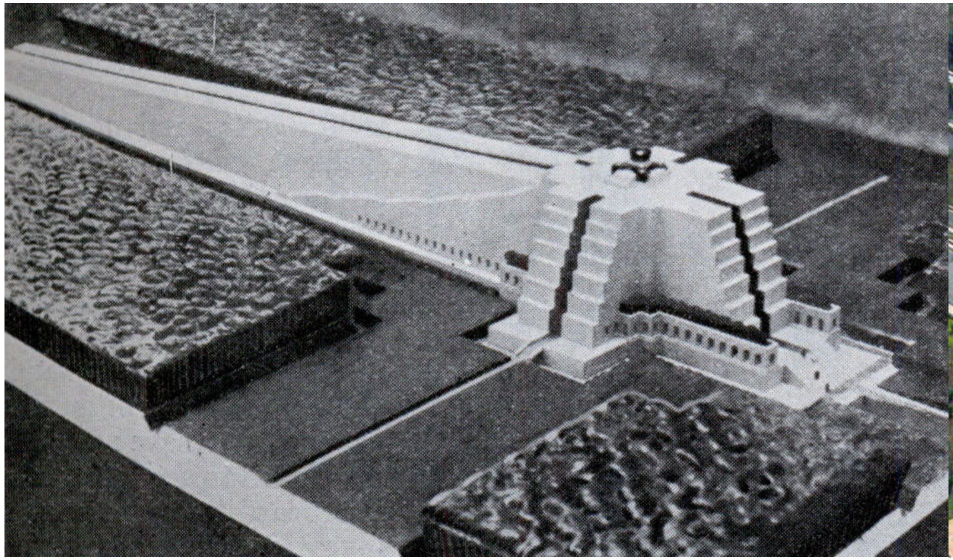
As Above, So Below

“Manhattan could have a half-dozen such atomic cities strung under the city proper…the real problem in an underground city would be the lack of views and fresh air, but its easy access to the surface and the fact that, even as things are, our air should be filtered and what most of us see from our window’s is somebody else’s wall.”
***Oscar Newman*, Architect**



In 1969, architect *Oscar Newman* suggested the idea of clearing out massive underground caverns with nuclear explosions, including hollowing-out one (or more) under Manhattan (left). The underground sphere would be a miniature version of whatever was above it; topside there would be a normal city with streets and high-rise buildings while underneath would exist an underground, spherical city. Only half of the sphere would be inhabited, preserving the top hemisphere for a “Cinerama’ (image projection). One-thousand foot tall (Q-Tip shaped) air-intakes/filters would provide ventilation for the city far below.

Columbus Remembered



“Earthquake-proof because of its massive and low-hung design, an impressive memorial is to be erected on the island of Santo Domingo in the Caribbean Sea to commemorate the arrival of Columbus on his historic voyage. It will be floodlit and surmounted by a powerful beacon, to serve as a lighthouse for mariners and airmen. An airport is to be built nearby. The design for the Columbus memorial, a tapering cross in form, was conceived by a twenty-four-year-old British architect, and recently was selected as the best of 450 submitted from architects of forty countries in an international competition.”

***Popular Science,* February 1932**

Left: caption: “This memorial to Columbus on Santo Domingo is earthquake-proof”

Right: caption: “Columbus Lighthouse Santo Domingo Este, Dominican Republic.” Construction began in 1986 (using plans drawn by Scottish architect *J.L. Gleave* in 1931) and was completed in time for the 500th anniversary of the discovery of the New World by Columbus in 1492. The monument has a powerful beacon, museum and mausoleum, containing what are believed to be the remains of *Christopher Columbus*.

QUE CON SU VISION SU CORAJE Y SU FE
TRANSFORMO EL MUNDO Y LA HUMANIDAD
CRISTOBAL COLON
GRAN ALMIRANTE DEL OCEANO·
VIRREY·GOBERNADOR GENERAL
DE LAS ISLAS Y CONTINENTE
DE ASIA Y DE AMBAS INDIAS·
CAPITAN GENERAL DE LA MAR·
MIEMBRO DE LA CORTE REAL
DEBAJO DEL REY Y LA REINA·

Roll Out the Barrel House

BARREL HOUSE READY FOR OCCUPANTS

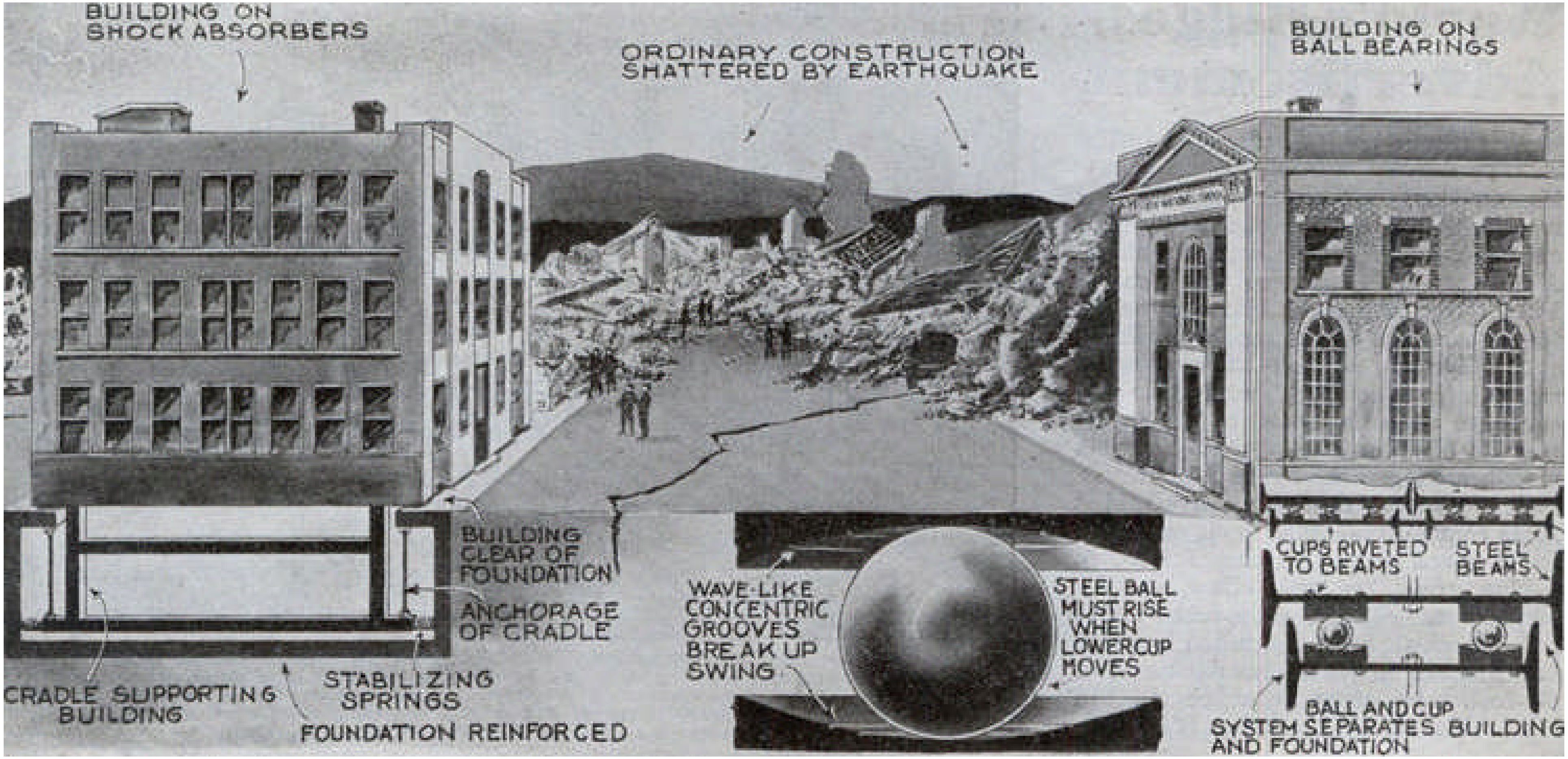
A HOUSE in which steel hoops take the place of joists, rafters and studding, has just been completed at Dusseldorf, Germany. According to the architect who originated the odd design, it provides strength and stability at reduced cost by eliminating the need for thick outer walls. The new style of construction, he asserts, is especially applicable in regions subject to earthquakes. Tests upon models preceded the construction of the first full-sized house, on which work began a few weeks ago and which is ready for occupancy (P. S. M., June '34, p. 29).

Above, a model of the barrel house showing how it is supported by the hoops that form its walls and roof. Right, exterior view of the completed barrel house ready for occupancy on its Dusseldorf, Germany, site

The Swing Era

“Until the age of steel construction, no building could be trusted to defy an earthquake; but a steel building, riveted or welded together, will stand quite a wrench without being pulled apart. Two patented ideas propose to separate the structure from its foundation so that, by the principle of inertia, it will stand still, like the pendulum of a seismograph, while the earth sways beneath it. The building, of course, will be somewhat shaken, but nothing in comparison with the shock through a solid foundation.”

***Science and Mechanics,* August 1936**



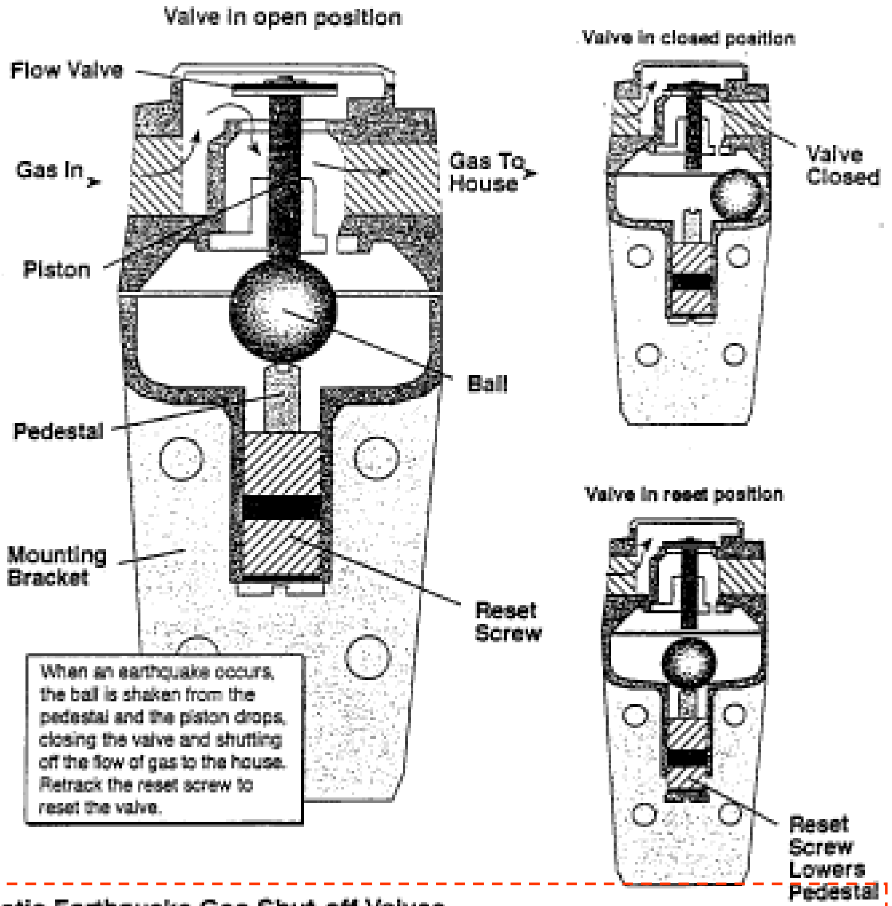
Above: caption: “Swinging Buildings to Defy Quakes. Two patents, issued the same day to two residents of the same California city, contemplate making earthquake-proof buildings which will be uninjured by tremors of the earth beneath them: they have slightly different methods of reaching the same results. (Patent Nos. 2,035,009 & 2,035,143)”

Safety First

“Fire following an earthquake often does more damage than the shock itself, and frequently the cause of fire is the ignition of gas from broken mains and pipes. To prevent escape of gas after a quake, an automatic shutoff valve has been devised which is operated by the earthquake itself. A heavy weight is suspended in the base of the valve by three metal wires, and when the body of the valve, attached to the building, is moved by the shock, the weight remains steady because of its flexible suspension. This the valve stem, which has been poised on a spindle projecting up from the weight, is displaced and the valve drops to its seat and shuts off the gas. A short curved lever or cam at one side of the weight can be operated manually to shut off the gas in the building in case of fire without an earthquake.”

***Popular Mechanics,* May 1939**

NEVADA EARTHQUAKE SAFETY COUNCIL



When an earthquake occurs, the ball is shaken from the pedestal and the piston drops, closing the valve and shutting off the flow of gas to the house. Retrack the reset screw to reset the valve.

Automatic Earthquake Gas Shut-off Valves

If you live in earthquake prone regions and have gas service, you may be interested in investing in a earthquake gas shut-off valve. Although there are many designs, most use the ball method. Its concept is simple and a typical example is shown above. A metal ball on a pedestal opens a valve allowing gas to pass from the service (either a tank or a utility hook-up) to the house. When sufficient shaking occurs, the ball drops from the pedestal, closing the valve - shutting off the flow of gas.

Most valve manufacturers have designed the valve of durable materials and to close only after a sufficient amount of shaking has occurred. They will not close when a large truck passes by or other incidental motion. The California State Architects Office has set 0.30 g horizontal as a minimum amount of shaking that may cause damage to gas service lines. The California State Architects Office has reviewed several automatic gas shut-off valves and has a comprehensive report available upon request that includes standards, testing results, and manufacturers address. Their phone number is 916-445-2163.

Some Insurance companies have provided deductions if earthquake shut-off valves are install. With the change in earthquake Insurance policies since the Northridge earthquake, check with your local insurance representative.

Prices for these products start at about $200. For additional information regarding automatic earthquake shut-off valves, contact your local earthquake supply outlet store.

<u>Left</u>: caption: “If you live in earthquake-prone regions and have gas service, you may be interested in an earthquake gas shut-off valve. Although there are many designs, most use the ball method. Its concept is simple and a typical sample is shown above. A metal ball on a pedestal opens a valve allowing gas to pass from the service (either a tank or a utility hook-up) to the house. When sufficient shaking occurs, the ball drops from the pedestal, closing the valve – shutting off the flow of gas. Most valve manufacturers have designed the valve of durable materials and to close only after a sufficient amount of shaking has occurred. They will not close when a large truck passes by or other incidental motion. The California State Architects’ office has set 0.30g horizontal as a minimum amount of shaking that may cause damage to gas service lines…Some insurance companies have provided deductions if earthquake shutoff valves are installed…Prices for these products start at about $200…”

Nevada Earthquake Safety Council

Rolling With the Punches

“Three top floors of a Los Angeles building will resist earthquake tremors by rolling six inches in any direction. This three-story addition now being built atop a six-story department store is the only structure in the world to rest on roller bearings. The store was built in 1929 before the earthquake code was enacted. Conventional earthquake-proof construction for the addition would have been too expensive, so engineers decided to ‘float’ the additional floors on rollers placed under the girders and cross members. The structure rests on 65 roller bearing units, each designed to support 240,000 pounds. Each unit weighs 600 pounds and consists of three steel plates and two layers of rollers. The rollers between the bottom and center plate roll in a north-south direction, while those above move east-west. In the event of an earthquake the building can move six inches in any direction, sliding on both sets of rollers if the shock moves diagonally. Each of the roller units is hermetically sealed so no foreign matter can enter the bearing, and is lubricated with a non-deteriorating type of oil.”

***Popular Mechanics*, January 1947**

Risky Business

“…There is no way of predicting an earthquake, except in the words of Dr. Bailey Willis, 91-year-old earthquake expert of Stanford University. Dr Willis says: ‘There is just one sure thing about earthquakes – the farther you are from the last one the nearer you are to the next one.’ Based in part on this reasoning, at least one insurance company has drastically raised its rates for coverage against earthquake damage and has stopped soliciting new business…”

***Popular Mechanics,* December 1948**

RE: *Earthquake Insurance* is a form of property insurance that pays the policy-holder in the event of an earthquake that causes damage to the property (most ordinary homeowners insurance policies do not cover earthquakes). Most earthquake insurance policies feature a high deductible, which makes this type of insurance useful if the entire home is destroyed but not useful if the home is merely damaged. Rates depend on location and the probability of an earthquake loss (rates may be cheaper for homes made of wood, which withstands earthquakes better than homes made of masonry). In the past, earthquake loss was assessed using a collection of mass inventory data and was based mostly on experts’ opinions. Today, it’s estimated using a *<u>D</u>amage <u>R</u>atio* (DR); a ratio of the earthquake damage money amount to the total value of a building. Another method is the use of *HAZUS* (a computerized procedure for loss estimation).

As with flood insurance and/or insurance on damage from a hurricane (or other large-scale disaster/s), insurance companies are careful when assigning this type of insurance because an earthquake strong enough to destroy one home will probably destroy dozens of homes in the same area. If one company has written insurance policies on a large number of homes in a particular city, then a devastating earthquake will quickly drain all the company's resources. As such, insurance companies use the principles of *Risk Management* to avoid such cases. In the U.S., insurance companies stop selling coverage for a few weeks after a sizeable earthquake has occurred due to the fact that damaging after-shocks can/do occur after the initial quake and rarely, it may be fore-shock. Although aftershocks are smaller in magnitude, they deviate from the original epicenter. If an aftershock is significantly closer to a populated area, it can cause much more damage than the initial quake. One such example is the 2011 *Christchurch Earthquake* (in New Zealand) which killed 185 people (it followed a much larger and more distant quake with no fatalities whatsoever).

Reducing the Risk

“…a tremendous amount of unpublicized and extremely important preparation has been going on. Building codes have been amended to require earthquake-resistant construction. The codes stipulate that concrete or masonry walls must be reinforced with steel bars or mesh. Roofs and floors of buildings must be tied ‘extra strong’ to their exterior walls. Residences must be anchored to their foundations instead of merely being erected on top of them. Walls must be braced laterally, a provision that is good against strong winds as well as quakes. Even one-story fireplace chimneys for homes must be held together with steel rods that extend down into the fireplace foundation…”

Popular Mechanics, **May 1958**

Detroit News

THE HOME NEWSPAPER FOR MORE THAN 79 YEARS

SEVEN CENTS

in Neighborhoods Monday

QUAKES STRIKE L.A. AND COAST

Bakersfield Jolted; 2 Dead, 32 Injured

Scout Calms Movie Crowd During Quake

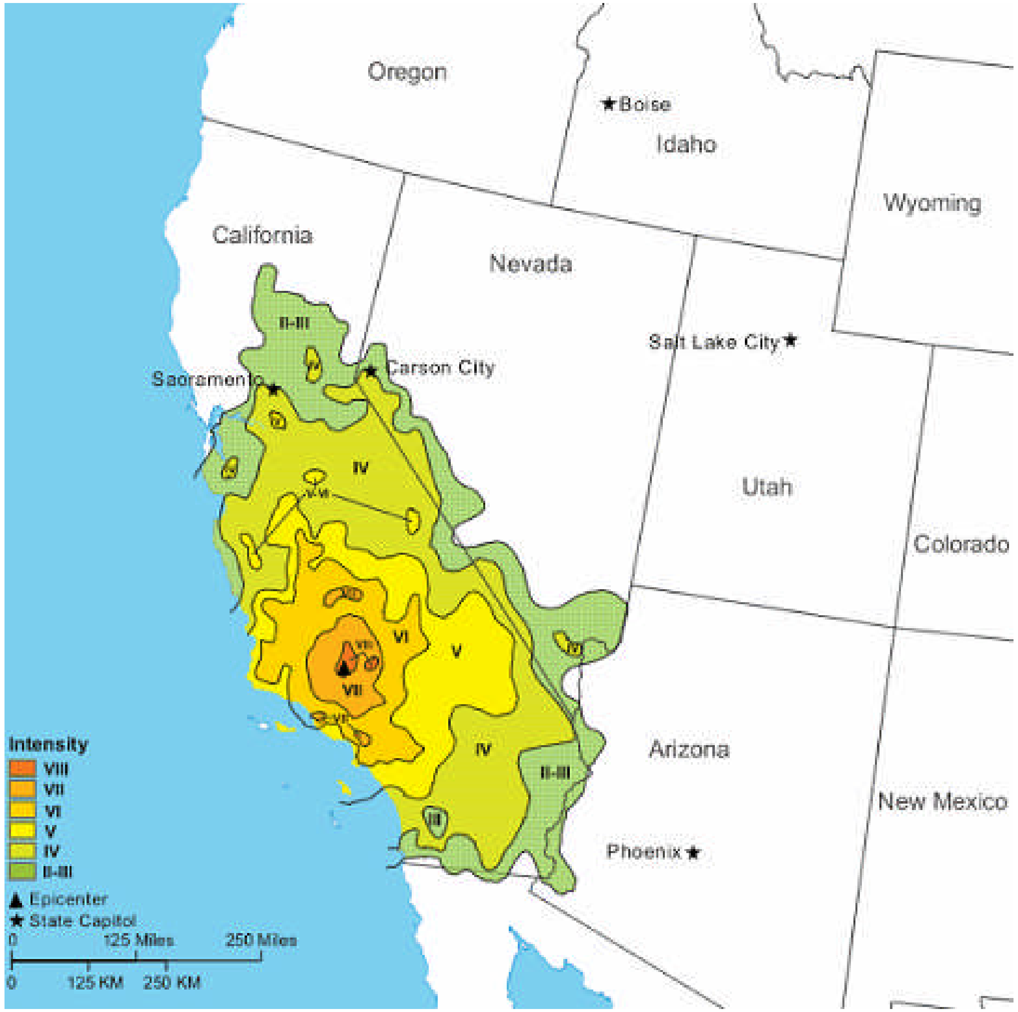
Success in Loop Spurs Extension

"…Requirements like these make a tremendous difference. Everyone who visited the Bakersfield-Tehachapi area after the 1952 quakes saw that the newer buildings, conforming to the code, suffered little or no damage even though they were next door to older structures that were completely destroyed…"

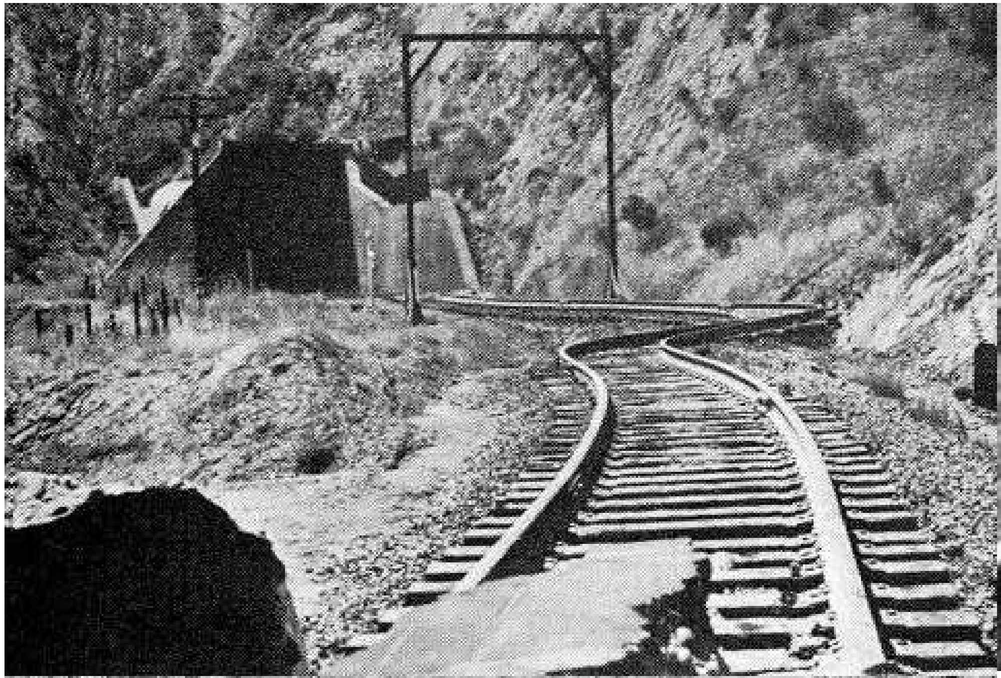
Popular Mechanics, **May 1958**

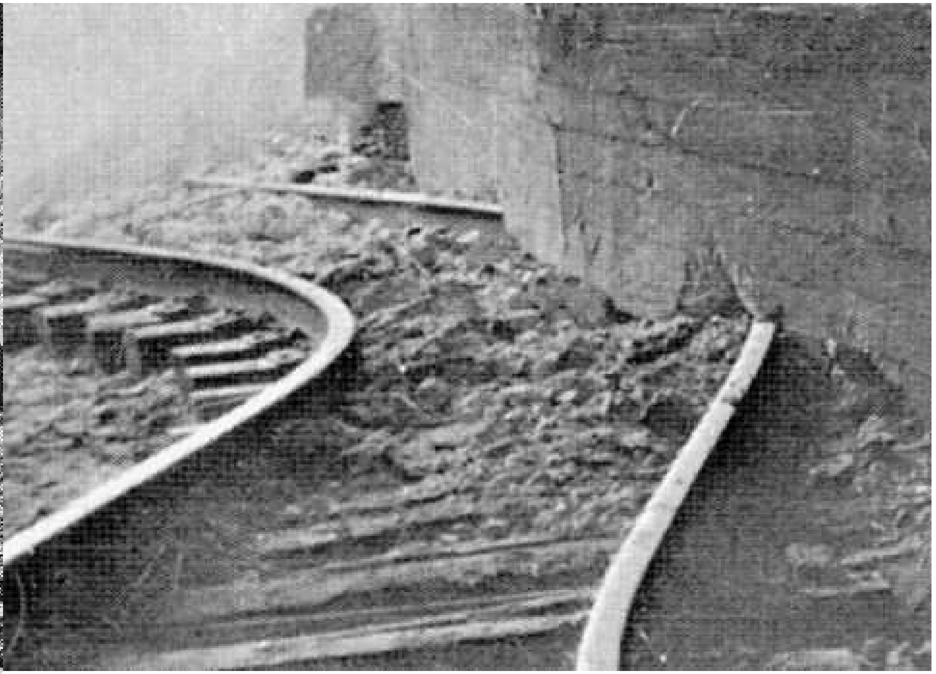
<u>Left</u>: *The Detroit News*, August 23rd 1952

The largest earthquake in southern California since the *Fort Tejon Earthquake* of 1857 and the *Owens Valley Earthquake* of 1872, the magnitude 7.5 *Kern County Earthquake* of 1952 caused immense and widespread damage. The quake occurred on the *White Wolf Fault*, a reverse (with a left-lateral component) fault north of the intersection of the *Garlock* and *San Andreas Fault/s* – twenty-three miles south of Bakersfield. The area shaken by this quake was quite large, being felt in Reno and Las Vegas, NV. In San Francisco, it was felt mainly by people on the upper floors of tall buildings. Power outages occurred in Los Angeles, along with minor building damage. It was felt in San Diego as well and even damaged one building there. At *Owens Lake*, about 200 km distant, the shaking broke a pipeline and disturbed salt beds, causing damage to a mining operation. The Kern County Earthquake claimed twelve lives, was responsible for at least eighteen injuries and caused at least $50 million in property damage. This quake and its aftershocks (at least twenty were of magnitude 5.0 or greater) were responsible for damaging hundreds of buildings in the *Kern County* area, at least one-hundred of which had to be torn down. It devastated a section of the *Southern Pacific Railroad* line near *Bear Mountain* and wreaked havoc on agriculture in the Arvin area (where the land was reclaimed from the *Kern River Delta*, creating conditions which amplified the effects of the quake). Slumping and surface rupture caused irrigation breaks and subsurface movement disturbed well output.



Left: caption: “Kern County Earthquake - 7.3 - July 21, 1952.” Reports of long-period wave effects from the earthquake were wide-spread. Water splashed from swimming pools in LA (where non-structural damage to many buildings occurred) and pressure tanks atop buildings in San Francisco. In Las Vegas, a building under construction required realignment of the structural steel. The main shock was felt over most of California and in parts of western Arizona and southwest Nevada. It was observed at such distant points as Stirling City, CA, Phoenix, AZ and Gerlach, NV. The *California Institute of Technology at Pasadena* recorded 188 aftershocks of magnitude 4.0 and higher through September 26th 1952 (six aftershocks on July 21st 1952 were of magnitude 5.0 and higher).

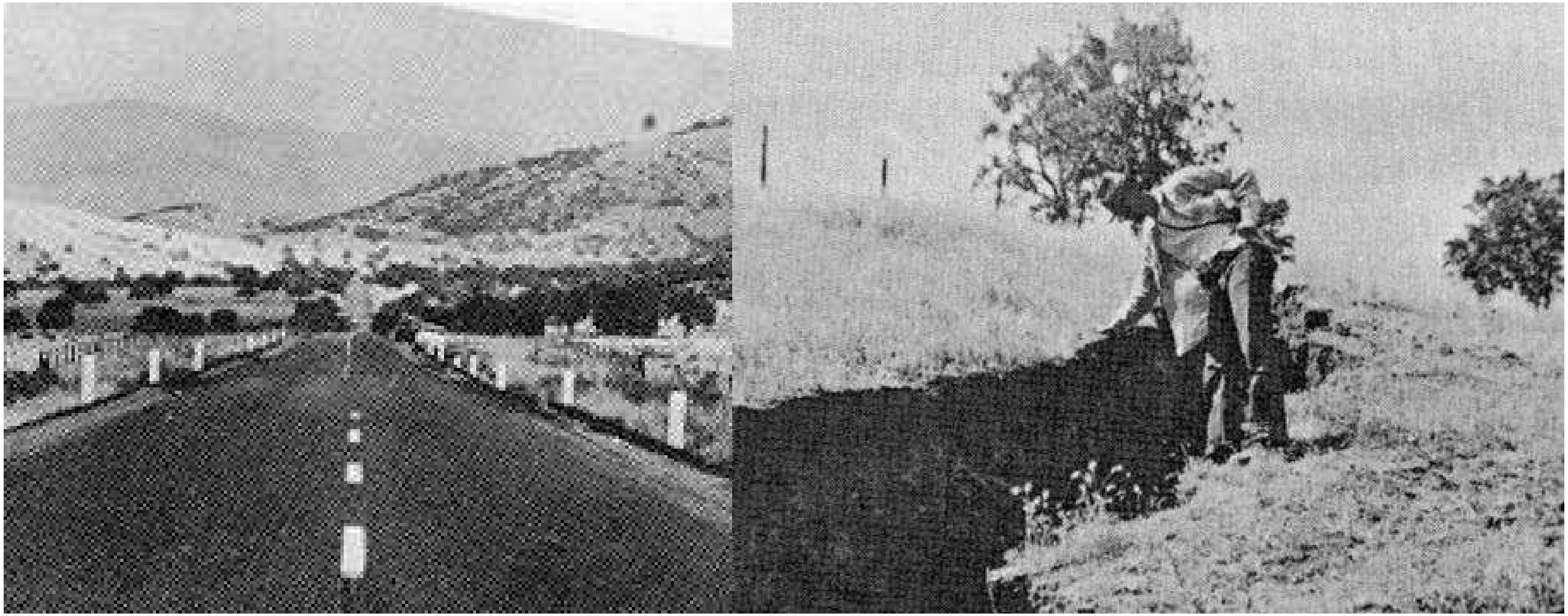




Top Left: caption: "A view from the entrance of a railroad tunnel (designated 'Tunnel No. 3') showing bent rails between two tunnels near a zone of intense fracturing along the White Wolf fault."

Top Right: caption: "Inside Tunnel No. 3. A close-up not only of bent rails, but of an unusual phenomenon - the rail is continuous underneath the tunnel wall, indicating that the wall lifted up enough for the rail to slide underneath."

Left: caption: "Rockslide damage to the Kern Canyon Plant Diversion Dam"



<u>Left</u>: caption: “Highway 466 (currently, Highway 58), west of the Caliente-Arvin Road (currently, Highway 223) junction, looking east. Note offset center line due to ground breakage.”
<u>Right</u>: caption: “Vertical fracture on the northeast side of Bear Mountain, along the White Wolf Fault. At this location, a vertical displacement of 60 cm (2 ft.) and a horizontal (left-lateral) displacement of 45 cm (1.5 ft.) were measured along the break.”

Property damage was heavy in Tehachapi, where both brick and adobe buildings were hit hard and nine people were killed (three people were killed in other towns). Although damage was severe, the total extent of damage to property did not exceed that in Long Beach in 1933. Only a few wood-frame structures were damaged seriously in this earthquake, compared to the 1933 shock in which many such structures were thrown off foundations. The generally moderate damage in Bakersfield was confined mainly to isolated parapet failure. Cracks formed in many brick buildings and older school buildings were damaged somewhat. In contrast, however, the *Kern General Hospital* was damaged heavily. Multistory steel and concrete structures sustained minor damage, which commonly was confined to the first story. Similar kinds of damage also occurred at Arvin, which lies southeast of Bakersfield and west of Tehachapi.

<u>Left</u>: caption: “Main Street, Tehachapi, after the earthquake of July 21, 1952. The two-story concrete (with wood floors and roof) structure in the background is the Catholic Youth Center. Despite the fact that most of Tehachapi’s business section was at least partially destroyed, this building suffered little damage.”

<u>Right</u>: caption: “A Bakersfield street after the August 22 shock. Brick parapets fell to the sidewalk - fortunately, the streets and sidewalks were empty at the time”

ASAP

"…Los Angeles has gone even further. Several years ago a retroactive law to make old buildings safer was pushed through by Gilbert Morris, head of the Los Angeles Department of Building and Safety. The law calls for the removal or strengthening of tall parapet walls around the sides of roofs, and the removal of ornamental projections that are located above public walks and entrances. The law is based on the observation that thousands of tons of debris are tumbled from buildings into the streets during a heavy quake, with more left hanging, ready to topple over. Most deaths from an earthquake occur when people run out into the streets and are then struck by material falling from the buildings…"

***Popular Mechanics,* May 1958**

RE: in California, construction of new *<u>U</u>n-reinforced <u>M</u>asonry <u>B</u>uildings* (UMBs) was prohibited in 1933 (in the aftermath of the *Long Beach Earthquake*) and state law required seismic retrofitting of existing structures (enacted in 1986). Retrofits are relatively expensive and may include the building being tied to its foundation, tying building elements (such as roof and walls) to each other so that the building moves as a single unit (rather than creating internal shears during an earthquake), attaching walls more securely to underlying supports (so that they don't buckle and collapse) and bracing or removing parapets and other unsecured decorative elements. Retrofits are generally intended to prevent injury and death to people, but not to protect the building itself. The California law left implementation and standards up to local jurisdictions.

“…Half a million tons of parapet walls and ornamentation have been removed from 3,696 office buildings and other commercial structures in Los Angeles as a result of the new safety law. Corrective work is proceeding on 1,900 other structures. The result is that all of downtown Los Angeles and many of its outlying shopping areas are now considered far safer in an earthquake than previously. Other cities enforce similar earthquake safety laws…”

***Popular Mechanics,* May 1958**

Left: caption: “Parked cars were not spared from the falling debris”

Right: caption: “Car smashed by falling debris in 1952 Kern County Earthquake”

“…The Long Beach earthquake of 1933 and the Bakersfield quake of 1952 proved that many schools are actually death traps. Parts of the structures toppled into the exits that children would have been using had the quakes occurred during school hours. There was other extensive damage…”

Popular Mechanics, **May 1958**

Left: caption: “A collapsed school in Kern County, California (1952)”

"…Because of these lessons, many old school buildings have been torn down and replaced by safer structures. But engineers are unhappy about many of the other old school buildings still in use. One opinion is that possibly half of the schools in Los Angeles alone still need some corrective work. Engineers and seismologists are urging that such structures be strengthened as soon as possible…"

***Popular Mechanics,* May 1958**

RE: there's particular cause for concern in regions which can generate strong earthquakes. Such regions may not have regulations limiting the construction of UMBs or have only implemented them recently. The lack of earthquake codes preventing the construction of UMBs was a major factor in the high death toll of the 2010 *Haiti Earthquake*.


