PDHonline Course C668 (5 PDH)

Mighty Mac: Bridging the Mackinac Straits

Instructor: Jeffrey Syken

2020

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Mighty Mac
Bridging the Mackinac Straits

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Part 1

A State Divided

The Narrow Gate

"Enter through the narrow gate. For wide is the gate and broad is the road that leads to destruction, and many enter through it. But small is the gate and narrow the road that leads to life, and only few find it."
Matthew 7:13-14

The Great Turtle (?)

A FRENCH TRADER

"The Outavois (Ottawa) live at the post of Michilimakina…an island opposite gave it its name of Michilimakina, which means turtle, because it seems to have the shape of this animal, which is very common there."

Antoine-Dennis Raudot

RE: excerpt from his memoir (1710). He served as "Co-Intendant" of *New France* along with his father.

<u>Left</u>: 18th Century French fur trader

"…Again, most every historian, or annalist so-called, who writes about the Island of Mackinac and the Straits and vicinity, tells us that the definition or the meaning of the word 'Michilimackinac' in the Ottawa and Chippewa language, is 'Large Turtle,' derived from the word Mi-shi-mi-ki-nock in the Chippewa language. That is, 'Mi-she' as one of the adnominals or adjectives in the Ottawa and Chippewa languages, which would signify tremendous in size; and 'Mikinock' is the name of the mud turtle - meaning therefore, 'monsterous large turtle,' as the historians would have it. But we consider this to be a clear error. Wherever those annalists, or those who write about the Island of Mackinac, obtain their information as to the definition of the word Michilimackinac, I don't know, when our tradition is so direct and so clear with regard to the historical definition of that word, and is far from being derived from 'Michimikinock,' as the historians have told us. Our tradition says that when the Island was first discovered by the Ottawas, which was some time before America was known as an existing country by the white man, there was a small independent tribe, a remnant race of Indians who occupied the Island, who became confederated with the Ottawa when the Ottawas were living at Manitoulin, formerly called Ottawa Island, which is situated north of Lake Huron. The Ottawas thought a good deal of this unfortunate race of people, as they were a kind of interesting sort of people; but , unfortunately, they had become most powerful enemies, who every now and then would come among them to make war with them. Their enemies were the Iroquois of New York. Therefore, once in the dead of the winter while the Ottawas were having a great jubilee and war dances at their island, now Manitoulin, on account of the great conquest over the We-ne-be-goes of Wisconsin…during which time the Senecas of New York, of the Iroquois family of Indians, came upon the remnant race and fought them, and almost entirely annihilated them. But two escaped to tell the story, who effected their escape by flight and by hiding in one of the natural caves at the island, and therefore that was the end of this race. And according to our understanding and traditions the tribal name of those disastrous people was 'Mi-shi-ne-macki-naw-go,' which is still existing to this day as monument to their former existence; for the Ottawas and the Chippewas named this little island 'Mi-shi-ne-macki-nong' for memorial sake of those former confederates, which word is the locative case of the Indian noun 'Michinemackinawgo.' Therefore we contend, this is properly where the name Michilimackinac originated…"

RE: excerpt from *History of the Ottawa and Chippewa Indians of Michigan* (1887). The term "Michilimackinac" is the modern accepted spelling and definition for an old *Michigan* native American term that is widely understood to mean "The Great Turtle," presumably named for the shape of Mackinac Island. The interpretation of the word is still debated by scholars.

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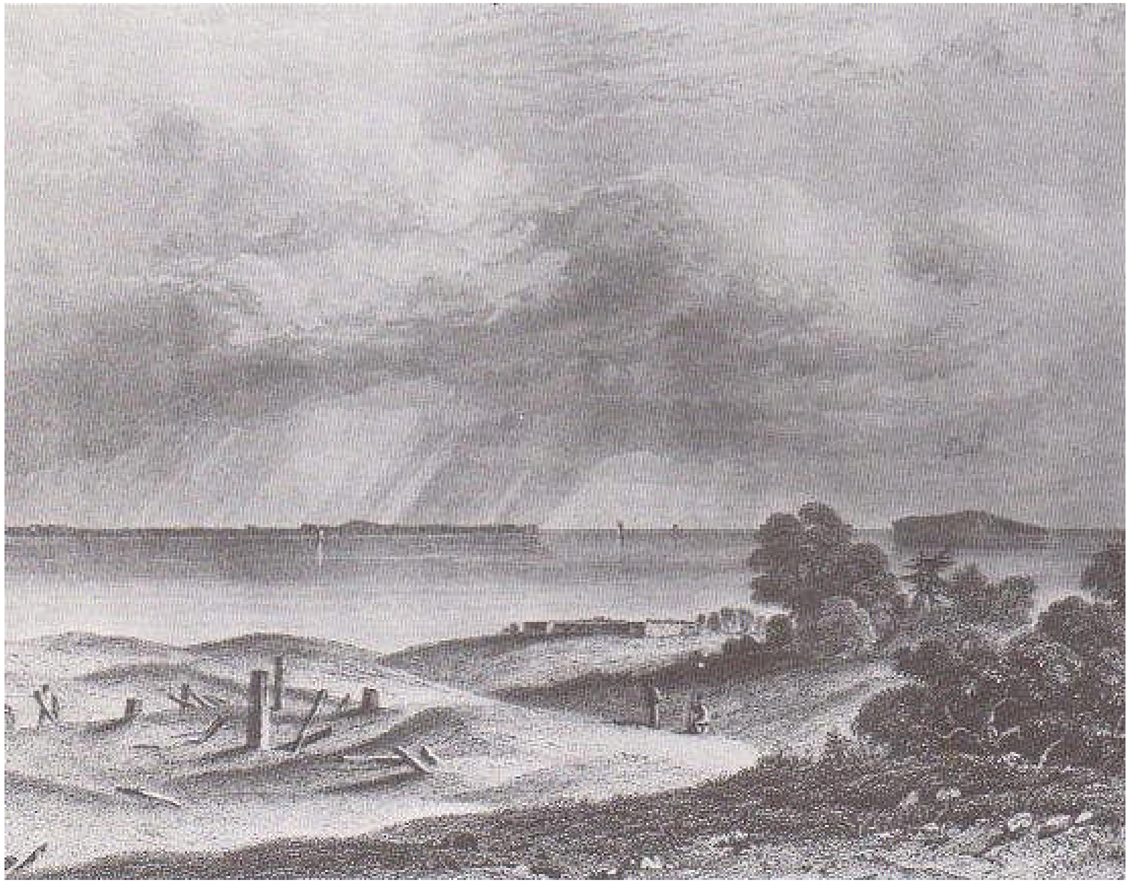
"Michilimackinac" typically refers to the area between Michigan's Upper and Lower Peninsula*/s*. The area consisting of present day *Straits of Mackinac*, *Emmet, Mackinac* and *Cheboygan Counties*, *Mackinac Bridge* and *Mackinac Island.* The French had first established a presence in the Straits of Mackinac in 1671 when *Father Marquette* established the Jesuit *St. Ignace Mission* at present-day *St. Ignace*. In 1683, they augmented the mission with *Fort de Buade*. In 1688 they established a mission at *Sault Ste. Marie*. In 1701, *Sieur de Cadillac* moved the French garrison to *Fort Detroit* and closed the mission. However, by 1715 the French built *Fort Michilimackinac* (above L&R) to re-establish a presence along the Straits of Mackinac. The primary purpose of the fort was not military. Rather, it served as a supply depot for traders in the western *Great Lakes* and as a link in the French trading post system that stretched from the *Mississippi River* through the *Illinois Country* to the *St. Lawrence River*. The French relinquished the fort along with their territory in *Canada* to the British in 1761 following their defeat in the *French and Indian War* (the British continued to operate the fort as a major trading post). Eventually, the British determined that the wooden fort on the mainland was too vulnerable to attack. Thus, in 1781 they built *Fort Mackinac*, a limestone fort on nearby Mackinac Island (the lieutenant governor of Michilimackinac, ordered the remains of Fort Michilimackinac destroyed after the move). The fort grounds were designated a *National Historic Landmark* in 1960 and It is a popular tourist attraction as part of *Colonial Michilimackinac State Park.* The fort grounds also contain the foot of the Mackinac Bridge, *Old Mackinac Point Light* (an 1892 lighthouse) and a day-use park with a view of the Mackinac Bridge and Mackinac Island.



<u>Left</u>: caption: "The ruins of Old Fort Mackinac as seen in 1820 by Captain Seth Eastman, U.S. Army. This fort stood on the south-side of the Straits near what is now the Mackinaw City end of the Mackinac Bridge. It was the scene of the massacre of most of the British garrison by the Indians in 1763. In 1781 the English established a new fort on Mackinac Island and the old fort deteriorated."

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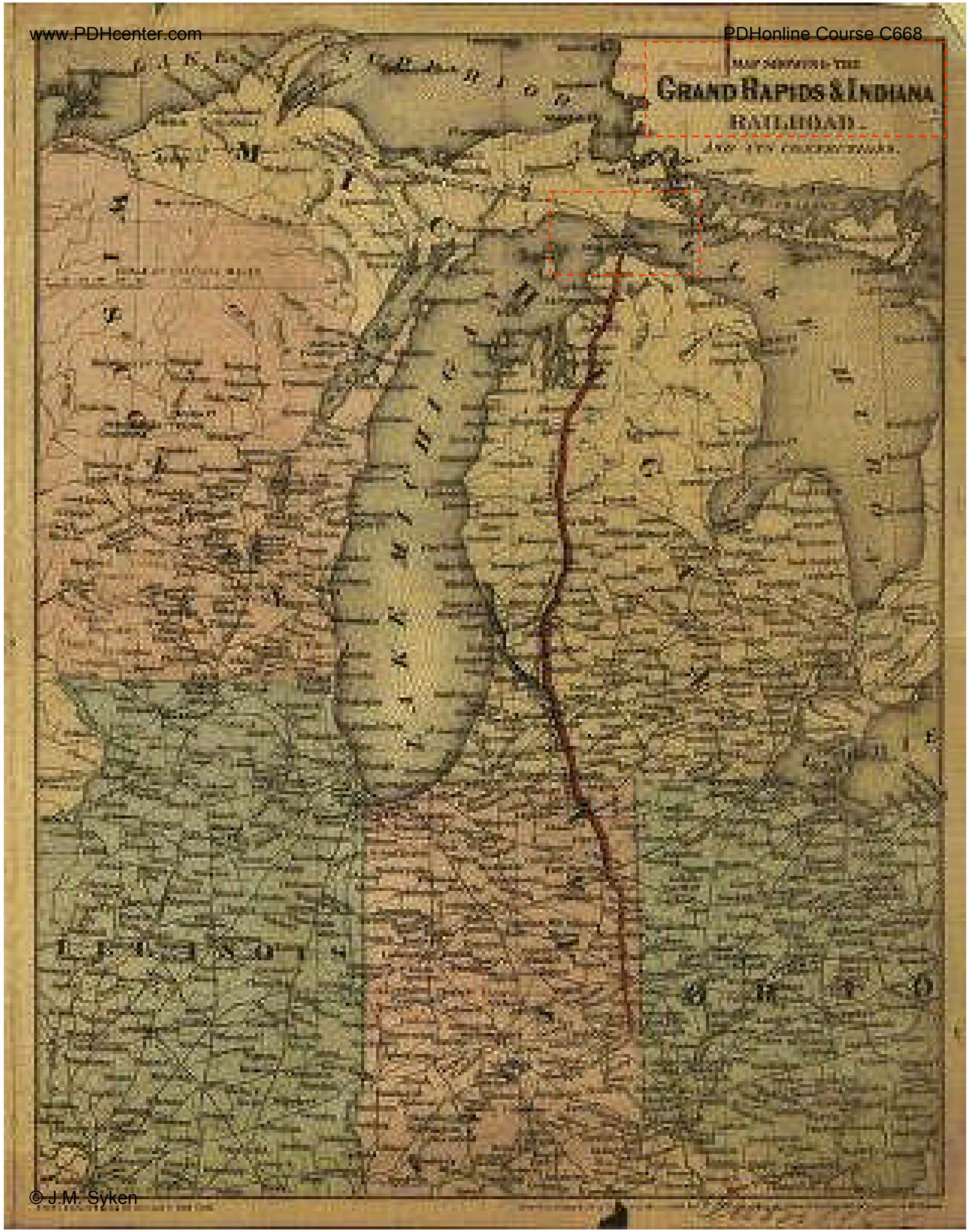
Two Peninsulas



__Left__: caption: "The Grand Rapids & Indiana RR was opened to Mackinaw City, Michigan and the Straits of Mackinac on July 3, 1882." The five-mile stretch of water separating Michigan's two peninsulas is the result of glacial action approximately twelve thousand years ago. It has long served as a major barrier to the movement of people and goods between the two opposing shores. Three railroads reached the *Straits of Mackinac* in the early 1880s; the *Michigan Central RR* and the *Grand Rapids & Indiana Railroad* from the south and the *Detroit, Mackinac & Marquette RR* from the north. In 1881, they jointly established the *Mackinac Transportation Company* to operate a railroad car ferry service across the Straits. The railroads and their shipping lines developed *Mackinac Island* into a major vacation destination in the 1880s.


2
31
St. Ignace
185
Mackinac Island
43
66
Pt. La Barbe
122
Straits
of
Mackinac
STATE FERRY
108
McGulpin Pt.
48
Mackinaw City
Cecil Bay
Cecil
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Carp L. 13
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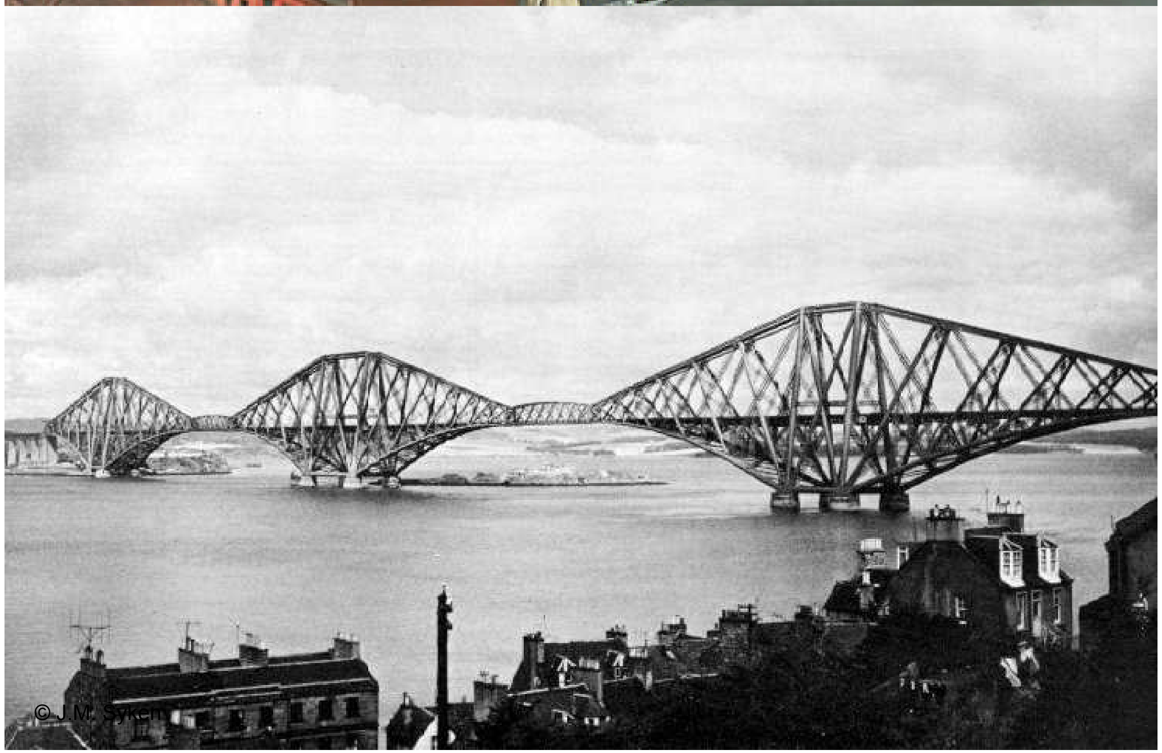

On February 5th 1884, the ***Lansing Republican*** reprinted a story from the ***Grand Traverse Herald*** pointing out that the experiment to provide all-year service across the Straits by boat was a failure and that if a great north-south route were ever to be established through ***Michigan,*** a bridge or tunnel would be required. The editor considered both as practicable, the only question in his mind was that of cost. The dedication of the ***Brooklyn Bridge*** (top) in 1883 gave ***Mackinac Bridge*** backers hope for a bridge across the straits. In 1884, ***William Saulson*** (a ***St. Ignace*** store owner) reprinted an artist's conception of the famous structure in his advertising and captioned it: "A Glimpse of the Future - Proposed Bridge Across the Straits of Mackinac." At the time, the great ***Firth of Forth RR Bridge*** (bottom) in ***Scotland*** was under construction. It was completed in 1890.