© Getty Images

ICFs

<u>Left</u>: *<u>I</u>nsulating <u>C</u>oncrete <u>F</u>orm* (ICF) is a system of formwork for reinforced concrete, usually made with a rigid thermal insulation that stays in place as a permanent interior and exterior substrate for walls, floors and roofs. The forms are interlocking modular units that are dry-stacked (without mortar) and filled with concrete. The units lock together in a manner somewhat like Lego blocks and create a form for the structural walls or floors of a building. ICF construction has become commonplace for both low-rise commercial and high-performance residential construction as more stringent energy efficiency and natural disaster resistant (i.e. seismic) building codes are adopted worldwide.

Part 9

The Delicate Balance

Throwing Stones

“…One modern trend in architecture has created a new earthquake hazard. Most new office buildings are literally walled with glass windows. These windows can splinter and rain down in lethal showers, as was learned in the 1957 quake in Mexico City. In California today measures are being considered for some sort of protection…”

Popular Mechanics, **May 1958**

RE: on July 28th 1957, a magnitude 7.7 quake struck Mexico City, bringing down buildings and the city’s iconic *Angel of Independence* monument (Mexico City was built on a lakebed that amplifies the waves that radiate out from an earthquake’s center). Seven hundred people died. On October 15th 1979, buildings crumbled during a powerful magnitude 7.9 tremor that also caused numerous deaths. On September 19th 1985, a magnitude 8.1 earthquake killed 10K, injured 30K, left thousands homeless and damaged 400 buildings. On March 20th 2012, a magnitude 7.4 quake caused some damage but no deaths. Stricter building codes and a city prepared by evacuation drills and early warning systems started to pay dividends.

MONDAY, JULY 29, 1957

32 Killed in Earthquake

Huge Damages as Many Buildings Crack, Fall

By BACK RUTLEDGE

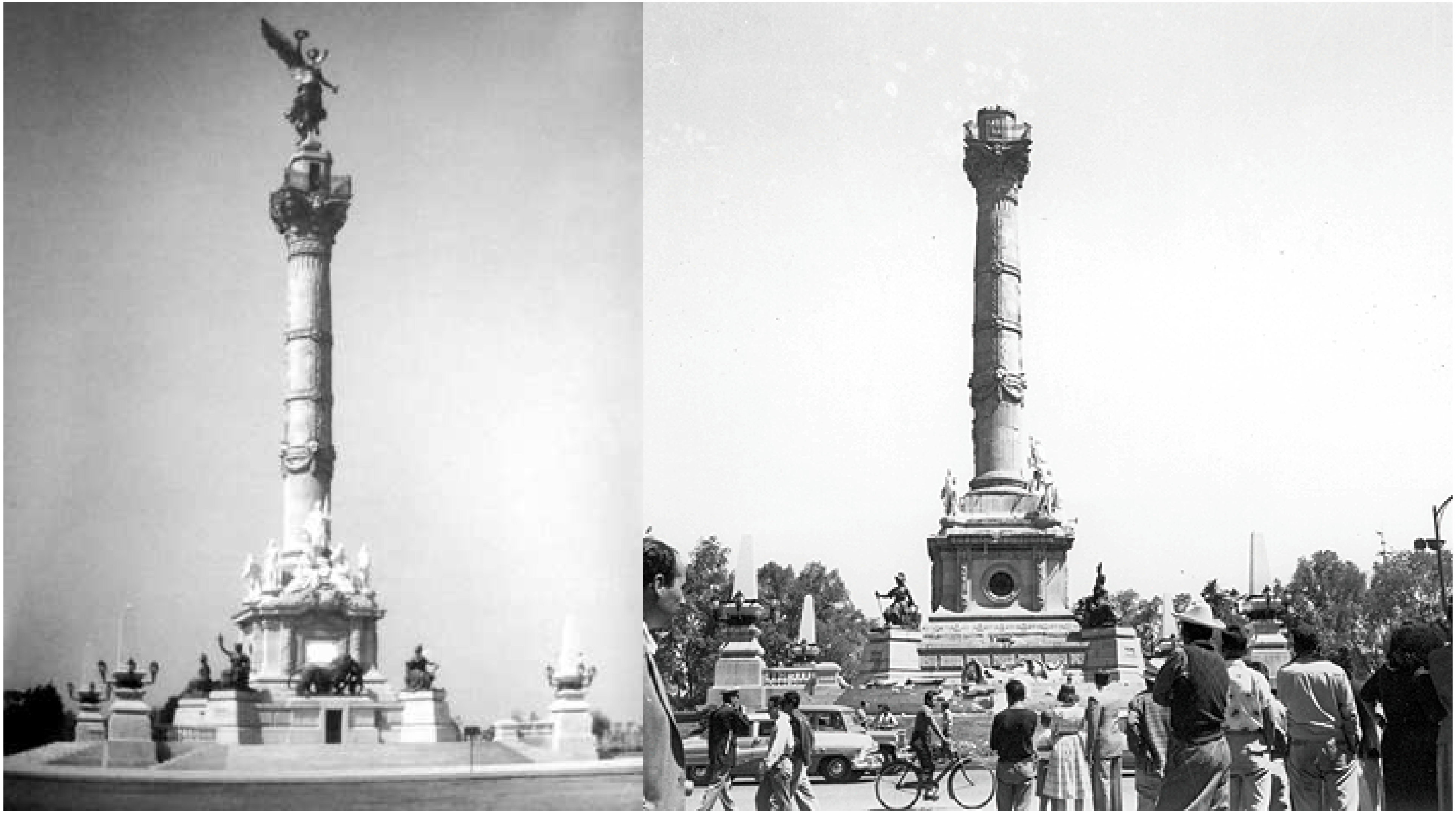
MEXICO CITY, July 28. (AP) — This capital of 4,000,000 persons, battered and bleeding from the worst earthquake in memory, anxiously waited word from other cities believed to be harder hit.

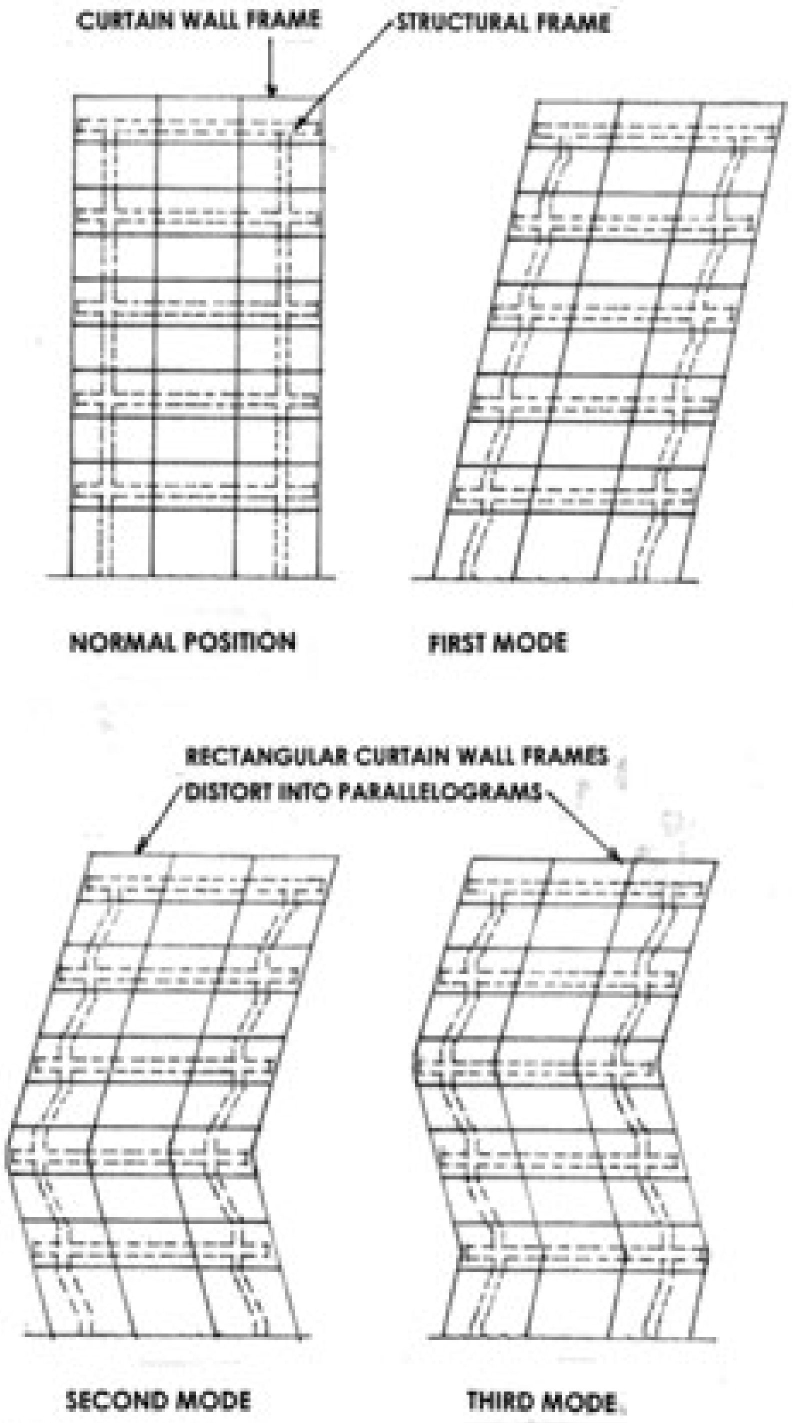
Communications were disrupted to Acapulco, the Pacific coast resort which seismograph officials say received the brunt of the early morning temblor, and Cuernavaca, Puebla, Oaxaca and other areas.

Federal District police reported that there were 32 dead and 450 injured in the capital.

México City was a capital of collapsed or cracked buildings, its streets littered by shattered glass. Only its "mud mattress" of spongy, water-saturated soil saved it from far worse damage. The soft sub-soil formed a cushion, and many buildings swayed instead of crumbling.

But damage was severe nevertheless. A five-story





Experience in earthquakes has shown that glass has considerable in-plane strength and out-of-plane flexibility (above). However, glass is vulnerable to forces applied to its edges and corners by rigid framing members (left). Earthquake forces cause the structure to drift and, in a typical curtain wall in which the framing is rigidly attached to the structure, framing systems deform and corners of the glass may impact the metal frame.

Above: caption: "Glass damage in Mexico City earthquake, 1985. Note the extreme distortion of the first floor, but only a few glass panels were severely damaged. Even with the massive shaking, glass in the upper floors is undamaged."

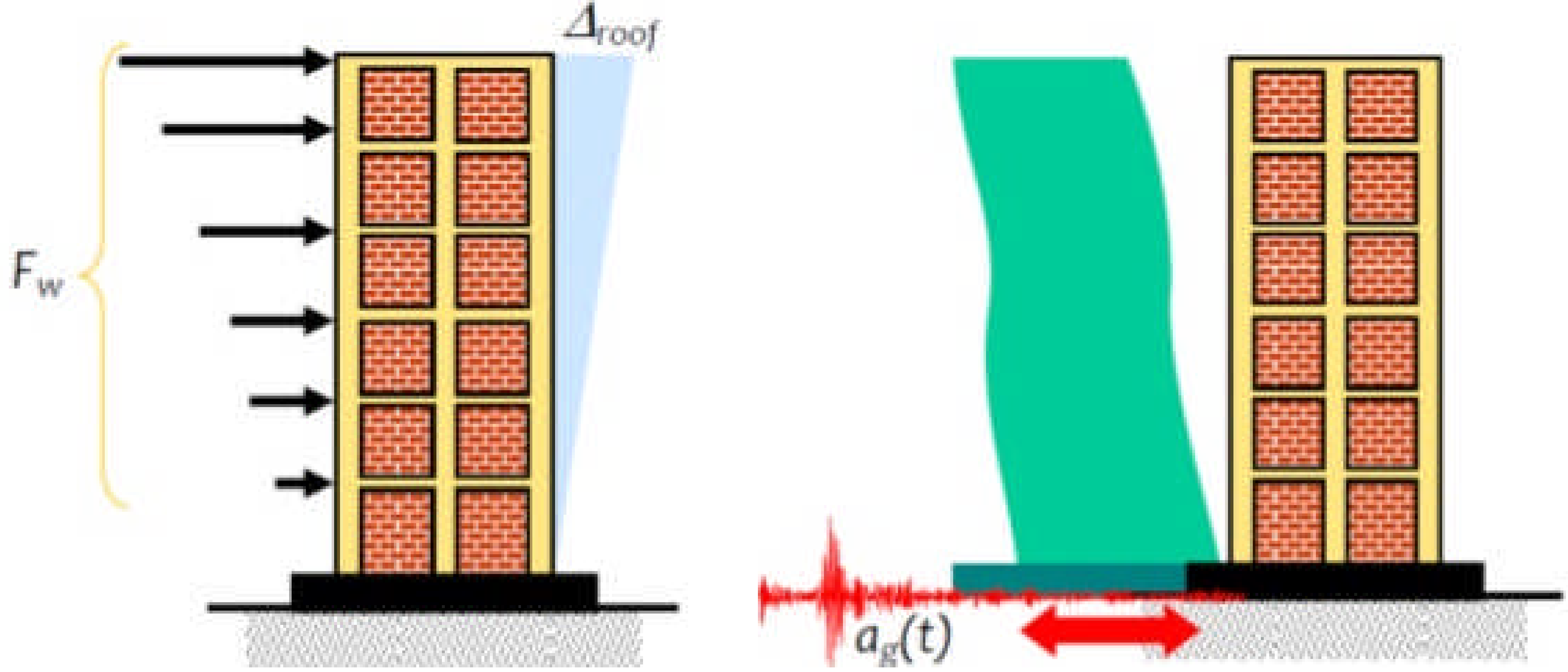
Left: caption: "Vibration modes of a typical building frame and its relationship to curtain wall"

Comparatively Safe

"…To keep property damage and loss of life at a minimum when a big shake comes, California towns and cities have strengthened their building codes to help make all new structures comparatively safe. Once it was thought that buildings which could withstand a strong wind were also earthquake-proof. Now it is understood that wind load is proportionate to the exposed area of a building, while earthquake load is proportionate to the weight of a building and building-code requirements are rewritten to comply…"

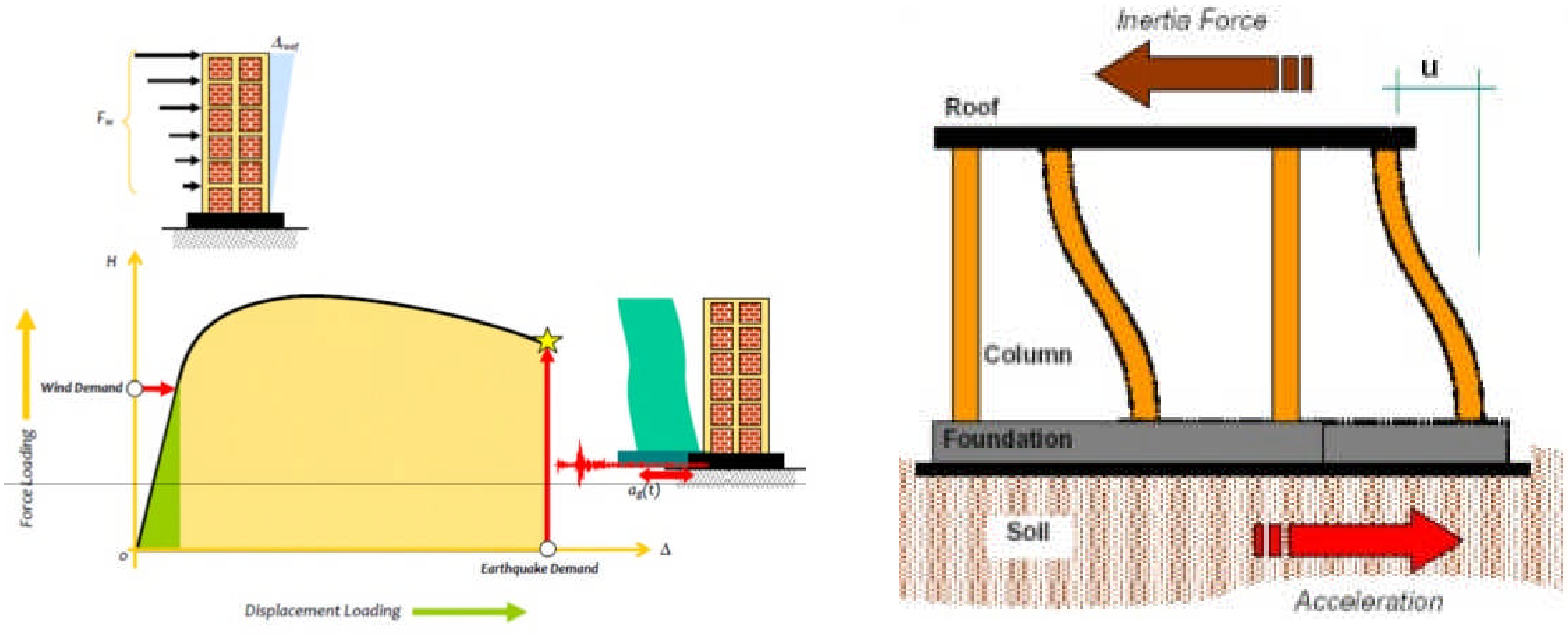
***Popular Mechanics,* December 1948**

RE: *Dynamic Action* (movement) is introduced to buildings by both wind and earthquake forces. However, design criteria for wind forces and earthquake effects are distinctly different by necessity.



<u>Left</u>: caption: “*Wind Loading* is a force-type loading whereby the building is subjected to a pressure on its exposed surface area”

<u>Right</u>: caption: “*Earthquake Loading* is a displacement-type load whereby the building is subjected to random motion of the ground at its base, which induces inertia forces in the building that in turn cause stresses”



<u>Above L&R</u>: caption: “Earthquake Loading concentrates particularly on the translational inertia forces, whose effects on a building are normally more significant than the vertical or rotational shaking component. Earthquake loading consists of the inertial forces of the building mass that result from the shaking of its foundation by seismic activity.”

“…Meanwhile, numerous older buildings have been overhauled and strengthened. Cornices and parapets that might be jarred loose have been reinforced or removed. Marquees that overhang sidewalks have been strengthened. Large advertising signs on the tops of buildings have been rebuilt. Water tanks, fuel tanks, and swimming pools on roofs or in upper stories are provided with stronger foundations…”

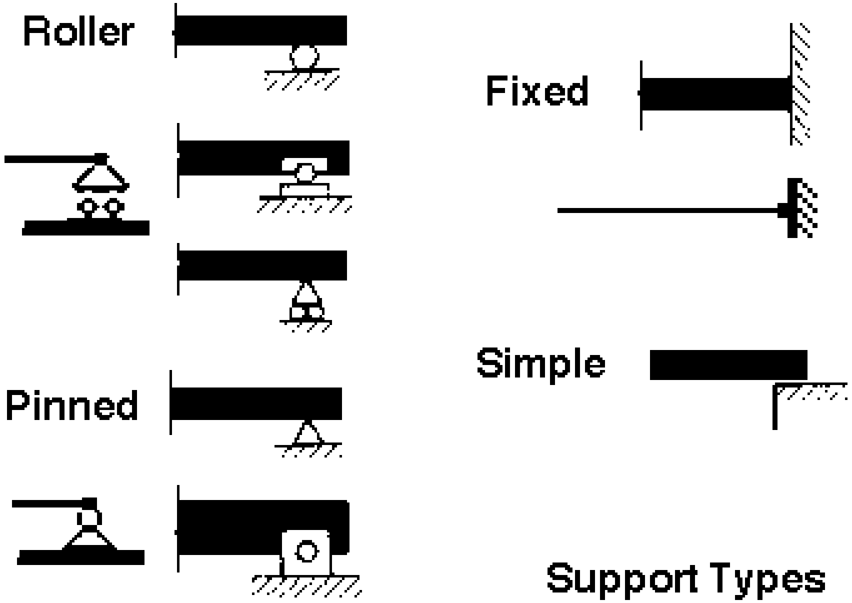
***Popular Mechanics,* December 1948**

Time Tested

“…‘Two types of structures are extremely resistant to earthquakes,’ so says Dr. Lydik S. Jacobsen, head of the Department of Mechanical Engineering and Director of the Vibration and Earthquake Laboratory operated by Stanford University. ‘One is the rigid mass exemplified by the Egyptian pyramids, the other is the pliant structure of which the California redwood tree is a good example. Both pyramids and redwoods have experienced numerous heavy quakes and yet each type has stood for thousands of years. Neither, however, is quite suitable for our needs. The best compromise is to construct small buildings as stiff and strong as is practicable and to construct tall buildings with a certain amount of flexibility. The lower stories in particular must be flexible so as to avoid a ‘crack the whip’ effect in the upper stories’…”

***Popular Mechanics,* December 1948**

Seismic Fuses



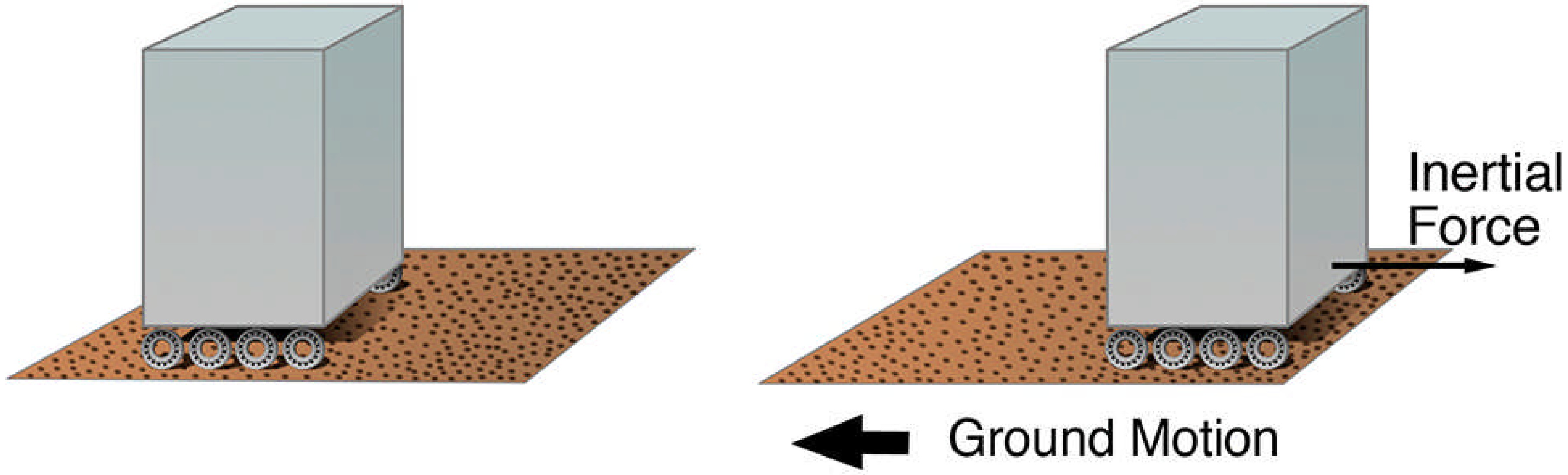
"…One way of avoiding earthquake damage is to mount an entire building on balls or rollers. This has been tried in New Zealand where some buildings are placed on thick foundations of loose, spherical gravel. The idea is hardly practicable for huge structures of the office-building type…"

***Popular Mechanics,* December 1948**

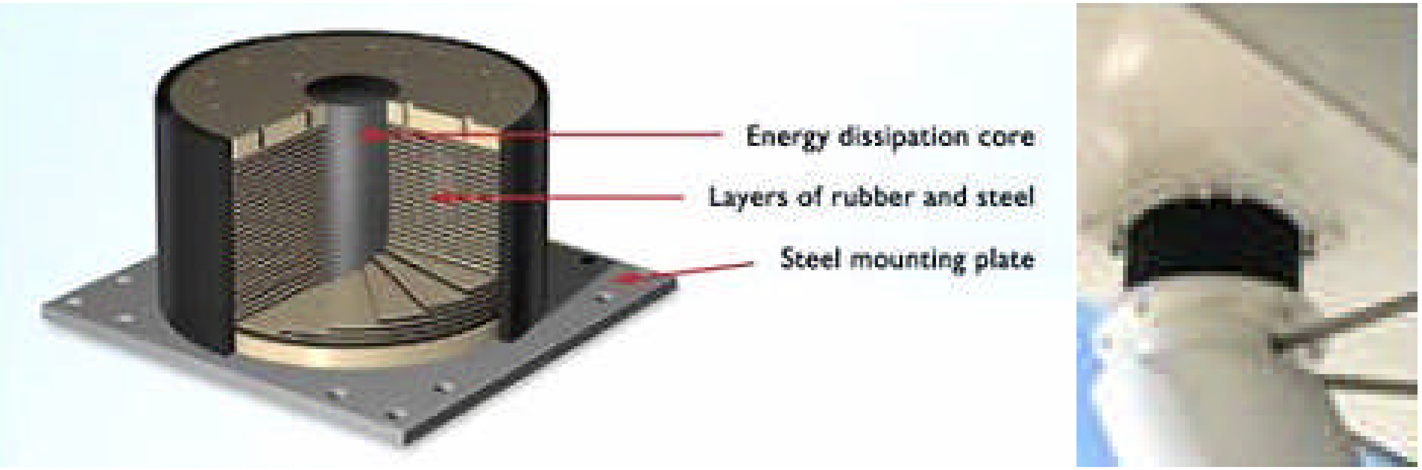
<u>Left</u>: caption: "Support Types"

<u>Right</u>: caption: "A *metallic roller bearing* is a base isolation device which is intended for protection of various building and non-building structures against potentially damaging lateral impacts of strong earthquakes. This bearing support may be adapted, with certain precautions, as a seismic isolator to sky-scrapers and buildings on soft ground."

Base Isolation



The problem with attaching a building firmly to the ground is that earthquake waves are absorbed by the building and its contents, often destructively. The key to solving this problem is to dissipate the energy in the foundation <u>*before*</u> it reaches the main floors of the building. In *Base Isolation,* the objective is to keep the ground motion from being transferred into the building. This is the same objective as in automobile suspension design; keep the passenger/s from feeling all the bumps in the road. To accomplish this, the automobile is designed with air-inflated tires, springs and shock absorbers to keep passengers comfortable. One way to do this is to put the building on roller bearings so that as the ground moves horizontally, the building remains stationary (above). A problem with this solution is that roller bearings would still transmit force into the building through friction. In addition, once the building began to roll, its inertia would tend to keep it moving. Thus, a structure that allows horizontal movement (with respect to the ground) but restrains (dampens) this movement (so that as the ground vibrates rapidly, the building vibrates much more slowly) is much more desirable. The solution is to separate the requirement for load bearing (vertical loads) from that for movement (horizontal loads).

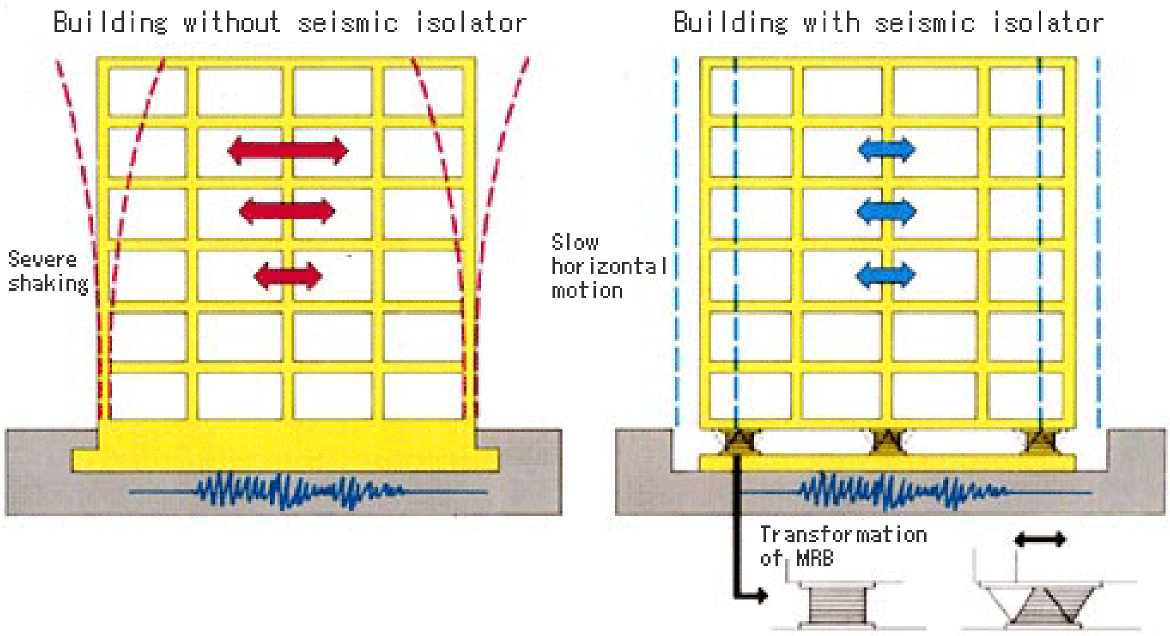


One way to do this involves a lead-rubber bearing. This bearing consists of alternating laminations of rubber and steel, which allow for up to six-inches of horizontal movement without fracturing but is strong enough to support the building. A cylindrical lead plug is placed in the center of the bearing to dampen the oscillations in the ground produced by an earthquake (just like the shock absorbers on a car). The energy of the earthquake waves is absorbed by the lead plug rather than by the building itself. The lead plugs do not deform in small earthquakes or high winds (in that respect, they serve as "seismic fuses"). Lead recovers nearly all of its mechanical properties after each deformation from an earthquake. This is analogous to the solid-state ductile deformation of lower crustal rocks without producing earthquakes. The lead-rubber bearings allow the ground under a building to move rapidly, but the building itself moves much more slowly, thereby reducing accelerations and maximum shear forces applied to the building.

<u>Above</u>: caption: "Base-isolation Lead Rubber Bearing (LRB). Alternating laminations of rubber and steel plates with a lead plug in the middle form a flexible structural support (top mounting plate not shown)"

“…The idea for a base-isolation system originated 30 years ago when engineers at Oil States Industries developed the first elastomeric bearings for bridges to mitigate the effects of heat expansion. Since then, base-isolation systems have been built around the world. Some 100 buildings in London rest on flexible bearings that attenuate the formidable vibrations of the city’s underground trains. Steel-and-rubber bearings are also used for earthquake protection on a half-dozen buildings worldwide, including two South African nuclear power plants, a few European schools, and a New Zealand government building. Plans for four nuclear power plants in France call for base-isolation systems…”

***Popular Science*, August 1985**

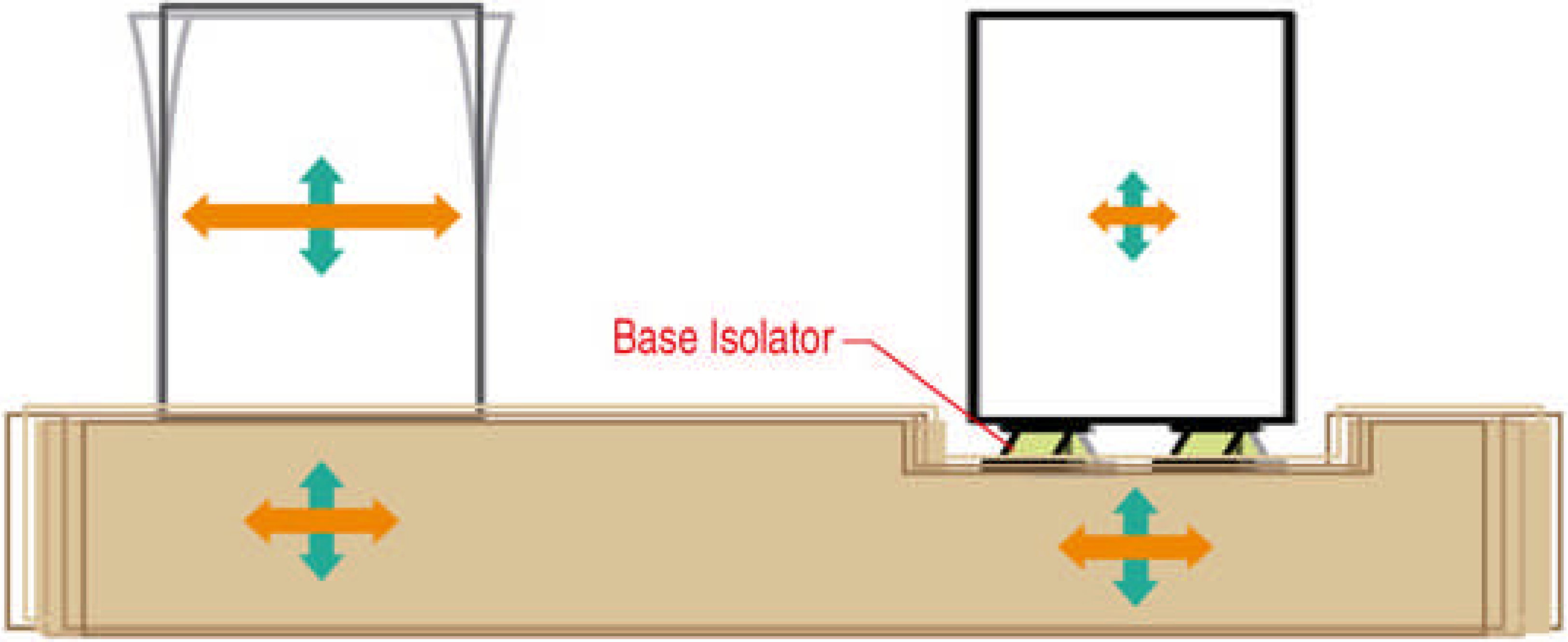


"…What makes the base-isolation system such an effective shock absorber? The answer lies in the composition of the bearings. Each round bearing…is 17 inches, 30 inches in diameter, and 1,800 pounds in weight. It is made from 1½-inch steel plates stuffed with 23 layers of cured natural Malaysian rubber and 22 layers of thinly sliced steel. If a quake hits, the bottom of a bearing, anchored to the ground, will move. The lower part of the steel-and-rubber sandwich will stretch back and forth, attenuating the shock, while the top of the bearing, where the supporting columns are connected, will move gently and smoothly, with no evidence of the vicious twisting or racking that can cause collapse in other structures…

***Popular Science,* August 1985**

The normal approach to providing seismic resistance is to attach the structure firmly to the ground. All ground movements are transferred to the structure, which is designed to survive the inertial forces of the ground motion. In large buildings, these inertial forces can exceed the strength of any structure that has been reinforced within reasonable economic limits. The structural engineer designs the building to be highly ductile in order that it will deform extensively and absorb these inertial forces without collapsing. Moment-resistant steel frame structures are good for this purpose (as are special concrete structures with a large amount of steel reinforcing). These buildings don’t collapse in a temblor, but they have a major disadvantage; in deforming, they can cause extensive damage to ceilings, walls and building contents. As well, equipment (including utilities) will stop operating. High-rise buildings will sway causing some occupants to become motion sick while others may panic.

<u>Left</u>: caption: “Failure of hanging light fixtures at library of Dawson Elementary School in California, fortunately unoccupied at time of earthquake. Note fallen ceiling tiles and plaster.”