"We now have the largest, well-equipped hotel of its kind in the world for a short season business. Now what we need is a bridge across the Straits."
Cornelius Vanderbilt II

RE: excerpt from minutes of the first meeting of the Board of Directors of the famous *Grand Hotel* at *Mackinac Island* held held on July 1st 1888. *Cornelius Vanderbilt II* was the grandson of shipping and railroad magnate *Cornelius Vanderbilt*. In 1886, the *Grand Rapids & Indiana Railroad* (left) joined with the *Michigan Central Railroad* (which had built its own line into *Mackinaw City* in 1881) and the *Detroit and Cleveland Steamship Navigation Company* to form the *Mackinac Island Hotel Company*. This new company built the *Grand Hotel* (above) on Mackinac Island, which opened in 1887.

Left: caption: "Car ferry service began on July 31, 1923, with the little 'Ariel,' a river boat which had operated in the Detroit River between Walkerville, Ontario and Detroit. The Ariel, which accomm-odated only twenty cars, went out of service at the end of the 1923 season."

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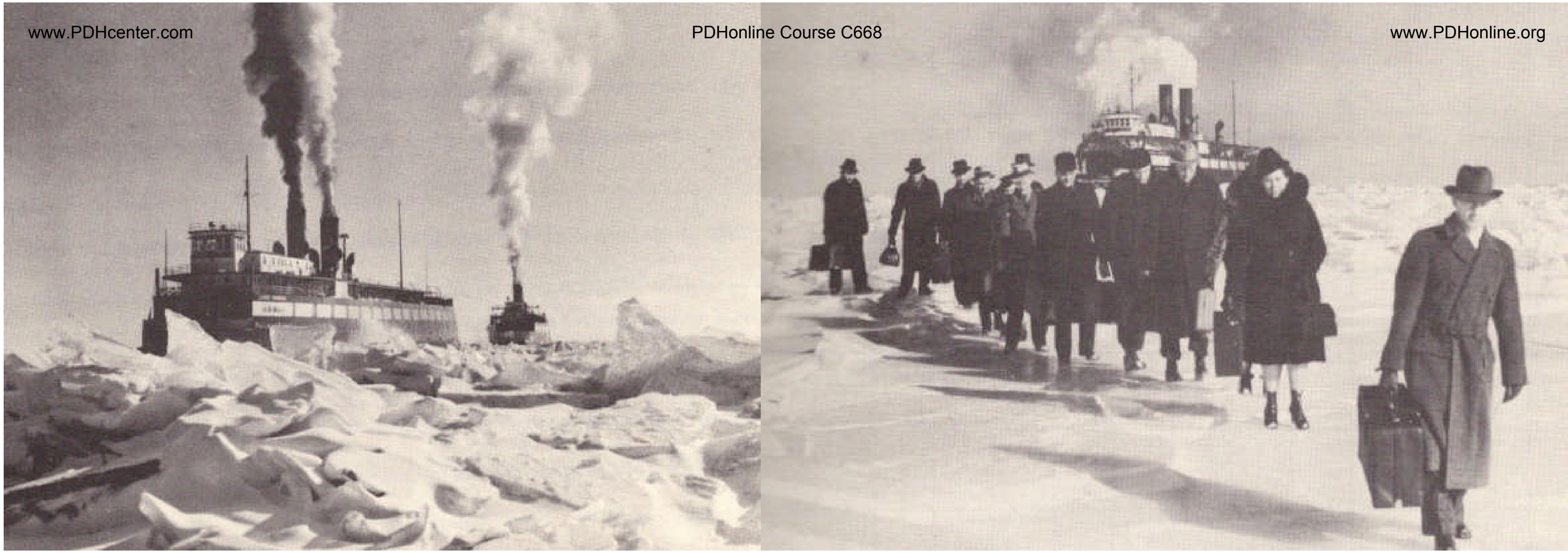
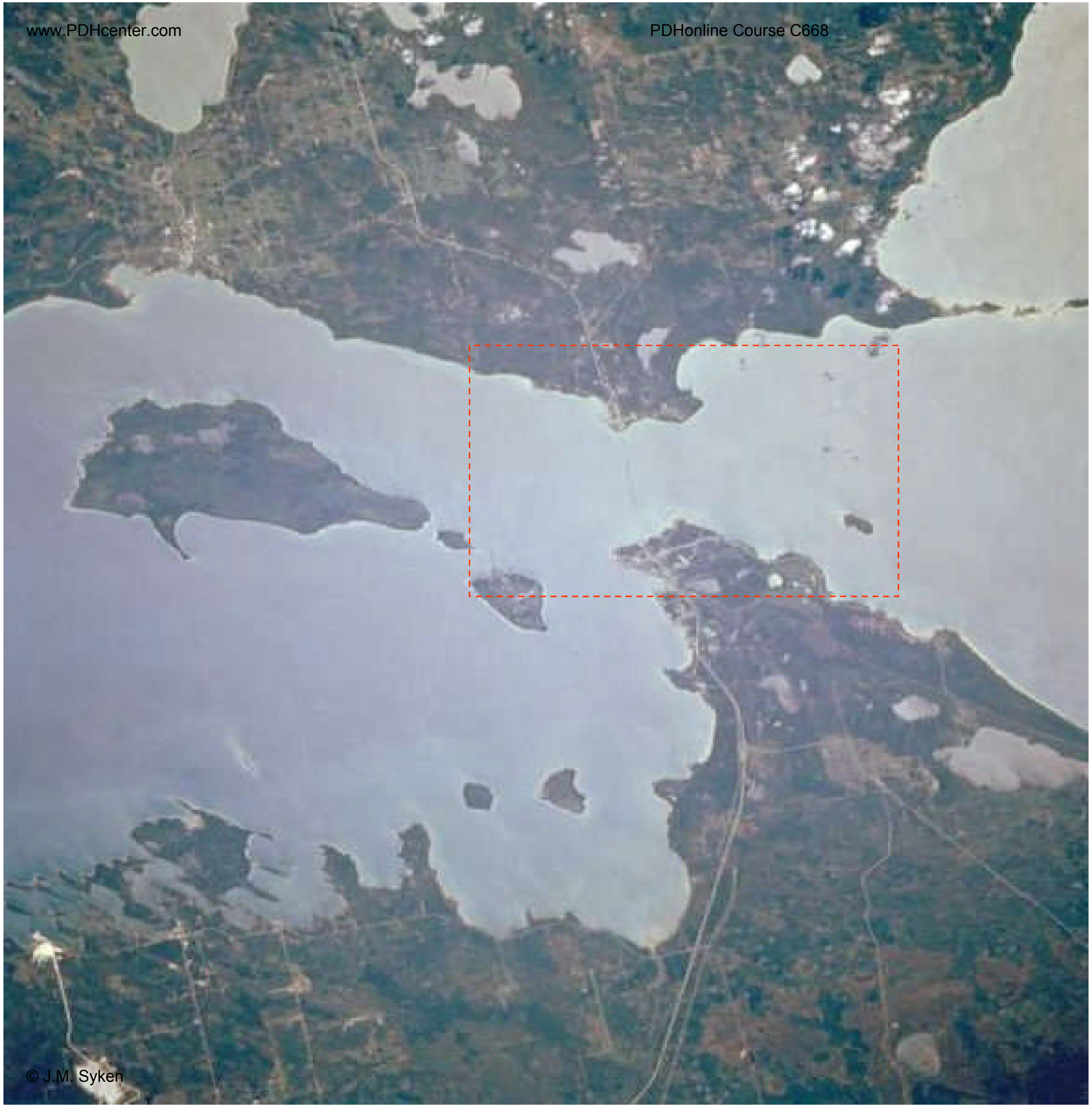
Mackinaw City, Mich.

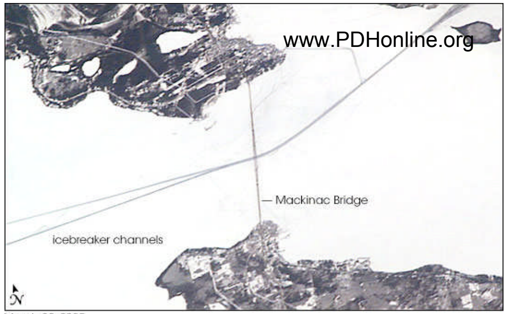
"…Melodramatic yet grimly real is the regularly recurring spectacle of ice-locked ferry boats in Michigan's Straits of Mackinac. As recently as last month this scene was re-enacted when jam-packed floes defied the dogged pounding of ferry boats. Faced with the prospect of indefinite delay amid anything but comfortable circumstances ferry passengers abandoned their cars and truck and, like Eliza crossing the ice, made their precarious way over treacherous paths to shore. Sick men in an ambulance were forced to wait more than twenty-four hours for an opportunity to cross this narrow stretch of water. A son hurrying to the bedside of his dying mother was trapped for hours in the ice jam. Thousands of vacationists have been left stranded for hours at a time, not only on the docks but even on the highways approaching the straits. The situation is especially acute each fall when thousands of deer hunters go to the Upper Peninsula. Motorists have been delayed more than twelve hours due to summer congestion and three days due to winter weather conditions…"

RE: excerpt from MSBA booklet (1939)

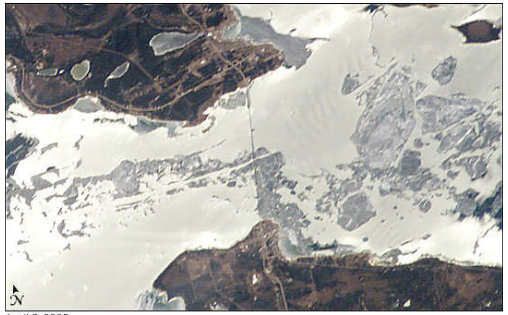


<u>Above L&R</u>: caption: "Passengers carrying their luggage were forced to walk from ferry boats trapped in the ice at the Straits of Mackinac." In 1939, the *State of Michigan* published a booklet showing these dramatic pictures of the ice-bound straits with ferry boats stuck and passengers forced to walk to shore. The publication was a report of the *Mackinac Straits Bridge Authority* (MSBA). Starting in the 1910s, improved highways along the eastern shore of Michigan's lower peninsula brought increased automobile traffic to the *Mackinac Straits* region. The State of Michigan initiated an automobile ferry service between *St. Ignace* and *Mackinaw City* in 1923 and eventually operated eight ferry boats. In peak travel periods (especially during the fall deer-hunting season) backups and long delays became common at the state docks at *Mackinaw City* and St. Ignace. Prior to the construction of the bridge, a fleet of nine ferries carried as many as 9K vehicles per day, with traffic backups stretching as long as sixteen miles.


© J.M. Syken



March 22, 2005


April 9, 2005

<u>Above</u>: caption: "This pair of images shows the Mackinac Straits while they were still frozen (top) and as they began to thaw (bottom). The March 22nd view shows shipping lanes opened by ice breakers. The April 9th view shows the ice broken into a series of irregular rafts. **The shipping channel is maintained even through remnants of the ice mass, but the ice ridges can be hazardous to shipping until the last of the ice breaks up."**

<u>Left</u>: caption: "South-facing overhead view of the Straits of Mackinac linking Lake Michigan (right) and Lake Huron (left)"

<u>Left</u>: caption: "Winter service began in 1931 when the Highway Department arranged with the Mackinaw Transportation Company to carry cars across the Straits on a railroad icebreaker during the cold months. This arrangement turned out to be poor business for the State, so in 1936 the Highway Department leased the railroad icebreaker 'Sainte Marie' for winter operations on a regular schedule."

<u>Right</u>: caption: "When the government purchased the 'Mackinaw City' and the 'Sainte Ignace' in 1940 for war purposes, the State obtained a Pere Marquette Railway boat for service at the Straits of Mackinac. The ferry was renamed the 'City of Petoskey'. The vessel could carry 105 vehicles."

In February 1942, the *U.S. Government* announced plans to spend an estimated $8 million to build a state-of-the-art icebreaker incorporating successful design ideas found on a fleet of privately owned rail ferries in service at the *Straits of Mackinac* that were capable of operating in heavy ice. Such a vessel was essential because a longer shipping season was needed to help vessels move vital raw materials on the *Great Lakes* during WWII. At the start of the conflict, all available cutters had been called to wartime duty leaving the Great Lakes with no available icebreakers. The project was completed by the *American Shipbuilding Co.,* and the vessel was launched on March 4th 1944. Her name was originally to have been *Manitowoc*, but that was changed to *Mackinaw* before entering service when it was discovered another government vessel already carried the name "Manitowoc." She was commissioned on December 20th 1944 at a final cost of $10 million, an enormous amount for the day. One of four "heavy" class icebreakers built for wartime service, the Mackinaw was the only one assigned to the Great Lakes. She was replaced in 2005.

<u>Top Left</u>: caption: "Pride of the Coast Guard – the new streamline $6,000,000 ice-breaking cutter Manitowoc which has cruising range of 6,000 miles and carries airplane with gear for raising and lowering (Popular Mechanics, April 1943)."

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The MSBA

"Early in 1934 the matter was again revived and proposed as a suitable P.W.A. project. In the extra session of 1934 the Legislature created the Mackinac Straits Bridge Authority of Michigan and empowered it to investigate the feasibility of such construction and to finance the work by issuance of revenue bonds. The Authority began its studies in May 1934 and has been continuously active since that date. Although limited funds precluded full and complete preliminary studies, the Authority was able to reach the conclusion that it was feasible to construct a bridge directly across the Straits at an estimated cost of not more than $32,400,000 for a combined two lane highway and one-track railway bridge. In its studies the Authority utilized soundings made by the War Department Engineers and was aided by the gratuitous counsel and advice of engineers and contractors experienced in work of this magnitude…Recent advances in engineering and construction now make it possible for Michigan to overcome the physical defect of her divided peninsulas and by the proposed link be welded into a single individual state."

***James H. Cissel*, Secretary of the *Mackinac Straits Bridge Authority* (MSBA), 1937**

RE: in 1923, the state legislature ordered the *Michigan State Highway Department* to establish a ferry service at the *Mackinac Straits*. Within five years, traffic on this facility had become so heavy that Governor *Fred Green* ordered the same agency to make a bridge feasibility study. The report came back favorable with an estimated cost of $32.4 million. Besides being Secretary of the MSBA, Cissel was a professor of engineering at the *University of Michigan*.

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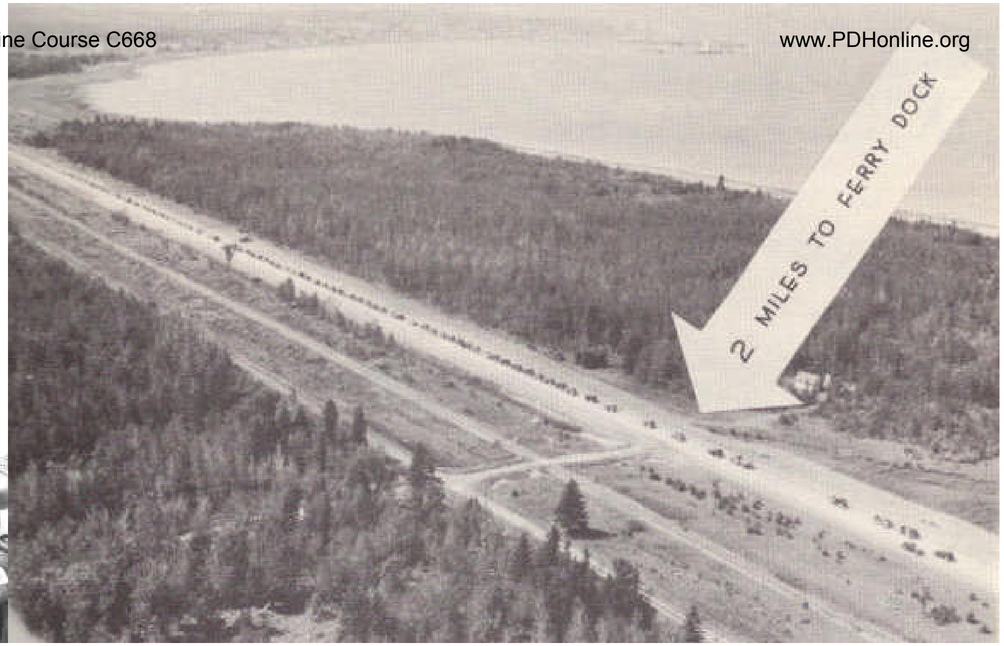
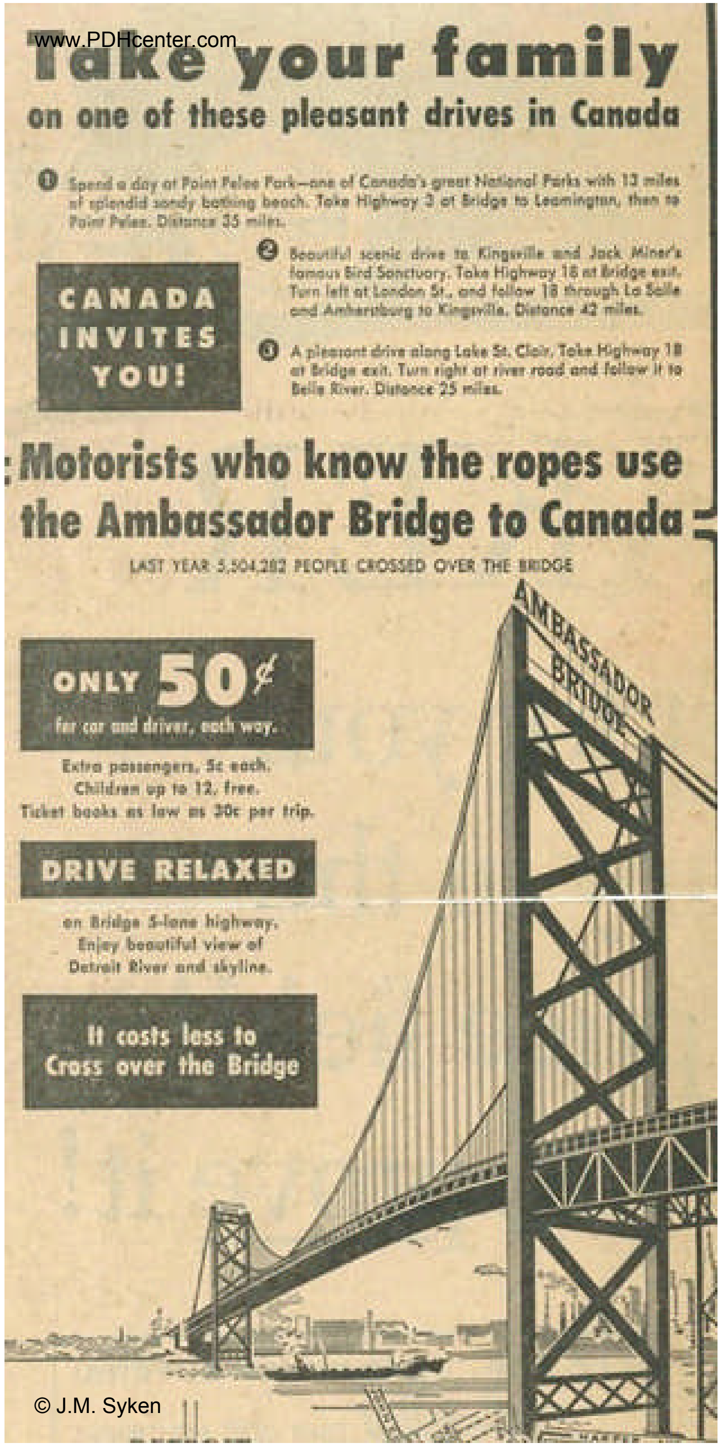


With an increase in public pressure to break the bottleneck, the *Michigan* legislature established the *Mackinac Straits Bridge Authority* (MSBA) in 1934, with the power to issue bonds for bridge construction. The MSBA supported a proposal first developed in 1921 by *Charles Evan Fowler* - the bridge engineer who had previously promoted a *Detroit-Windsor* bridge. Fowler's plans called for an island-hopping route from the *City of Cheboygan* to *Bois Blanc*, *Round* and *Mackinac Island/s*, thence to *St. Ignace* along a twenty-four-mile route. However, the *Public Works Administration* (PWA) flatly rejected a request for loans and grants to implement the project.

Left: caption: "In 1937, the Highway Department bought a converted Lake Michigan railway car ferry to provide additional service. The vessel was renamed the 'City of Cheboygan.' It had a capacity of 85 vehicles."

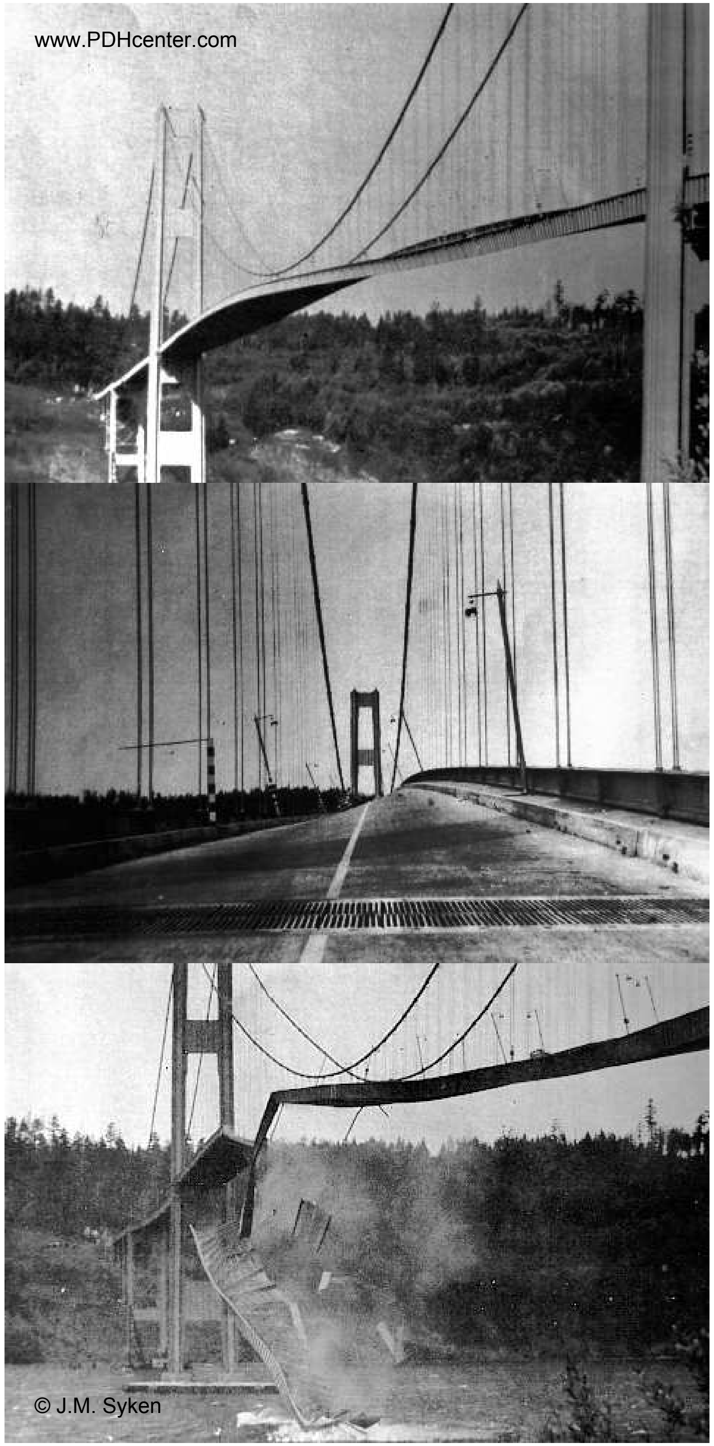
Right: caption: "Autos were lined up more than two miles trying to reach the Straits of Mackinac in this state aerial photo taken near Mackinaw City in 1939"



Left: in 1903, the *Detroit Board of Commerce* formed an *International Bridge Committee* and during 1919-1921, plans were developed by *Charles Evan Fowler* for a combination railway and highway bridge between *Detroit, Michigan* and *Windsor, Ontario*. Fowler was a consulting engineer for the *American Transit Company*. However, at the time the railway system took little interest in his idea and the project was canceled. In 1924, *Joseph A. Bower* organized and financed the construction of the *Ambassador Bridge* (left). The actual construction began on May 7th 1927 and the bridge opened to traffic on November 11th 1929. **On March 5th 1929, Bower received word from the engineers that there was an emergency with the construction of the bridge; the galvanized steel cables were splitting and 11K miles of wire would have to be removed and replaced which would delay the opening for another year. Although the news was bad, the work was completed in only twenty-seven weeks and the dedication remained November 11th 1929. *Ralph Modjeski* - the world-famous bridge designer, served as consultant on the project. Connecting Detroit with Windsor across the *Detroit River*, it was the only "International" bridge in the world at the time of its completion. The Ambassador Bridge opened up the Canadian tourism industry and provided a shorter route across *Canada* between *New York, Buffalo* and *Niagara Falls.***

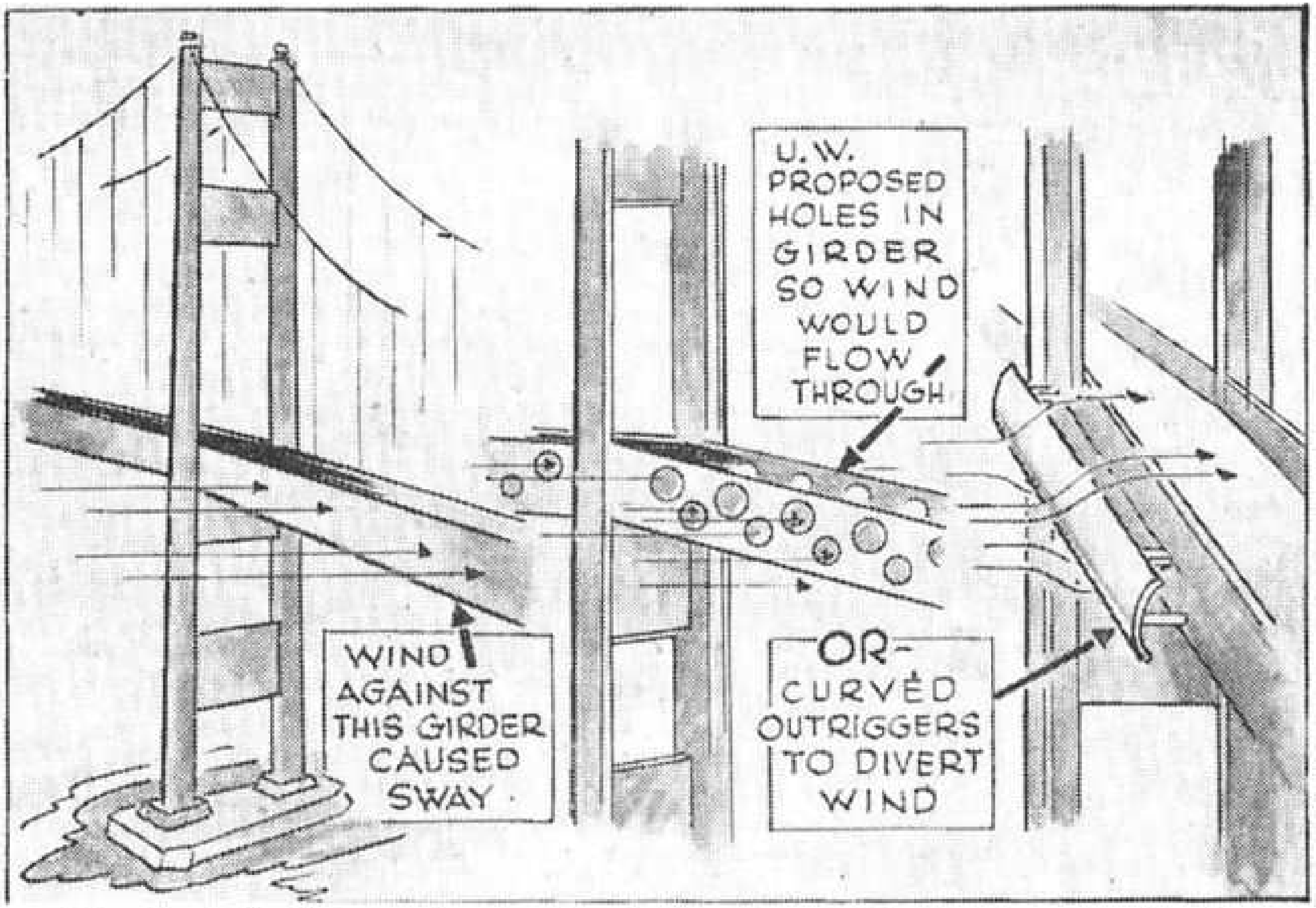
A plan was drawn up in 1935 for a direct crossing from *Mackinaw City* to *St. Ignace*, but the PWA again denied funds despite the endorsement of the *U.S. Army Corps of Engineers* and POTUS *Franklin Roosevelt*. In 1940, a plan was submitted for a suspension bridge with a main span of 4,600-feet. This design was a larger version of the ill-fated *Tacoma Narrows Bridge* in *Washington State* - a structure destroyed by high winds on November 7th 1940. Although the disaster delayed any further action, the activities of 1938-1940 produced significant results including selection of a direct route, comprehensive traffic, geological, ice and water current studies. The MSBA also conducted a series of soundings and borings across the straits and built a causeway (a.k.a. "mole") extending 4,200-feet south from the *St. Ignace* (north) shore. Preliminary plans for a double suspension span were drawn up and the possibility of a bridge across the straits became very real. However, WWII ended any supplemental work and after the war the state legislature dissolved the MSBA (in 1947).

Galloping Gertie



The *Tacoma Narrows Bridge* collapsed due to wind induced resonance on November 7th 1940. *Resonance* is a process in which an object's natural vibrational frequency is amplified by an identical frequency. In this case, the identical frequency was caused by sustained 42 mph wind gusts normal (perpendicular) to the bridge which created regions of high and low pressure above and below the bridge deck. Thus were produced violent oscillations or waves in the bridge leading to its collapse. The up and down movement of the deck tensed or relaxed the supporting cables, which acted much like rubber bands, increasing the oscillations. The bridge fell because of "vortex shedding" (when wind is interrupted by an object and a violent twisting motion or "eddies" are formed). The photographs at left show the violent twisting that the bridge withstood (top & middle) prior to its collapse (bottom). The Tacoma Narrows Bridge spanned the narrows of the *Puget Sound* (at the mouth of the *Puyallup River*) between the city of *Tacoma, Washington* and the *Olympic Peninsula*. Construction began in early 1938 and, two years later, it was finished. It only stood for four months. Prior to the collapse, drivers would lose sight of the car ahead when, due to movement of the deck in the wind, it dropped into a trough (low point). Thus it earned the nickname "Galloping Gertie" (on windy days children asked their parents to drive over the bridge as an amusement).

WOULD THIS HAVE SAVED BRIDGE?



University of Washington engineers made a test Saturday on their $14,000 model of The Narrows Bridge, attempting to eliminate the dangerous wind sways which finally caused the real-life structure to collapse yesterday. The sketch at left shows the flat horizontal girder which offered resistance to winds, causing the sway. University recommendations were (center) to drill holes with a torch in the girder, permitting the wind to pass through; or (right) to erect an $80,000 streamlined buffer alongside the girder, to divert winds. Their tests showed the latter materially reduced the vibrations, might have saved the bridge.

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Above: cartoon from the *Seattle Times* - November 8, 1940

"The Tacoma Narrows bridge failure has given us invaluable information...It has shown that every new structure that projects into new fields of magnitude involves new problems for the solution of which neither theory nor practical experience furnish an adequate guide. It is then that we must rely largely on judgment and if, as a result, errors, or failures occur, we must accept them as a price for human progress."

Othmar H. Ammann

RE: Ammann was a member of the *Federal Works Agency* (FWA) Commission investigating the collapse of the *Tacoma Narrows Bridge.* The *Bronx-Whitestone Bridge*, which is of similar design to the 1940 Tacoma Narrows Bridge (*Leon Moissieff* was a consultant on the project), was reinforced with a single cable-stay shortly after the collapse (still in-place). In 1943, 14-foot high steel trusses were installed on both sides of the deck to stiffen the bridge in an effort to reduce its noticeable oscillations in the wind. In 2003, the stiffening trusses were removed and aerodynamic fiberglass "fairings" were installed along both sides of the road deck.

<u>Left</u> (top-to-bottom): original configuration (w/plate girder truss) at top / retrofit after TNB collapse (middle) / present day (w/fairing) at bottom.

In 1949, William Stewart Woodfill – President of the *Grand Hotel* on *Mackinac Island*, formed the statewide *Mackinac Bridge Citizens Committee* (MBCC) to lobby for a new bridge authority, which the legislature created in 1950 (*Mackinac Bridge Authority*). A panel of three prominent engineers (*Othmar H. Ammann, David B. Steinman* and *Glenn B. Woodruff*) conducted a feasibility study and made recommendations to the bridge authority on the location, structure and design of the bridge. However, the *Michigan State Highway Department*, which had just placed the $4.75 million ferry *Vacationland* (above) into service at the straits in January 1952, remained hostile to the bridge plan.

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Mackinac Bridge Authority Preliminary Report

January 1951

State of Michigan

Mackinac Bridge Authority

PROPOSED MACKINAC STRAITS BRIDGE
PRELIMINARY REPORT

MACKINAC BRIDGE AUTHORITY

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Fred. M. Zeder, *Vice Chairman*
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Murray D. Van Wagoner
Charles M. Ziegler
Lawrence A. Rubin, *Secretary*

BOARD OF ENGINEERS

O. H. Ammann
D. B. Steinman
G. B. Woodruff

January 10, 1951

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January 10, 1950

Mackinac Bridge Authority
Mr. Prentiss M. Brown, Chairman
Lansing, Michigan

Gentlemen:

In accordance with our assignment we present a preliminary report describing our investigation of the feasibility of constructing a bridge across the Mackinac Straits, and including preliminary design plans, estimates of cost of construction, operation and maintenance and a summary of our conclusions.

While the statements and estimates presented are subject to refinement and amplification in our final report, we believe they are adequate as a basis for your consideration at this time.

Possibly, as a result of such consideration, you may wish to give us further instructions on certain phases of the project.

Respectfully submitted

O. H. Ammann
D. B. Steinman
Glenn B. Woodruff

O. H. Ammann
D. B. Steinman
Glenn B. Woodruff

Board of Engineers

INTRODUCTION

The Straits of Mackinac divides the State of Michigan into the upper and lower peninsulas. The desirability of uniting these areas by a bridge or tunnel has long been apparent. In 1920 the late Horatio S. Earle, highway commissioner, suggested a submerged floating tunnel and invited discussion of its feasibility and advantages. A counter-proposal was made by Mr. C. E. Fowler, who suggested a series of causeways and bridges starting at a point near Cheboygan and proceeding via Bois Blanc Island, Round Island, and Mackinac Island to St. Ignace. In 1923 in response to the growing demand for better facilities the State inaugurated a highway ferry service.