Normal building

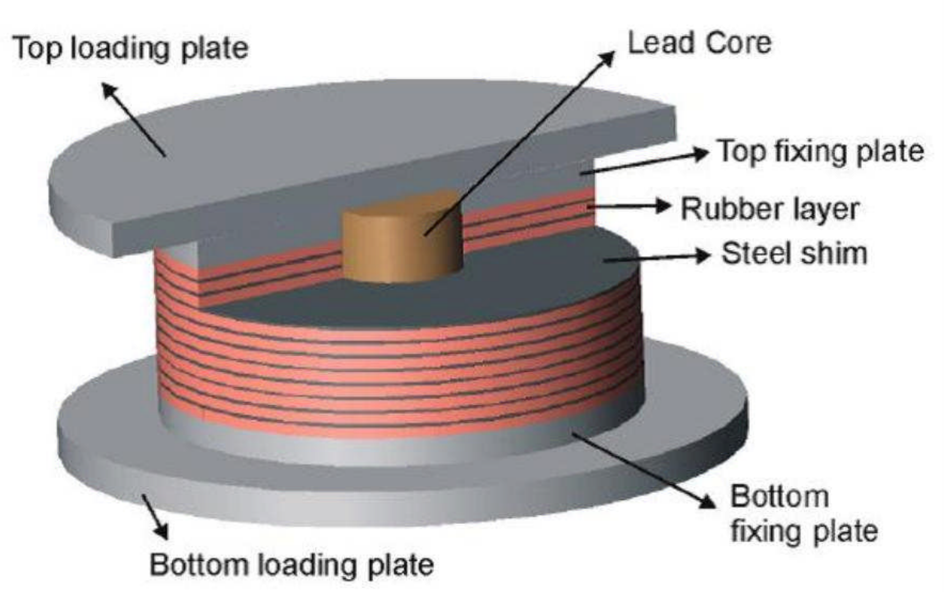
When the building experiences vibrations via the soil, it deforms. Also the higher the story, the larger the amplitude.

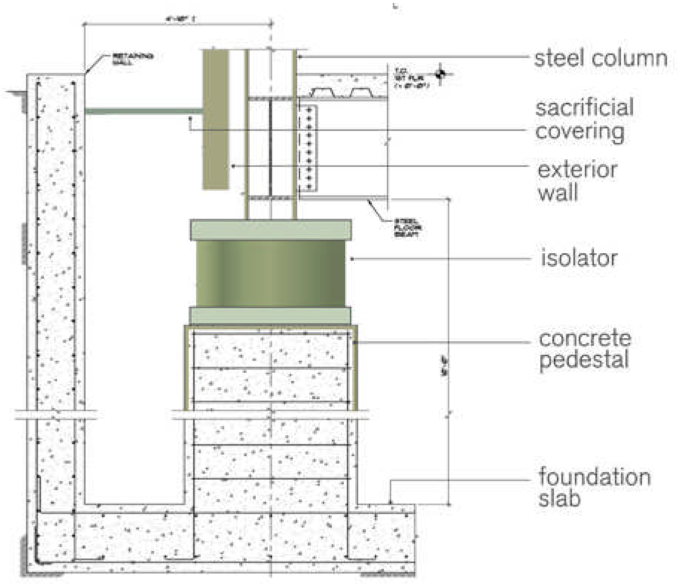
Building having base isolation structure

The isolator absorbs the shocks caused by an earthquake which prevent the building from being deformed and damaged.

"…One approach is simply to semi-isolate a building from the ground by anchoring it on flexible moorings, which will bend, not break, in an earthquake, protecting both the structure and its occupants…"

***Popular Science*, August 1985**





“…the bearings can stretch 15 inches horizontally while maintaining sufficient strength to support up to 1.2 million pounds (a 16-inch seismic isolation gap between the structure and surrounding basement retaining wall allows displacement). This flexibility translates to the ability to withstand an earthquake of 8.3 on the Richter scale (equivalent to the San Francisco earthquake of 1906) – the most severe earthquake that computer-aided seismologic analysis predicts for the next 100 years…Should predictions fall short, a back-up system…stub steel columns (flanking the bearings) will support the structure and prevent collapse…”

Popular Science, **August 1985**

Left: caption: “Seismic Base Isolator cut-away view”

Right: caption: “Typical Exterior Wall Section at Concrete Pedestal Isolator”

“…Why adopt this technology now? According to Alexander Tarics of Reid & Tarics, the design solves problems that other earthquake-proofing methods don’t. Engineers can design buildings to withstand earthquakes, but they haven’t been able to design them to protect their contents from damage. ‘They tie the structure to the foundation, and during earthquakes the buildings become large mixing bowls,’ says Tarics. That’s particularly serious in hospitals and emergency medical centers, where expensive lifesaving equipment may be ruined, and bedridden patients maimed or injured, by loose objects tossed about during a building’s contortions…”

***Popular Science*, August 1985**

Left: caption: “Shake-table crash testing of a regular building model (left) and a base-isolated building model (right). The building is allowed to move about six-inches horizontally. A six-inch slot around the building is built for this purpose and covered by a replaceable metal grating. Thus, damage to the building and costly repairs are greatly reduced and, in some instances, almost entirely eliminated.”

Right: caption: “Base Isolation Bearings are used to modify the transmission of the forces from the ground to the building. This seismic design strategy involves separating the building from the foundation and acts to absorb shock. As the ground moves, the building moves at a slower pace because the isolators dissipate a large part of the shock.”

“…Buildings equipped with base-isolation bearings will not only survive earthquakes, says Tarics, but will come through with very little of the damage that often renders earthquake-proof buildings unfit for use after a quake has struck. Flexible bearings also offer an inexpensive route to earthquake-proofing a structure. Because base isolators dampen horizontal ground motion, a building resting on them needs less of expensive structural materials such as steel and concrete to shrug off an earthquake…”

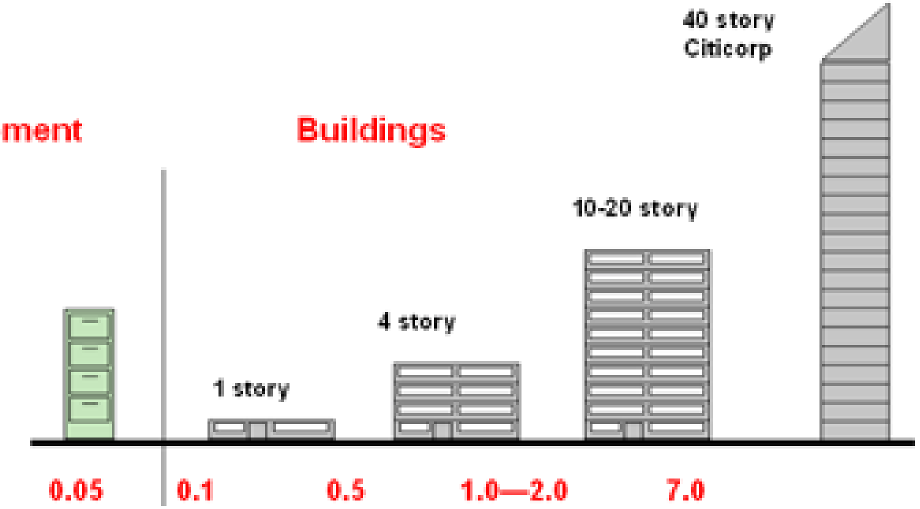
Popular Science, **August 1985**

RE: although base isolation adds to the cost of construction, some cost savings are possible within the building itself because so much of the earthquake force is absorbed at the base of the building rather than transmitted into the structure. Research is underway in Japan, New Zealand and the U.S. to design other methods of base isolation and other ways to dissipate seismic energy in a building. After the 1989 *Loma Prieta Earthquake*, the *California State Legislature* passed *Senate Bill 920*, requiring the state architect to select one new and two existing buildings to demonstrate new engineering technologies, including base isolation.

Lebensraum

“…‘Buildings do odd things in an earthquake,’ Doctor Jacobsen states. ‘A low building of only a few stories, located next to a taller structure, is apt to batter its tall neighbor with its roof. Even two buildings, side-by-side, of the same height may slam into each other like a pair of gladiators. The reason in each of these cases is that the buildings have different periods of vibration. They get out of step because of different heights or types of construction’…”

***Popular Mechanics,* December 1948**



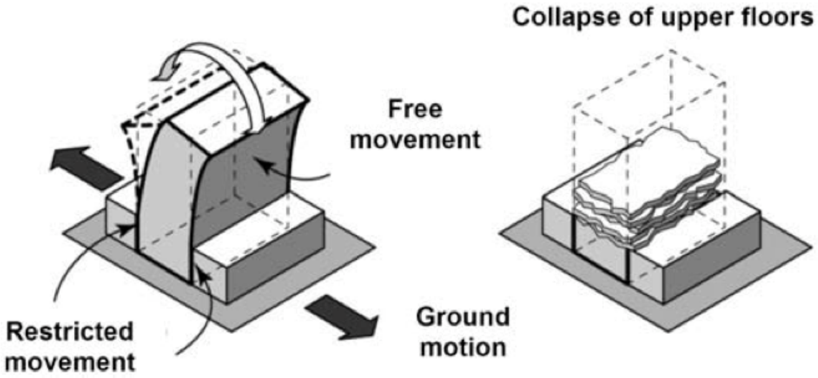
Earthquakes generate waves that may be slow and long, or short and abrupt. The length of a full cycle in seconds is the *Period* of the wave and is the inverse of the *Frequency*. All objects, including buildings, have a *natural* (a/k/a *Fundamental*) *Period* at which they vibrate if jolted by a shock. The *Natural Period* is a primary consideration for seismic design, although other aspects of the building design may also contribute to a lesser degree to mitigation measures. If the period of the shock wave and the natural period of the building coincide, then the building will “resonate” and its vibration will increase or “amplify” several times. Soil also has a period (varying between 0.4 and 1.5 sec., very soft soil being 2.0 sec.). Soft soils generally have a tendency to increase shaking as much as 2 to 6 times as compared to rock. Also, the period of the soil coinciding with the natural period of the building can greatly amplify acceleration of the building and is therefore a design consideration.

<u>Above</u>: caption: “Height is the main determinant of fundamental period - each object has its own fundamental period at which it will vibrate. The period is proportionate to the height of the building.”

“…‘The recommended procedure in active seismic regions is to provide an air space or sway-way between all large, adjoining structures, particularly for buildings in excess of 15 storeys. A sway-way of six inches is usually considered sufficient to prevent one building from damaging another building adjacent to it. When an open sway-way is undesirable, it is customary to provide the space and then fill it with some friable filler material that will crumble under pressure. Quite often a church tower is protected from the rest of the church structure by a wall of this type of material…”

***Popular Mechanics,* December 1948**

RE: the greater the mass (weight) of a building, the greater are the internal inertial forces generated. Lightweight construction with less mass is typically an advantage in seismic design. Greater mass generates greater lateral forces, thereby increasing the possibility of columns being displaced, out-of-plumb and/or buckling under vertical load.



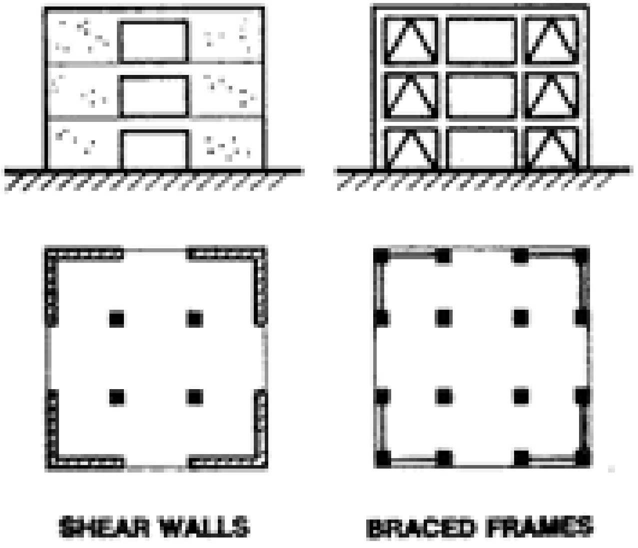
<u>Above L&R</u>: caption: “Partial immobilization of lower stories. Pounding between adjacent buildings due to inter-story drift can occur when, (a) adjacent buildings have a different period of vibration, each building moves in a different direction at the same time, and they can crash into each other; (b) each adjacent building has a different inter-story height the crashing of slabs of one into vertical components of the other can produce serious damages and even building collapse. Another problem between adjacent buildings without seismic joints is the partial immobilization of lower stories of a tall building by lower adjacent buildings that can produce damage in the transition zones between the lower stiffened stories and the free flexible portion as illustrated.”

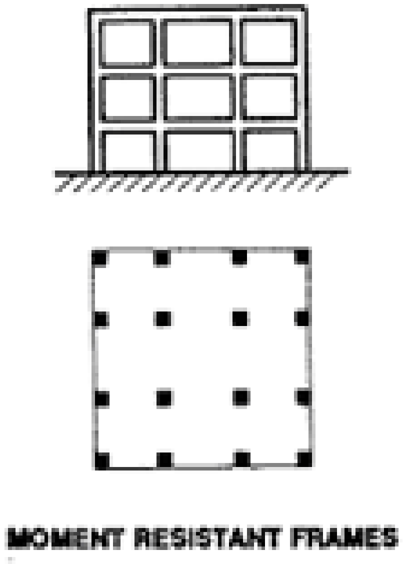
Configuration

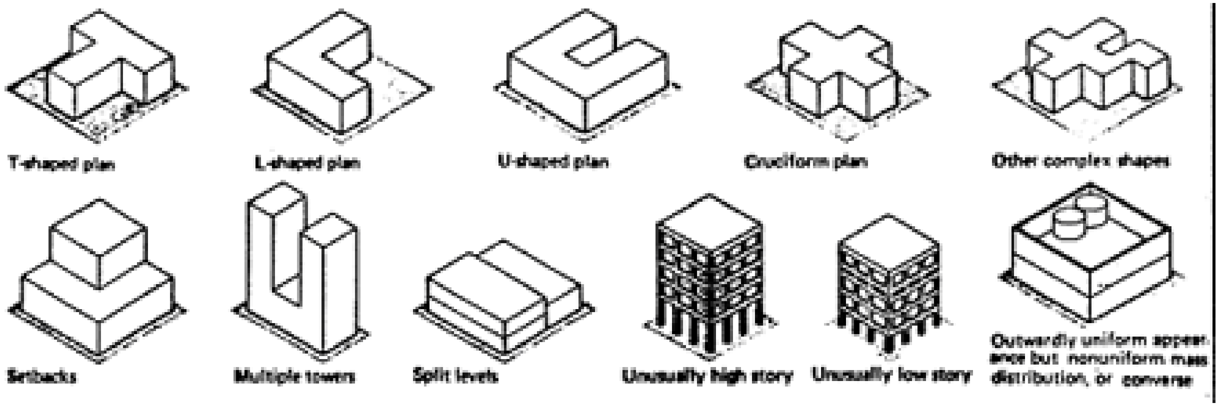
“…All large buildings should have two-fold mass-rigidity symmetry to avoid the destructive twisting effects that may occur to odd-shaped buildings. A structure of rectangular shape will experience minimum damage while an L-shaped or U-shaped building tends to twist when subjected to vibration, increasing the damage. Unsymmetrical damage should be especially strong or be built as several units, each symmetrical in itself…”

***Popular Mechanics,* December 1948**

RE: the term *Building Configuration* defines a building’s size, shape and structural/nonstructural elements. Building configuration determines the way seismic forces are distributed within the structure, their relative magnitude and problematic design concerns.





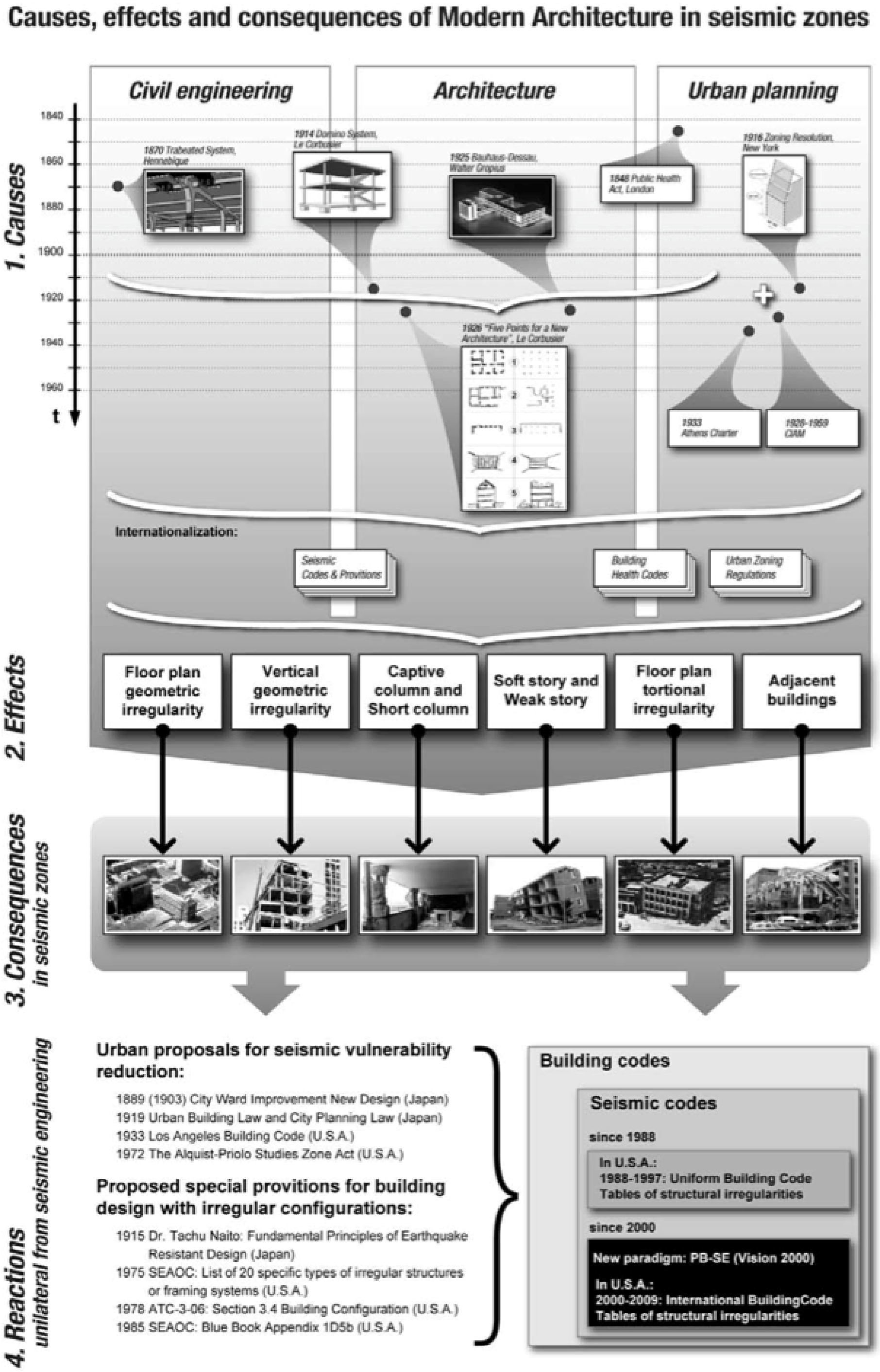


Above: caption: "Buildings with Irregular Configurations." ***Irregular Configuration*** **buildings are those that differ from the "Regular" definition and have problematic stress concentrations and tor-sion.**

Left: caption: "Regular Building Configurations." ***Regular Configuration*** **buildings have** ***Shear Walls*** **or** ***Moment-Resistant Frames*** **or** ***Braced Frames*** **and generally have:**

- **Low Height to Base Ratios;**
- **Equal Floor Heights;**
- **Symmetrical Plans;**
- **Uniform Sections and Elevations;**
- **Maximum Torsional Resistance;**
- **Short Spans and Redundancy, and;**

Prior to 1974, building codes did not include special provisions for buildings with irregular configurations. In 1975, the *Structural Engineers Association of California* (SEAOC) included in *Recommended Lateral Force Requirements and Commentary* (*Blue Book,* 1974) twenty examples of irregularities that had to use dynamic analysis methods (instead of the traditional equivalent static force method) and recommended them to be included in the next version of the *Uniform Building Code* (UBC). These recommendations were not considered for the 1976 UBC. In 1978, the SEAOC published *ATC306: Tentative Provisions for the Development of Seismic Regulations for Buildings,* which included a section on Building Configuration with a series of drawings (they were supposed to be included in the 1979 UBC, but were not). After the Mexico earthquake of 1985, the 1988 UBC edition included two tables defining some parameters for the identification of "irregular" configurations (in plan and elevation). Since then, many recent seismic codes around the world have included special provisions for many irregular building configurations.



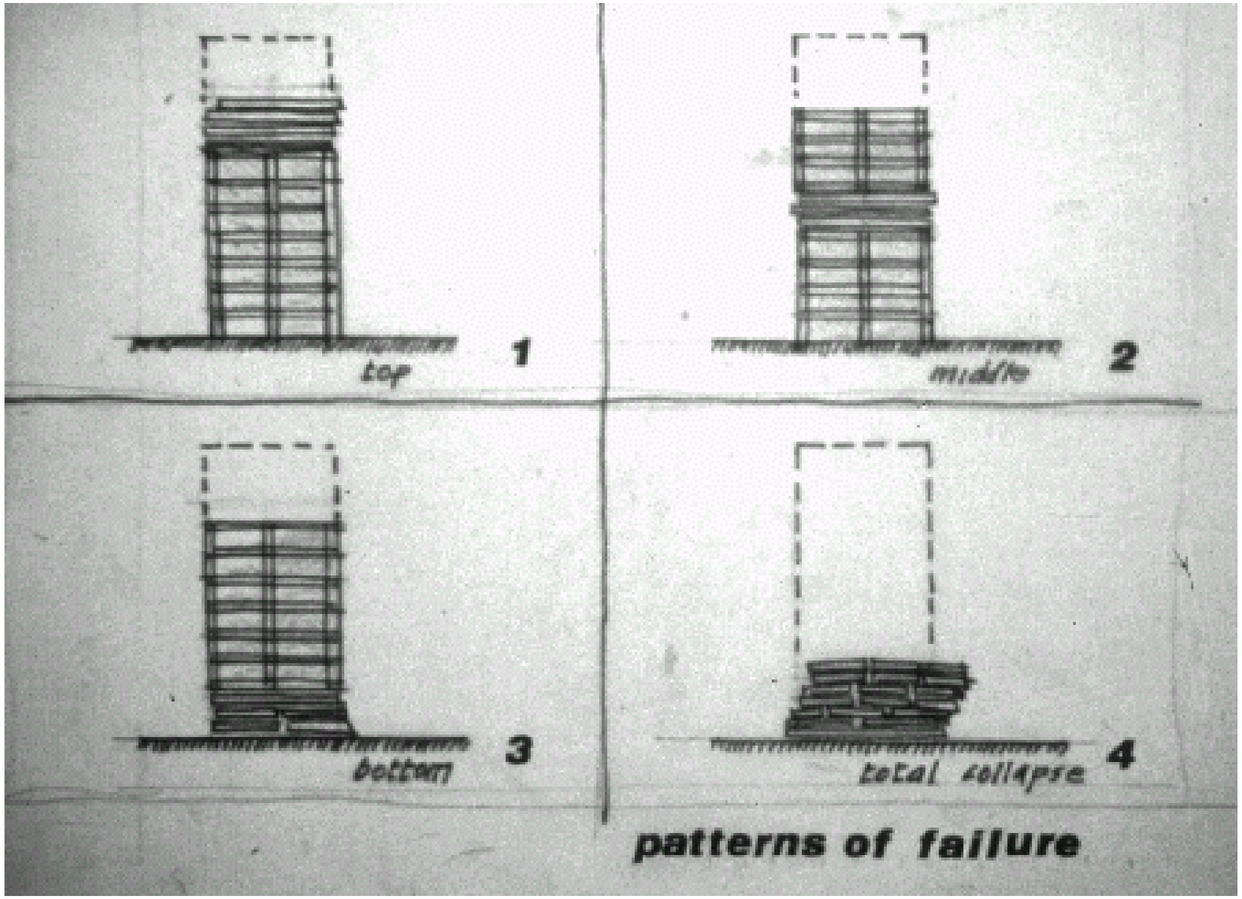
Left: caption: "Fig. 9. Causes, effects and consequences of modern architecture in seismic zones. Figure 9 illustrates the origin of modern building and urban configurations in contemporary cities; some examples of modern building irregular configurations and the effects of ground motion on them and, as a consequence, the development during the 20th century of earthquake engineering and of seismic provisions for the design and construction of reinforced concrete (RC) earthquake-resistant buildings."

]

Damage Control

“…Earthquake engineers try to minimize the damage a quake will cause but they don’t try to avoid it entirely. Minor cracks and scaling are considered unavoidable. What the engineers try to prevent is the collapse of structures and walls, even the falling of a single brick. They design stairways with extra strength and insist on vertical steel reinforcements in chimneys to prevent their falling over…”

***Popular Mechanics,* December 1948**


1
top
2
middle
3
bottom
4
total collapse
patterns of failure

The aim of *earthquake-resistant* building design is to prevent total collapse of building structures:

- It saves human lives;
- It relies on ductility (ability to deform in-elastically) and redundancy (many load paths).

The aim of *earthquake-proof* building design is also to control structural and nonstructural damage in structures:

- It minimizes economic loss in not so severe earthquakes;
- Earthquake forces have great uncertainty and it is uneconomic and infeasible to design for no damage.

Earthquake-resistant/proof building design generally include four steps:

1. Sound initial planning: layout, plan and structural form;
2. Appropriate analysis and design;
3. Proper detailing of structural and nonstructural components;
4. Quality control in design and construction.

Planning considerations of design:

1. Site Conditions:

- Liquefaction;
- Stability of slopes;
- Site period.

2. Geometrically Sample Forms:

- Uniformity and regularity is highly desirable in earthquake resistant building design;
- Avoid concentration of mass especially near the top (massive roofs).

3. Symmetrical and Compact Plan Forms:

- Square or rectangular footprint is desirable;
- No complex L, T, or U plans.

4. Enough Clearance Between Adjoining Buildings.

5. Enough Redundancy: Backup Elements.

“…The ability of a structure to withstand a shock depends on the quality of the workmanship. Tests of damaged and un-damaged buildings after the Long Beach earthquake showed that good workmanship could make a building 16 times stronger than another. This was found true in the recent Japanese earthquake…”

***Popular Mechanics*,** **December 1948**

The *Fukui Earthquake* occurred in *Fukui Prefecture*, Japan. The magnitude 6.8 quake struck on June 28th 1948. The strongest shaking occurred in the city of Fukui. Most damage was reported in the alluvial *Fukui Plain*, where the building collapse rate was +60%. Many of the buildings were recently built as part of the post-WWII recovery. At the time (early morning), many people were cooking causing many fires to spread rapidly. Although the *Daiwa Department Store* collapsed (right), the *Fukui Bank Building* adjoining it had no significant damage (highlighted). It is believed the 500, 10-meter deep foundation piles used for the Fukui Bank Building spared it its neighbor's fate.

"…Fire is always an immediate threat after a destructive quake. One precaution being taken is the requirement that all new chimneys be lined with fire-clay materials. Schools and public buildings should have earthquake valves that immediately shut off the flow of gas from the mains when a quake occurs…"

***Popular Mechanics*, December 1948**

The Compromise

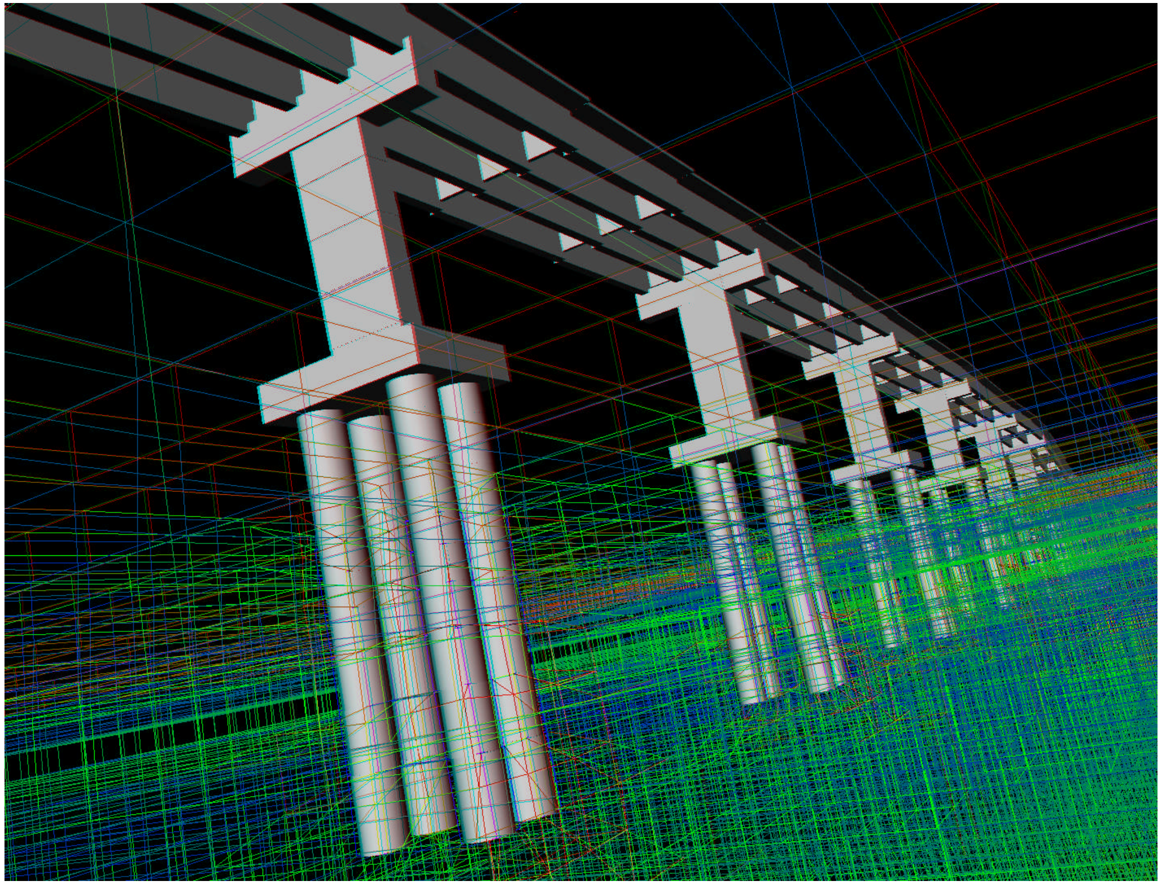
“…It’s impractical to build tall ‘earthquake-proof’ structures because few could afford them. The engineering compromise is to design buildings that are ‘resistant’ to quakes. California officials define the idea as ‘a building that holds its occupants safely during a major quake and that suffers only non-structural damage’…”

***Popular Mechanics,* July 1964**

RE: a list of *earthquake coefficients* is used in structural design for earthquake engineering around the world. For example, a coefficient of 0.09 indicates that a building is designed that 0.09 of its weight can be applied horizontally during an earthquake.

Seismic Loading

Seismic loading **is one of the basic concepts of earthquake engineering. It is the application of an earthquake-generated agitation to a structure. It occurs at contact surfaces of a structure either with the ground and/or adjacent structures or with gravity waves from a tsunami. Seismic loading depends, primarily, on the ability of a structure to resist it without being broken, partially or completely. Due to their mutual interaction, seismic loading and seismic performance of a structure are intimately related.**



The EERI

"…Recently the Coast and Geodetic Survey asked a number of engineers, university research people and other earthquake experts to serve as a committee that would make recommendations concerning future earthquake studies. The committee is creating an Earthquake Engineering Research Institute that will coordinate and centralize much of the research on the effects of earthquakes on structures. To be located in California, the institute's findings will help designers and engineers to design buildings that are even more resistant to earthquakes than the best of today."

***Popular Mechanics,* December 1948**

RE: the *E̲arthquake E̲ngineering R̲esearch I̲nstitute* (EERI) is a national, nonprofit, technical society of engineers, geoscientists, architects, planners, public officials and social scientists. EERI members include researchers, practicing professionals, educators, government officials and building code regulators.

EERI

Earthquake Engineering Research Institute

Dedicated to reducing earthquake risk

"The objective of the Earthquake Engineering Research Institute is to reduce earthquake risk by (1) advancing the science and practice of earthquake engineering, (2) improving understanding of the impact of earthquakes on the physical, social, economic, political, and cultural environment, and (3) advocating comprehensive and realistic measures for reducing the harmful effects of earthquakes."

EERI Mission Statement

"EERI's Vision: A world in which potential earthquake losses are widely understood and for which prudent steps have been taken to address those risks.

EERI's Role: EERI is a leader in earthquake investigations and in the dissemination of earthquake risk reduction information both in the U.S. and globally in cooperation with its international partners."

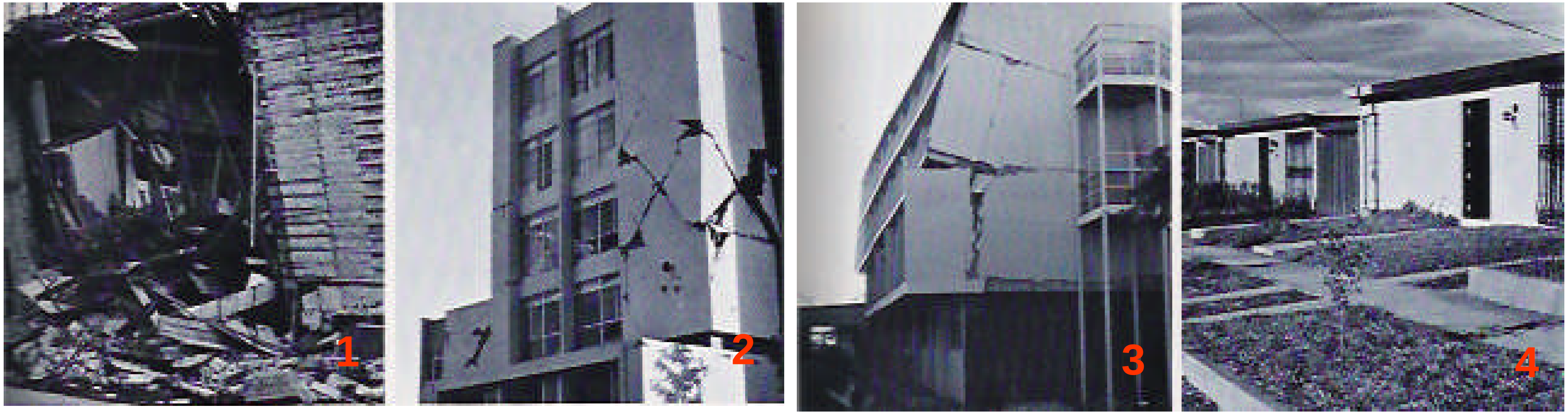
EERI Vision and Role

Case Study

"…In reinforced-concrete structures, the amount of steel and the way it is mounted determines the strength, and more importantly, the resilience of the building when the ground beneath it shakes. A University of Michigan study of the recent devastating earthquake in Managua, Nicaragua, found that many reinforced concrete buildings were flexible enough to resist severe structural damage…"

Popular Mechanics, **January 1977**

RE: on December 23rd 1972, at 12:29 a.m. local time, a magnitude 6.2 earthquake struck near Managua, the capital of Nicaragua, causing widespread damage. Two aftershocks occurred after the main shock, one of 5.0 magnitude and the other 5.2. The earthquake destroyed 80% of the city. An estimated 5K were killed, 20K injured and 250K were left homeless. It was the worst earthquake in terms of destruction in South America's history.



<u>Above</u>: caption: “Damage to structures in Managua and the distribution of damage, were consistent with a shallow focus near the center of the city. A type of construction common locally, in which walls consist of a wooden frame filled with rubble (1), frequently performed poorly because the timber frames were rotten or termite-ridden. Some modern buildings performed well and suffered only slight structural damage. Others were badly damaged, with failure frequently resulting from the use of stiff masonry walls in reinforced concrete frames, which caused high stresses and damage at the corners of the frames (2) and typical ‘X-cracks’ (shear cracks) in the masonry walls. Failure of columns in the American-Nicaraguan school (3) resulted in partial collapse, with the top two stories tipping forward into the crushed lower stories. Damage decreased rapidly away from town. These masonry residences (4) only three miles from the earthquake source were undamaged.”