In 1928 after some limited studies, the highway department concluded that it was feasible to build, for about $30,000,000, a highway bridge directly across the Straits from Mackinaw City to St. Ignace. Although negotiations were undertaken and partially completed for the financing of such a bridge, the project was dropped.

Early in 1934, the state legislature created the Mackinac Straits Bridge Authority of Michigan and empowered it to investigate the feasibility of constructing a bridge to connect the peninsulas and to issue and sell the necessary revenue bonds and fix and collect the necessary tolls. In April 1934, Governor Comstock appointed Messrs. S. T. Stackpole, Otto W. Lang, and Patrick H. Kane as members of the Authority.

The Authority engaged Mr. Fowler as temporary chief engineer. The plan developed by Mr. Fowler followed closely the one proposed by him in 1920. In August 1934 the plan was submitted to the Public Works Administration with a request for a loan of 70 per cent and a grant of 30 per cent of the estimated cost of the project. This application was formally disapproved by PWA on July 18, 1935.

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"The Straits of Mackinac divide the State of Michigan into the upper and lower peninsula. The desirability of uniting these areas by a bridge or tunnel has long been apparent…"

In the meantime many objections to the proposed route had been brought to the attention of the Authority. As a result, the Authority continued its studies and ultimately reached the conclusion that a direct crossing was both feasible and preferable. Mr. Francis C. McMath was engaged to prepare such data on a direct crossing as would be necessary for a new application to PWA. Mr. James E. Cissel served as consulting engineer. A new application was submitted to PWA on September 7, 1935.

On December 23, 1935, following a request by President Roosevelt, the Chief of Engineers, U. S. Army, reported on the proposed bridge informally as follows: The construction of the bridge on the direct line appears to be entirely feasible; it will unquestionably be of great public convenience in facilitating communication between the peninsulas; and there is a reasonable possibility that the revenue from tolls will meet the carrying charges of the loan requested. However, PWA disapproved the latest application on September 18, 1935.

In 1936, the Mackinac Straits Bridge Authority engaged Modjeski and Masters, with Leon S. Moisseiff as an associate, to make a further investigation of the project. These engineers submitted their report to the Authority on June 3, 1940, recommending the construction of a bridge "extending almost due north across the Straits from the point at which highway routes U. S. 31 and U. S. 23 converge on the south shore."

This report was submitted by the Bridge Authority to the Governor and the State Highway Commissioner on June 25, 1940. Before further steps could be taken World War II started.

The present Mackinac Bridge Authority was created by Enrolled House Bill No. 24, Extra Session of 1950 of the 65th Legislature of the State of Michigan. Section 4 of this bill provided, "The Authority shall employ three consulting engineers to be recommended by the dean of the college of engineering of the University of Michigan, who shall constitute a board of consulting engineers and

- 2 -

"…'The Authority shall employ three consulting engineers to be recommended by the dean of the college of engineering of the University of Michigan, who shall constitute a board of consulting engineers and who shall determine whether a bridge can be safely and feasibly constructed across the Straits of Mackinac and the probable cost thereof'…"

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who shall determine whether a bridge can be safely and feasibly constructed across the Straits of Mackinac and the probable cost thereof."

The Authority invited the three engineers who were recommended by the dean to meet with them at the site on July 12, 1950. The investigations described herein were started on that date.

The combination of deep channels, exceptional rock formations, severe ice conditions and winds present unusual engineering problems. The extreme peaking of traffic compared to the average volume required careful consideration in establishing the capacity of the bridge.

The work of the Board of Engineers included a review of previous investigations, study of the conditions at the site - geology, currents, wind and ice formations and their effect on the structure - alternate design studies and cost estimates to determine the most appropriate type and arrangement of structure and the preparation of plans in sufficient detail to permit an adequate estimate of the required quantities and the cost of construction.

On recommendation of the board of consulting engineers the Authority also engaged the firm of Coverdale and Colpitts to undertake a traffic analysis and assist in the economic study. In view of the important and controversial question of the suitability of the rock formations under the Straits to carry the bridge foundations the Authority further engaged the advisory services of Dr. Charles P. Berkey and Dr. Sidney Paige, two of the most outstanding engineering geologists.

CONDITIONS AT THE SITE

The Straits of Mackinac are a comparatively narrow body of water joining Lakes Michigan and Huron. They also divide the State of Michigan into Upper Peninsula with its resources of minerals and the Lower Peninsula which, with Detroit as its major city, is rapidly becoming highly industrialized. The Upper

- 3 -

"…The combination of deep channels, exceptional rock formations, severe ice conditions and winds present unusual engineering problems. The extreme peaking of traffic compared to the average volume required careful consideration in evaluating the capacity of the bridge…"

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peninsula is also noted as recreation area. The Straits and the crossing of St. Mary's River at Sault Ste. Marie form a gateway into the Province of Ontario which also provides a vast recreation area.

Geology

With its unusual brecciated formation, the geology of the area has, for over 100 years, attracted the attention of the geologist. With the agitation for a crossing of the Straits, the geology was exhaustively studied by Professors Kenneth K. Landes, George M. Ehlers and George M. Stanley, under the direction of State Geologist R. A. Smith. Two features are pertinent to the planning of the bridge--the breccia formation and the hidden rock gorge. The breccia formation has been fully described by Messrs. Landes, Ehlers and Stanley. We have discussed the matter with Professors Ehlers, Landes and W. S. Housel, and with State Geologist G. E. Eddy and Mining Engineer F. G. Pardee of the State Department of Conservation. The report of Professors Berkey and Paige has been submitted to the Authority under separate cover. In addition, the Authority requested Mr. W. W. McLaughlin, Director of Testing and Research of the State Highway Department, and Professor Housel to make compression tests on samples of the material and also to make "in-place" loading tests. The borings and probings at the site in 1939 are reproduced on Plate 5.

As a result of the above data, with the sole qualification that further core borings at the site of the main piers and anchorages are a prerequisite to the final design of such construction, we have no doubt that the rock strata underlying the Straits along the recommended location are entirely capable of withstanding the moderate pressures assumed in the design.

A second geological feature of importance to the construction of the bridge is the hidden rock gorge underlying the channel between Mackinac City and St. Ignace. (Plate 1) East of the proposed crossing the gorge veers north,

- 4 -

"…With its unusual brecciated formation, the geology of the area has, for over 100 years, attracted the attention of the geologists…Two features are pertinent to the planning of the bridge – the breccia formation and the hidden rock gorge…to make compression tests on samples of the material and also to make 'in-place' loading tests. The borings and probings at the site in 1939 are represented on Plate 5. As a result of the above data, with the sole qualification that further core borings at the site of the main piers and anchorages are a prerequisite to the final design of such construction, we have no doubt that the rock strata underlying the Straits along the recommended location are entirely capable of withstanding the moderate pressures assumed in the design…"

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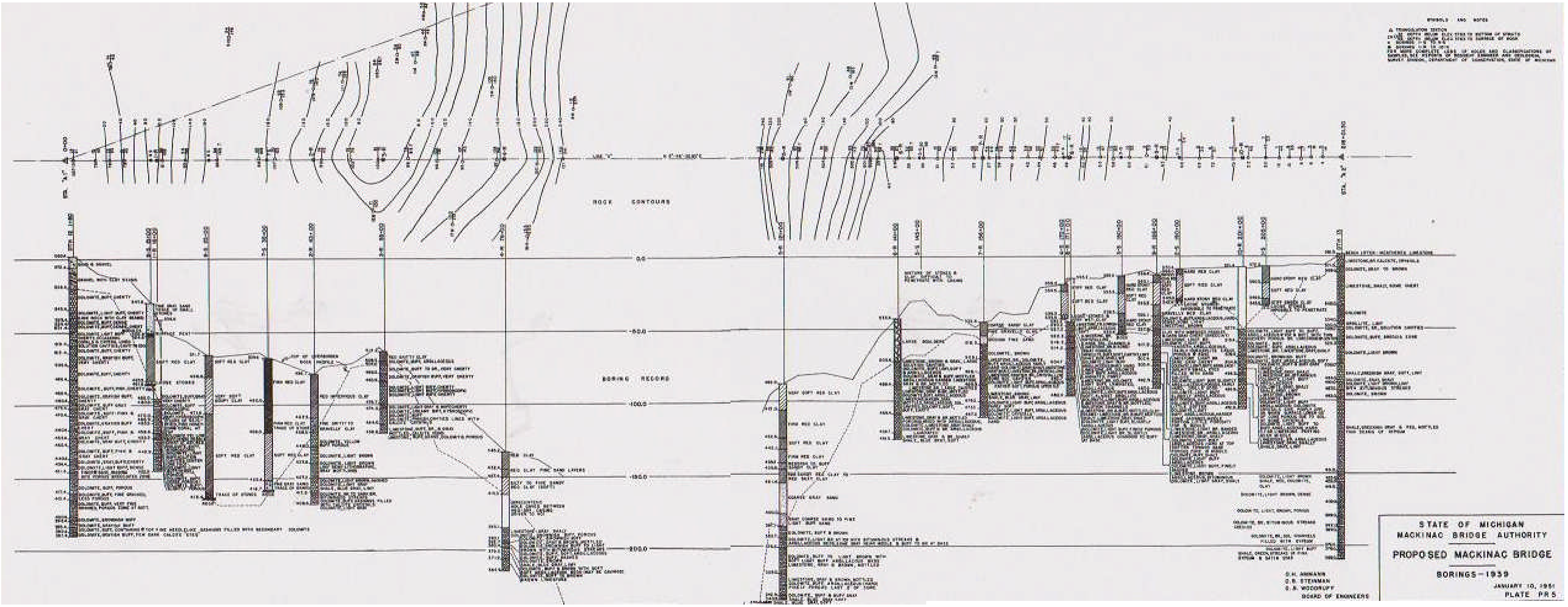
ROCK CONTOURS
BORING RECORD
STATE OF MICHIGAN
MACKINAC BRIDGE AUTHORITY
PROPOSED MACKINAC BRIDGE
BORINGS—1939
PLATE PR5
BOARD OF ENGINEERS

Plate No. PR5

makes a loop around Mackinac Island and enters Lake Huron. This gorge was eroded through the breccia at a time when the level of Lake Huron was much lower than at present. The 1939 subaqueous explorations did not extend to depths greater than were necessary to locate the rock bed of the gorge.

Currents

The average volume of water flowing through the Straits is so small that currents produced by this volume are negligible. The maximum currents result from two causes; seiches or oscillations of the lake caused by passing changes in air pressure or barometric waves or from protracted wind in any given direction.

The results of certain observations made in 1939, gave a maximum of 1.97 mph. Higher Velocities may be anticipated. It is certain that no current velocities such as those experienced in the construction of the Trans-Bay, Golden Gate and Tacoma Narrows Bridges are probable and that the difficulties, from this cause, of pier construction or of lifting sections of the suspended spans from barges will be less than those experienced in the case of the bridges above listed.

Ice

A very complete report of the ice conditions at the Straits has been made by Mr. W. C. Fremont of the State Highway Department. Mr. Fremont carried his investigations to an appraisal of the forces from the ice. These observations have been supplemented by those of State Highway Commissioner Charles M. Ziegler.

We have carefully considered the data and have further investigated information on ice pressure on engineering structures. As a result of these investigations we have adopted the very severe assumptions of an ice pressure of 230,000 pounds (half of this amount for circular surfaces) per lineal foot

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"…A second geological feature of importance to the construction of the bridge is the hidden rock gorge underlying the channel between Mackinac City and St. Ignace (Plate 1). East of the proposed crossing the gorge veers north, makes a loop around Mackinac Island and enters Lake Huron. This gorge was eroded through the breccia at a time when the level of Lake Huron was much lower than at present. The 1939 subaqueous explorations did not extend to depths greater than were necessary to locate the rock bed of the gorge…"

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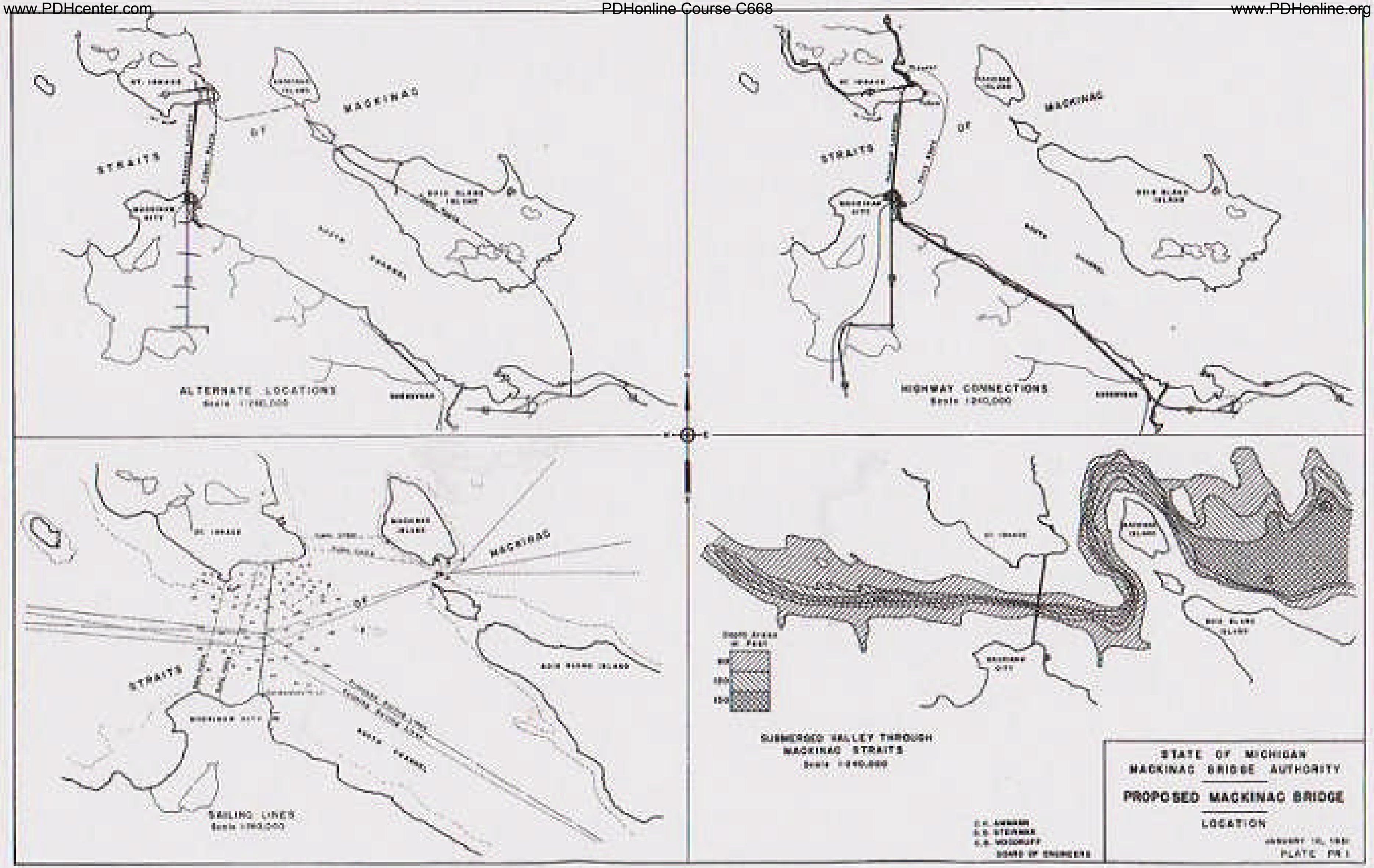

Plate No. PR1

46

of pier width at the water line. The resulting forces are considerably greater than those generally assumed for engineering structures under comparable climatic conditions. We are confident that these forces are in excess of those to which the piers will ever be subjected.

Wind

The Straits of Mackinac are north of the "tornado belt" but are subjected to comparatively heavy wind. The highest recorded velocity at the site was 78 mph on November 11, 1940.

BRIDGE LOCATION

We have considered the locations shown on Plate 1 which are designated as the Fowler, Cissel and Masters locations. Neither Mr. Fowler nor Mr. Cissel had any information as to the depths to rock at the center of the "hidden gorge". With the information now available it is certain that the cost of a bridge at either of the Fowler or Cissel locations would be much greater than at the location herein recommended. Our conclusions in this respect may be summarized as follows:

1. The construction of a bridge on the recommended location is entirely feasible.

2. The recommended location fits the existing State Highway System better than any other.

3. It is possible, though not probable, that a very extensive subaqueous investigation might develop a site that would permit a slight reduction in the cost of construction. In view of the existing mole which will serve to protect the piers of the short spans at the north end of the bridge against ice, the chances of finding a more economical location are so remote that the cost of the investigation is not warranted.