"…The report points out though, that rigid interior finishes like tile and brick should not have been used on the resilient buildings. The two elements just don't mix. The motion of the quake caused clay tile walls to break loose, turning the interior into a nightmare of flying debris. Rigidly framed staircases, another example of poor design, were pulled away from landings as the buildings flexed…"

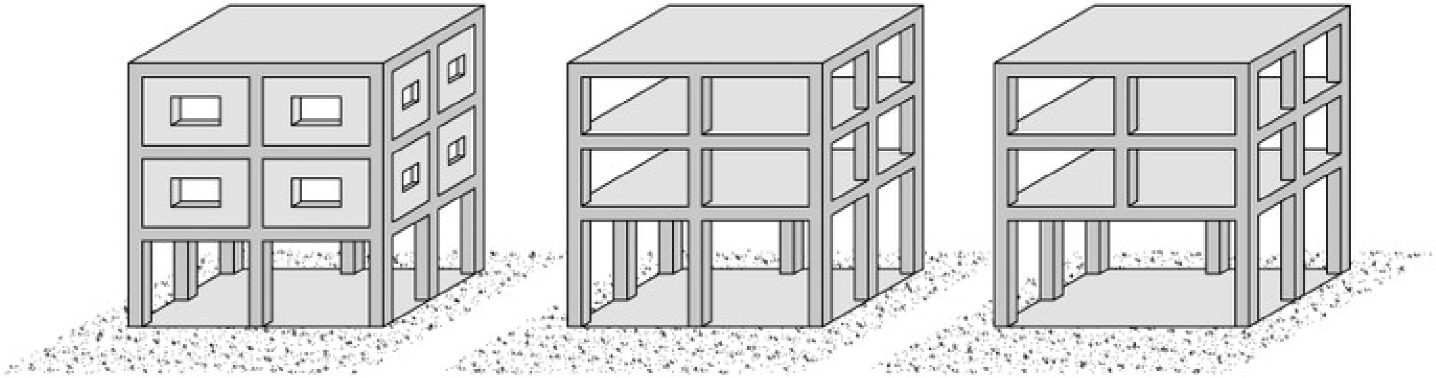
***Popular Mechanics,* January 1977**

<u>Left</u>: caption: "This Managua nightclub collapsed during the December 23rd shaking, killing dozens of the late-night patrons."

Above: caption: “Construction equipment knocks down remaining walls of a building damaged in the Managua earthquake. Large areas of the city were declared ‘contaminated areas’ and leveled and covered with lime to serve as mass graves.”

Left: caption: “A Nicaraguan soldier patrols against looters in the ruined city of Managua after the devastating earthquake”

The Soft Approach



(a) Stiff and strong upper floors due to masonry infills

(b) The columns in one storey longer than those above

(c) Soft storey caused by discontinuous column

"…research has led to many interesting design approaches. One is the 'soft-story' concept. In this system the foundation and lower stories are massively constructed. The bulk of the upper building is linked to the foundation section through a flexible story that absorbs much of the quake's energy, thereby minimizing damage to the upper floors…"

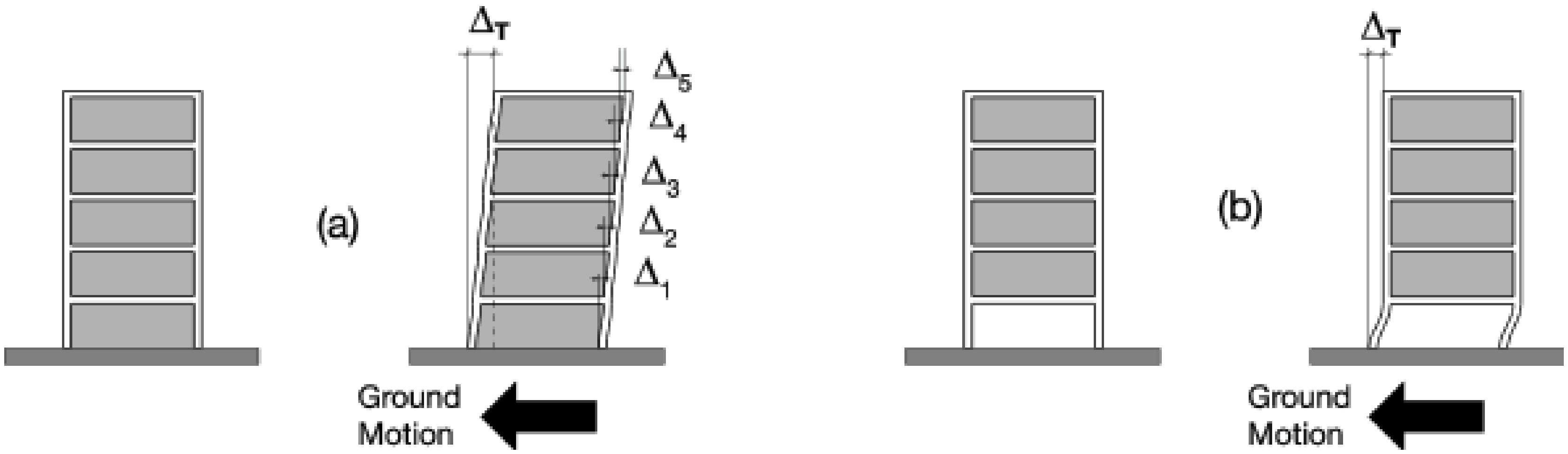
Popular Mechanics, **January 1977**

Above: caption: "Examples of soft-story configurations." One of the most common examples of the "soft-story" can be observed in the so called "open floor" of the first or ground floor/story of modern residential buildings. The structural elements are homogenously distributed throughout the building, but the apartments are located on the upper floors with many masonry walls while the lowest floor is left totally or partially free of partitions for parked vehicles or for social areas that require wide spaces. In the case of double-height first soft stories, columns are very flexible not only due to the total or partial absence of walls, but as a result of their significantly greater height in relation to those of the upper floors. This configuration is one of the characteristic models of modern design for office buildings, hotels and hospitals in which the access for the general public has great importance.

The numerous advantages of this concept of modern architectural design (both aesthetically and functionally) is the reason why the soft-story has been encouraged around the world since the mid-1920s. In particular, by the Swiss-French architect *Le Corbusier.*

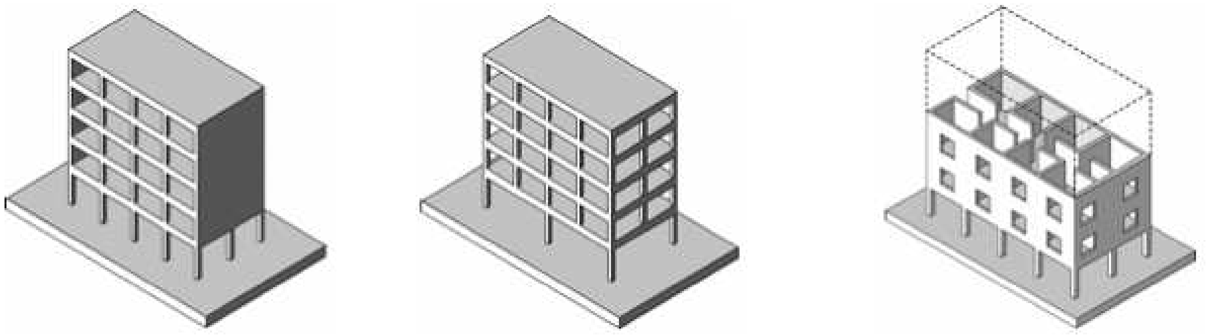
Above: caption: “Soft-story in reinforced concrete buildings, India”

Left: caption: “Soft-story in a reinforced concrete building, New Zealand”



Above: caption: “Distribution of total displacement generated by an earthquake in: (a) a regular building, and; (b) a building with soft-story irregularity.” The soft first story is the most common feature of soft-story irregularity. It usually is present in modern frame buildings when a large number of nonstructural rigid components (i.e. masonry walls) are attached to the columns of the upper floors of a reinforced concrete frame structure while the first story is left empty of walls or with a reduced number of walls in comparison to the upper floors. The rigid nonstructural components limit the ability to deform the columns, modifying the structural performance of the building to horizontal forces. In a typical building, the earthquake shear forces increase towards the first story. The total displacement induced by an earthquake tend to distribute homogeneously in each floor throughout the height of the building thus, deformation in each floor would be similar. When a more flexible portion of the lower part of the building supports a rigid and more massive portion, the bulk of the energy will be absorbed by the lower significantly more flexible story while the small remainder of energy will be distributed amongst the upper, more rigid stories, producing on the most flexible floor larger relative displacement between the lower and the upper slab of the soft-story (a/k/a “inter-story drift”) and, therefore, the columns of this floor will be subjected to large deformations.

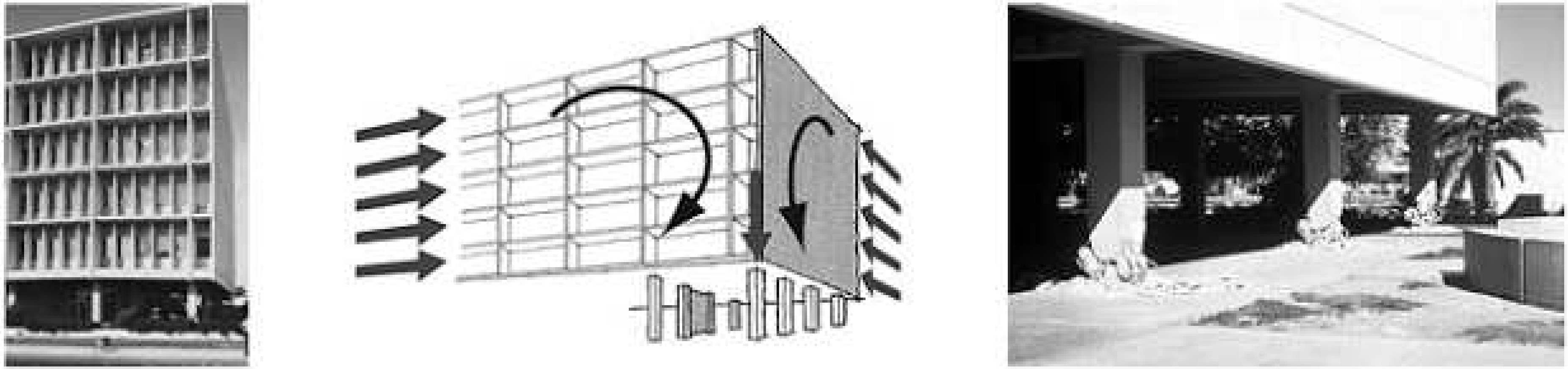
<u>Above L&R</u>: caption: “Olive View Hospital suffered severe damage in the 1971 San Fernando, California, due to discontinuous reinforced concrete shear walls shown shaded on the vertical section drawing (left). A soft two-story layer of rigid reinforced concrete frames supported a stiff shear wall-frame structure above. Severe damage occurred in the soft-story portion, as shown in the photograph (right).” Soft-story building configurations are a significant source of serious earthquake damage. These irregular configurations have long been recognized by earthquake engineering as seismically vulnerable. In terms of seismic regulations, their irregular condition requires the application of special considerations in their structural design and analysis. The results of studies have established a link between the *open floor* architectural configuration and the effects produced by earthquakes on buildings with this configuration. In the 1970s, a group of architects from California participated in significant studies, with earthquake engineers, to promote the inclusion of special recommendations for the design and construction of buildings with such configurations in seismic codes. it was not until after the *Michoacan* (Mexico) *Earthquake* of 1985, that the 1988 UBC edition included, for the first time, two tables for defining some parameters for the identification of “irregular” configurations (in plan and elevation). Since then, in the majority of the international seismic provisions, the degree of irregularity in the configuration of a building is one of the most important factors that are established for defining the analysis procedure that is used for the design of earthquake resistant buildings. The category “vertical structural irregularities” in seismic codes usually includes the types: “stiffness-soft story” and “discontinuity in lateral strength” (a/k/a “weak-story”).



Above: caption: “Examples of weak first story irregularity.” *Soft-story* and *weak-story* are often mistaken for one another and, sometimes, used interchangeably although each one of is related to a different physical feature of the structure:

- The soft-story or flexible-story, with the difference of stiffness (resistance to deformation), between one building floor and the rest, and;
- The weak-story, with the difference of lateral strength or resistance to earthquake forces, between one building floor and the rest.

These irregularities may be present simultaneously and each of them could be on the first story or at an intermediate level. Weak-story irregularity refers to the existence of a building floor presenting a lower lateral structural resistance than the immediate superior floor or the rest of the floors of the building. The building’s weakest part would suffer severe damage due to its inability to withstand the different types of loads (lateral, vertical and moment) produced by the ground motion. Weak-story configuration is often generated in hotel and hospital buildings in which not only the first floor is designed with less walls than the other floors, but generally, due to its importance, it also has a greater height than the rest of the floors. Weak story can be generated by: (1) elimination or weakening of seismic resistant components at the first floor; (2) mixed systems: frames and structural walls, with wall interruption at the second floor or at intermediate floors. This irregularity can also be present at the first floor or at intermediate floors. There are numerous examples of many buildings presenting a combination of these types of irregularities, soft and weak-story, making them particularly seismically vulnerable.



“…this building suffered a major structural failure, resulting in column fracture and shortening - by compression - at one end (the east) of the building. The origin of this failure lies in the discontinuous shear wall at this end of the building. The entire building was subsequently demolished. The fact that the failure originated in the configuration is made clear by the architectural difference between the east and west ends. The difference in location of the first floor shear walls was sufficient to create a major behavioral difference in response to rotational, or overturning, forces on the large end shear walls.”

***Arnold and Reitherman*, 1982**

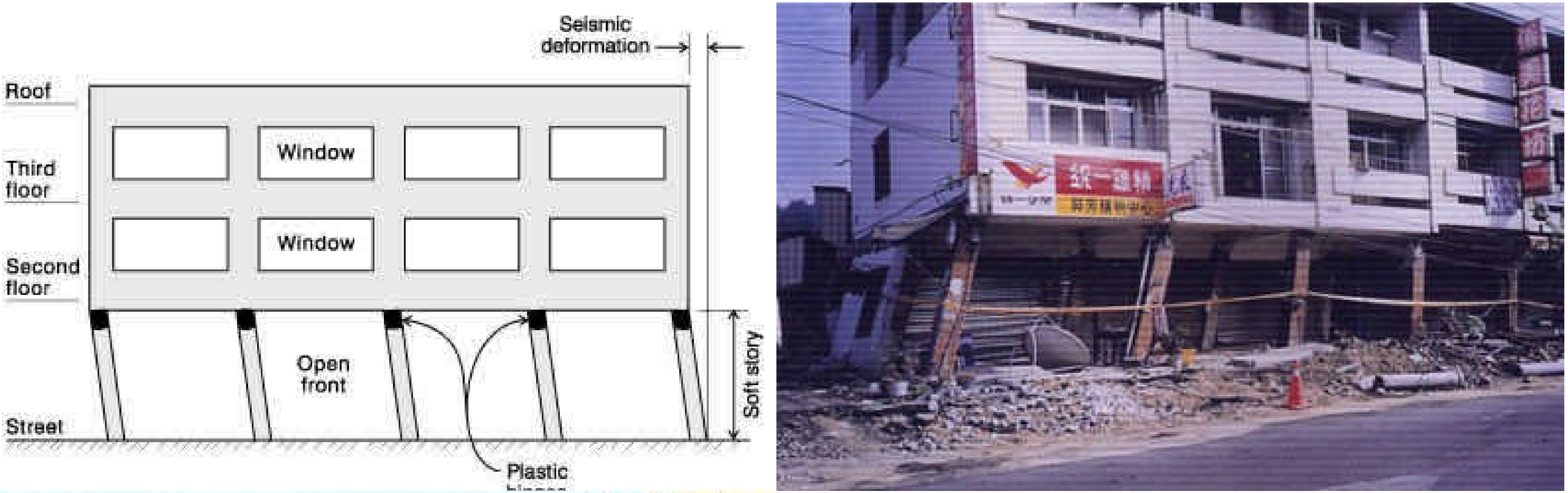
Re: *Imperial County Services Building*

<u>Above</u>: caption: “The Imperial County Services Building consisted of six floors and a penthouse. It suffered damage to corner columns in the Imperial Valley Earthquake of 1979.”

“When shear walls form the main lateral resistant elements of the building, they may be required to carry very high loads. If these walls do not line up in plan from one floor to the next, the forces created by these loads cannot flow directly down through the walls from roof to foundation, and the consequent indirect load path can result in serious overstressing at the points of discontinuity. Often this discontinuous-shear-wall condition represents a special, but common, case of the weak first story problem. The programmatic requirements for an open first floor result in the elimination of the shear wall at that level, and its replacement by a frame. It must be emphasized that the discontinuous shear wall is a fundamental design contradiction: The purpose of a shear wall is to collect diaphragm loads at each floor and transmit them as directly and efficiently as possible to the foundation. To interrupt this load path is a fundamental error. To interrupt it at its base is a cardinal sin. Thus the discontinuous shear wall which stops at the second floor represents a ‘worst case’ of the weak floor condition.”

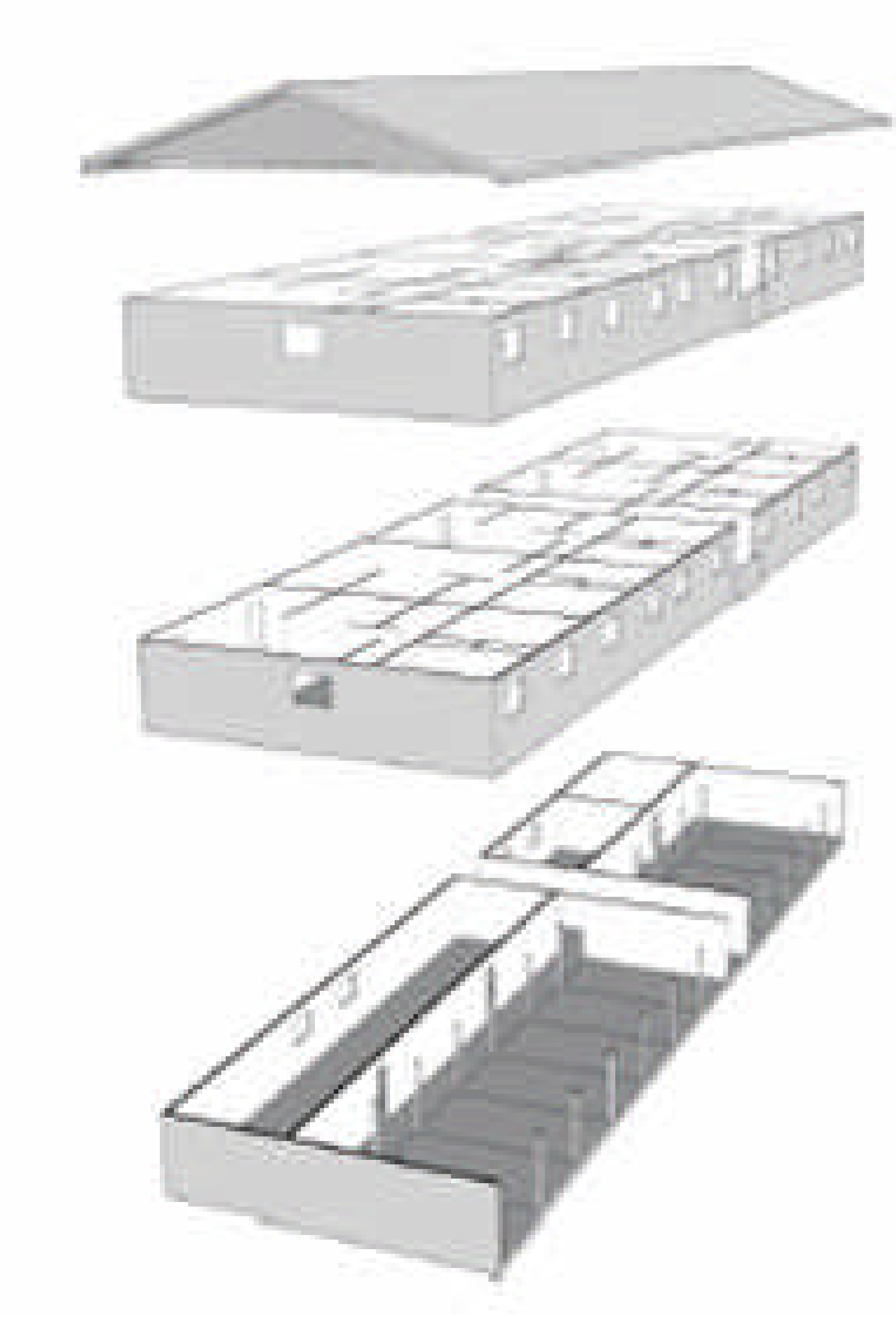
***Arnold and Reitherman*, 1982**

<u>**Above L&R**</u>**: caption: “Ground floor is used for parking in many reinforced concrete framed buildings in Indian cities. Many buildings of this type experienced severe damage or collapse in the 2001 Bhuj earthquake. Left photo shows a building with open ground floor adjacent to a similar building that lost its ground floor due to the soft-story effect; right photo shows extensive damage in the columns at the ground floor level due to the earthquake, also due to the soft-story mechanism”**



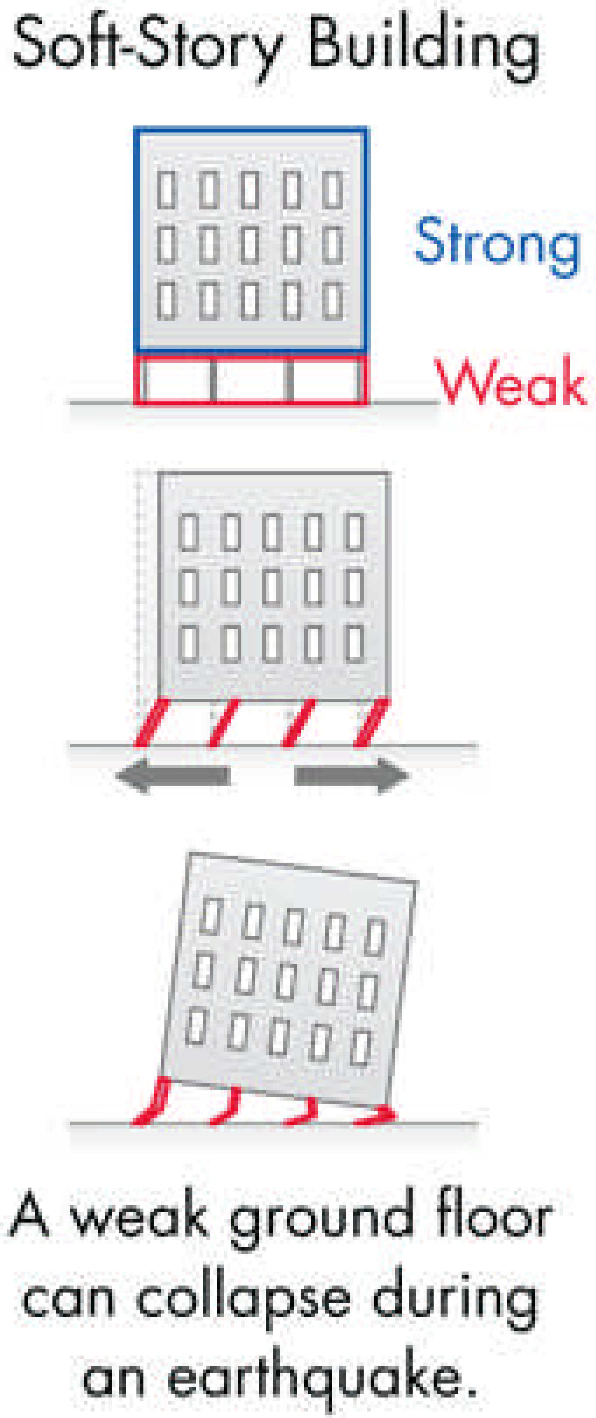
<u>Above L&R</u>: caption: “Several reinforced concrete frame buildings with open front suffered damage in the 1999 Chi Chi, Taiwan earthquake. These buildings had masonry infill walls in the upper storeys. The rigid upper storeys caused significant lateral displacements in the columns at the lower level, as shown on the drawing (left). The photograph shows a typical damage observed in these buildings (right).”

<u>Left</u>: caption: “Several mixed occupancy buildings with stores at the ground floor were severely damaged or experienced collapse in the 2001 Bhuj, India earthquake”



Above: caption: “Soft-story wood-frame buildings are common in suburban areas of California (such as Berkeley) and the Pacific Northwest. In most cases, these are residential apartment buildings and the ground floor is used for parking, as shown in the photograph.”

Left: caption: “An exploded view of a typical soft-story wood-frame building is shown in the drawing”



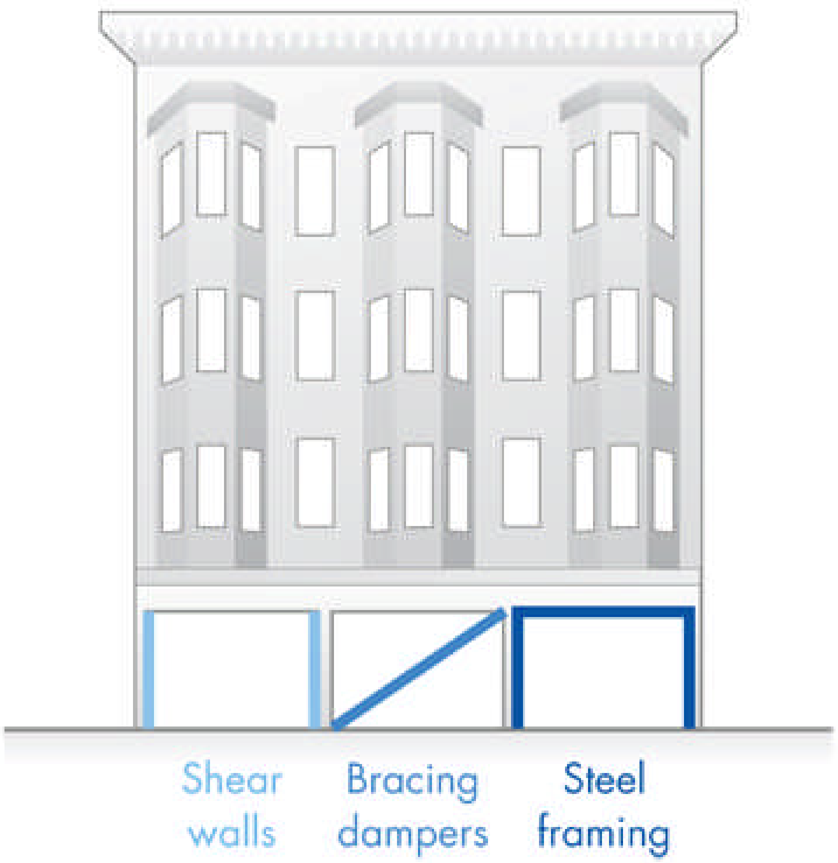
"We have at-risk buildings out there - these are dangerous buildings. Such buildings collapsed in the Northridge quake, and in the Bay Area, they collapsed in the 1989 Loma Prieta quake. But these soft-story buildings can be retro-fitted."

John van de Lindt*, Structural Engineer – *Colorado State University

RE: soft-story buildings have one or more floors of residential space resting above a more open floor, often used for parking or retail space, at street level. These open floors are known to be structurally weak, leaving the building vulnerable to heavy shaking. In San Francisco alone, there are about 2,800 such buildings - including many in historic neighborhoods such as the *Mission*, *Pacific Heights* and *Marina District/s*, among others. These house roughly 58K people along with 2K businesses, according to a 2009 report for the city by the *Applied Technology Council* (ATC). The report concluded that 1,200 to 2,400 of these structures would likely suffer severe damage or outright collapse if a magnitude-7.2 earthquake were to strike on the nearby portion of the *San Andreas Fault.*

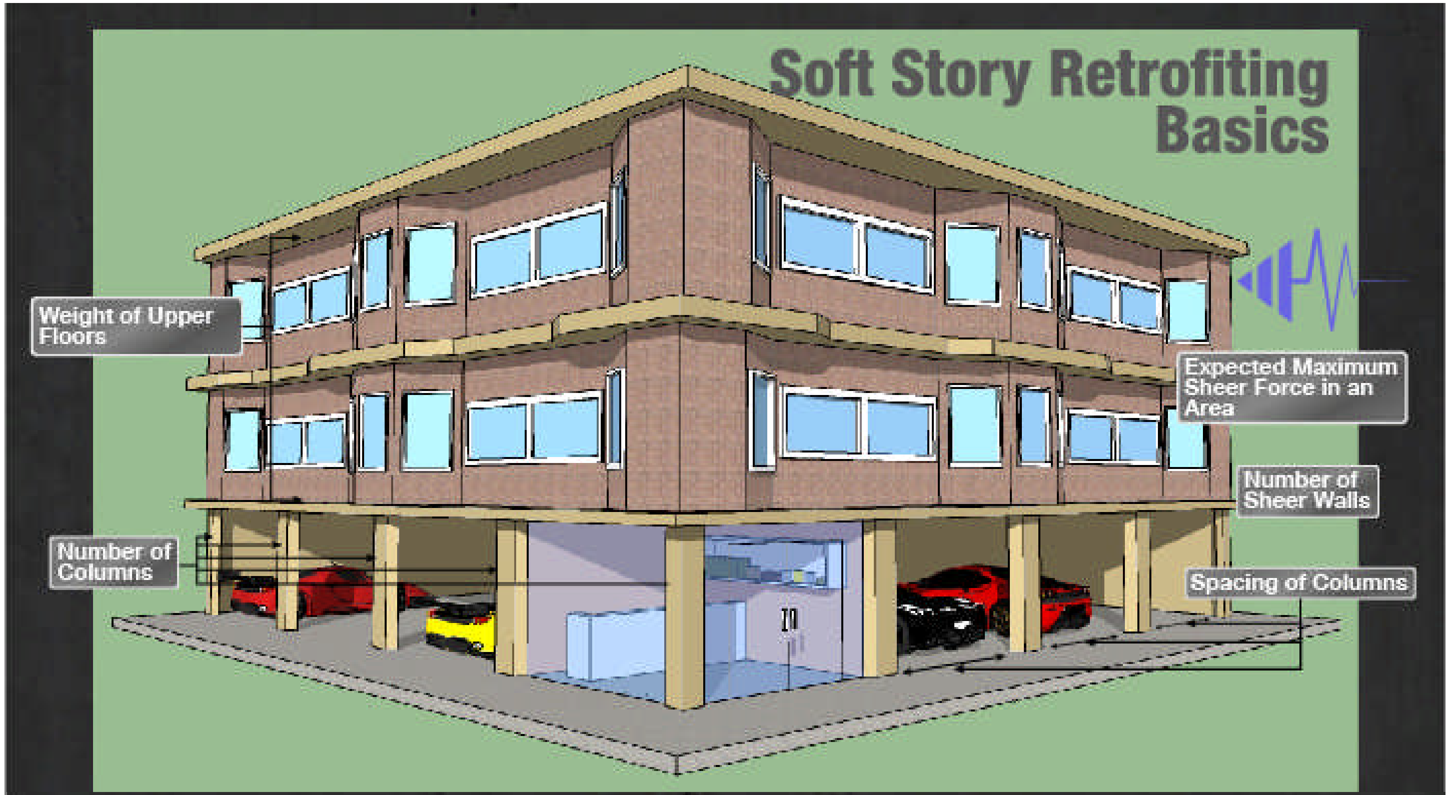
<u>Above & Left</u>: caption: “Many soft-story wood-frame buildings were damaged in the 1994 Northridge earthquake (left) and the 1989 Loma Prieta, California earthquake (top L&R)”

Soft-Story Retrofits



The ATC's findings prompted the *City of San Francisco* to pass a mandatory ordinance in 2013 requiring soft-story buildings with three or more stories and five or more residential units to be evaluated and, if deemed necessary, retrofitted to meet building strength standards issued by the *Federal Emergency Management Agency* (FEMA), the *American Society of Civil Engineers* (ASCE) or others. Specific retrofits required vary on a case-by-case basis, but could include, for example, steel framing or additional shear walls to better absorb lateral shaking (left).

Soft Story Retrofiting Basics



Weight of Upper Floors:

The more floors the building has, the more soft story retrofit work that needs to be done.

Number of Columns:

The more columns a building has, the stronger it is in withstanding seismic activity.

Expected Maximum Shear Force in Area:

The nearer the building is to earthquake faults and the bigger the expected magnitude of any seismic activity on that fault, the more retrofitting work will be needed by the building.

Number of Shear Walls:

The more shear walls the building has, the less retrofitting work that needs to be done.

Spacing of Columns:

The less distance between columns the stronger the building is in withstanding seismic activity.

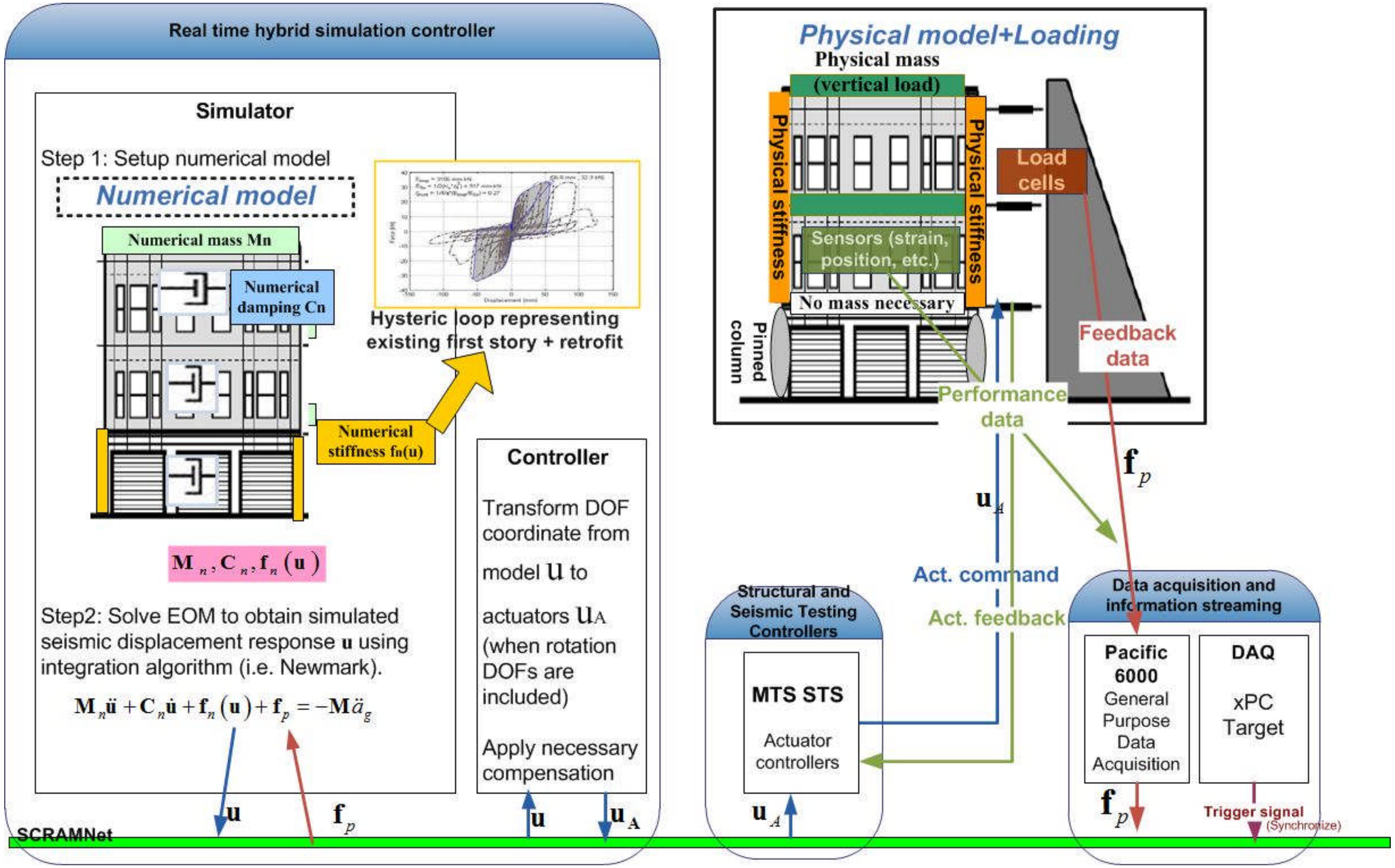

201
PT 15


Earthquake Warning
This is a soft story building with a soft, weak, or open front ground floor.
You may not be safe inside or near such buildings during an earthquake.