- 6 -

"…We have carefully considered the data and have further investigated information on ice pressure on engineering structures. As a result of these investigations we have adopted the very severe assumptions of an ice pressure of 259,000 pounds (half of this amount for circular surfaces) per lineal foot of pier width at the water line. The resulting forces are considerably greater than those generally assumed for engineering structures under comparable climatic conditions. We are confident that these forces are in excess of those to which the piers will ever be subjected…The Straits of Mackinac are north of the 'tornado belt' but are subjected to comparatively heavy wind. The highest recorded velocity at the site was 78 mph on November 11, 1940…"

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DESIGN OF BRIDGE

From the start of the investigation it was apparent that the project would be finally feasible only by keeping the cost of construction to a minimum consistent with adequate capacity, safety of traffic, conservative design and structural details conducive to economical maintenance. On the other hand it was recognized that reasonable allowance must be made to meet the needs of the future.

Traffic Capacity

From the traffic analysis it appears probable that, immediately after opening of the bridge to traffic, northbound traffic may be as high as 1,500 vehicles per hour. Within the following 50 years it is possible that the volume will be tripled. During the northbound peak southbound traffic will be less than half this volume.

A three-lane bridge provided with moveable traffic barriers or changeable traffic lights, so that the bridge could be operated with two lanes in one direction and a single lane in the opposite direction might meet these requirements except for interruptions caused by accidents or car stoppages. These interferences with smooth flow of traffic do occur, however, and may be serious enough during peak traffic to throw the operation into confusion. This is of particular importance on a bridge of such great length.

For this reason we recommend that a capacity of not less than four lanes, two in each direction, be provided. However, in accordance with instructions, we have also prepared a cost estimate for a three-lane bridge.

Consideration has been given to provision of a traffic barrier along the center line between the two roadways to avoid possible head-on collisions by vehicles getting off the inner lanes. Modern practice with respect to the character of traffic barriers varies greatly. On some large bridges high walls have been installed preventing any crossing by vehicles. On others low curbs, raised traffic markers or even only lines

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"…A three-lane bridge provided with movable traffic barriers or changeable traffic lights, so that the bridge could be operated with two lanes in one direction and a single lane in the opposite direction might meet these requirements except for interruptions caused by accidents or car stoppages. These interferences with smooth flow of traffic do occur, however, and may be serious enough during peak traffic to throw the operation into confusion. This is of particular importance on a bridge of such great length. For this reason we recommend that a capacity of not less than four lanes, two in each direction, be provided. However, in accordance with instructions, we have also prepared a cost estimate for a three-lane bridge…"

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painted on the pavement are used which permit the crossing of vehicles when necessary under proper control.

Barriers of the low type, not over two feet wide, have been assumed for the Mackinac Straits Bridge for the following reasons. While it is not recommended that direction of traffic in any lane be regularly reversed, it is highly desirable, especially on a long bridge with only two lanes in each direction wide, that in the case of emergencies for vehicles to be detoured across the barrier at any point under police control and to permit more direct access by tow cars to vehicles requiring their services.

A low well marked barrier will also induce vehicles to stay closer to it than to a high wall thus justifying a somewhat narrower traffic lane next to it.

These considerations, as well as reasons of economy, have led to an overall width of roadway between curbs of 48 feet, of which not more than two feet would be occupied by the center barrier, 12 feet by each outer lane and not less than 11 feet by each inner lane.

These lane widths compare favorably with those of other modern long bridges and tunnels.

No provision is considered necessary on this four mile long bridge for regular pedestrian traffic. However, footwalks on each side are essential for maintenance and operating personnel and only in emergency cases for occupants of vehicles. A width of three feet between curb and railing has been assumed for each of these two footwalks. Substantial railings are provided on the outside of the footwalks. The overall width of the floor between railings is 54 feet.

- 8 -

"…Barriers of the low type, not over two feet wide, have been assumed for the Mackinac Straits Bridge…It is highly desirable, especially on a long bridge with only two lanes in each direction wide, that in the case of emergencies for vehicles to be detoured across the barrier at any point under police control and to permit more direct access by tow cars to vehicles requiring their services…led to an overall width of roadway between curbs at 48 feet, of which not more than two feet would be occupied by the center barrier, 12 feet by each outer lane and not less than 11 feet by each inner lane…No provision is considered necessary on this four mile long bridge for regular pedestrian traffic. However, footwalks on each side are essential for maintenance and operating personnel and only in emergency cases for occupants of vehicles. A width of three feet between curb and railing has been assumed for each of these two footwalks…The overall width of the floor between railings is 54 feet…" 49

Design Specifications

The specifications for materials, loads and permissible stresses which have been used as a basis for the design of the Mackinac Straits Bridge follow general practice for modern structures of this type and magnitude.

For the floor structure throughout and for the shorter main girders and trusses the current specifications of the American Association of State Highway Officials have been followed, with the basic loading of H20-S16-44 as generally applied to the design of bridges on major highways.

The latter specifications are intended to apply to bridges of ordinary type and modern spans. For the design of the stiffening trusses, cables, towers and anchorages of the suspension bridge and for the long trusses of the other spans of the main crossing, special load and stress specifications were adopted in accordance with best modern practice for structures of such magnitude.

For the four-lane bridge design a live load of 2000 lbs. per lin ft. of bridge has been adopted, representating a continuous line of heavy trucks about 50 ft. apart on each of the four lanes, a load which will probably never be obtained under actual conditions. Under ordinary heavy traffic the average load will probably be less than one third of that load.

For the three-lane design the relatively somewhat larger load of 1800 lbs. per ft. has been assumed.

- 9 -

"…For the design of the stiffening trusses, cables, towers and anchorages of the suspension bridge and for the long trusses of the other spans of the main crossing, special load and stress specifications were adopted in accordance with best modern practice for structures of such magnitude. For the four-lane bridge design a live load of 2,000 lbs. per linear foot of bridge has been adopted, representing a continuous line of heavy trucks about 50 feet apart on each of the four lanes, a load which will probably never be obtained under normal conditions. Under ordinary heavy traffic the average load will probably be less than one third of that load. For the three-lane design the relatively somewhat larger load of 1,800 lbs. per foot has been assumed…"

On account of the possibility of high winds of considerable extent and the exposed location of the bridge a static wind pressure of 50 lbs. per square foot of exposed area was assumed over the entire structure. This corresponds to a wind velocity of about 120 miles per hour as compared with the maximum recorded velocity of 78 mph observed in that vicinity.

Type of Structure and Span Arrangements

Fairly extensive borings at the proposed bridge location in connection with the report of Modjeski & Masters in 1940 made it possible to determine the most appropriate type of structure and span arrangement. Time and available funds for the present study did not permit the making of supplementary borings to explore to a greater extent the slopes of the hidden rock gorge under the main channel. However, it may be reasonably concluded from the information available that any piers located closer to the gorge than now proposed would probably become excessively deep and expensive to justify a shorter span across the gorge.

As proposed that span has a length of 3,800 feet between centers of piers. The outstandingly appropriate type of structure for a span of that length is a suspension bridge. The side spans from main piers to the anchorages were given a length of 1,500 feet, which under the given conditions is in the most appropriate ratio to the center span.

A number of alternate layouts made for the remainder of the crossing over the waterway between the south shore and the end of

- 10 -

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the mole at the north shore led to a series of truss spans on concrete piers as the best solution. Twenty-two spans over the deeper portions of the waterway are of unusual length for a structure of this character, ranging from 560 feet to 302 feet. Four spans near each shore have spans of 160 to 200 feet. The comparatively long spans are economically necessitated because of the deep and expensive piers, which have to be designed to withstand the heavy ice pressures.

Along the mole in the St. Ignace side it was found appropriate to carry the roadway on a viaduct with short spans resting on pile foundations driven through the existing embankment.

Grades, Clearances and Lengths

From the end of the mole and the Mackinac City shore the bridge roadway ascends by easy grades, not exceeding 2.5 per cent, to the towers of the main bridge. Over the center span of the latter the roadway is cambered by a parabolic curve.

These grades allow a minimum clear height above mean lake level of 135 feet for a width over 3,000 feet of the main channel. The minimum clear height at the center of the span is 150 feet.

The clearances under the approach viaducts range from 84 feet near the anchorages of the main bridge to a minimum of 20 feet near the south shore or the end of the mole respectively.

These clearances are believed to meet fully the requirements of navigation. They are subject, however, to the approval of the Department of the Army after a public hearing.

Upon an informal inquiry sent to Lt. Colonel John D. Brister,

"…A number of alternate layouts made for the remainder of the crossing over the waterway between the north shore and the end of the mole at the north shore led to a series of truss spans on concrete piers as the best solution. Twenty-two spans over the deeper portions of the waterway are of unusual length for a structure of this character, ranging from 560 feet to 302 feet. Four spans near each shore have spans of 160 to 200 feet. The comparatively long spans are economically necessitated because of the deep and expensive piers, which have to be designed to withstand the heavy ice pressure. Along the mole on the St. Ignace side it was found appropriate to carry the roadway on a viaduct with short spans resting on pile foundations driven through the existing embankment…From the end of the mole and the Mackinac City shore the bridge roadway ascends by many grades, not exceeding 2.5%, to the towers of the main bridge. Over the center span of the latter the roadway is cambered by a parabolic curve. These grades allow a minimum clear height above mean lake level of 135 feet for a width over 3,000 feet of the main channel. The minimum clear height at the center of the span is 150 feet. The clearances under the approach viaducts range from 84 feet near the anchorages of the main bridge to a minimum of 20 feet near the south shore or the end of the mole respectively. These clearances are believed to meet fully the requirements of navigation. They are subject, however, to the approval of the department of the Army after a public hearing…"

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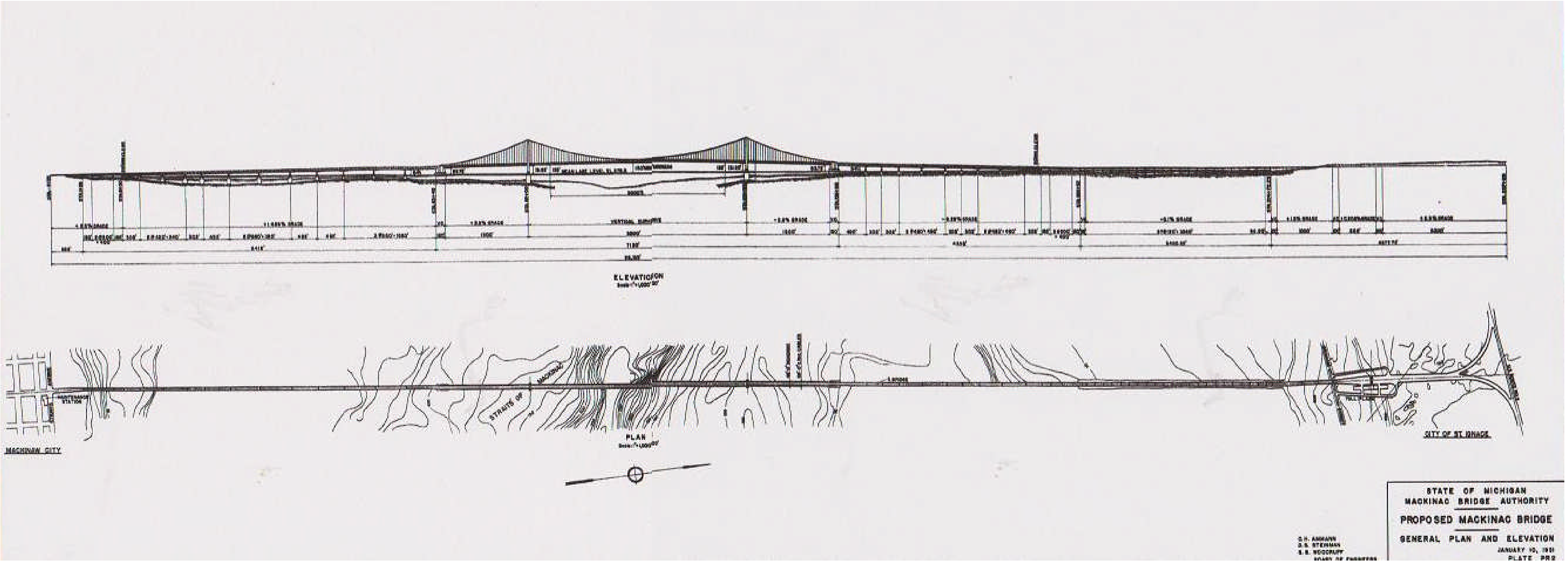
ELEVATION
PLAN
MACKINAW CITY
CITY OF ST IGNACE
STATE OF MICHIGAN
MACKINAC BRIDGE AUTHORITY
PROPOSED MACKINAC BRIDGE
GENERAL PLAN AND ELEVATION
PLATE PR2

Plate No. PR2

District Engineer of the Corps of Engineers for the Detroit District, by Mr. Fred M. Zeder, Chairman of the Engineering Committee of the Mackinac Bridge Authority, Col. Brister answered with the statement that "it appears that the indicated horizontal and vertical clearances would be generally adequate for navigation, however, this opinion must be considered an informal expression not binding in any way on the Department of the Army".

The total length of the proposed bridge and approaches if five miles, made up as follows:

Main Crossing		
Suspension Bridge, including Anchorages	7, 120 ft.	
South Truss Spans	6, 412	
North Truss Spans	4, 392	
		17,924 ft.
Approaches		
Mole Viaduct	3, 420	
Mackinac City Approach	563	
St. Ignace Approach	4, 278	
		8,261
Total length - Bridge and Approaches		26,185 ft.

Floor Construction

One of the controlling factors in the economical design of long span bridges is the weight of the roadway floor. Heavy concrete slabs such as are extensively and appropriately used on shorter bridges become too costly on long spans. In the case of the Mackinac Straits Bridge, in particular, it appeared essential to reduce the weight of that structural element as far as consider-

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"…'It appears that the indicated horizontal and vertical clearances would be generally adequate for navigation, however, this opinion must be considered an informal expression not binding in any way on the Department of the Army'…"

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ations of usefulness and economy of maintenance would permit.

A number of different types of light flooring were considered. In the outer lanes preference was given to a solid flooring consisting of a steelgrid filled with a lightweight concrete and topped, either initially or later, with a layer of bituminous concrete. During most of the time traffic will be confined to this lane.

For the inner lanes, which will be used mainly during the exceptional peak hours, an open-grating floor is proposed. It is the lightest type commercially available at present and has for this reason been used on a number of long-span and moveable bridges on which saving in dead weight in the floor is of importance. Its weight is about one third of that of the solid flooring proposed for the outer lanes.

It is recognized that this open grating flooring has certain disadvantages, such as the somewhat annoying effect of a distinct "hum" from tires passing over the grating and the probability that on the Mackinac Straits Bridge a considerable amount of sanding or spraying with salt will be necessary during the winter season, when the surface may become coated with ice. However, these objections are not considered to be of sufficient importance to outweigh the possible saving in cost due to the lightness of the flooring.

Superstructure of Suspension Bridge

With a central span of 3,800 feet the suspension bridge across the north channel will be second only in length to the Golden Gate Bridge in San Francisco, which has a span of 4,200 feet.

"…For the inner lanes, which will be used mainly during the exceptional peak hours, an open-grating floor is proposed. It is the lightest type commercially available at present and has for this reason been used on a number of long-span and movable bridges on which saving in dead weight is about one third of that of the solid flooring proposed for the outer lanes…"

In its major carrying members, the cables, towers and anchorages, the design of the Mackinac Straits Bridge follows closely the practice established by other modern long-span suspension bridges.

For the four-lane capacity each of the two cables is to be composed of 37 strands, each strand containing 398 wires of 0.192 inch diameter before galvanizing. The finished cables will be 25.6 inches in diameter. A cable sag of 350 feet, or about one eleventh of the center span, is somewhat less than in some other suspension bridges, but is conducive to gracefulness and greater stiffness of the structure.

The steel towers are of the slender flexible type with fixed base. The tower shafts are of cellular construction, with access for the cleaning and painting of all interior surfaces. They reach to a height of about 565 feet above mean lake level. Service elevators are proposed in the towers for more convenient access to all parts.

The two shafts of each tower are connected by horizontal struts, which are also of closed cellular construction. The shafts and struts form integral parts of a rigid frame designed to transmit the large lateral wind forces to the piers.

The anchorages above foundations are conceived as huge concrete blocks to resist the pull of the cables and transmit the same to the foundations. However, through proper distribution of the mass of concrete and by hollowing out as far as practicable, the weight of the anchorage block is reduced to a minimum so as to lighten the load on the deep foundations as far as possible.

- 14 -

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The suspenders which transmit the load of the suspended structure to the cables are standard steelwire ropes. For the four-lane bridge each suspender is composed of four ropes of 1 3/4 inch diameter.

The suspended structure includes two stiffening trusses, one in the plane of each cable. They transmit the floor loads to the suspenders and stiffen the structure against excessive distortions and possible oscillations under the action of dynamic loads and wind forces.

The question of adequate resistance against aerodynamic action has received intensive attention on the part of the engineering profession since the failure of the original Tacoma Narrows Bridge in 1940 both in this country and in England and has been given prominent consideration in connection with the design of the Mackinac Straits Bridge.

This is reflected in several features of the proposed design which differ from those of some of the large suspension bridges built in the past, namely:

1. The stiffening trusses have been given a depth of 45 feet or about 1/85 of the length of the center span. The above ratio is the same as that of the recently completed new Tacoma Narrows Bridge of 2,800 feet span, which under winds of up to 60 miles per hour has not developed any noticeable oscillations. A corresponding ratio of 1/100 has been adopted, after extensive research, for the 3,600 ft. span of the proposed Severn River Bridge in England.