“The vision for the NEES-Soft Project is twofold: To provide a methodology to retrofit soft story woodframe buildings to (1) protect life, safety, and property by avoiding soft story collapse and excessive upper story accelerations, and (2) provide a mechanism by which soft story woodframe buildings can be retrofitted using Performance-Based Seismic Design (PBSD) to achieve a level of performance commensurate with stakeholders’ target. This vision has been accomplished through a comprehensive combination of new numerical modeling procedures and full-scale experimental investigation…”

Western Michigan University

RE: to address the vulnerability associated with soft-story structures, five universities and various industry partners were brought together to form the *NEES-Soft Project*, whereby different types of retrofits were designed and tested using historical earthquake ground motions. In addition, the un-retrofitted structure was tested to evaluate its potential for collapse. Special attention was given to introducing a sufficient amount of retrofit in the soft ground story to achieve a pre-defined performance objective, while at the same time, minimizing the requirement for retrofit and post-earthquake repair in the upper stories. The multi-university project was led by *Colorado State University* (CSU), with participants from *Rensselaer Polytechnic Institute*, *California State Polytechnic University - Pomona*, *Clemson University* and *Western Michigan University*.



Step 1: Setup numerical model

$\mathbf{M}_n, \mathbf{C}_n, \mathbf{f}_n(\mathbf{u})$

Step2: Solve EOM to obtain simulated seismic displacement response **u** using integration algorithm (i.e. Newmark).

$$\mathbf{M}_n\ddot{\mathbf{u}} + \mathbf{C}_n\dot{\mathbf{u}} + \mathbf{f}_n(\mathbf{u}) + \mathbf{f}_p = -\mathbf{M}\ddot{a}_g$$

Transform DOF coordinate from model $\mathbf{u}$ to actuators $\mathbf{u}_A$ (when rotation DOFs are included)

Apply necessary compensation

"…To better understand the mechanisms of woodframe collapse and the effect of these two levels of retrofit on system performance. The project includes the following test phases: Slow hybrid simulation at the University of Alabama (UA), Real Time Hybrid Simulation (RTHS) at UA, Hybrid simulation test at University of Buffalo, and STT at UCSD. Western Michigan University is leading the hybrid testing task essential in gaining a full understanding of soft story collapse mechanisms…"

Western Michigan University

A full-scale, multi-story wood-framed building with soft ground story was constructed and tested during the summer of 2014 at the NEES (*Network for Earthquake Engineering Simulation*) laboratory at the *University of California, San Diego* (UCSD), as part of the *National Science Foundation* (NSF)-sponsored *NEES-Soft Project*. The project focused on seismic performance of multi-story buildings with weak (soft) ground stories. The test specimen was designed and constructed to resemble the architectural and structural characteristics of soft-story residential buildings located in high-seismicity regions of the western U.S. The system consisted of seismic dampers that, under cyclic motion, dissipate energy from the earthquake thereby reducing the energy dissipation demand on the lateral force resisting elements (shear walls) of the structure. Two earthquake ground motions were used in the shaking table tests.

Left: caption: “Test Specimen mounted on the UCSD seismic shake table”

Right: caption: “Two damper frames installed in ground story of the test specimen”


NEES-Soft
NEES @ UCSD

Self-Tensioning

“…Engineers also see the possibility of computer-controlled, self-tensioning structures. In this system the construction is tied to a tubular core to compensate for the violent quake motions and keep the building stable…”

Popular Mechanics, **January 1977**

Seismic Damping

"…A new type of earthquake damper puts displaced buildings in their original positions. Called a Paraseismic Insolator support, the device consists of two blocks of Bayer Vulkolan elastomer that fit between the foundation and the structure. One block is molded with a truncated cone in its center. Its companion has a mating cap. Layers of more supple polymer fit horizontally between the blocks. The size and number of cones used depends on the dimensions and weight of the building…"

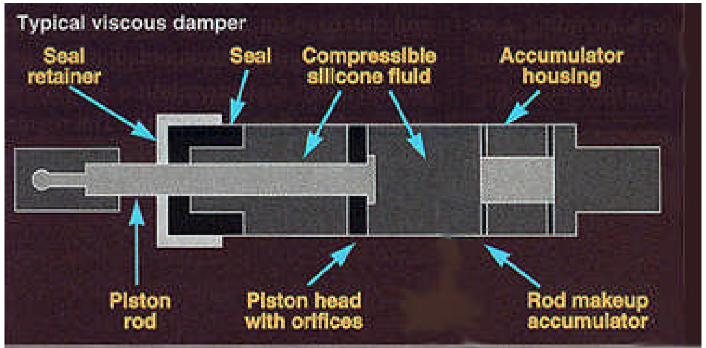
***Popular Mechanics,* June 1997**

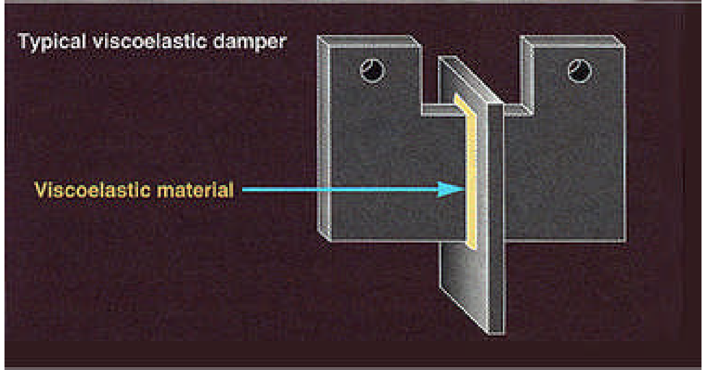
“…During a mild earthquake, the polymer material absorbs small amounts of motion. If shaking increases, the cone enables the foundation and structure to rotate relative to each other. After the earthquake, the cone releases energy. This decompression in turn causes the building to naturally right itself. The developer says the dampers are equally useful in earthquake-free terrain, where they can compensate for the effects of normal settling.”

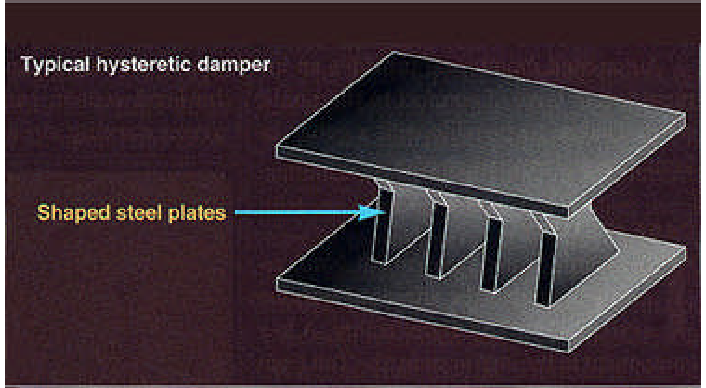
***Popular Mechanics,* June 1997**

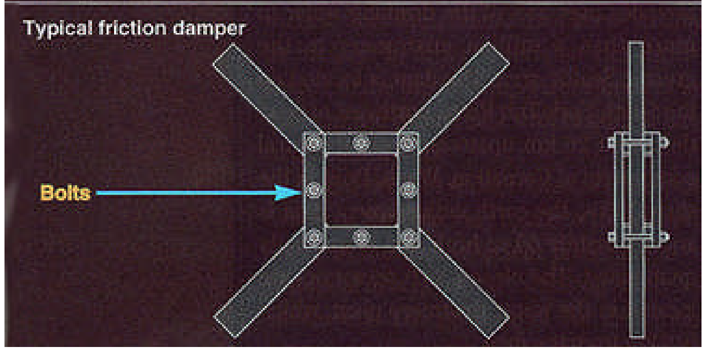
RE: *Seismic Dampers* are used in place of structural elements (i.e. diagonal braces) for controlling seismic damage in structures. They absorb part of the seismic energy and help reduce the amount of motion, acting much like hydraulic shock absorbers on a car. Types include:

- ***Viscous Dampers* – energy is absorbed by silicone-based fluid passing between a piston-cylinder arrangement;**
- ***Friction Dampers* – energy is absorbed by surfaces with friction between them rubbing against each other, and;**
- ***Yielding Dampers* – energy is absorbed by metallic components that yield.**



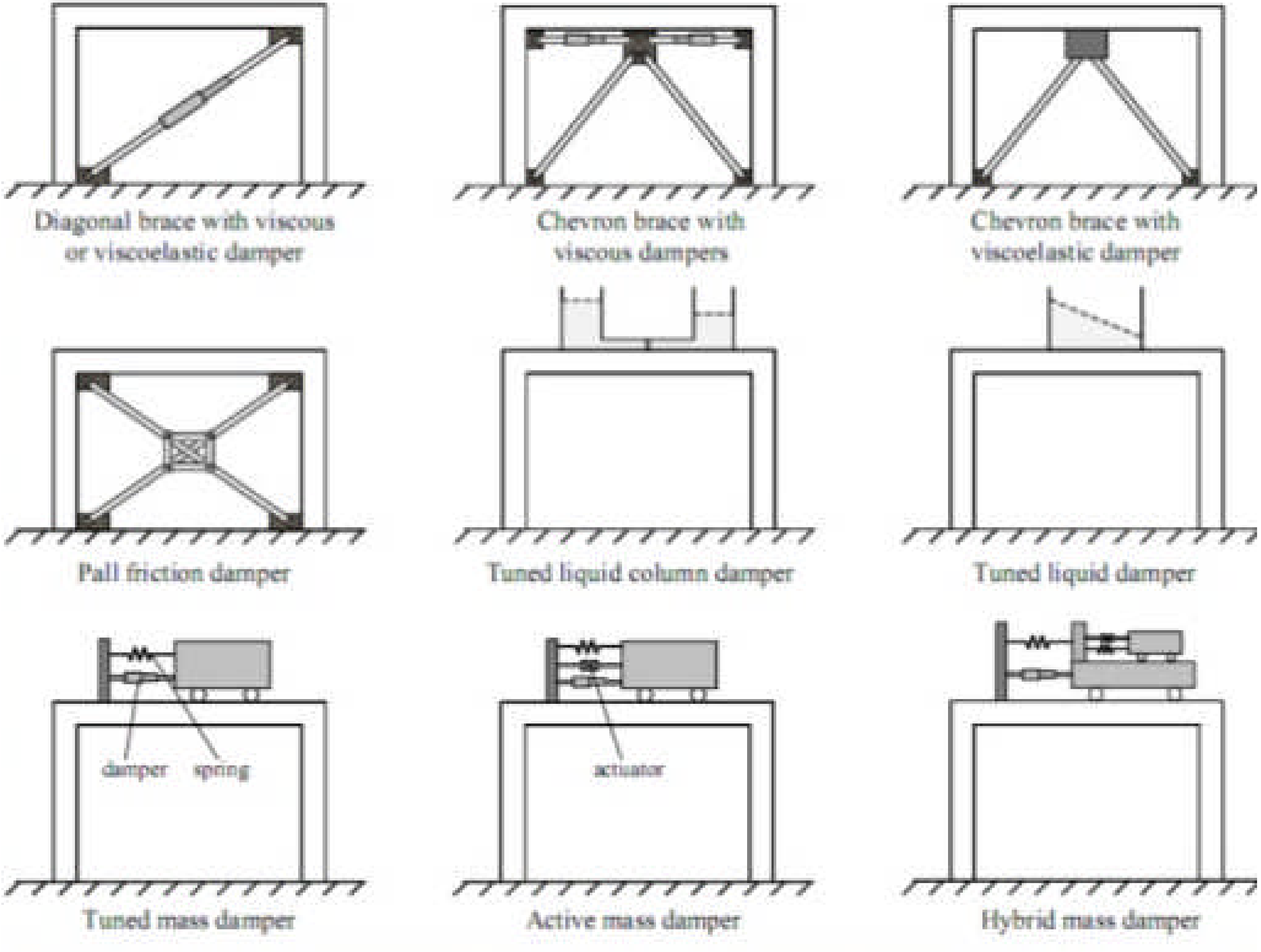




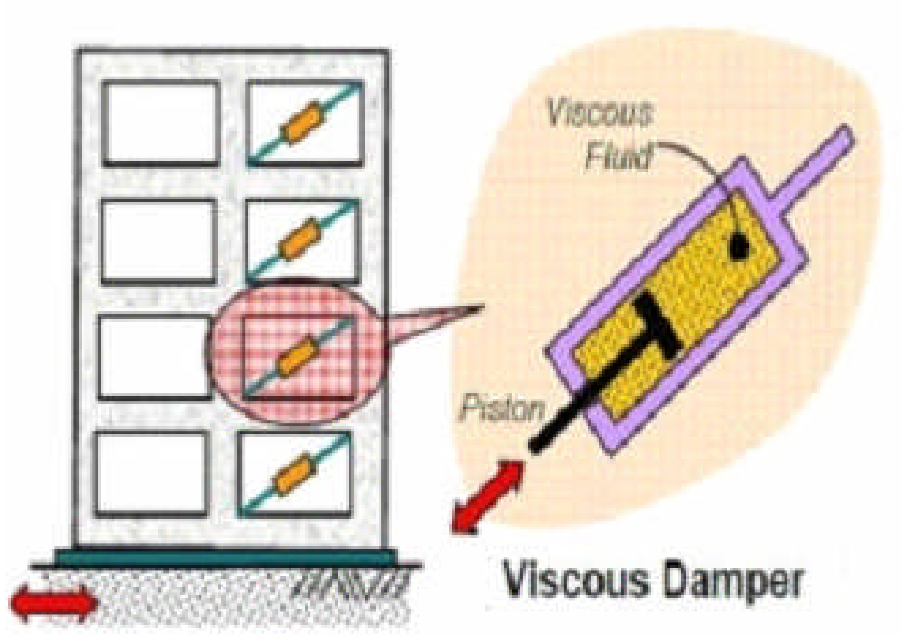


A damper is a device that eliminates or progressively diminishes oscillations. There are several types of dampers available for structural applications. Types include:

- ***Fluid Viscous* dampers are metal cylinders with pistons and work like shock absorbers. Fluid viscous dampers have shown to be the superior device for seismic and wind structural applications;**
- ***Viscoelastic* devices are stacked plates separated by inert polymer materials. These devices have proven to be problematic over a varying temperature range;**
- ***Hysteretic Steel Yielding* dampers were developed in the 1980s. They were given the name A.D.A.S. (Applied Damping And Stiffness). These devices consist of multiple steel plates which yield, and;**
- ***Friction* dampers consist of sliding steel plates. These devices are subject to corrosion and cold welding, which will effect the yielding threshold thus posing a long-term maintenance problem.**

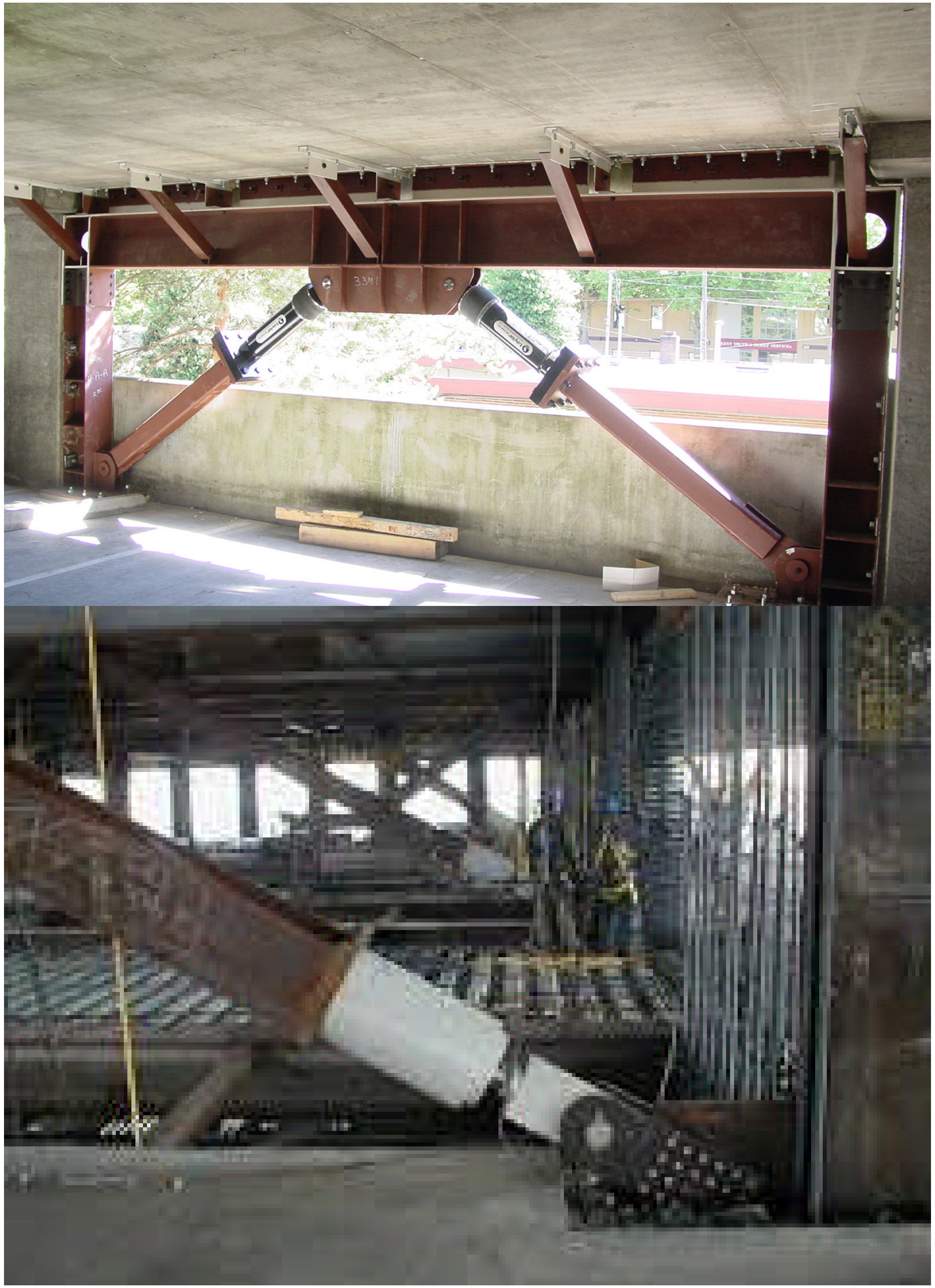


<u>Above</u>: caption: “Energy Dissipation Devices”



<u>Above</u>: caption: "Viscous Dampers absorb energy via a silicone-based fluid passing between a piston-cylinder arrangement"

<u>Left</u>: caption: "Fluid Viscous Dampers literally soak up the energy of earthquake induced motion, preventing structural damage. Compact, yet powerful, Fluid Viscous Dampers increase structural damping levels to as much as 50% of critical, offering truly dramatic seismic stress reduction in any structure."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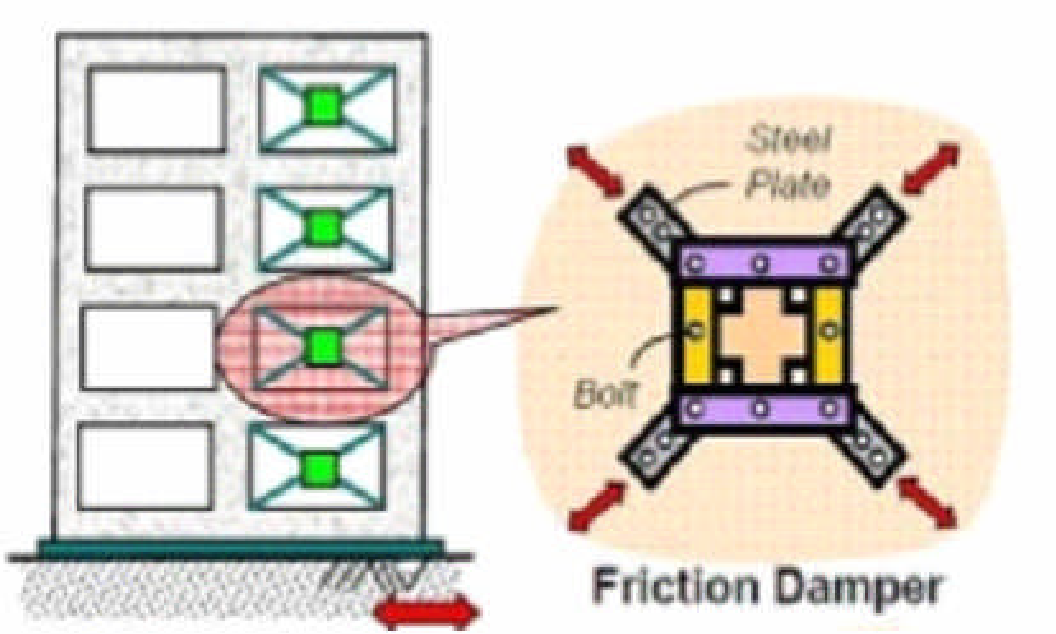
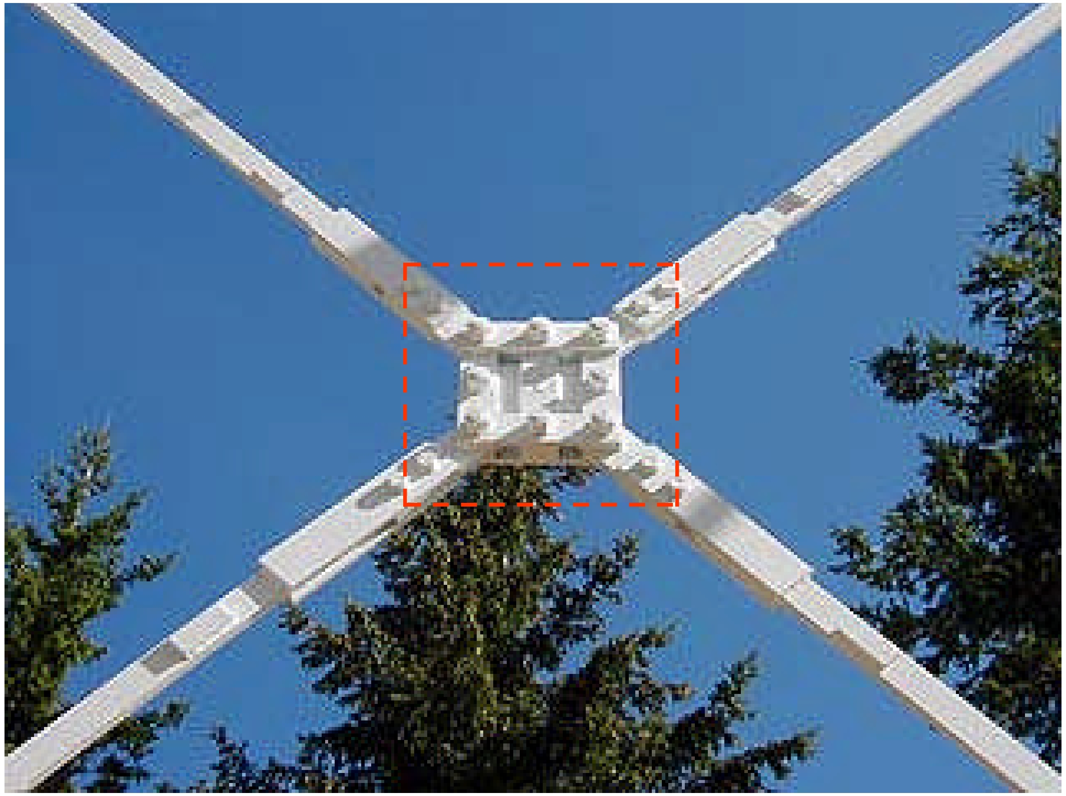
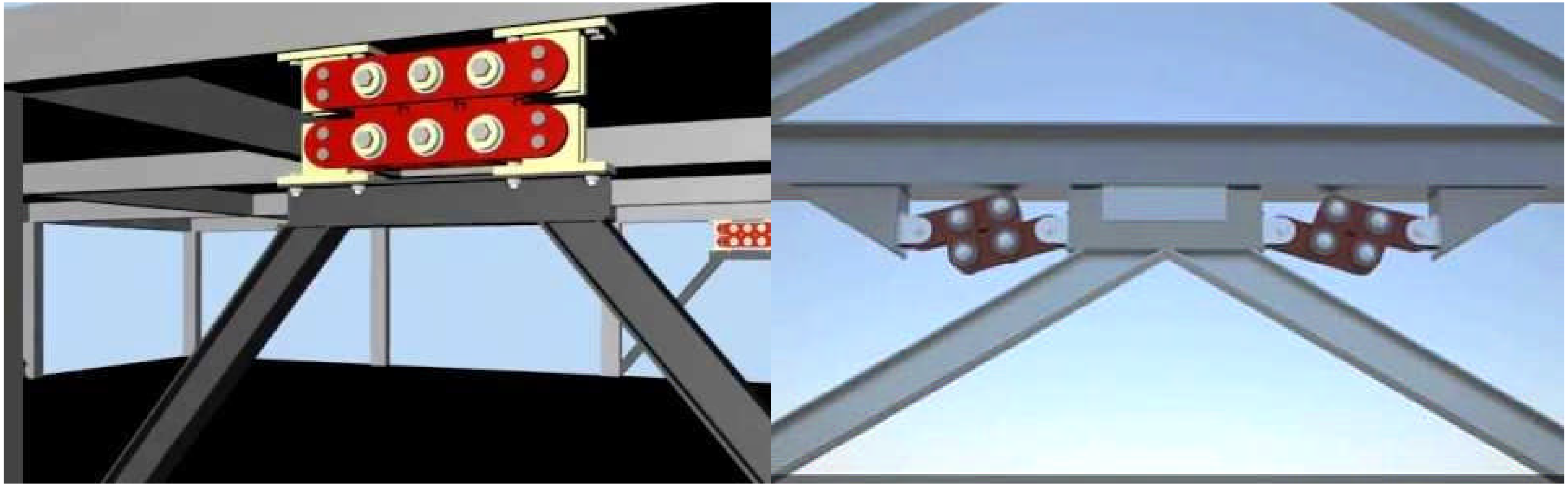


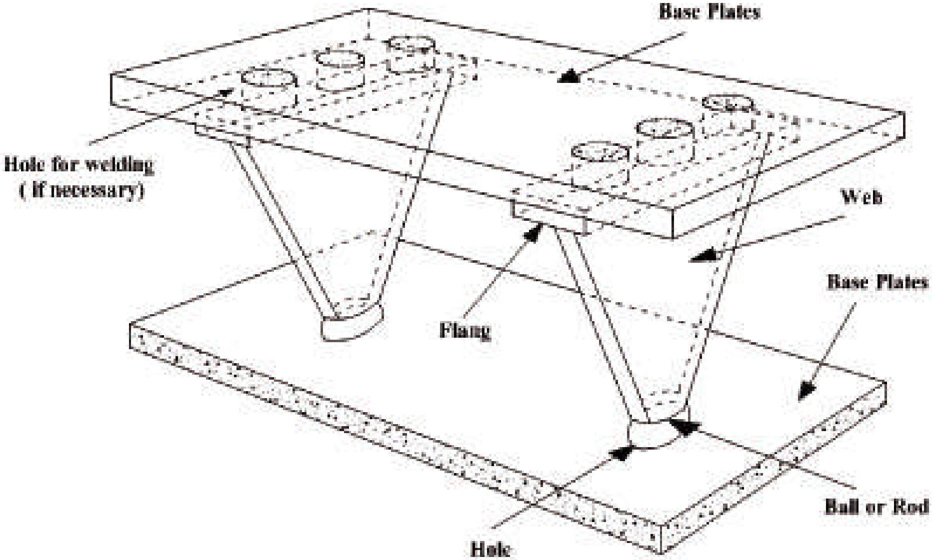


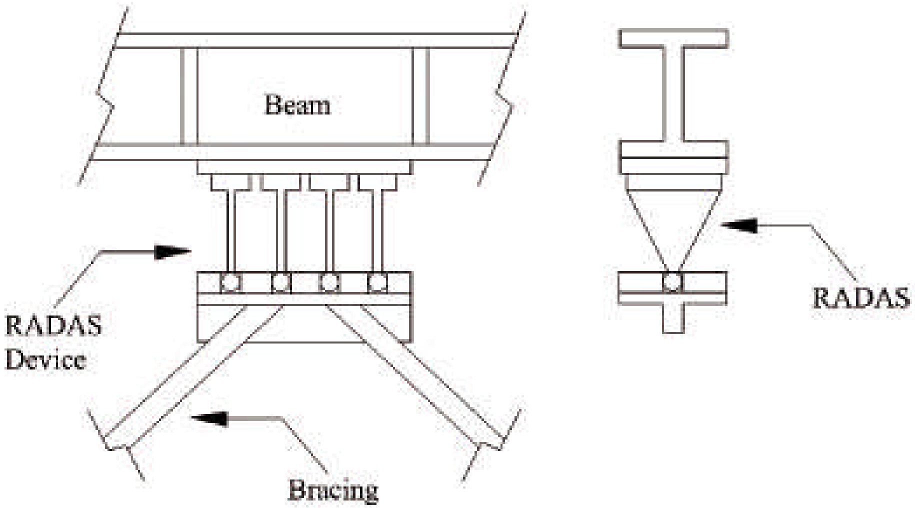
<u>Top</u>: caption: “Friction dampers are designed to have moving parts that will slide over each other during a strong earthquake. When the parts slide over each other, they create friction which uses some of the energy from the earthquake that goes into the building. The damper is made up from a set of steel plates, with slotted holes in them, bolted together. At high enough forces, the plates can slide over each other creating friction. The plates are specially treated to increase the friction between them.”

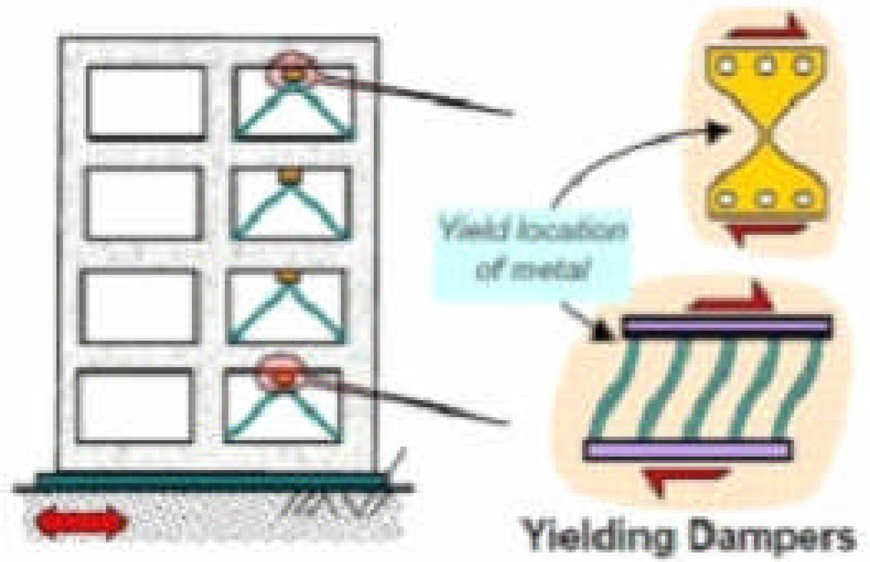
<u>Bottom</u>: caption: “During an earthquake, tension in one brace will force the plate in the damper to slip. In response, the damper shortens the other brace and keeps the tank’s frame from buckling.”



Above L&R: caption: “Mechanism/s for friction damper with inverted V-bracing.” When a lateral external force excites a frame structure with a large force, the top of the frame structure starts to displace horizontally due to this force. The bracing system and the frictional forces developed between the frictional surfaces of steel plates and friction pad materials will resist the horizontal motion. When the frame structure is moved to the left the left damper is lengthened while the right damper is shortened and both dampers dissipate energy. Similarly, when the frame structure is moved to the right the right damper is lengthened while the left damper is shortened and the dampers dissipate energy. During an earthquake, a frame structure in a building will be moved from left to right repeatedly and thus dissipating energy as the dampers are lengthened and shortened.





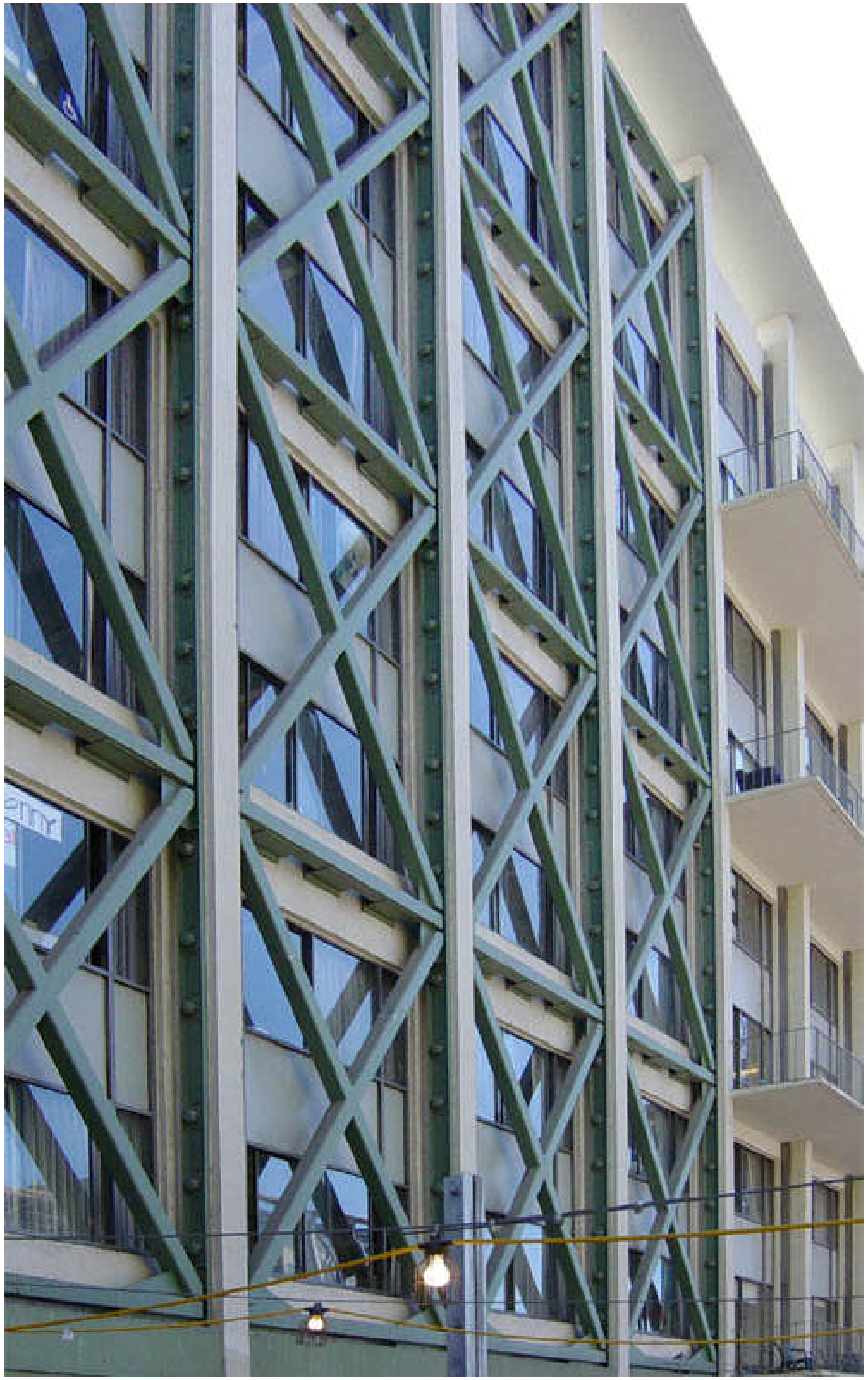


Above: caption: “Yielding Dampers absorb energy via metallic components”

Left T&B: caption: “Arrangement of ADAS Devices.” To dissipate the energy present in the vibration of a structure during an earthquake, the inelastic deformation of metals can be effective. Much research has been done based on the use of low-yield metals with triangular and hourglass shapes. Among the best known devices are the patented *Added Damping and Stiffness* (ADAS) device. Such a device exhibits stable hysteretic behavior, is insensitive to thermal effects and is extremely reliable. A typical ADAS device is shown in the figure/s at left.

Seismic Retrofitting

Seismic Retrofitting **is the modification of existing structures to make them more resistant to seismic activity, ground motion or soil failure due to earthquakes. With better understanding of seismic demand on structures and recent experiences with large earthquakes near urban centers, the need of seismic retrofitting is well established. Prior to the introduction of modern seismic codes in the late 1960s for developed countries (i.e. U.S., Japan) and late 1970s for many other parts of the world (i.e. Turkey, China etc.), many structures were designed without adequate detailing and reinforcement for seismic protection.**



To deal with the ever-present threat of earthquakes, various research work has been carried out around the world. State-of-the-art technical guidelines for seismic assessment, retrofit and rehabilitation have been published around the world, such as the ASCE-SEI 41 and the *New Zealand Society for Earthquake Engineering* (NZSEE) guidelines. These codes must be regularly updated For example, the 1994 *Northridge Earthquake* brought to light the brittleness of welded steel frames. Current practice of seismic retrofitting is predominantly concerned with structural improvements to reduce the seismic hazard of using the structure, it is also essential to reduce the hazards and losses from non-structural elements. Although there is no such thing as an “earthquake-proof structure,” seismic performance can be greatly enhanced through proper initial design and/or subsequent modifications.

No Worries

“…In the old days of short, squatty buildings, nobody worried about wind; they worried only about earthquakes. And you solved stability problems with mass and brute strength. You simply built heavy masonry structures that resisted outside forces with shear bulk…”

***Popular Science*, August 1985**

"…Then about 100 years ago, architectural engineer William Jenney designed Chicago's Home Insurance Building. It was supported not by masonry but by a steel skeleton, which provided the framework for concrete walls. New, lighter buildings leapt upward. Later, bolstered with higher strength steels and featuring still lighter cladding, they positively soared…"

***Popular Science,* August 1985**

Left: caption: "The first steel skeleton skyscraper – The Home Insurance Building, Chicago (1883), designed by William LeBaron Jenney."

Worries

“…The problem is that high-strength steels, coupled with aluminum or reflective glass – which save builders money and allow skyscrapers to shoot upward – come with a price: lowered rigidity. That means flexibility…Today, designers are sketching plans for the next generation of super-skyscrapers: 150 stories, 190 stories, even a 500-floor Chicago building to reach up one-half mile. All of which causes wrinkled foreheads on structural engineers when they think about building movement…”

***Popular Science,* August 1985**

"…If the rhythm of an earthquake is close to a flexible building's fundamental natural period of oscillation (the time a structure, like an upside-down clock pendulum, takes to swing back and forth), the result could be disaster. Even if the building survived, its tenants, in a mixing bowl of flying objects, might not…"

Popular Science, **August 1985**

<u>Left</u>: artist's depiction of a San Francisco skyscraper shedding its masonry veneer while the steel frame stands firm during the 1906 earthquake

If Only

“…Oddly, to building designers, the forces of moving air and moving earth present nearly the same structural problems. To counter such forces, to protect buildings from twisting, shifting, and swaying, engineers are using new materials and clever new construction techniques. But, engineers muse, if only those buildings could respond, could counteract those forces, could, by adjusting themselves, keep their balance…”

***Popular Science*, August 1985**

“…Over the years, engineers have devised various methods of protecting buildings from wind and earthquakes – some simple, some complicated. The following designs are already in place or may be used in the near future:

- ***Separation joints that turn a building into what Frank Lloyd Wright envsioned as a ‘jointed monolith.’ In an earthquake, they allow the structure to give instead of cracking apart. Another approach – beam-column connections that would deform – rather than snap – during an earthquake, and that are replaceable;***
- ***Apertures through which wind might pass, or venetian-blind-like curtain walls that could automatically adjust to deflect the wind. Wind tunnel tests have demonstrated that such designs can disrupt airflow and decrease vortex shedding, a major cause of building sway;***
- ***Building shapes that prevent oscillations. Two of the more efficient designs: tapered structures that disrupt the wind, and buildings twisted 45-degrees from base to top so that the corner columns enhance rigidity;***
- ***Framed tubular construction (used in the World Trade Center) made by diagonally stiffening the outer walls so that the building acts like a giant, rigid hollow tube…”***

continued…

***Popular Science,* August 1985**

"…continued

- *Viscoelastic dampers (also used in the World Trade Center Towers), which consist of a taffy-like polymer sandwiched between steel. Dampers separate the walls from the floors. As the building sways, the sticky plates move across each other only with reluctance. This decreases motion and converts the energy into harmless heat;*
- *Superframe, a system of giant boxes about 100 feet high, made of huge beams and columns, developed by engineers at Skidmore, Owings and Merrill. Extremely rigid corners make this construction particularly resistant to wind-caused torsional forces. The superframe technique will be used for Chicago's 75-story Dearborn Center, schedule to rise by the time you read this;*
- *Skyway-linked monoliths, a concept developed by the New York structural-engineering firm, DeSimone & Chaplin, in which four or more thin towers would be linked by elevated covered walkways, each building, in effect, steadying its neighbor;*
- *Last, but not least, is the oldest method; pyramid construction, perhaps the best wind and earthquake-resistant design of all…"*

Popular Science, August 1985

TMD

“…One method of counteracting both seismic jiggles and wind sway is to simply build in additional stiffness. ‘But large increases are needed to produce appreciable changes,’ points out Kenneth Weisner of the structural consulting firm of LeMessurier Associates/SCI, in Cambridge, Mass. ‘That’s expensive and inefficient, so there’s a real incentive for the structural engineer to find a more effective approach’…”

***Popular Science,* August 1985**

RE: most skyscrapers built since WWII are clad with a curtainwall typically made of aluminum and glass (a/k/a “Glass Box”). Consequently, these buildings have mass, stiffness and damping values that are relatively low. Thus, these buildings tend to be more susceptible to wind-loading than traditional masonry-clad buildings. For example, the *Empire State Building* has a very stiff steel frame structure, with beams and columns that are rigidly connected. Additionally, it is clad with heavy masonry walls made from limestone and granite (with brick backing). The friction between the wall sections and structural elements provides a relatively high amount of damping. As a result of its high mass, high stiffness and high damping, the ESB is able to resist significant wind loads.

"…Solutions are coming. Impressive structures such as New York's 960-foot-high Citicorp Center, the eighth tallest building in the world, which has a tuned mass damper – a movable 410-ton block of concrete that relies on its own bulk to counteract building sway – are a first step…"

***Popular Science,* August 1985**

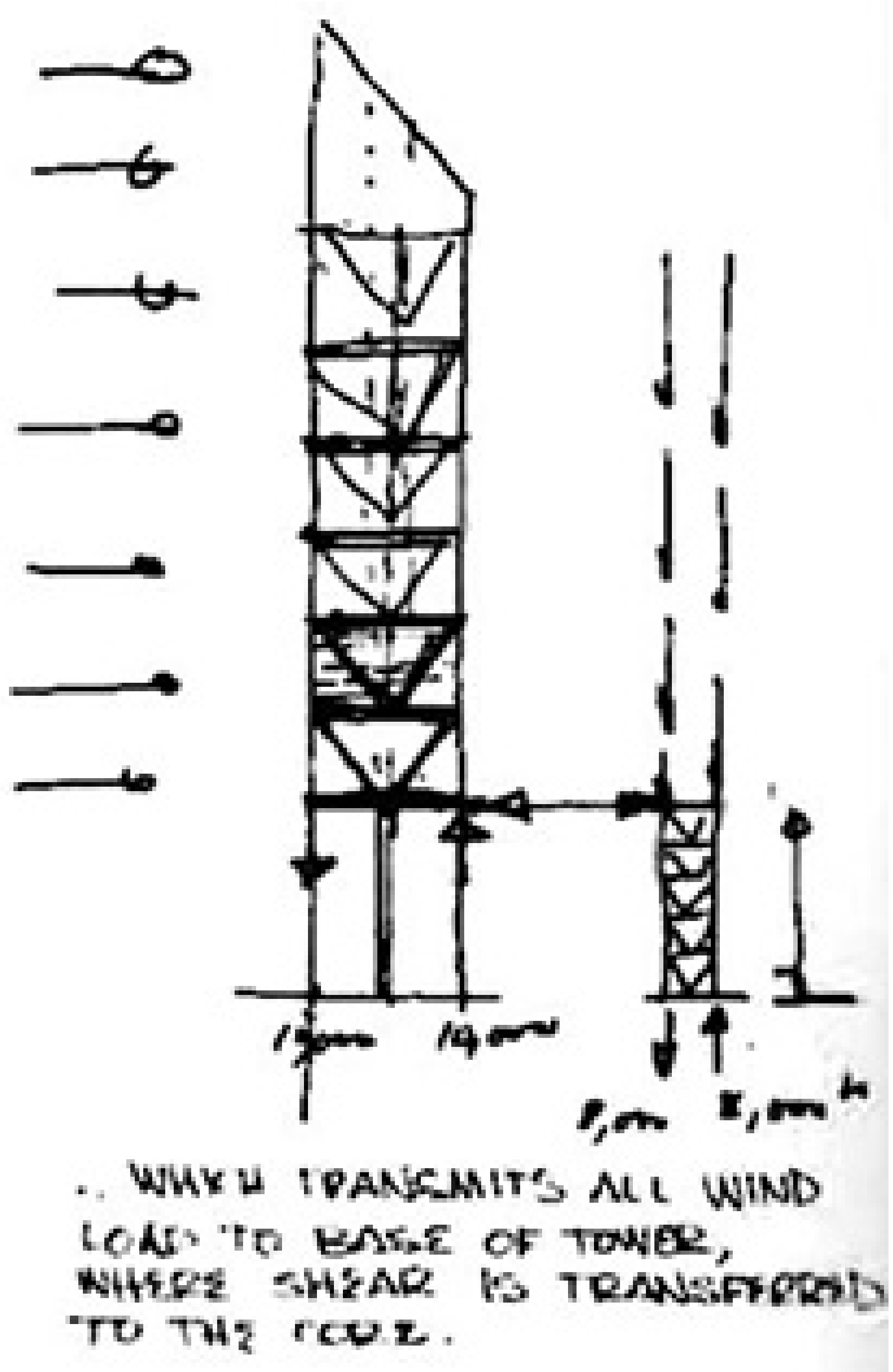
Left: *Citigroup Center* (formerly *Citicorp Center*) was built in 1977 to house the headquarters of *Citibank*. The building is one of the most distinctive and imposing on NYC's skyline, thanks to a 45-degree angled top and a unique four-column base.

Isaac Newton **wrote as his first** ***Law of Motion*** **that a mass either remains at rest or moves at a constant velocity unless acted upon by an unbalanced force. This law is also referred to as the** ***Principle of Inertia*****. A** ***Tuned Mass Damper*** **(TMD) consists of a concrete block weighing many tons, set on a thin layer of oil at the top of the building. Steel springs and shock absorbers connect the mass to the building's outer walls. As the building begins to sway back and forth, the inertial mass tends to remain still, relative to a fixed point on the ground outside the building. The building thus slides under the mass on the oil layer. As this happens, the springs on one side of the mass are compressed and thus try to push the building back to its rest position. At the same time, the springs on the other side are stretched and try to pull the building back. The mass tends to remain still (relative to the fixed point on the ground). The mass does experience a relative displacement, however, as measured from a moving point at the top of the building. Furthermore, the mass damper system must be tuned to have the same natural frequency as the building's natural frequency, in order to optimize the vibration attenuation (wind gusts can excite this natural frequency). The** ***Citicorp Building*** **has a period of: T = 6.5 seconds, which corresponds to a natural frequency: fn = 0.15 Hz.**

"…When you first walk into the Damper Room, you're in for two surprises. First, the space is cavernous; you wouldn't expect to find an 80-by-80-foot machine room 59 stories above the sidewalk. And second, dominating the room is a concrete block the size of a two-car garage. It appears to be floating…"

Popular Science, **August 1985**

RE: the *Citicorp Building* was designed with a TMD in order to control the swaying induced by wind (it was the first building to have such a system). The 400-ton mass damper is located in a large room at the top of the building (the block is supported on a series of twelve hydraulic-oil bearings). A major design goal for the building was to minimize the weight of the structural steel frame. As a result, the building is an unusually lightweight building, with 25K-tons of steel in its skeleton. By contrast, the *Empire State Building* has a 60K-ton superstructure. For most buildings, the main concern in regard to wind loading is the comfort of occupants on the upper floors, who might suffer from motion sickness if the building sways too much (i.e. *World Trade Center*).



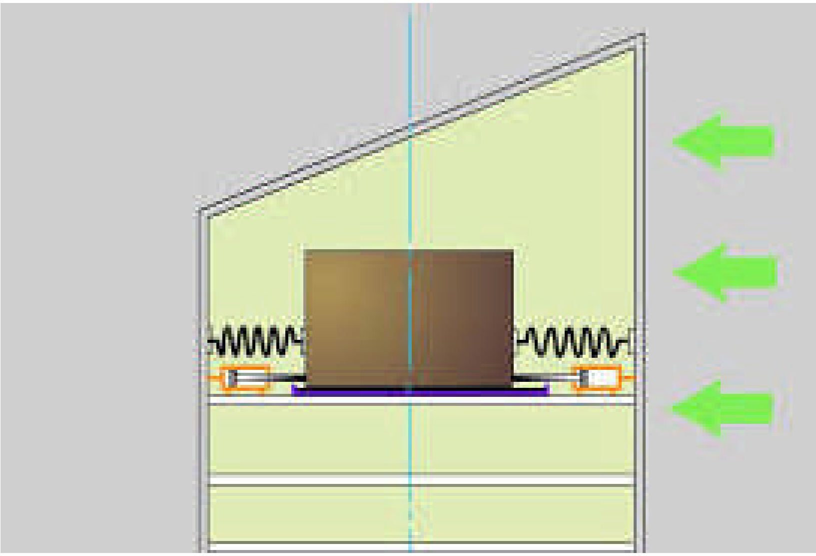
“…A pair of sensitive accelerometers bolted to the Citicorp building’s frame check for horizontal movement. When the sway exceeds three milli-gs (three thousandths of the acceleration of gravity) – a motion you can just barely sense – a relay snaps, a 50-horsepower oil pump thumps into action and slowly the block begins to rise…”

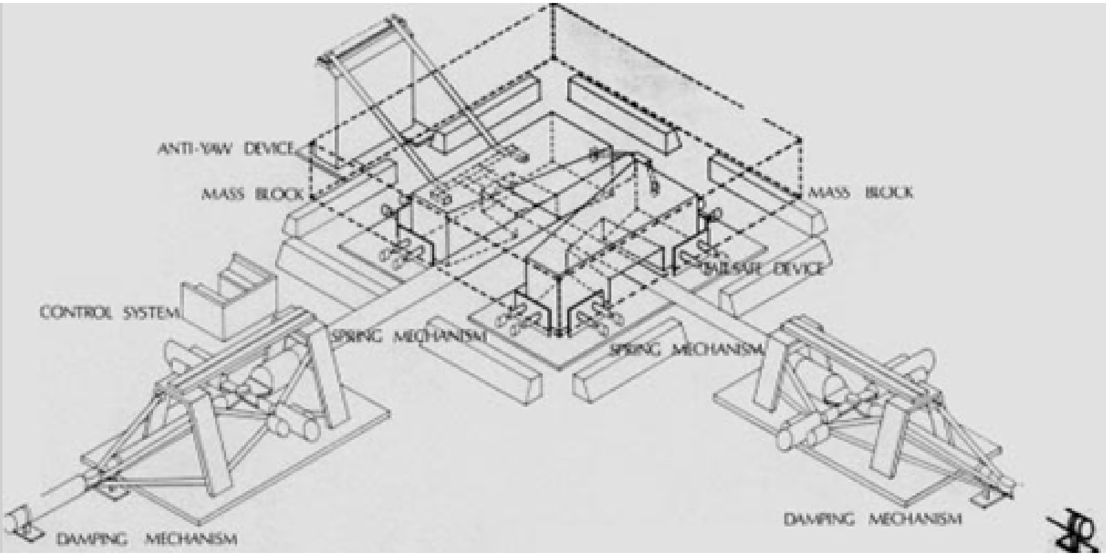
***Popular Science,* August 1985**

<u>Left</u>: caption: “Proposed solution to wind-loading problem sketched on a paper napkin by structural engineer Bill LeMessurier.” The wind load plus one-half of the gravity load is directed to the trussed fame on the outside of the Tower. The core carries the remaining gravity load. Specifically, the building frame has a unique set of diagonal steel cross-beams set in a chevron pattern to transfer the loads to the four base columns.

"…Four minutes later, the block has lifted ¾-inch. Now its standing on twelve hydraulic footpads the size of manhole covers, each separated from the 30-square-foot polished-steel floor beneath the block by a near friction-less layer of oil. The block, all 400 tons of it, is now free to glide ponderously across the floor – or, more accurately, the floor is free to slip under the block…"

Popular Science, **August 1985**





The damper system is activated whenever the horizontal acceleration exceeds 0.003 G for two consecutive cycles. This acceleration corresponds to a peak-to-peak displacement of 2.6 inches (assuming that the swaying is occurring at the natural frequency of 0.15 Hz). Once activated, the damper continues until the acceleration does not exceed 0.00075 G in either lateral axis over a 30-minute interval. For activation, a separate hydraulic system raises the block mass about ¾-inch to its operation position in about three minutes.

Left: caption: “When the wind pushes the building to the left, the mass remains still relative to a fixed point on the ground. However, the mass experiences a displacement to the right, relative to the building’s moving walls.”

Right: caption: “Citicorp Center’s Tuned Mass Damper (TMD) reduces building sway caused by winds. TMD utilizes 400-ton concrete mass which moves in opposite direction from building to reduce building sway by some 40%”

“…When the building sways – that is, as it begins to slide under the block – the blocks movement is inhibited by two sets of cleverly designed pneumatic gas springs. The block and the stiffness of the springs have been ‘tuned’ to the natural oscillation period of the building (in the Citicorp Center’s case, 6.7 seconds)…”

Popular Science, **August 1985**

RE: the TMD is tuned to be “bi-axially resonant” (with a variable operating period of 6.25 seconds and with a margin of +/-20%). Its damping rate is adjustable from 8% to 14%. Furthermore, the springs are designed to have a peak displacement of +/-55 inches (1.4 meters). The damper is designed to reduce the building sway by 50%. This reduction corresponds to increasing the basic structural damping by 4%, to a total of 5%.

Out of Rhythm, Out of Sync

"…Now the computer comes into effect, supplying the intelligence to drive two servo hydraulic rams, one pushing and pulling the mass in an east-west direction, the other north-south. The computer uses the accelerometers to determine how much the building is swaying, then 're-tunes' the block motion, allowing it to move in time with the building. But it moves 90-degrees out of phase, the only way to absorb the energy of a swaying or resonating structure. The result: out of rhythm, out of sync, the block inertially damps the building sway. Finally, if the sensors detect little motion for half an hour, the oil pump flips off. The block, with a hydraulic sigh, slowly settles back down on its base…"

Popular Science, **August 1985**

"…The TMD uses little more electricity than is required to run the oil pump (it's on about 200 hours a year), yet it reduces building sway by about 45 percent. The damper produces an improvement, estimates Citicorp's structural engineer William LeMessurier, equivalent to quadrupling the building's structural bracing. That's a saving of nearly $4 million…"

***Popular Science,* August 1985**

<u>Above & Left</u>: structural bracing of the steel frame – Citicorp Building

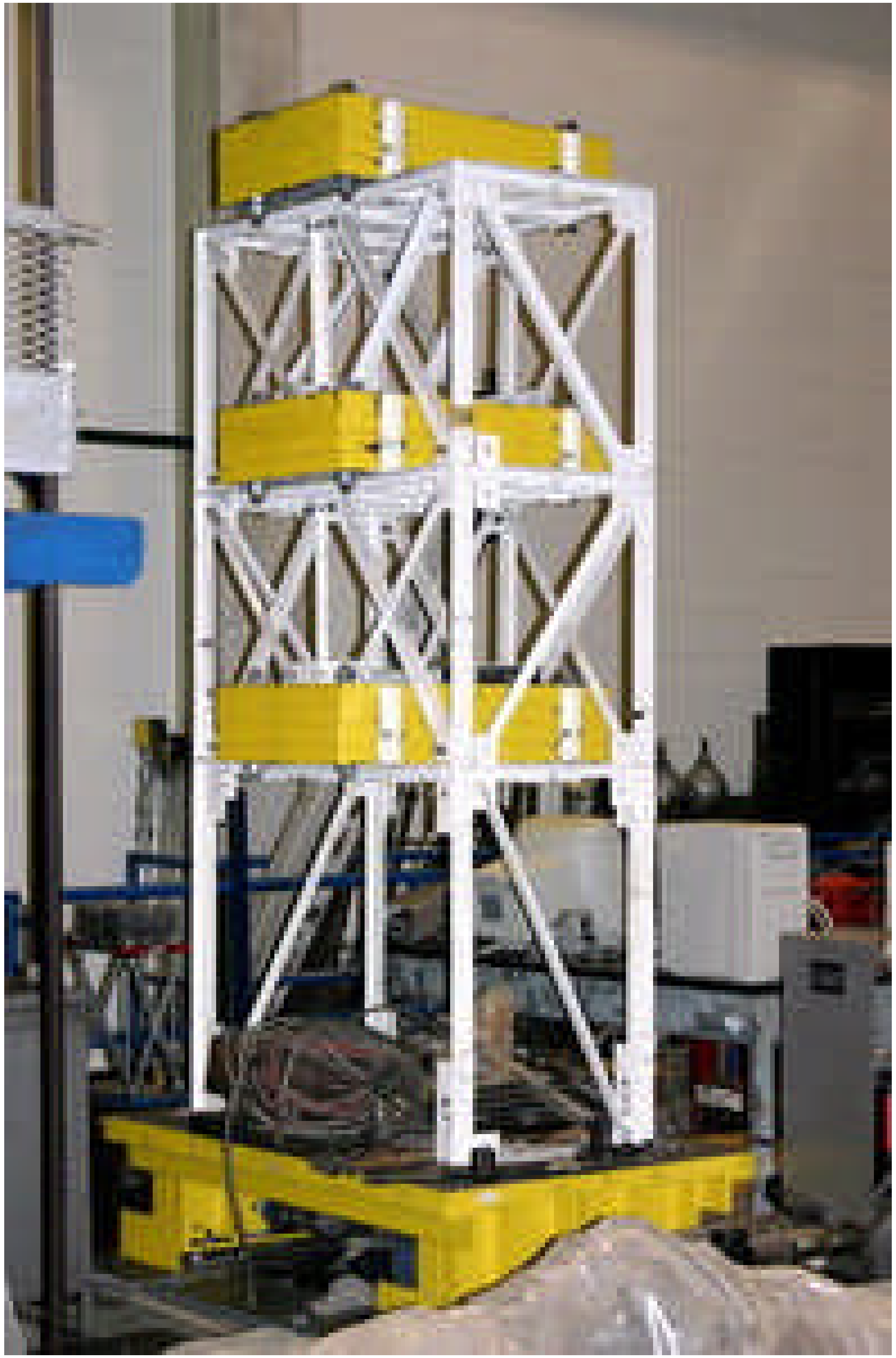
A traditional TMD wasn't good enough for the new *Shanghai Tower* (left) which, at 2,073-feet, is the second tallest building in the world (after the *Burj Khalifa* in Dubai). On the upper floors (where the flex is greatest) the oscillations would have been fast and wide enough to cause motion sickness To counter the sway, the building's design team came up with a solution; they installed a huge TMD - the heaviest-ever flex-reducing weight in a building, and paired it with a magnetic system to create the first eddy-current damper ever used in a skyscraper.

Not Enough (?)

“…Nevertheless, as efficient as a TMD is, some engineers feel that the system isn’t effective enough. ‘It’s a halfway measure,’ says University of Virginia engineer and architect William Zuk. ‘It’s a semi-passive system, not a fully active system. A truly active system wouldn’t simply have a mass floating around; it would have forces and sensors and jacks running a tendon system – particularly to counteract seismic events’…”

***Popular Science*, August 1985**

Just Such a System



"…The embryo of just such a system is growing in a laboratory at the State University of New York's Buffalo campus. There, on what is being billed as the most versatile seismic simulator in North America, civil engineer Tsu Soong is directing the development of miniature buildings with a sense of balance…'Much work on the idea of tensile tendons has been done on paper,' he says, 'but this is the first time such a thing has ever been done in the laboratory'…"

***Popular Science,* August 1985**

Left: caption: "Shake Table S with proprietary model"

“…One objective of the SUNY program is to find out how many sensors, cables, and controllers are needed and where they should go. When that’s established, Soong foresees the ideas being quickly applied to TV towers, radio telescopes, bridges, and then buildings…”

***Popular Science*, August 1985**

Curb Your Enthusiasm

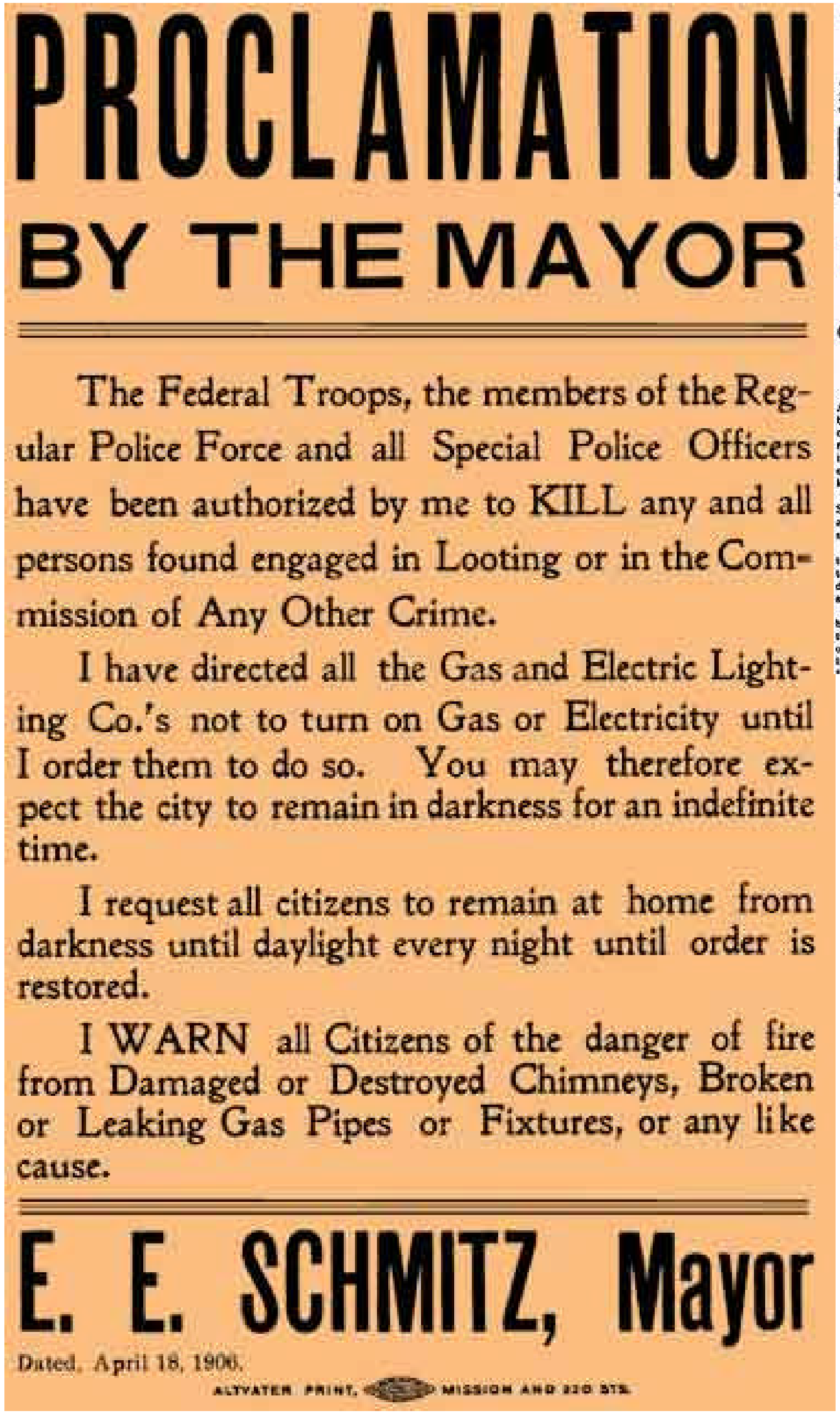
“…Engineer-architect Zuk, an active-system advocate for at least a decade, can barely contain his enthusiasm for the tendon approach. ‘Active systems can do certain things that passive systems just cannot do,’ he recently told a conference of structural engineers. ‘Active systems can reduce deflection to absolute zero – not just to a small amount, but zero…”

***Popular Science,* August 1985**

“…Adds Soong: ‘When we complete our studies, the only question remaining will be, is it practical?’ The answer, he believes, is yes. ‘The tensile tendon system, you see, could substitute small amounts of energy for mass. It could be most cost-effective.’ ‘The problem,’ Soong continues, ‘is not practicality. It’s convincing the professionals – the structural engineers, the architects, the building owners – that the idea is sound and that it makes sense’…”

***Popular Science,* August 1985**

Don’t Print That



PROCLAMATION
BY THE MAYOR

The Federal Troops, the members of the Regular Police Force and all Special Police Officers have been authorized by me to KILL any and all persons found engaged in Looting or in the Commission of Any Other Crime.

I have directed all the Gas and Electric Lighting Co.'s not to turn on Gas or Electricity until I order them to do so. You may therefore expect the city to remain in darkness for an indefinite time.

I request all citizens to remain at home from darkness until daylight every night until order is restored.

I WARN all Citizens of the danger of fire from Damaged or Destroyed Chimneys, Broken or Leaking Gas Pipes or Fixtures, or any like cause.

E. E. SCHMITZ, Mayor

Dated, April 18, 1906.

ALTVATER PRINT, MISSION AND 22D STS.

PRINTED ON PAPER CULLED FROM THE MAJESTIC SEQUOIA.

THE ONION

EXTRA! LATEST EDITION.

Sunday, April 22, 1906. The Best Source of News-worthy Items in our Great Republic. Price Five Cents.

EARTH-QUAKE MARKS LEAST GAY DAY IN SAN FRANCISCO HISTORY

'QUEEN CITY ON THE PACIFIC' LIES IN RUINS.

Garment District Still Flaming.

San Francisco, California, April 18.—Gaiety was not to be had on the streets of the city this morning, as it lies in ruins from what fair citizens in the city are calling the most outlandish earth-quake in known history.

"This is not a gay day for San Francisco," the honorable Mayor Eugene Schmitz said.

At precisely 5:12 a.m., local time, the quake shook the city to its conservative core, rendering it no more than rubble, ash, and faggots.

Earth and rock were ouled by the great quake from the northernmost 200 miles of the San Andreas fault line northwest of San Juan

ABOVE IS THE DEVASTATION IN ITS TOTALITY, AS DEPICTED BY MODERN PHOTO-GRAPH, DELIVERED TO THE ONION OFFICES BY RAIL-CAR FROM SAN FRANCISCO IN ONLY SIX DAYS.

"…To help with that selling job, seismic engineers could use a little assistance from nature, an engineer from another institute told PS. 'What we need,' he said, 'is another San Francisco earthquake or two.' Then he added, 'But don't print that.'"

***Popular Science,* August 1985**

<u>Above</u>: *The Onion* headline – April 22nd 1906

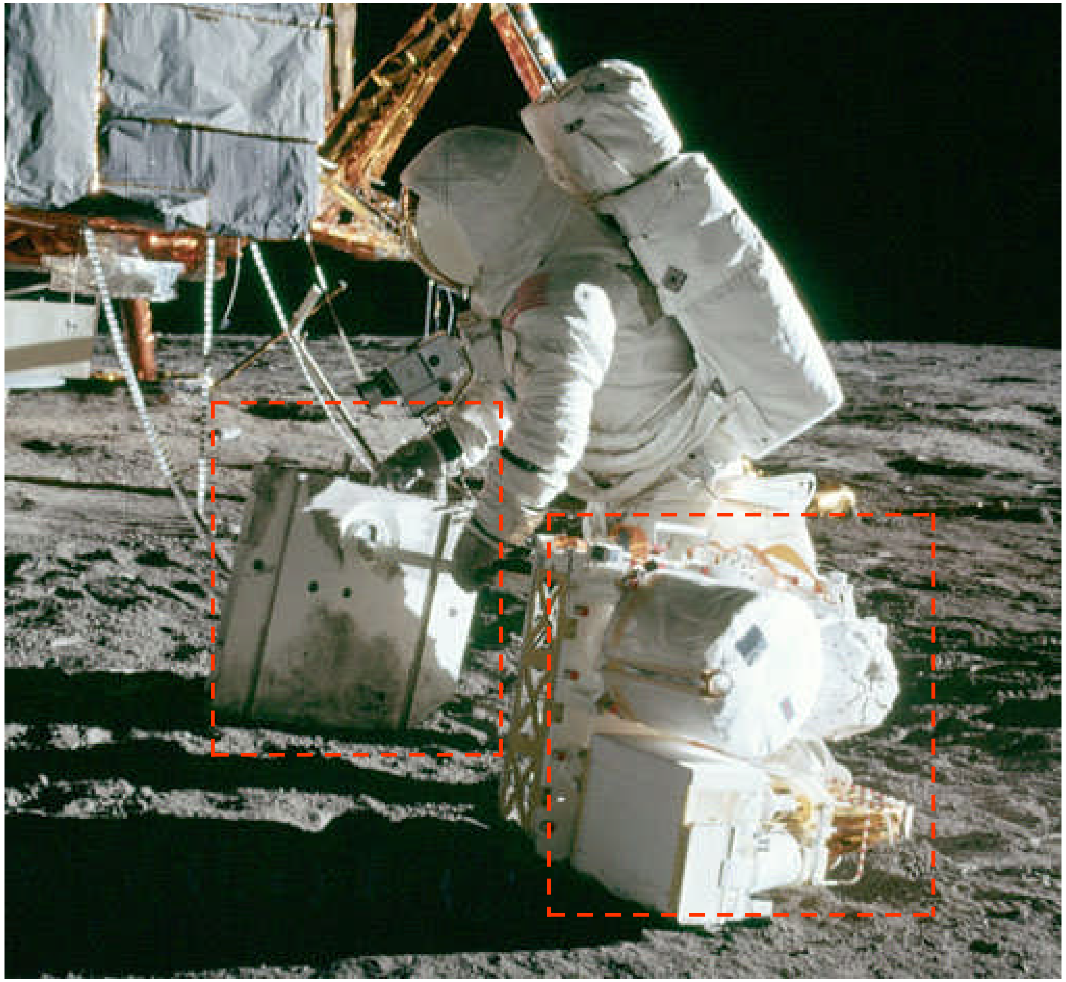
<u>Left</u>: San Francisco Mayor E.E. Schmitz's "Shoot-to-Kill" Order – April 18th 1906

Part 10

Out of This World

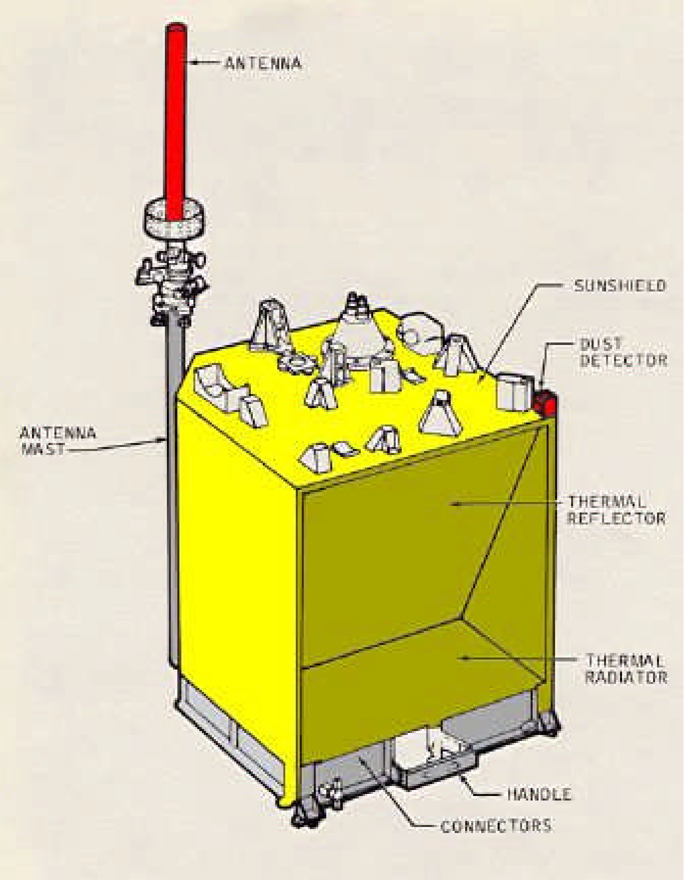
ALSEP

ALSEP (*Apollo Lunar Surface Experiments Package*) was a collection of geophysical instruments designed to continue to monitor the environment of each Apollo landing site for a period of at least a year after the astronauts had departed. Designed for a life of one year (*Apollo 17* was for two years), they ended up working for up to eight years (the ALSEP experiments were permanently shut-down by NASA on September 30th 1977). Due to the experimental nature of the first landing of *Apollo 11*, especially the mechanics of getting to the lunar surface and back, science took a lesser role thus, Apollo 11 had a simpler version known as the *Early Apollo Surface Experiments Package* (EASEP), with only two experiments.