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"…The suspenders which transmit the load of the suspended structure to the cables are standard steel wire ropes. For the four-lane bridge such suspension is composed of four ropes of 1.75 inch diameter. The suspended structure includes two stiffening trusses, one in the plane of each cable. They transmit the floor loads in the suspenders and stiffen the structure against excessive distortions and possible oscillations under the action of dynamic loads and wind forces. The question of adequate resistance against aerodynamic action has received intensive attention on the part of the engineering profession since the failure of the original Tacoma Narrows Bridge in 1940 both in this country and in England and has been given prominent consideration in connection with the design of the Mackinac Straits Bridge. This is reflected in several features of the proposed design which differ from those of the large suspension bridges built in the past, namely;…"

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2. The traverse floor-beams which carry the floor and longitudinal stringers and transmit their load to the stiffening trusses are designed as open trusses in place of solid-web girders, so as to minimize wind pressure against them.

3. Double lateral trusses, one in the plane of the top chords and one in the plane of the bottom chords of the stiffening trusses, are provided. This increases very substantially the torsional rigidity of the suspended structure as compared to that provided by a single system which has been used in a number of large suspension bridges.

4. The relatively narrow floor structure and the fact that the supporting stiffening trusses and cables are located considerably beyond the floor with open spaces between render the section of the suspended structure aerodynamically more favorable than if, as in other bridges, the floor would extend the full width between trusses.

5. The tests made in connection with the redesign of the Tacoma Narrows Bridge and for the design of the Severn Bridge demonstrate the beneficial effects of openings in the floor structure. It is quite possible that the openings need not be as extensive as those proposed in our design.

We have arranged with Professor F. J. Maher for tests on a model of the proposed cross section in the wind tunnel of the Virginia Polytechnic Institute. The results of these tests have reinforced our conclusion that the suspension spans as proposed will be aerodynamically stable and safe against any dangerous or objectionable motions under wind action.

- 16 -

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2. The transverse floor-beams which carry the floor and longitudinal stringers and transmit their load to the stiffening trusses are designed as open trusses in place of solid-web girders, so as to minimize wind pressure against them.

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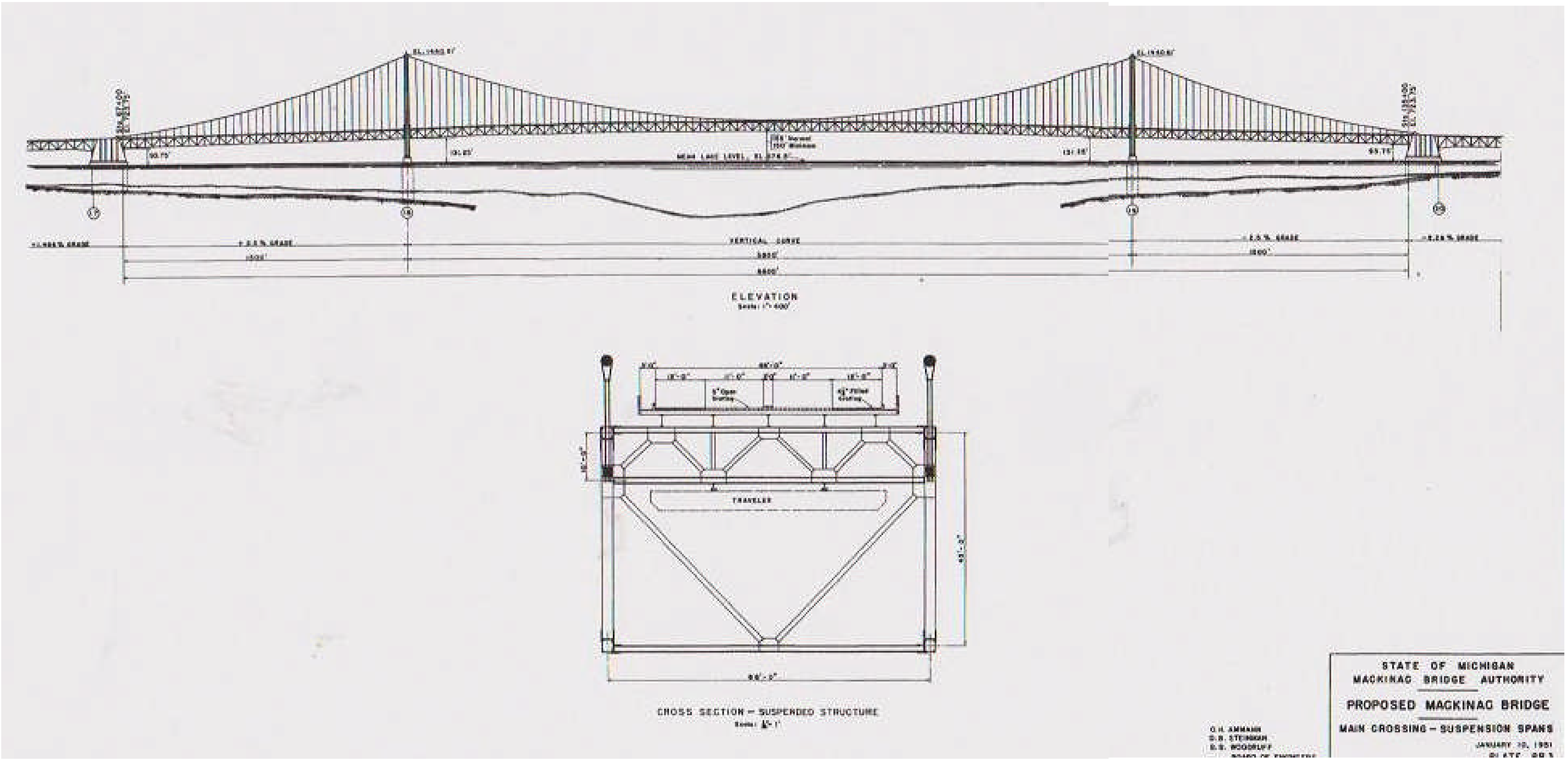
ELEVATION
VERTICAL CURVE
CROSS SECTION – SUSPENDED STRUCTURE
TRAVELER
STATE OF MICHIGAN
MACKINAC BRIDGE AUTHORITY
PROPOSED MACKINAC BRIDGE
MAIN CROSSING – SUSPENSION SPANS
O.H. AMMANN
D.B. STEINMAN
G.S. WOODRUFF

Plate No. PR3

To facilitate access for, and thereby decrease the cost of maintenance of the suspended structure travelling platforms carried on tracks suspended from the floorbeams are proposed for all spans.

Superstructure of Truss Spans

Because of the great depth to rock of 170 ft. in the secondary gorge near the Mackinac City side of the crossing, the layout recommended by Modjeski and Masters in their 1940 report, and some of the layouts studied by us included a secondary suspension bridge.

The secondary suspension bridge, however, was found to offer no economy compared to the design we now propose. Moreover, the secondary suspension bridge had the effect of detracting from the general composition and impressiveness of the bridge. Accordingly, we propose to cross the secondary gorge with continuous truss spans ranging up to 560 ft. in length. These spans are balanced by similar, though shorter, spans north of the suspension bridge where the depth to rock nowhere exceeds 60 ft.

The floor adopted for the truss spans throughout their length of almost two miles is the same as that used on the suspension spans. The center lanes of open grating flanked on each side by a lane of grating filled with light weight concrete and an open grating emergency walkway, all supported on cross beams and continuous stringers yield a light roadway and floor system resulting in maximum economy in the supporting trusses. To keep the size of the foundations to a minimum and to effect maximum economy in the floorbeams, the trusses are set 34 ft. apart and the floorbeams are cantilevered to reduce their required section.

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"…Because of the great depth to rock of 170 feet in the secondary gorge near the Mackinac City side of the crossing, the layout recommended by Modjeski and Masters in their 1940 report, and some of the layouts studied by us included a secondary suspension bridge. The secondary suspension bridge, however, was found to offer no economy compared to the design we now propose. Moreover, the secondary suspension bridge had the effect of detracting from the general composition and impressiveness of the bridge. Accordingly, we propose to cross the secondary gorge with continuous truss spans ranging up to 560 feet in length. These spans are balanced by similar, though shorter, spans north of the suspension bridge where the depth to rock nowhere exceeds 60 feet…To keep the size of the foundations to a minimum and to effect maximum economy in the floor beams, the trusses are set 34 feet apart and the floor beams are cantilevered to reduce their required section…"

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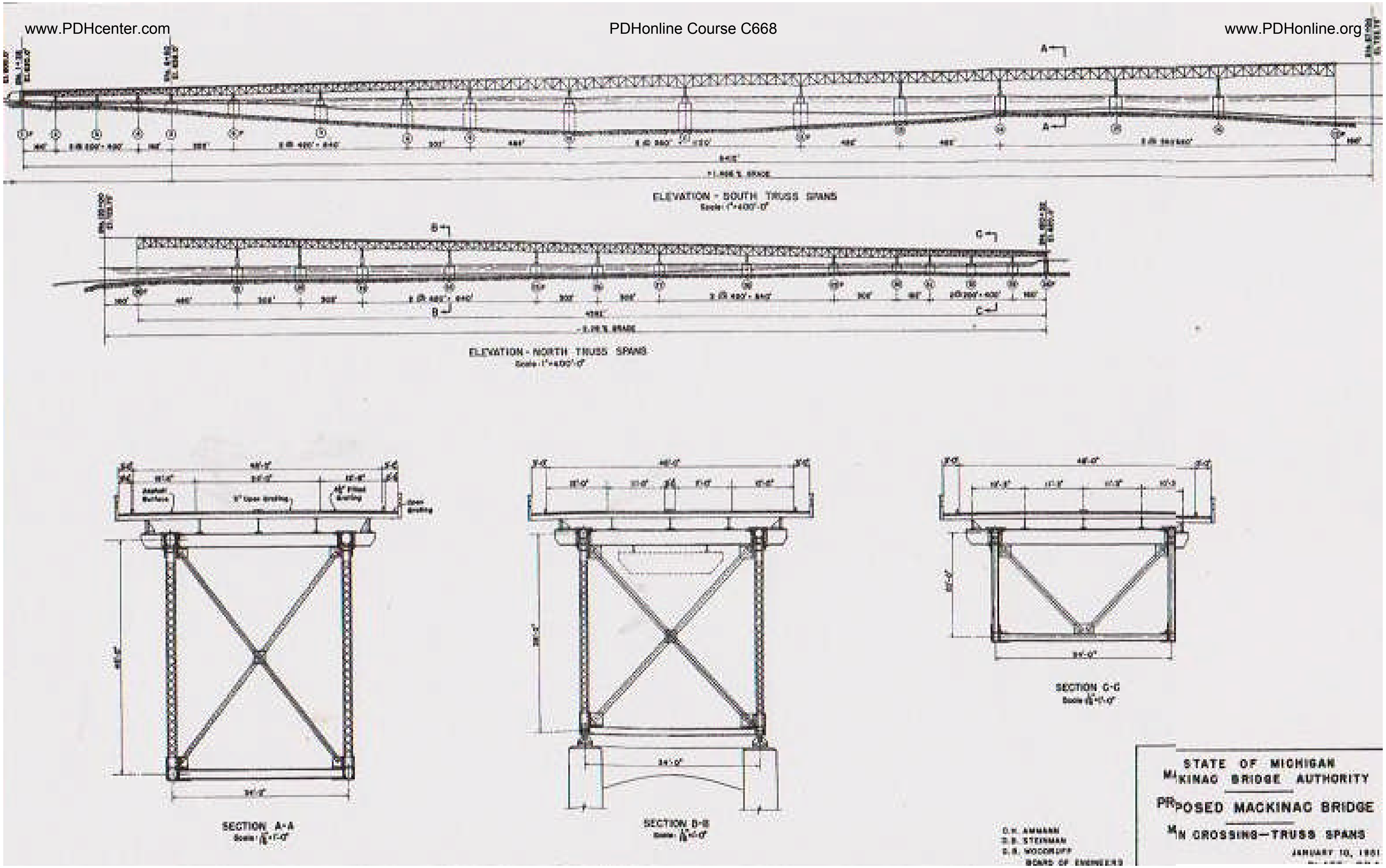

Plate No. PR4

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Analysis and comparative estimates indicated that fairly long spans would be advantageous from the viewpoint of economy and decrease in hazard involved in the construction of piers to the depths required, particularly for the spans south of the main suspension spans. To reduce the number of expansion joints and at the same time to obtain simplicity and economy of detail and erection and minimum cost, the four-span continuous type of construction was adopted for the truss spans.

Maintenance travellers are proposed which can pass under the floors of all spans between the anchorages and the approaches.

Foundations

The recommended layout of the bridge involves 32 subaqueous piers. Of these the largest are the two anchorages and the two main piers of the suspension spans. The six piers at the secondary gorge with depths from 100 to 170 ft., may also be considered major piers.

As a result of the investigations of the underlying rock and of the ice conditions, the substructure has been designed for the live and wind loads outlined above and for the forces arising from the severe assumption of ice four feet thick with a crushing strength of 400 pounds per square inch. The very conservative bearing pressures of 15 tons per sq. ft. for live and dead load, increased to 25 tons for combinations including wind and ice, have been adopted for the design.

In order to prepare reliable cost estimates, complete designs of all piers have been made on the basis of assumed construction methods. Open dredge caissons have been assumed for the major piers and cofferdams for the remainder of the foundations. The cofferdam for the south anchorage, 115 ft. by 180 ft. in plan and extending 140 ft. below lake level, involves a continuous seal pour of 90,000 cu. yds., eclipsing, by far, all past records.

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Approaches

The approaches are naturally divided into three sections: the construction over the 3500 ft. rock faced mole constructed in 1940, the Mackinac City Approach and the St. Ignace Approach.

The rock-faced mole at the north of the Straits was built with the thought that it would be used temporarily as a ferry terminal at its south end and later to carry an earth embankment to support the bridge approach. To protect the roadway from excessive spray from waves breaking on the rock face of the mole, it has been considered advisable to place the roadway surface at a minimum of 30 ft. above lake level. The mole is too narrow to accommodate a four-lane roadway at this level with the necessary side slopes of the embankments. Moreover, tests made on the underlying clays by the State Highway Division indicate the probability of a lateral flow of these clays leading to the failure of the mole if a fill were placed to such height.

Faced with these conditions and after investigating alternate types of construction, we have concluded that the most suitable construction is a series of 29 continuous plate girder spans supporting a reinforced concrete roadway with provision for a future wearing surface of asphaltic concrete.

These girders will be supported by reinforced concrete piers which, in turn, will be supported by concrete piles driven to rock. In this connection, the question arises as to the practicability of driving piles through the rock. During the construction of the fill efforts were made to place the larger rocks at the edge of the fill. This matter has been discussed with representatives of the Highway Department who witnessed the fill construction. The consensus is that, while some difficulties may be experienced, they will not be serious.

For the Mackinac City approach the alternates of filled retaining walls, concrete rigid frames and steel girders with a concrete paving on con-

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"…The approaches are naturally divided into three sections: the structure over the 3,500 rock faced mole constructed in 1940, the Mackinac City Approach and the St. Ignace Approach. The rock-faced mole at the north of the Straits was built with the thought that it would be used temporarily as a ferry terminal at its south end and later to carry an earth embankment to support the bridge approach. To protect the roadway from excessive spray from waves breaking on the rock face of the mole, it has been considered advisable to place the roadway surface at a minimum of 30 feet above lake level. The mole is too narrow to accommodate a four-lane roadway at this level with the necessary wide slopes of the embankment. Moreover, tests made on the underlying clays by the State Highway Division indicate the possibility of a lateral flow of these clays leading to the failure of the mole if a fill were placed to such height…we have concluded that the most suitable construction is a series of 29 continuous plate girder spans supporting a reinforced concrete roadway with provision for a future wearing surface of asphaltic concrete. These girders will be supported by reinforced concrete piles driven to rock…"

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crete piers have been considered. The last has been found the most economical and is therefore recommended. The roadway on this approach will be widened to three lanes in each direction, thereby forming a traffic reservoir in order that the capacity of the bridge will not be controlled by the street intersections in Mackinac City.

The St. Ignace Approach consists of a four lane roadway, partly on embankment, partly in cut, extending northward from the mole to a junction with Highway U.S. 2. At this junction the approach splits to accommodate the traffic turning westward and that continuing northward toward Sault Ste. Marie. An alternate plan has been developed eliminating all grade crossings. This would increase the cost by over $100,000. It is not considered necessary at this time and, therefore, has not been included in the estimates of cost.

Electrical Installations

The electrical installations on the bridge may be divided into the following categories:

1. Required for safety of water and air navigation - navigation lights, radar screen, fog siren and airway beacons.
2. Required for operation of bridge -

   Administration building lighting.
   Lighting of toll plaza.
   Convenience outlets - towers and anchorages.

3. Desirable for operation of bridge -

   Tow and fire call.
   Bridge lighting.
   Traffic signals - north end connection.

A question is whether or not, in the interests of economy, roadway lighting may be eliminated. The estimates which follow are based on a complete installation. Approximately $300,000 could be deducted by omitting such provision from the initial installation.

"…For the Makinac City Approach the alternates of filled retaining walls, concrete rigid frames and steel girders with a concrete paving on concrete piers have been considered. The roadway on this approach will be widened to three lanes in each direction, thereby forming a traffic reservoir in order that the capacity of the bridge will not be controlled by the street intersections in Mackinac City. The St. Ignace Approach consists of a four lane roadway, partly on embankment, partly in cut, extending northward from the mole to a junction with Highway U.S. 2. At this junction the approach splits to accommodate the traffic turning westward and that continuing northward toward Sault Ste. Marie…"

Administration Buildings and Toll Plaza

It is proposed that tolls be collected at a plaza located on the St. Ignace Approach. With the two northbound lanes at their full capacity, approximately 3000 vehicles per hour, and half this volume in the southbound direction, 12 toll collectors will be required. We therefore have based our estimate on a total of 12 lanes through the plaza of which the center four would be reversible in direction.

Adjacent to the Toll Plaza an administration building will be required to house the operating and maintenance personnel. The layout of this building will depend largely on the organization developed for this purpose. We have made layouts of this building, based on experience at other locations, for the purpose of estimates only.

In the case of several major structures it has been found desirable to provide office space for a detail of the State Highway Patrol. Our estimates include $70,000 for this purpose.

Because of the great length of the bridge it will be found desirable to have an auxiliary maintenance building at the Mackinac City end of the bridge. Our estimates allow for this facility.

Our estimates also provide for the necessary operating and maintenance equipment.

CONSTRUCTION SCHEDULE

Because of climatic conditions and especially the ice, the working season for the foundations of the main crossing will be confined to the eight months of April to November inclusive. The erection of steelwork including the spinning of the cables could be carried on during the winter. However, such winter work might be too costly and, for the purpose of setting up the construction schedule, we have assumed a complete shut down during this period.

To minimize the interest charges during construction, it is essential

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"…It is proposed that tolls be collected at a plaza located on the St. Ignace Approach. With the two northbound lanes at their full capacity, approximately 3,000 vehicles per hour, and half this volume in the southbound direction…Adjacent to the Toll Plaza an administration building will be required to house the operating and maintenance personnel…Because of the great length of the bridge it will be found desirable to have an auxiliary maintenance building at the Mackinac City end of the bridge…"

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that the total construction period be reduced to a minimum. We have investigated the records on other major bridges and have discussed the program with experienced contractors. With an adequate amount of construction equipment, especially for the foundations, the assumed schedule given below is entirely practicable.

Sept. 1951	Award Foundation Contract
Season 1952	Anchorages 17 and 20 - First Stage Piers 2-8, 18, 19, 28-33 Mackinac City Approach - Foundations Mole Approach - Foundations St. Ignace Approach - Grading
Season 1952	Erection - Main Towers - Suspension Spans Anchorages - 2nd Stage Piers 9-16 and 21-27 Superstructure - Mackinac City Approach Spans Truss Spans between Piers 2 and 6 Truss Spans between Piers 28 and 30. Mole Approach. Paving St. Ignace Approach
Season 1954	Spinning of Cables Superstructure - Truss Spans between Piers 6 and 16 Truss Spans between Piers 21 and 28 Administration Buildings and Toll Plaza
Season 1955	Complete project

ESTIMATED COSTS - FOUR-LANE VEHICULAR BRIDGE

Following is a general summary of our cost estimate of the project. At this critical time, when many of the building materials, more particularly the metals, are becoming scarce and fabricating plants are working at full capacity, it is very difficult to forecast unit prices. We believe, however, that if it were possible to let contracts on a competitive basis at this time and prospective bidders could be assured of a supply of materials, the cost level would be approximately as we have assumed. We believe, therefore, that our estimates

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are as realistic as possible under present conditions.

Estimate of Cost

Main Bridge	- Foundations	$24,000,000
	- Superstructure, Suspension Spans	29,600,000
	- Superstructure, Truss Spans	10,600,000
Approaches	- Mole Section	2,000,000
	- Mackinac City	500,000
	- St. Ignace	500,000
Administration Buildings and Toll Plaza		500,000
Operating and Maintenance Equipment		400,000
Electrical Equipment		650,000
Borings		250,000
Engineering, Administration & Contingencies		6,900,000
Total Construction Cost		75,900,000
Real Estate		100,000
Preliminary Expenses		300,000
Total Estimated Cost of Project (before financing)		$76,300,000

We have not included an estimate of interest during construction nor other costs connected with the financing, since these will depend largely on the method of financing that the Authority may adopt.

ESTIMATED OPERATING AND MAINTENANCE COSTS--FOUR-LANE VEHICULAR BRIDGE

Pending a determination of the organization for operating the bridge, we submit no estimate in detail of operating and maintenance costs of the pro-

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posed structure. Based on the experience of other major toll bridges, considering the differences in conditions from the other major bridges, and based on an estimate of 1,800,000 vehicles for the first year of operation, we believe that the costs of operation, maintenance and insurance in that year will not exceed $300,000.

With increasing traffic the above would probably increase to $350,000 for the fifth year after opening.

THREE-LANE VEHICULAR BRIDGE

For the reasons given above, we recommend that a four-lane vehicular bridge be constructed. The Authority has requested an alternate estimate on a bridge with three vehicular lanes.

We have made no detail plans for the three-lane bridge. We assume the roadway would be as proposed for the four-lane bridge with 12 ft. of grating eliminated, thereby reducing the weight of the floor by only ten per cent. The width of the suspension spans was fixed for adequate lateral rigidity. No reduction would be advisable for the three-lane bridge. The spacing of the trusses for the other spans of the main crossing could be reduced to 28 ft.

By the A.A.S.H.O. Specifications which we are following in general, a three-lane bridge is designed for 2.7 lane loads, a four-lane bridge for 3.0 lane loads. For the suspension spans the corresponding ratio for the live loads is 1800 to 2000 pounds per lineal foot of bridge. The design of the substructure is controlled to a large extent by the forces assumed for ice action.

From the foregoing it is apparent that a comparatively small saving is possible by reducing the width of the bridge from four to three lanes. Our estimate for the three-lane bridge on a price basis comparable to that used for the four-lane bridge is $70,000,000 (before financing) compared with $76,300,000 for the four-lane bridge. The difference in operating costs between a three and four-lane bridge would be negligible.

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PROVISION FOR RAILWAY FACILITIES

Rail traffic across the Straits of Mackinac is presently handled by car ferries. At the request of the Authority we have investigated the feasibility of providing facilities on the proposed bridge to accommodate rail traffic in addition to the vehicular traffic.

The suspension type structure is required for the long spans over the deep rock gorge, whether the bridge is designed for railway or highway loading. The same span layout as that used for the highway bridge has been assumed for the combined four-lane highway and single track railway bridge.

A single-track railway has been assumed to be sufficient to handle the traffic which can be expected to use the proposed facility, and an E-50 loading has been adopted as adequate. A single track, located under the center of the roadway, is more advantageous than a double track, particularly for the suspension spans on account of the severe distortions of the bridge which would result from loading of one of the two tracks.

The estimated maximum grade change on the suspension span for combined highway and railway loading and temperature change gives a maximum calculated adverse railway grade of three per cent at the towers.

Our estimate of the cost of a combined highway and railway bridge has been prepared on the basis of carrying the railway between the Mackinac City Abutment and the St. Ignace abutment and does not include the cost of bringing the railway to the bridge abutments.

The estimated additional cost for provision of a single-track railway on this bridge is $60,000,000 (before financing).

STUDY OF A SUBAQUEOUS TUNNEL

We have made a study of a four-lane vehicular tunnel at the same site

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as that proposed for the bridge. In this study we have had the advice and assistance of Mr. Ralph Smillie, Consulting Engineer of New York, an outstanding expert on tunnel construction.

The assumed tunnel structure would consist of 56 twin-type precast tunnel sections, each approximately 300 feet long, supported generally at the junctures by multiple steel-shell concrete-lined caissons sunk to rock or to firm material. In the gorge the caissons would have to be sunk to the unprecedented depth of about 300 feet below lake level.

The top of the precast tunnel sections would be located to provide a minimum water depth of 50 feet for a channel width of 12,300 feet, which will allow the largest type vessels to pass. As the tunnel roadways climb towards the shores the tunnel structure would be protected on each side and on top by substantial rip-rap fill.

The length of tunnel from portal to portal would be approximately 16,700 feet. Full use would be made, as in the case of the bridge, of the existing mole on the north side of the strait. Two ventilation buildings have been located approximately at the quarter points between portals, each building housing 32 ventilation fans with attendent electrical switch boards and controls. Ventilation in the tunnel will be by the transverse distributed method, similar to that used in the principal vehicular tunnels around New York City.

The study is not entirely completed, but approximate estimates indicate that the cost of the tunnel project may be as high as $141,000,000.00 (before financing).

The estimated cost of operation for the first year is approximately $1,000,000.00.

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"…We have made a study of a four-lane vehicular tunnel at the same site as that proposed for the bridge…The assumed tunnel structure would consist of 56 twin-type pre-cast tunnel sections, each approximately 300 feet long, supported generally at the junctures by multiple steel-shell concrete-lined caissons sunk to the rock or to firm material. In the gorge the caissons would have to be sunk to the unprecedented depth of about 300 feet below lake level. The top of the pre-cast tunnel sections would be located to provide a minimum water depth of 50 feet for a channel width of 12,300 feet, which will allow the largest type vessels to pass. As the tunnel roadways climb towards the shores the tunnel structure would be protected on each side and on top by substantial rip-rap fill. The length of tunnel from portal to portal would be approximately 16,700 feet… Ventilation in the tunnel will be by the transverse distributed method, similar to that used in the principal vehicular tunnels around New York City…the cost of the tunnel project may as high as $141,000,000 (before financing)…"

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Conclusions

CONCLUSIONS

The conclusions from our investigations as outlined in this report may be summarized as follows:

1. The construction of a bridge across the Straits of Mackinac with construction methods which have proven successful on other large bridges in entirely feasible.

2. The location of a bridge directly northward from Mackinac Point is more suitable than other locations which had previously been proposed.

3. It has been definitely established that the rock formation underlying the Straits has much greater strength than necessary to resist the moderate pressures which would be imposed upon it by the structure, even under severest combination of ice and wind forces.

4. A bridge designed for two lanes of traffic in each direction is recommended. It will be adequate for a reasonable number of years to come. The proposed design provides for the heaviest vehicular loadings specified by the American Association of State Highway Officials. Special attention was given in the design of the long-span suspension structure to assure safe resistance against dynamic wind action.

5. The bridge can be completed, ready for traffic, within four years of the award of the first construction contract.

6. Based on prevailing prices we estimate that the bridge can be built as proposed at a sum of $76,300,000, exclusive of the cost of financing and interest during construction.

7. Operating and maintenance expenses are estimated at $300,000 during the first year.

8. A bridge with three traffic lanes would cost only about $6,300,000 less than one with four lanes and is not recommended.

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1. ***The construction of a bridge across the Straits of Mackinac with construction methods which have proved successful on other large bridges is entirely feasible.***
2. ***The location of a bridge directly northward from Mackinac Point is more suitable than other locations which had previously been proposed.***
3. ***It has been definitely established that the rock formation underlying the Straits has much greater strength than necessary to resist the moderate pressures which would be imposed upon it by the structure, even under severest combination of ice and wind forces.***
4. ***A bridge designed for two lanes of traffic in each direction is recommended. It will be adequate for a a reasonable number of years to come. The proposed design provides for the heaviest vehicular loadings specified by the American Association of State Highway Officials. Special attention was given in the design of the long-span suspension structure to assure safe resistance against dynamic wind action.***
5. ***The bridge can be completed, ready for traffic, within four years of the award of the first construction contract.***
6. ***Based on prevailing prices we estimate that the bridge can be built as proposed at a sum of $76,300,000, exclusive of the cost of financing and interest during construction.***
7. ***Operating and maintenance expenses are estimated at $300,000 during the first year.***
8. ***A bridge with three traffic lanes would cost only about $6,300,000 less than one with four lanes and is not recommended.***

continued….

9. The construction of a four-lane subaqueous tunnel is feasible, but its construction would involve unprecedented operations. Its construction cost would be much greater than for a bridge and the cost of operation would also be materially higher.

10. Provision for a single track standard railway is feasible, but it would increase the cost of the four-lane highway bridge by approximately $60,000,000 (before financing), in addition to the cost of necessary railway approaches.

11. The estimates of traffic and revenue made by Coverdale & Colpitts indicate that a four-lane bridge as proposed herein is economically justified and feasible if the saving of present costs of the ferry operation is taken into consideration.

We acknowledge the courtesies extended throughout our investigation by the Authority. Its Secretary, Mr. Lawrence A. Rubin, has been most helpful in securing the basic data for our investigations.

The State Highway Department has rendered valuable assistance in our studies. The advice and cooperation of State Highway Commissioner Charles M. Ziegler, Mr. George M. Foster, Bridge Engineer, Mr. W. W. McLaughlin, Director of Testing and Research, and Professor W. S. Housel have been most helpful.

In connection with our study of the geology of the site we acknowledge the aid freely given by State Geologist G. E. Eddy, Mining Engineer F. G. Pardee, and Professors K. K. Landes and G. M. Ehlers of the University of Michigan.

We have drawn freely on the previous studies for a bridge at this location, including those of Mr. C. E. Fowler, Mr. James E. Cissell and Modjeski and Masters.

…continued

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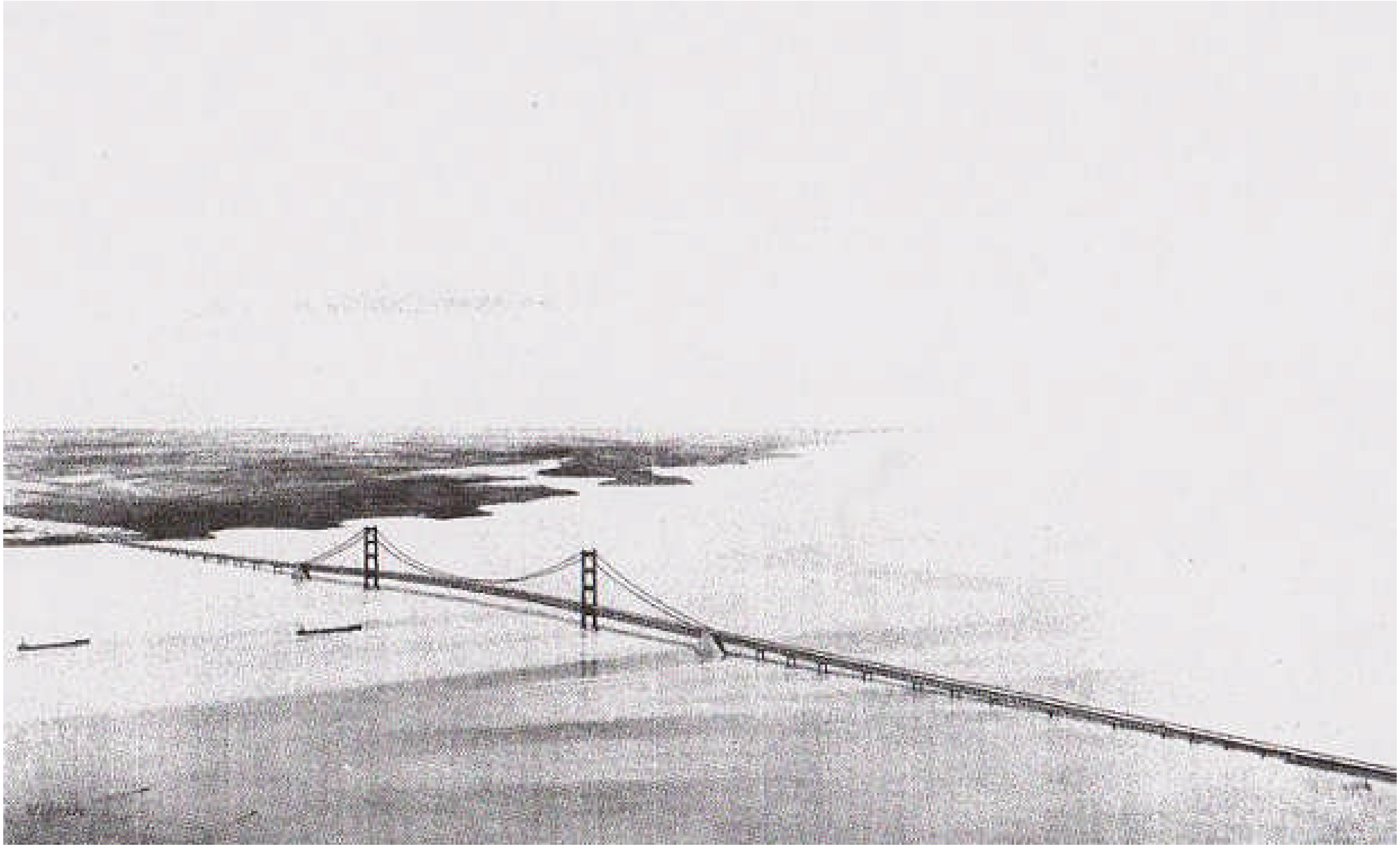

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In January of 1951 the new *Mackinac Bridge Authority* (MBA) submitted their very favorable preliminary report stating that a bridge could be built and financed with revenue bonds for +$76 million. However, because of the shortage of materials due to the *Korean War*, legislation to finance and build the structure was delayed until early in 1952. Immediately, the Authority asked the *Reconstruction Finance Corporation* (RFC) to purchase $85 million worth of bonds. In April 1952, the *Michigan State Legislature* authorized the bridge authority to issue bonds for the project, choose an engineer and proceed with construction. The authority selected *David B. Steinman* as the Chief Engineer in January 1953. While the RFC was studying the request, a private investment banker became interested in the project and offered to manage a group of investment companies which would underwrite the sale of the bonds. The Authority accepted the offer and was ready to offer its bonds for sale by March of 1953. In April 1953, the authority tried unsuccessfully to sell the bonds. However, there were not enough takers to guarantee successful underwriting of the bonds due to a weakening in the bond market. In order to make the bonds more attractive, the state legislature passed an act during the spring of 1953 whereby the operating and maintenance cost of the structure; up to $417K annually, would be paid for out of gasoline and license plate taxes. Another effort to provide financing with this added incentive (in June 1953) was also unsuccessful. Fortuitously, by the end of the year the bond market had recovered and $99,800,000 worth of *Mackinac Bridge* bonds were bought by investors all over the country. Contracts which had been awarded contingent upon this financing were immediately implemented. With financing in-place, construction of the great bridge could begin in earnest.