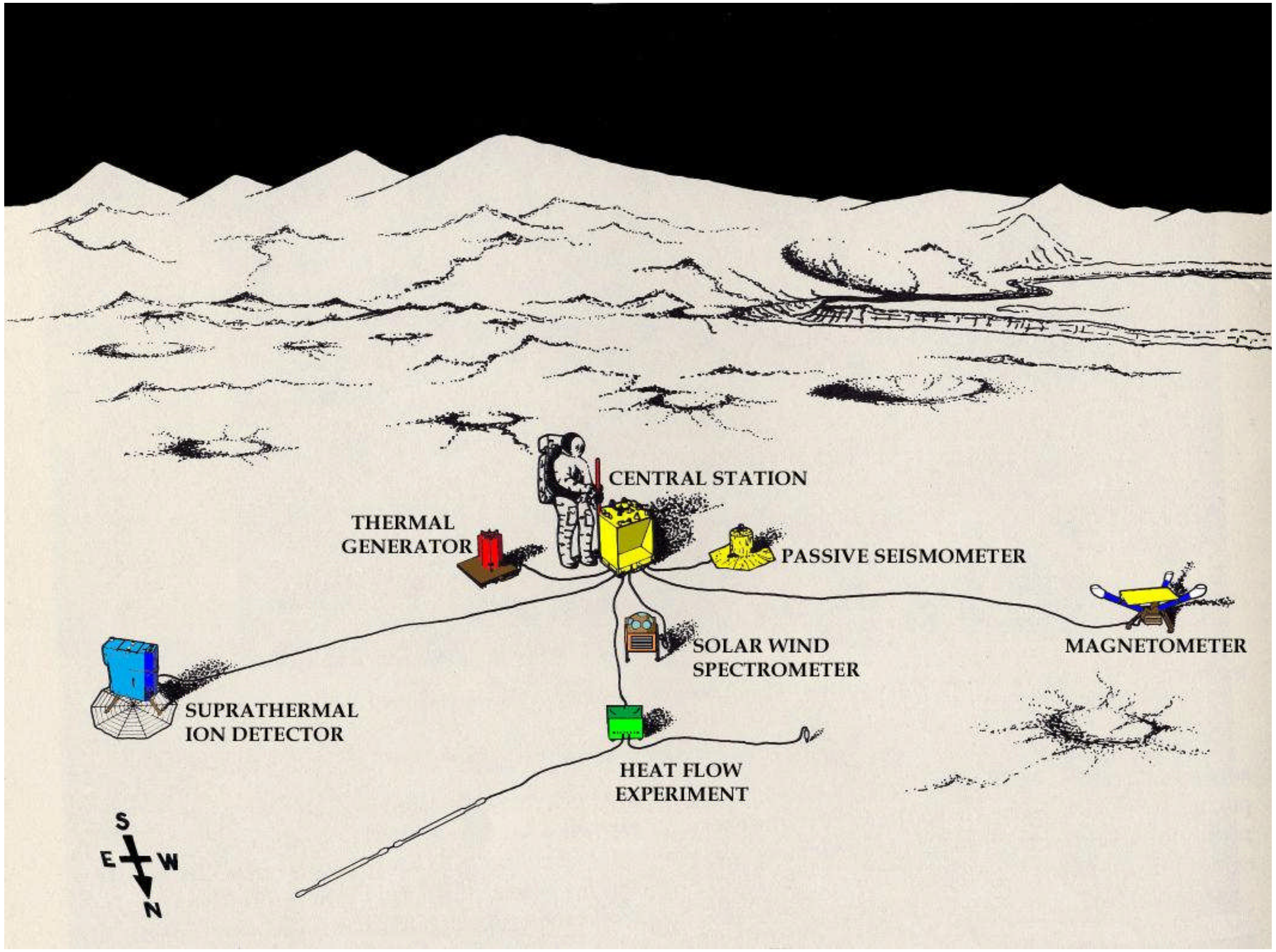
The ALSEP was packaged on two major sub-pallets in the *Lunar Module,* which were removed and then attached to a "barbell" (which later became the antenna mast) to enable hand carrying to the selected site. The total mass of the ALSEP on *Apollo 17*, for example, was 163 kilograms on Earth, or 27 kilograms on the Moon.

Left: caption: "Alan Bean attaches ALSEP package No. 2 to the carry bar, which will later serve as the antenna mast. Package No. 1 is in the foreground, already attached to the carry bar. On package No. 1, the LSM, with its distinctive gold-colored arms, is nearest the ground."



<u>**Left**</u>**: caption: “The ALSEP Central Station formed the base of Package No. 1 and, on the top in this diagram, we see various pieces of hardware where experiments were attached prior to removal and deployment. The antenna mast served as the carry-bar when the LMP brought the packages out to the deployment site. On top of the antenna mast are a set of gimbals used to point the antenna at Earth. Ribbon cables from the various experiments were attached at the bottom of the side facing us in this view. The thermal radiator and thermal reflector kept the Central Station electronics in the base from overheating.”**

A level site for the ALSEP station was desired. Generally, 100-meters to the west of the *Lunar Module* (but not in its shadow at sunrise) was seen as adequate. Craters and slopes were to be avoided since they would degrade the thermal control of the unit (*Apollo 14* had trouble finding such a site). As well, the location had to be far enough away from the Lunar Module to avoid the dust and debris of ascent and the seismic disturbance of the venting propellant tanks and thermally creaking structure was desired. Added to this was the need for a reasonably straight and level area for a geophone line on those missions with ASE (*Active Seismic Experiment*) or LSPE (*Lunar Seismic Profiling Experiment*) and a clear area for mortar firings for LASE (*Lunar Active Seismic Experiment*). Needless to say, a perfect site was difficult to find. The *Central Station* and most, if not all, of the individual experiments needed to be leveled to within 5-degrees of vertical and oriented with respect to the Sun. The central station was aligned within 5-degrees of the East-West line (for proper thermal control).

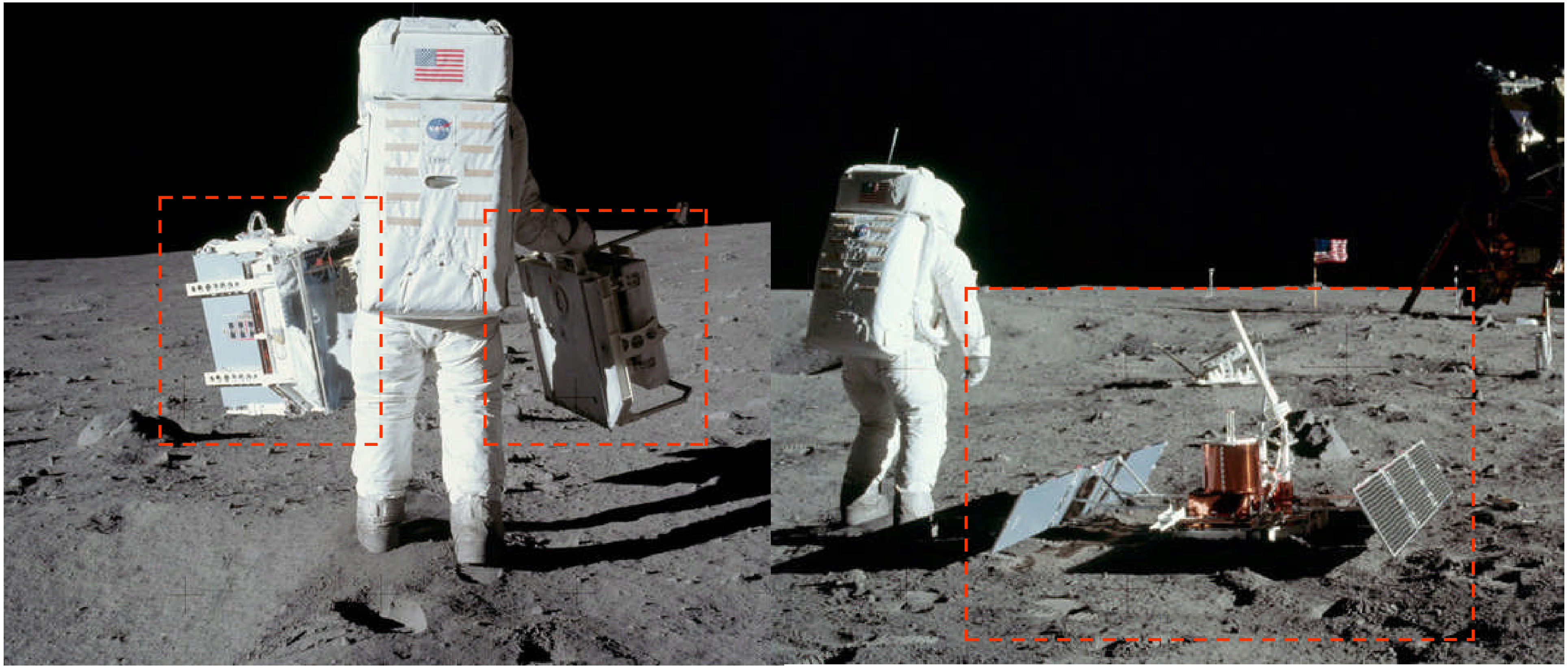

CENTRAL STATION
THERMAL GENERATOR
PASSIVE SEISMOMETER
MAGNETOMETER
SOLAR WIND SPECTROMETER
SUPRATHERMAL ION DETECTOR
HEAT FLOW EXPERIMENT
S
E
W
N

The ALSEP program began on March 31st 1963 with a series of meetings between NASA, *Jet Propulsion Laboratory* (JPL) and the *Goddard Space Flight Center* (GSFC). The first choice of experiments was proposed in December 1963 and consideration was given to those experiments that promised maximum return for least weight and complexity. Suggested experiments were active and passive seismic devices, instruments to measure the surface bearing strength, magnetic field, radiation spectrum, soil density and gravitational field. Due to *Apollo 11* being more of a test flight than a scientific mission, a simplified package was chosen. The EASEP was approved to be supplied by *Bendix Systems Division, Bendix Corporation,* on November 5th 1966 for Apollo 11. EASEP consisted of only two experiments:

1. ***Passive Seismic Experiment Package* (PSEP, Exp. S-031)**
2. ***Lunar Dust Detector* (LDD, Exp. M-515). This experiment measured the amount of dust accumulating on the lunar surface. It also measured the damage to solar cells by high-energy radiation as well as the reflected infrared energy and temperatures of the lunar surface. It consisted of three photocells mounted on the EASEP.**

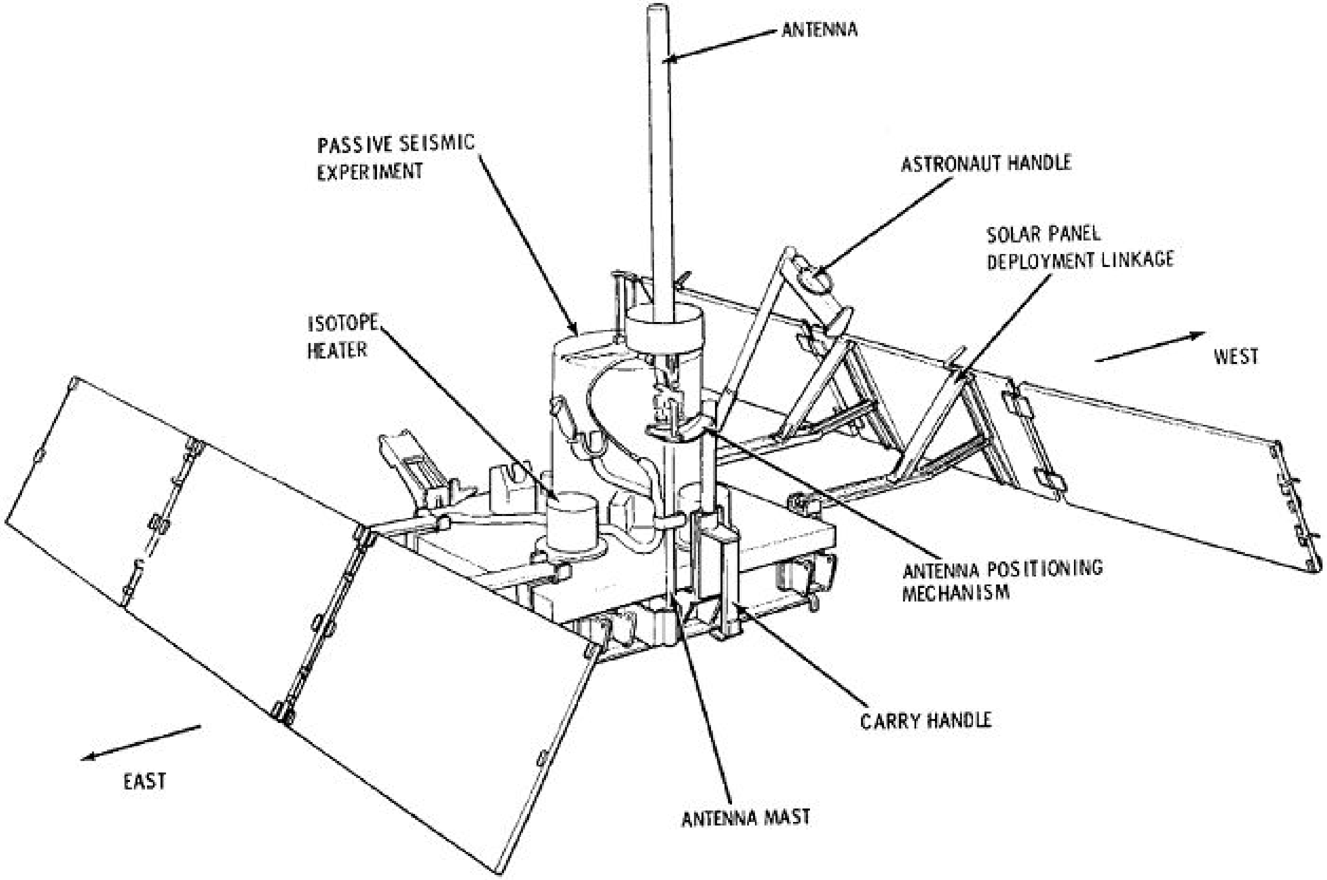
PSEP

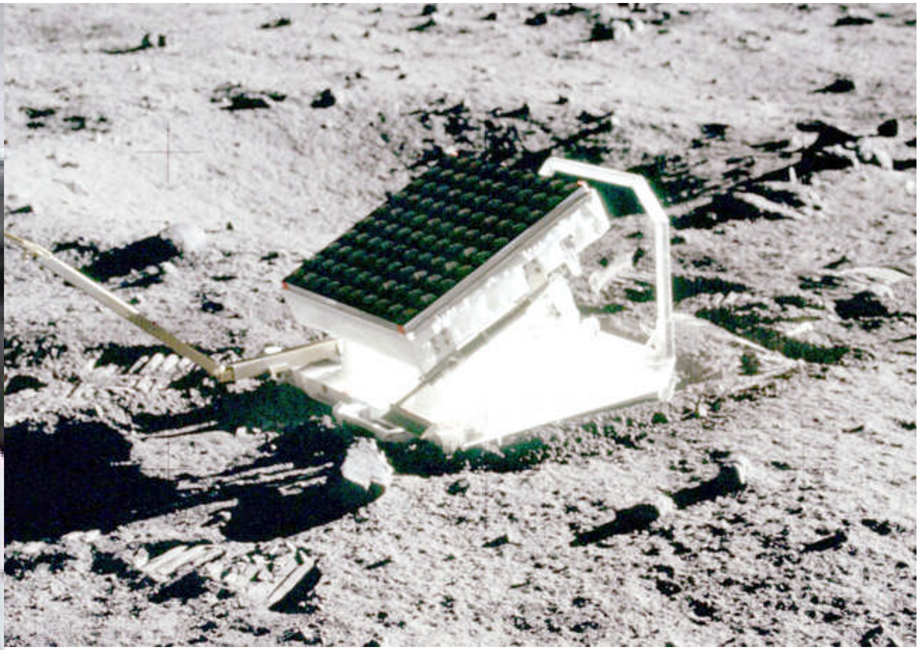
PSEP contained four seismometers powered by two panels of solar cells, which converted solar energy into electricity. It used three long-period seismometers and one short- period vertical seismometer for measuring meteorite impacts and moonquakes, recording about 100 to 200 hits by meteorites during its lifetime (the EASEP station, located 20-meters south of the *Lunar Module* was turned on July 21st 1969 and failed on August 27th 1969, 31 days beyond its designed lifetime). Data regarding the strength, duration and approximate direction of the seismic event were relayed to tracking stations on Earth. Because it was only powered by solar cells, the experiment only operated during the lunar days. During the 340 hour lunar night, when temperatures can plummet to minus 170-degrees Celsius, the instrument was kept to a minimum of minus 54-degrees C by a radioisotope heater; the first major use of nuclear energy in a NASA manned mission. Any temperature below this could damage the instrument. At the other end of the scale, NASA scientists tried controlling the daytime heat on the electronic components by a series of power "dumps" (cutting-off the systems electrical power). Then, just before the lunar night began, the seismometer automatically shifted into stand-by mode, stopping transmission of all data.



Left: caption: “Buzz Aldrin carries the laser reflector in his right hand and the seismometer in his left”

Right: caption: “Buzz with the seismic experiment. Solar panels have deployed on the left and right and the antenna is pointed at Earth. The laser reflector is beyond the antenna and, in the distance, the TV camera is silhouetted against the black sky. The stereo close-up camera is near the right-hand edge of this detail.”

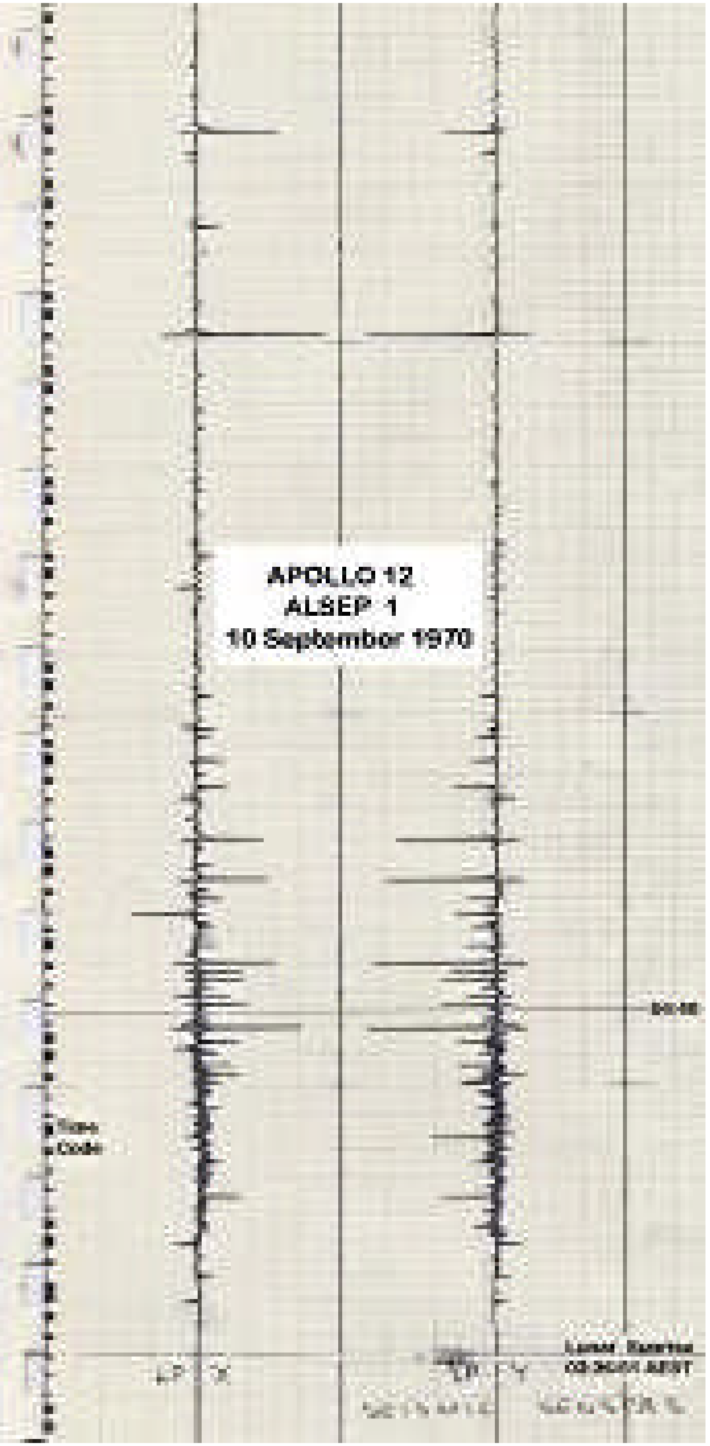

ANTENNA
PASSIVE SEISMIC EXPERIMENT
ASTRONAUT HANDLE
SOLAR PANEL DEPLOYMENT LINKAGE
ISOTOPE HEATER
WEST
ANTENNA POSITIONING MECHANISM
CARRY HANDLE
EAST
ANTENNA MAST



Above: caption: “Enhanced detail of the Laser Ranging Retro-Reflector (LRRR)”

Left: caption: “Dr. Garry Latham (left), from the Lamont Geological Observatory, studies seismometer tracings in the Mission Control Center’s ALSEP control room shortly after Buzz Aldrin deployed the instrument on the Moon. The instrument was sensitive enough to detect the astronaut’s footfalls as they walked around the site.”

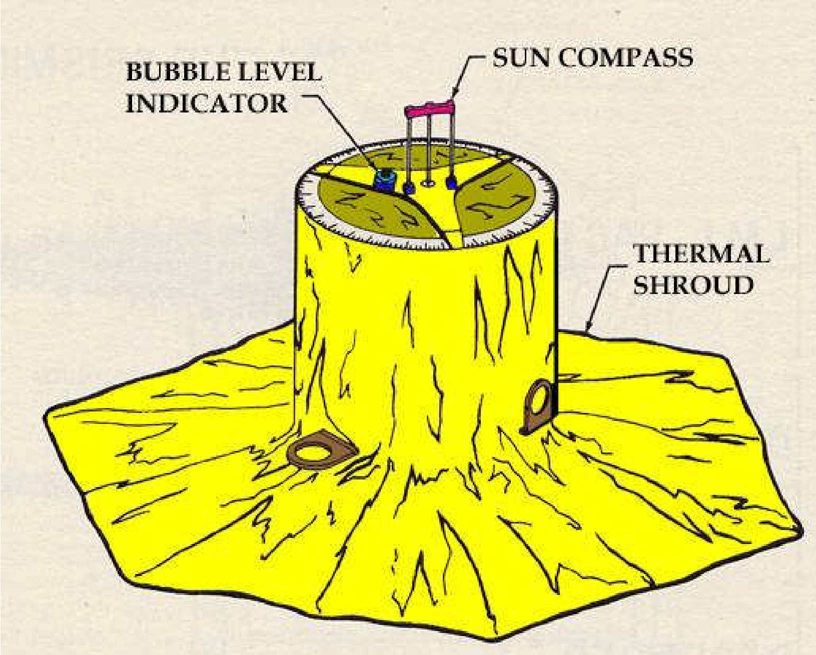
LPSE

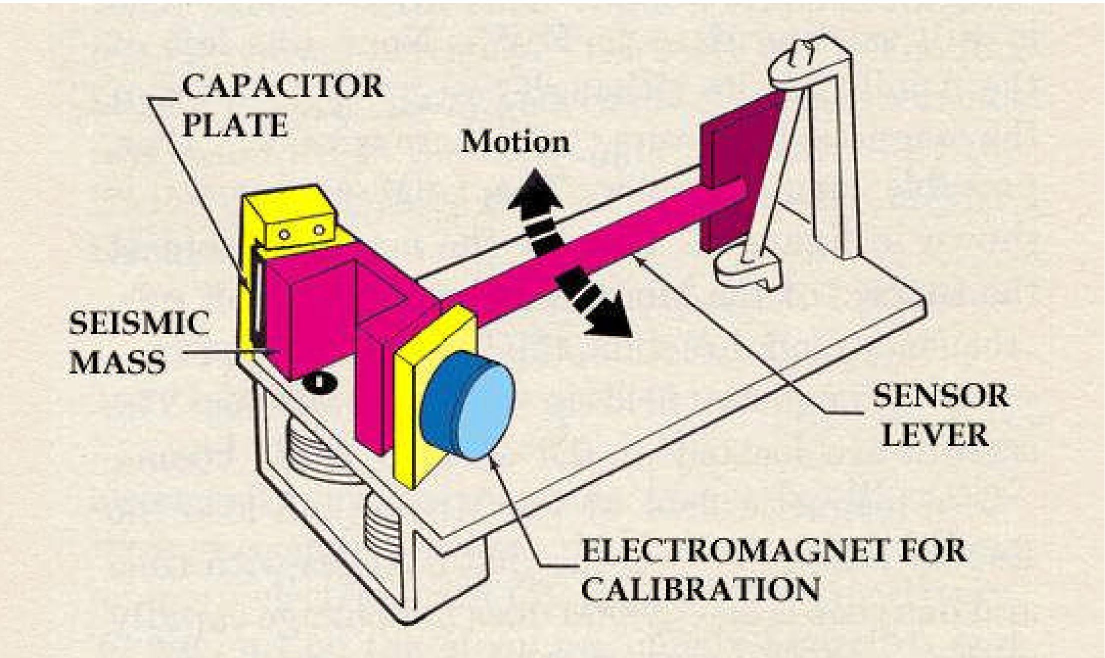


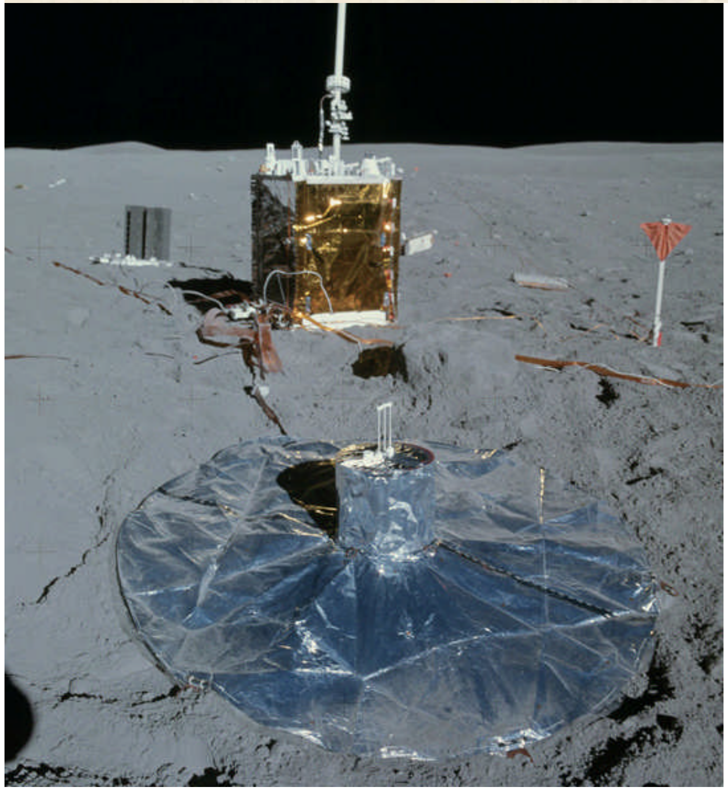
To determine sub-surface properties and measure extremely small vibrations of the lunar surface caused by distant moonquakes, man-made explosions and spacecraft impacts, *Apollo 12, 14, 15* and *16* conducted the (*Lunar Passive Seismic Experiment* (LPSE). When the instrument vibrated in response to movement of the ground surface, the inertia of the central lever and the mass on the end caused it to vibrate in sympathy, which was detected electronically by the capacitor effect of the mass on the end of the lever. An internal set of motors kept the seismometers constantly level within a few seconds of arc. Seismic motions were recorded on Earth with a magnification factor of 10 million. The network of four instruments deployed during these Apollo missions enabled seismologists to locate moonquakes in three dimensions and to study the seismic velocities and propagation characteristics of the lunar subsurface materials. The LPSE measured daily meteorite impacts and an average of two moonquakes per month (up to depths of 800 km).

Left: caption: “Plot of seismic activity generated by heating of the lunar surface at sunrise”

Seismic events on Earth exceed one million per year. On the Moon, there may be up to 300 (but much smaller in magnitude than those on Earth). It was noted that there was increased activity when the Moon was farthest from, and nearest to, the Earth. Signals generated by heating at sunrise on the Moon's surface was recorded by ALSEP each lunar day. The LPSE studied the propagation of seismic waves through the Moon and provided a detailed examination of the Moon's internal structure. The *Apollo 11* seismometer returned data for just three weeks but provided a useful first look at lunar seismology. More advanced seismometers were deployed at the *Apollo 12, 14, 15* and *16* landing sites, transmitting data to Earth until September 1977. Each of these seismometers measured all three components of ground displacement (up-down, north-south and east-west).







Top Left: caption: “Labeled Sketch of the PSE”

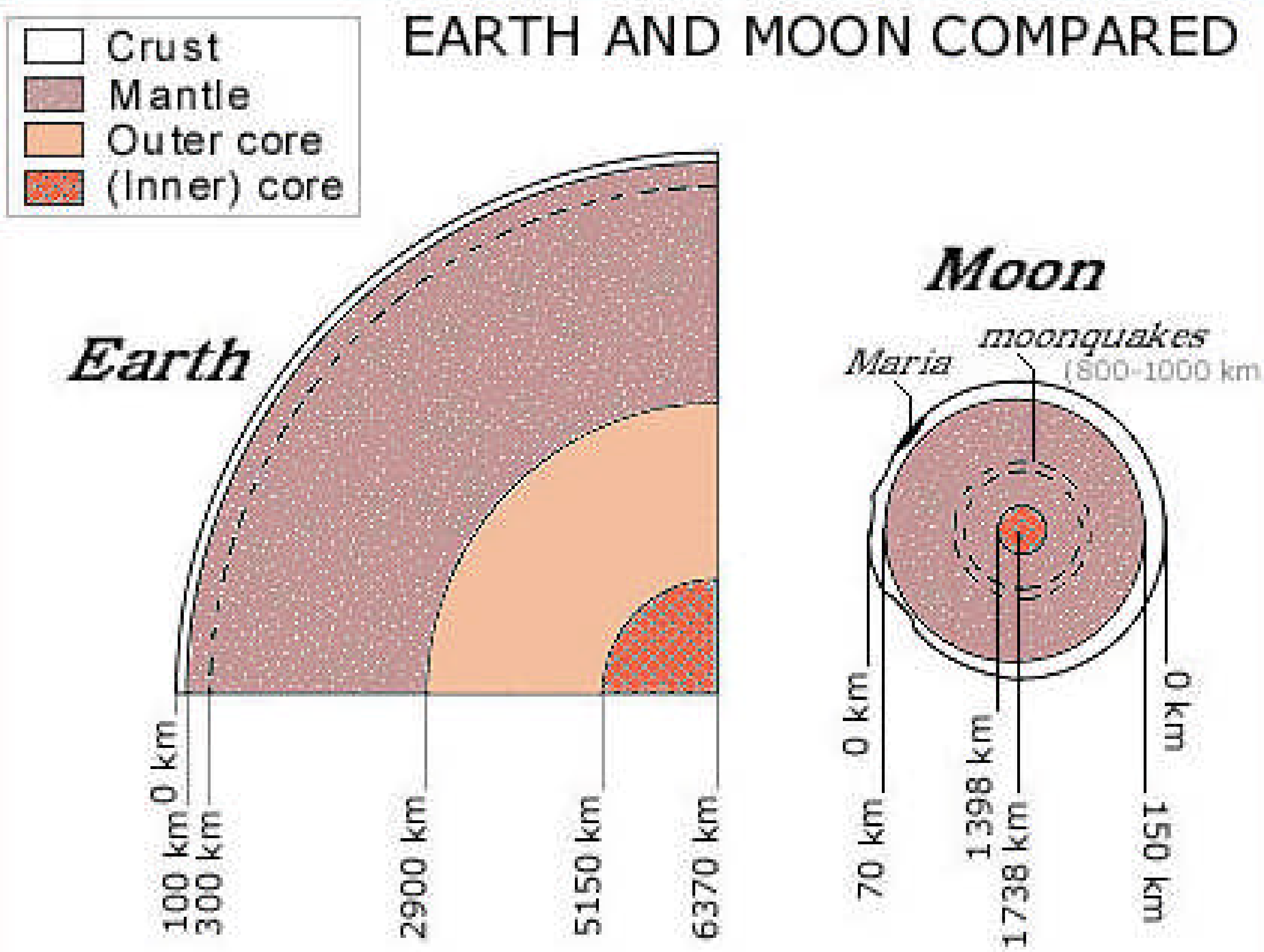
Top Right: caption: “Detail of the PSE lever for sensing surface vibrations”

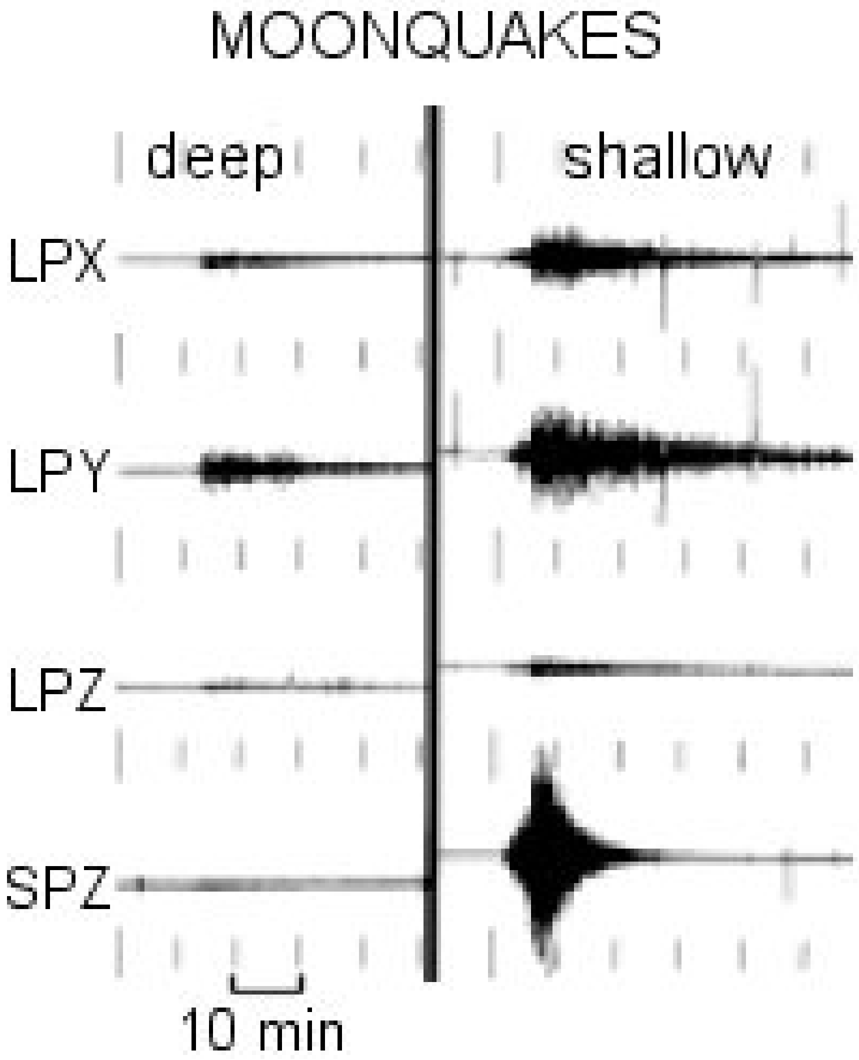
Left: caption: “The Apollo 16 PSE is in the foreground, surrounded by its reflective thermal skirt. An orange-topped anchor for the Active Seismic Experiment geophone line is on the right, near the Central Station.”

If a seismic event is observed by three or more seismometers separated by distance, the time and location of the event can be determined. Because seismic waves from distant events travel deeper into the Moon than waves from nearby events, by measuring events at various distances from the seismometer, seismologists could determine how seismic velocities vary with depth in the Moon. In turn, this information could be used to study the Moon's internal structure. Most of the events observed by the seismometers were due either to moonquakes or to meteoroid impacts. However, the third stages of several *Saturn 5* rockets and the ascent stages of several lunar modules were deliberately crashed onto the Moon after they were discarded. These man-made crashes produced seismic events of known times and locations and helped to calibrate the network of seismometers.

The LPSE produced several important scientific results:

- **Knowledge of Lunar Interior Structure**. Like the Earth, the Moon has a crust, mantle and core. The lunar crust is rich in the mineral plagioclase and has an average crustal thickness of 50 km. The lunar mantle lies between the crust and the core and consists mostly of the minerals olivine and pyroxene. The core is probably composed mostly of iron and sulphur and extends from the center of the Moon out to a radius of no more than 450 km (i.e. the core radius is less than 25% of the Moon's radius, which is quite small). In comparison, the Earth's core radius is 54% of the Earth's radius.
- **Distribution of Lunar Seismic Sources**. More than 1,700 meteoroid impacts were recorded by the seismometer network, with impactor masses estimated to be between 0.5 and 5K kilograms. Most moonquakes occur at depths of 800 to 1K km. These occur at monthly intervals at about 100 distinct sites, indicating that these moonquakes are caused by stresses from changes in lunar tides as the Moon orbits the Earth. These moonquakes are quite small, mostly with Richter scale magnitudes < 2. The amount of energy released by earthquakes in a typical year is about 10 million times larger than that released by moonquakes in a year. Only a few near-surface moonquakes were detected.
- **Attenuation of Seismic Waves**. Meteoroid impacts cause heavy fracturing in the upper 20 km of the lunar crust. These fractures in turn cause scattering of seismic waves in these regions. Below 20 km, seismic wave scattering decreases as a result of either closure of these fractures due to increasing pressure or of a change in chemical composition of the crust. In the mantle, seismic waves are attenuated much less on the Moon than they are on Earth. Seismic wave attenuation is enhanced at high temperatures and in the presence of water and the low attenuation on the Moon indicates a cold, dry interior. Because the Moon is smaller than Earth, it is expected to have cooled more rapidly, producing a cold interior. The total absence of water on the Moon is due to its formation from dry volatile-depleted material, a consequence of the impact of a Mars-sized body with the Earth. Below 1K km depth, seismic wave attenuation increases, possibly indicating the presence of a small amount of molten rock.


EARTH AND MOON COMPARED
Crust
Mantle
Outer core
(Inner) core
Earth
Moon
Maria
moonquakes
(800-1000 km
0 km
100 km
300 km
2900 km
5150 km
6370 km
0 km
70 km
1398 km
1738 km
150 km
0 km



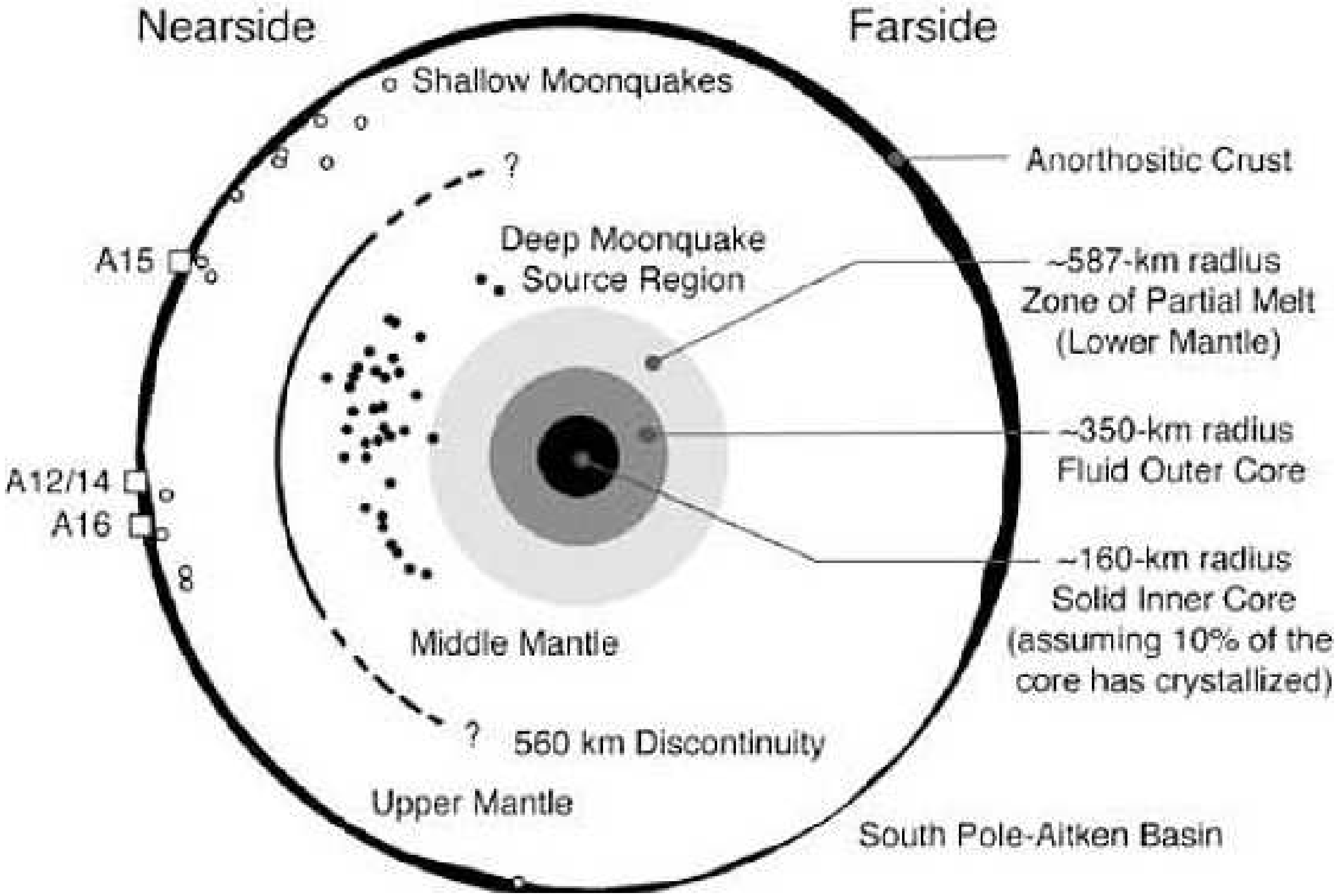
Scientists hoped that moonquakes and meteorite impacts would answer two fundamental questions:

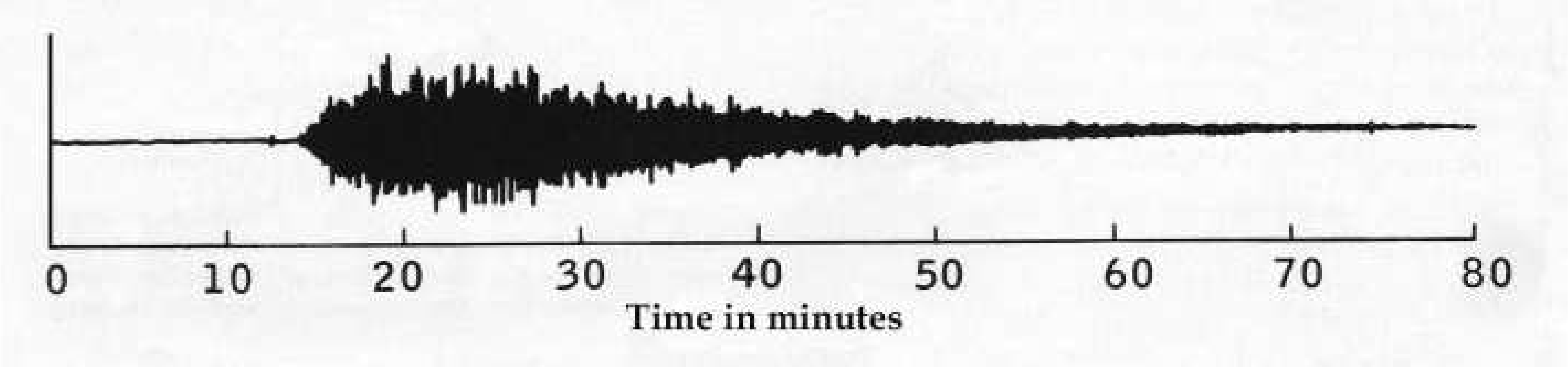
- **Does the Moon have a molten core? and;**
- **What is the deep interior of the Moon like?**

To answer these questions they needed at least one impact event of at least 1019 ergs on the far side of the Moon. On May 13th 1972, a near-side event with an energy of 1,100 kilograms was recorded. On September 19th 1973, a large back-side event with an energy of 1018 ergs took place. On July 17th 1972, only three months after it was set up, Apollo 16's seismometer registered the largest impact ever recorded on the moon when a meteorite hit the far side of the moon near *Mare Moscoviense*. Over the eight years of the ALSEP's lives, around 10K moon-quakes and 2K meteorite impacts were registered by the seismometers.

Left: caption: "Lunar seismograms from the Apollo 16 station"

The seismic information, magnetometer and heat flow experiments contributed the principal information about the Moon’s interior. It is now believed the Moon’s crust is multi-layered and 50 km thick, with a secondary boundary occurring about 20 km under the surface. The upper mantle has been determined to consist of olivine or olivine-pyroxene matter and to be quite homogeneous, extending about 500 km down. Below this level, the seismic data infers the interior is iron-enriched, although there is insufficient data to determine if the Moon has a molten core. Moonquakes were discovered to show periodicity and recur at several places in the interior. The time cycle of the deep focus moonquakes follows the tidal cycles so closely it appears likely that tidal forces are a major factor in triggering deep focus moonquakes.


Nearside
Farside
Shallow Moonquakes
Anorthositic Crust
?
Deep Moonquake
Source Region
A15
~587-km radius
Zone of Partial Melt
(Lower Mantle)
~350-km radius
Fluid Outer Core
A12/14
A16
~160-km radius
Solid Inner Core
(assuming 10% of the
core has crystallized)
Middle Mantle
?
560 km Discontinuity
Upper Mantle
South Pole-Aitken Basin



"As for the meaning of it, I'd rather not make an interpretation right now. But it is as though one had struck a bell, say, in the belfry of a church a single blow and found that the reverberation from it continued for 30 minutes."
***Maurice Ewing*, PSE Experiment Director (the reverberations continued for another 25 min.)**
RE: the first man-made crash directed at the Moon that could be detected by a seismometer occurred after the *Apollo 12* astronauts had returned to the CSM and the *Lunar Module* ascent stage was sent smashing into the Moon's surface. When the LM hit the lunar surface at 6,048 kilometers per hour (72 km from the landing site, digging an estimated 9-meter wide crater), the results were astonishing. All three seismometers in the package recorded the impact. The shock waves of this impact surprised the NASA/JPL scientists; the Moon vibrated for over 55 minutes. Also, the kinds of signals recorded by the seismometers were entirely different from any ever received before, starting with small waves, gaining in size to a peak and then lasting for lengthy periods of time. A seismic wave took 7 to 8 minutes to reach the peak of impact energy and then gradually decreased in amplitude over a period that lasted almost an hour. It was claimed that even after an hour, the minutest reverberations had still not stopped. Nothing like this had ever been measured on Earth.

<u>Above</u>: caption: "LM impact occurred at 1617 USCST November 20, 1969 – impact measured at the Apollo 12 seismometer"

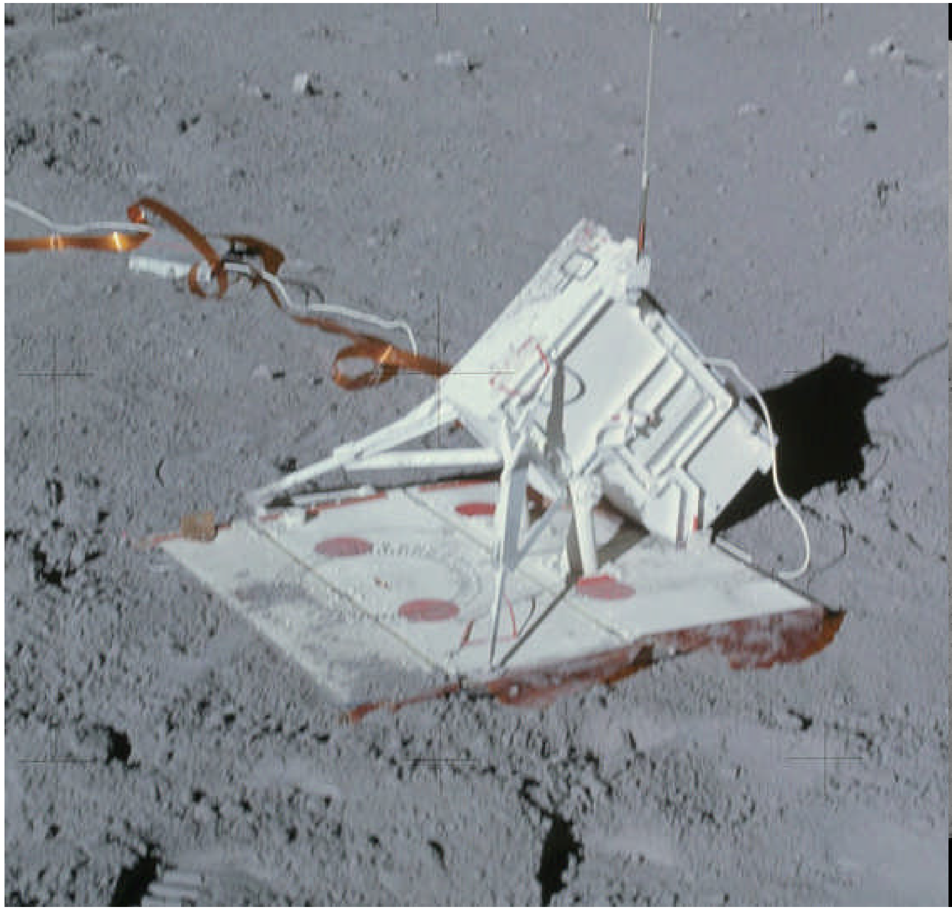
“This was one of those extraordinary things. When you had the impact of these things on the Moon, unlike a terrestrial earthquake, which dies away quickly, the shock waves continued to reverberate around the Moon for a period of an hour or more, and this is attributed to the extremely dry nature of the lunar rock. As far as we know there is no moisture on the Moon, nothing to damp out these vibrations. The Moon’s surface is covered with rubble and this just transmits these waves without them being damped out in any way as they are on Earth. Basically, it’s a consequence of the Moon being extremely dry.”

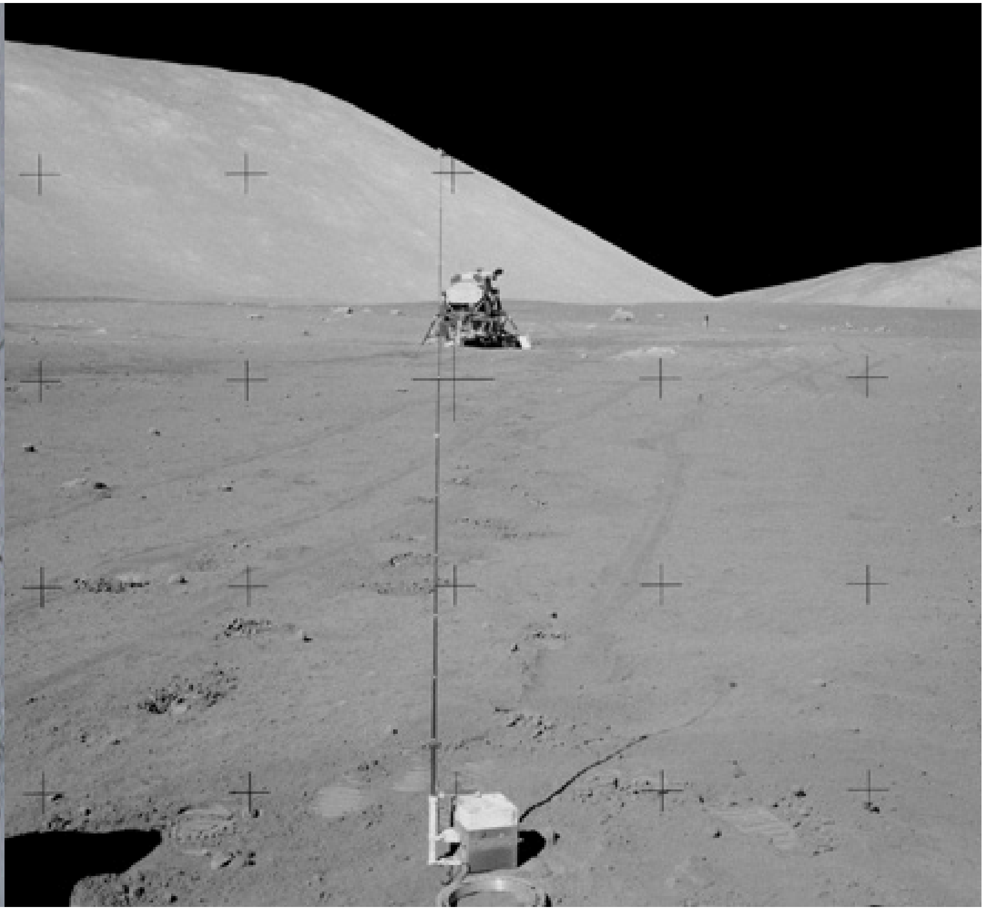
***Dr. Ross Taylor*, Lunar Scientist**

LASE

The *Lunar Active Seismic Experiment* (LASE) conducted by *Apollo 14* and *16* was complementary to the LPSE in two ways; scale and source of energy. The LPSE was designed to study the whole Moon while the LASE studied the local area. Rather than wait passively for natural events to occur on the Moon to produce shock waves, the LASE provided its own sources. The shock waves were produced by explosions on the lunar surface. Two different kinds were used; small ones (made while the astronauts were on the surface) and large ones (after they left the site and returned to the Earth). The different kinds of sources for the LASE were a "thumper" and a "mortar." The thumper was used by the astronaut to explode "shotgun-like" charges. The thumper contained nineteen such charges. It was fired at evenly spaced intervals along the geophone line. The results from this part of the experiment were available while the astronauts were still on the surface of the Moon.

The second kind of charge was similar to that of a mortar. In fact, the unit that fired these charges was referred to as a mortar package assembly. It contained four grenades that were launched using self-contained rockets sometime after the astronauts had left the Moon. The astronauts aligned the mortar launcher and armed it for firing. This unit contained geophones for measuring the velocity of each grenade on launch and the exact time of launch. Each grenade contained a rocket motor, a high explosive charge, provisions for igniting the rocket and a device to detonate the charge, a battery, a transmitter that provided information as to the length of time of the flight and the moment of impact on the Moon and a thread with which to measure the distance of the impact from the launcher. Because there is no atmosphere on the Moon, the thin thread trailing the grenade remained taut and measured accurately the horizontal distance from the point of launch to the point of impact. They had been designed to impact the Moon at distances of 137, 282, 853 and 1372-meters from the launcher. The size of the explosive charge increased with distance. Any layering in the Moon that is present in the first 300-meters beneath the surface would be seen via the LASE.



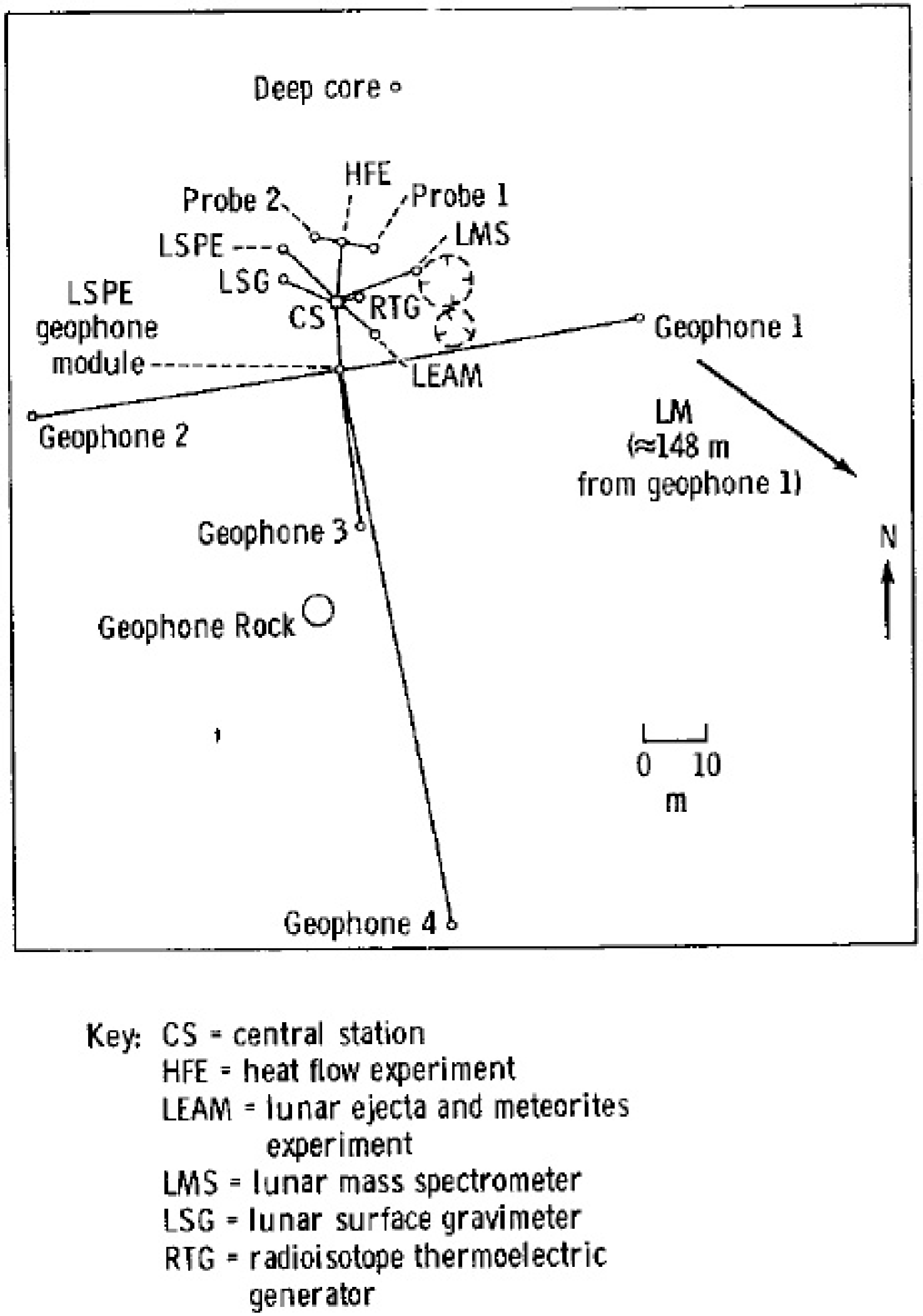


<u>Left</u>: caption: “This detail from AS16-113-18378 shows the Apollo 16 mortar package mounted on its base. The ribbon cable running off to the left connects the experiment to the Central Station. The mast sticking upwards has a red-warning flag at the top so that the crew could stay well clear when driving the Rover.”

<u>Right</u>: caption: “This detail from AS17-143-21936 shows Apollo 17 Seismic Charge No. 3, which Gene Cernan deployed 110 meters WNW of the LM late in EVA-3. The charge antenna received a command, sent from Earth through the ALSEP Central Station, to detonate the 57-gram charge at 0307 GMT on 18 December 1972, at which time the crew was about halfway back to Earth. The aluminum ring next to the charge marks the end of the west arm of the SEP transmitter array and is 35 meters west of the SEP transmitter.”

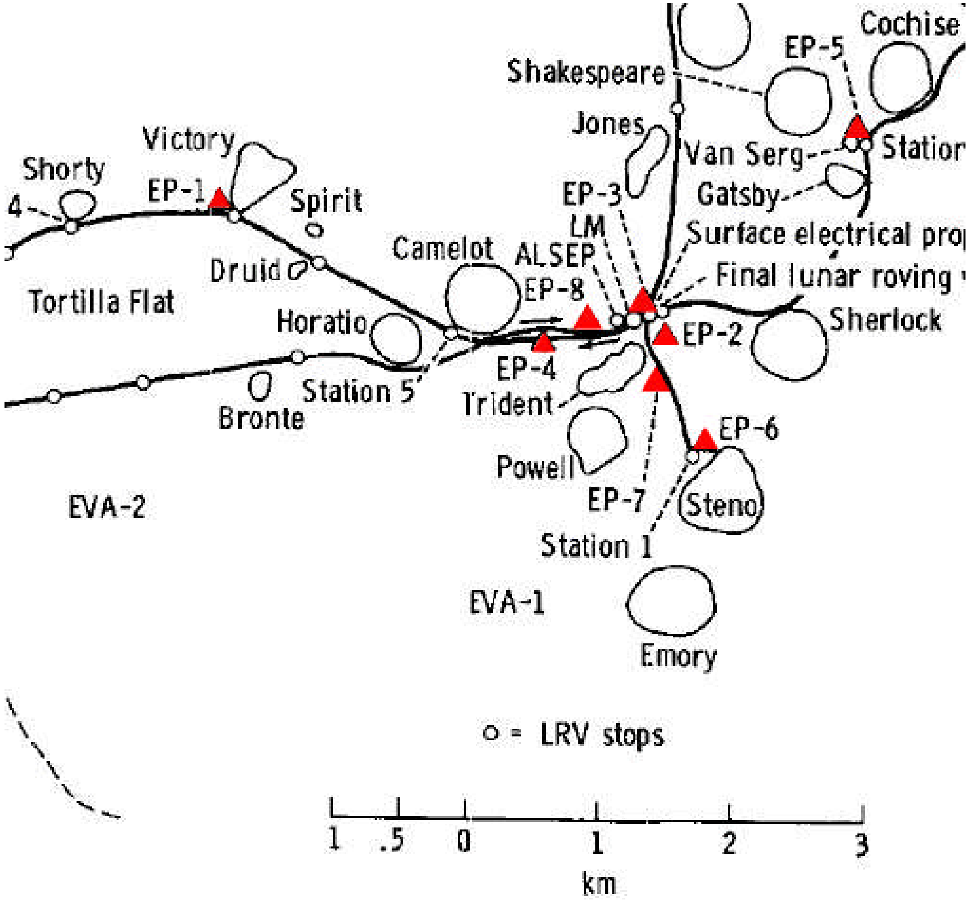
LSPE

Two experiments, the LASE on *Apollo 14* and *16* and the ***L**unar **S**eismic **P**rofiling **E**xperiment* (LSPE) on *Apollo 17*, were performed to determine the detailed structure of the upper kilometer of the lunar crust. Both experiments involved detonation of a series of small explosives. The seismic waves, or ground vibrations, caused by these explosions were measured by a network of geo-phones (a type of electronic stethoscope). On Apollo 14 and 16, up to nineteen small explosions were detonated by an astronaut using a thumper along a 90-meter-long geophone line. On Apollo 16, three mortar shells were also used to lob explosive charges to distances of up to 1,300-meters from the ALSEP. Both the Apollo 16 mortar shells and the Apollo 17 explosives were detonated by radio control after the astronauts left the lunar surface. These experiments showed that the lunar seismic velocity is between 0.1 and 0.3 kilometers per second (kps) in the upper few hundred meters of the crust at all three landing sites, which agreed closely with the passive data. These velocities are much lower than observed for intact rock on Earth but are consistent with a highly fractured or brecciated material produced by the prolonged meteoritic bombardment of the Moon. At the Apollo 14 site, there was a regolith surface layer of 8.5-meters. At the Apollo 17 landing site, the surface basalt layer was determined to have a thickness of 1.4 km, slightly higher than the 1 km thickness determined from the ***P**ortable **T**raverse **G**ravimeter **E**xperiment* (PTGE) which measured variations of the gravitational acceleration resulting from sub-surface structure at the *Taurus-Littrow* landing site of Apollo 17.



This LSPE was similar in principle to the previous ALSEP seismometers, but very different in design. It consisted of a seismic data gathering network of four geophones, placed in the center and at each corner of a 90-meter equilateral triangle. Explosive charges on the surface generated seismic waves of varying strengths to provide a structural profile of the *Apollo 17* site. The triangular arrangement of the geophones allowed measurement of the azimuths and velocities of the seismic waves more accurately than the LASE on *Apollo 14* and *16*.

<u>Left</u>: caption: “Layout of the LSPE geophones and other elements of the ALSEP”



A location for the *Central Station* that would satisfy various constraints for the other experiments was selected. Then, the geophone layout was modified to avoid the 3-meter-tall boulder now known as "Geophone Rock." To profile the site terrain, eight explosive charges were positioned during Apollo 17's three EVAs. After the charges were detonated by ground command, the experiment became a *Passive Seismometer*.

<u>Above</u>: caption: "A colored detail from the Apollo 17 Preliminary Science Report shows the locations where the charges were deployed"

Top Ten

The ALSEP program cost NASA an estimated $200 million, including the design and development of the stations and experiments, support engineering work in Houston and the analysis of the data by dozens of University laboratories around the world (it cost NASA $2 million per year to operate). The top-ten scientific discoveries made during the Apollo mission's exploration of the moon include:

1. The Moon is not a primordial object; it is an evolved terrestrial planet with internal zoning similar to that of Earth;

2. The Moon is ancient and still preserves an early history (the first billion years) that must be common to all terrestrial planets;

3. The youngest Moon rocks are virtually as old as the oldest Earth rocks. The earliest processes and events that probably affected both planetary bodies can now only be found on the Moon;

4. The Moon and Earth are genetically related and formed from different proportions of a common reservoir of materials;

5. The Moon is lifeless; it contains no living organisms, fossils or native organic compounds;

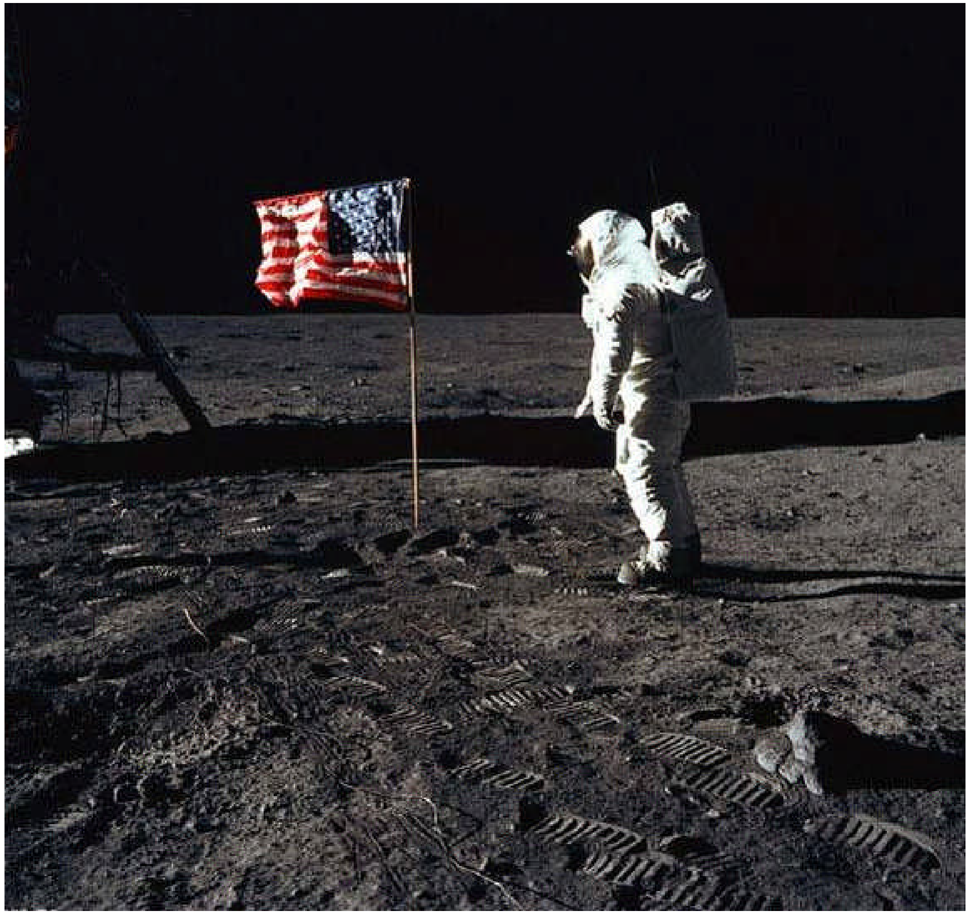
6. All Moon rocks originated through high-temperature processes with little or no involvement with water. They are roughly divisible into three types: basalts, anorthosites and breccias;

7. Early in its history, the Moon was melted to great depths to form a “magma ocean.” The lunar highlands contain the remnants of early, low-density rocks that floated to the surface of the magma ocean;

8. The lunar magma ocean was followed by a series of huge asteroid impacts that created basins that were later filled by lava flows;

9. The Moon is slightly asymmetrical in bulk form, possibly as a consequence of its evolution under Earth's gravitational influence. Its crust is thicker on the far side, while most volcanic basins - and unusual mass concentrations - occur on the nearside, and;

10. The surface of the Moon is covered by a rubble pile of rock fragments and dust, called the lunar regolith, that contains a unique radiation history of the Sun that is of importance to understanding climate changes on Earth.



We Ain’t Fakin’

"…Come over baby

whole lot of shakin' goin' on

Yes, I said come over baby

baby you can't go wrong

We ain't fakin'

Whole lot of shakin' goin' on…"
RE: excerpted lyrics from the song: "Whole Lotta Shakin' Goin' On," by *Jerry Lee Lewis*