The Father of the Mackinac Bridge

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"…Now 64 years old, Prentiss Brown spent a lifetime in his old home town of Saint Ignace, Michigan. He was once a bellhop at the old Astor Hotel on Mackinac Island. Probably the bridge idea would have died completely in the last year - if it had not been for an incident that happened to Brown 34 years ago. He was 30 years old then and a lawyer. He was scheduled to appear before the State Supreme Court in Lansing to argue a case. Brown had to get across the Straits to catch a train at Mackinaw City. However, both of the ferry boats were stuck in the winter ice. He and another hardy voyager, who also had important business on this side of the Straits, hired a horse and a cutter. They started across the ice. They ran into ice hummocks ten feet high and had to send the cutter back to Saint Ignace. They proceeded on foot. They ran into 50 acres of open water, like a big pond, and had to circle it. All in all, they hiked four miles across the ice. The wind was blowing up a small gale. It was snowing. By the time they had spent most of the day walking - well, they missed their train. Brown said in a recollection today, 'That bitter hike across the Straits made a lasting impression on me - for the need of a bridge across the Straits.' Prentiss Brown never forgot. That is the reason that 20 years ago Brown became legal counsel for the first Mackinac Bridge Commission. Back in 1933 under Governor Comstock. And Prentiss worked for love. He would accept no money. Four years ago he became chairman of the Mackinac Bridge Authority…"

RE: *Jack Carlisle* - in a radio broadcast over radio station WWJ on Feb. 22nd 1954.

"…After a 20-year fight which often seemed hopeless, there finally is going to be a five-mile bridge across the Straits of Mackinac. As one of the states most ambitious projects, it will link Michigan's two peninsula's. It will cost about $99 million. It is scheduled for completion in November, 1957. The bridge project had many stalwart partisans. However, the project actually became a reality through the determination of one man - Prentiss M. Brown, Chairman of the Michigan Mackinac Bridge Authority. Brown, a former United States Senator and Chairman of the Board of the Detroit Edison Company, refused to accept defeat when it seemed inevitable. Prentiss M. Brown just wouldn't stay licked. His energetic determination to get the Mackinac Bridge financed is undoubtedly due to the fact that he was born and raised in the midst of a daily realization of the need for the bridge…Michigan will not soon forget the gallant fight of Prentiss M. Brown for the Straits of Mackinac Bridge."

RE: *Jack Carlisle* - in a radio broadcast over radio station WWJ on February 22nd 1954, told his listeners of Brown's long struggle. For his tireless and selfless efforts, Prentiss M. Brown would forever be remembered as: "The Father of the Mackinac Bridge."


Prentiss M. Brown
Father of the
Mackinac Bridge
May 30th
2003
MACKINAC BRIDGE
2003
AUTHORITY

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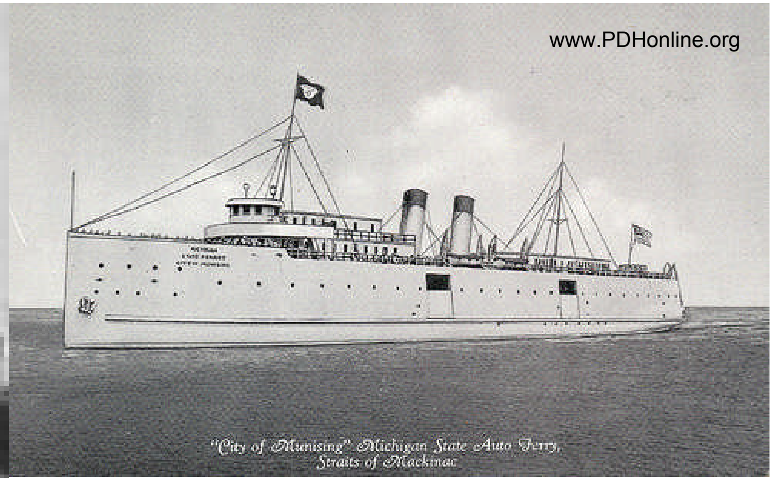
Formal ceremonies held at *St. Ignace* and *Mackinaw City* on May 7-8, 1954 officially began construction of the bridge. *Chapman & Scott Corporation* won the $25,735,600 contract to build all the foundations leading to the mobilization of the largest bridge construction fleet ever assembled. The major construction achievement of 1954 was the erection of the bridge's six principal piers, including those for the two towers, the anchorages and the backstay spans. Enormous steel caissons were sunk into the mud under the straits and then driven to bedrock. After removing all the mud and loose rock, two reinforced concrete piers, which extended to bedrock, more that 200-feet below the water's surface, were poured. In 1955, the remaining twenty-eight piers were built and the anchorage was completed. The *American Bridge Division* of *United States Steel Corporation* (USS) was awarded a $44,532,900 contract to build the superstructure of the bridge, inclusive of all the various steel shapes for the towers, suspended deck, wire-rope suspenders and parallel wire cables The *Mackinac Bridge* began to take shape in 1956, when the main cables were strung and the twenty-eight truss spans that made up the approaches were built. The four-year construction effort ended in 1957, with the erection of the main suspension span and paving of the roadway. The new bridge opened to traffic on November 1st 1957, according to schedule, despite the many hazards of marine construction over the turbulent *Straits of Mackinac* (although the contractors did not complete all the work until September 1958). The official bridge dedication ceremonies began on June 25th 1958, with the first "Governor's Walk" across the bridge and ended four days later. The last of the Mackinac Bridge bonds were retired July 1st 1986. Fare revenues are now used to operate and maintain the bridge in perpetuity. On-going maintenance of the bridge included a resurfacing of the deck and replacement of the center lane/s grating.

<u>Above</u>: the opening of the *Mackinac Bridge* in November 1957 ended decades of the two peninsulas being solely linked by ferries. Nine months later, the five-mile bridge (including approaches) was formally dedicated as the world's longest suspension bridge between cable anchorages.

<u>Left</u>: except for the early 1940s; the WWII years (when gas rationing sharply curtailed travel), the ferry business rose year after year. Vehicles carried by the fleet topped 900K for the first time in 1955. The record was broken again in the first ten months of 1957. When he Mackinac Bridge opened to traffic on November 1st 1957 the ferry fleet was no longer needed, effectively ending ferry service across the straits.

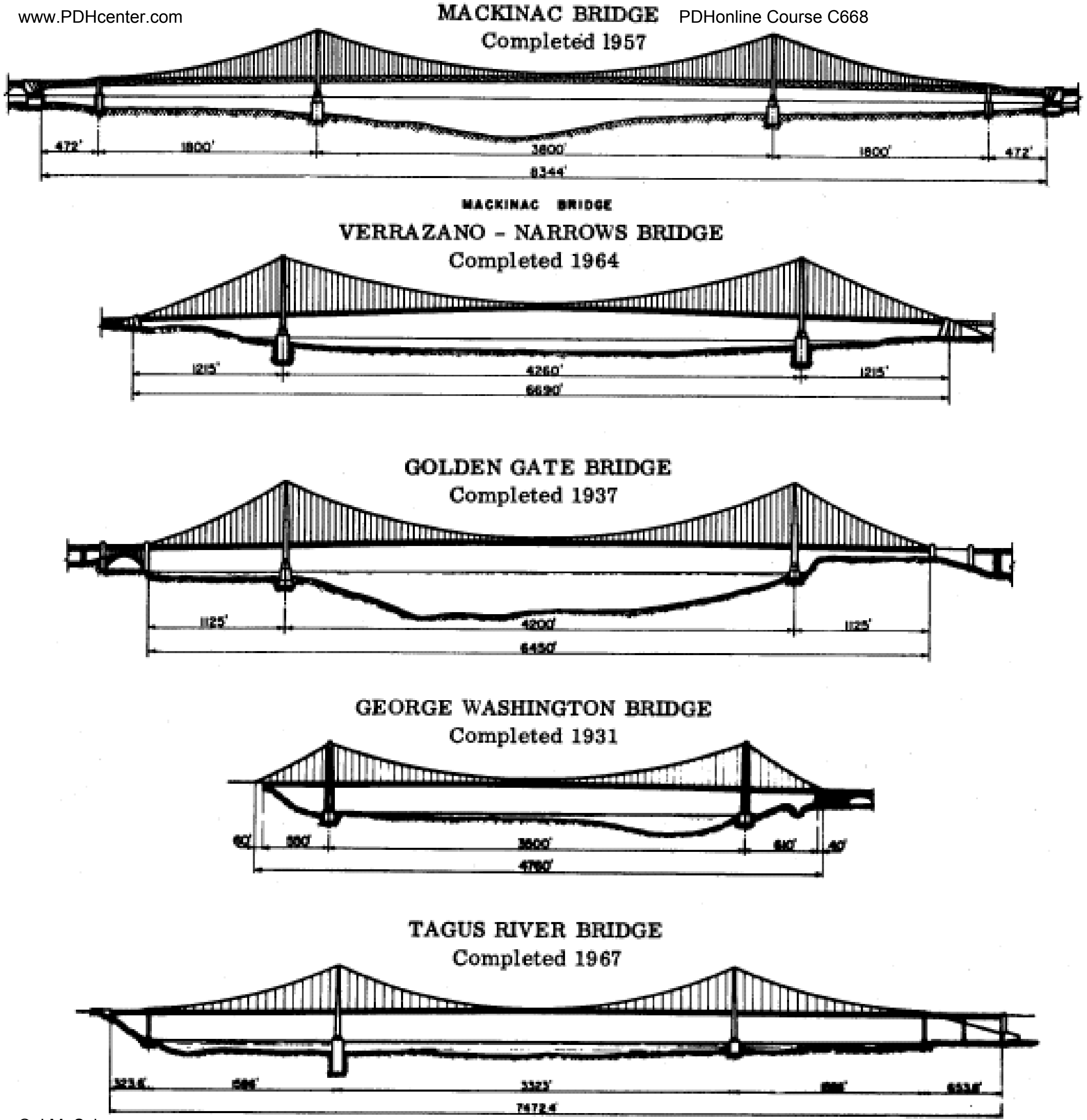


<u>Above</u>: caption: “Built by the American Ship Building Company of Cleveland in 1903 for the Pere Marquette Railway Company, the ‘Pere Marquette 20’ became the ‘City of Munising’ in 1937. The Michigan Department of Highways used the ship to ferry autos across the Straits of Mackinac until 1959.”

<u>Left</u>: caption: “Mackinaw Straits Ferry - Mackinaw, Michigan - 1950 When the Mackinac Bridge opened to traffic on November 1, 1957, car ferry service between Mackinaw City and St. Ignace ended. In 34 years of service, the ferries operated by the Department of State Highways carried approximately twelve million vehicles and more than thirty million passengers across the Straits of Mackinac.”

"Second only to the Golden Gate bridge in tower-to-tower span, a proposed suspension bridges and its approaches will connect the upper and lower peninsulas of Michigan across the Straits of Mackinac. Distance between its two 565 foot towers will be 3,800 feet, 400 less than the San Francisco bridge, though the distance between cable anchorage points will be longer – 8,614 feet. Approach viaducts will be supported by 34 concrete piers heavy enough to resist terrific ice pressure and varying in depth from 50 to 200 feet below water level. The bridge will clear the water by 20 to 84 feet under the approach viaducts and 135 to 150 feet under the main span. With approaches, the four-lane bridge will be five miles long, will eliminate the present ferries and cut crossing time from 53 minutes to 10 minutes. Costing approximately $95,000,000, it is scheduled to be finished Nov. 1, 1956. Toll charges are expected to pay for the structure in twenty years."

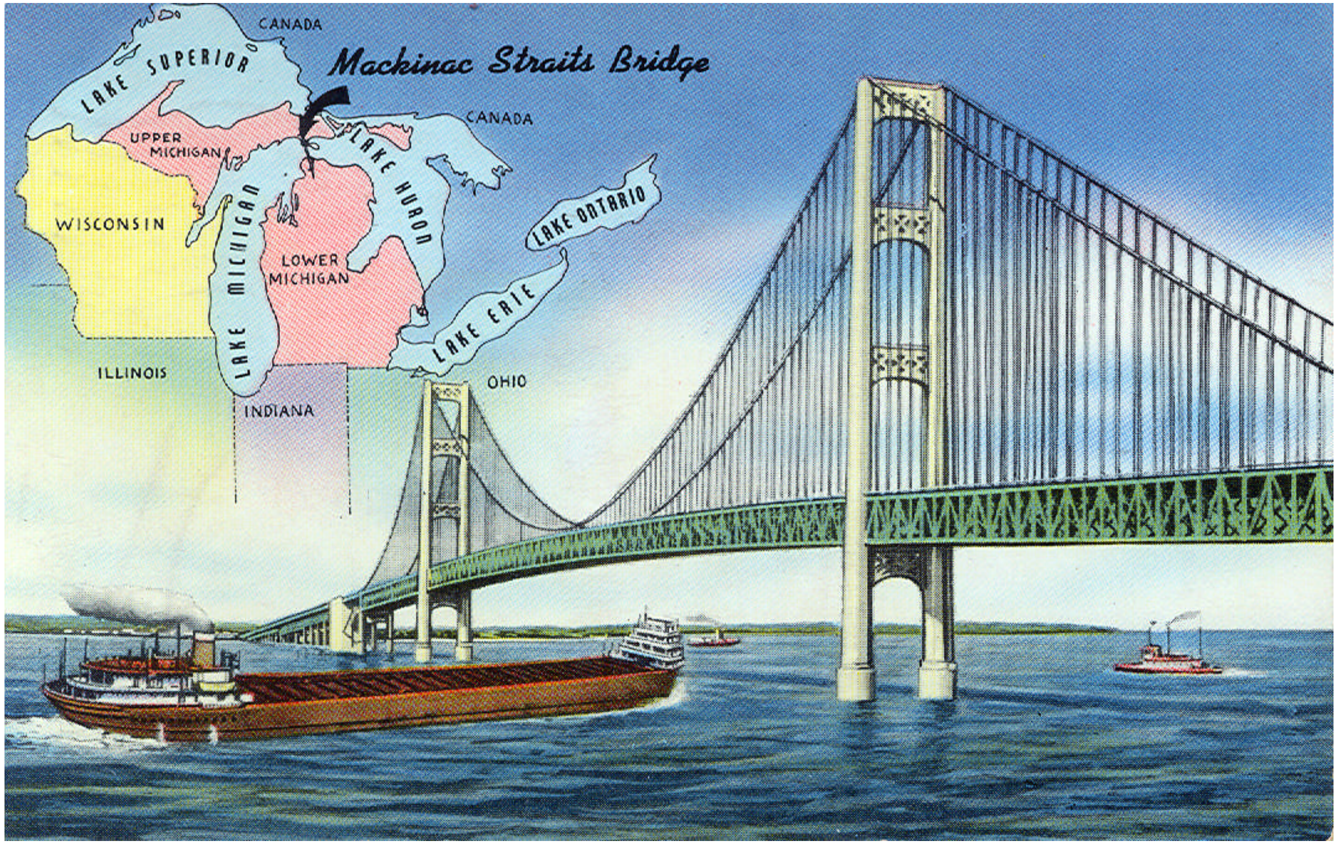
***Popular Mechanics,* August 1953**



<u>Left</u>: caption: "Comparative Magnitude of World's Great Suspension Bridges." By stating: "between anchorages," the bridge could be considered longer than the *Golden Gate Bridge*, even though the Golden Gate Bridge's main span exceeds that of the *Mackinac Bridge.* The Mackinac Bridge remains the longest suspension bridge between anchorages in the western hemisphere. The length of the bridge's main span (between towers) is 3,800-feet, which makes it the third longest suspension span in the *United States*, behind the Golden Gate (4,200-feet) and *Verrazano-Narrows* (4,260-feet) bridge/s. At present (2013), it is the twelfth longest bridge in the world. The Mackinac Bridge was recognized as a *National Historic Civil Engineering Landmark* by the ASCE in 2009.

"The dream at last was a reality of steel and stone. Michigan's two great peninsulas were linked and the state was united. The barrier was forever broken"

David B. Steinman


Mackinac Straits Bridge
CANADA
LAKE SUPERIOR
CANADA
UPPER MICHIGAN
LAKE HURON
WISCONSIN
LAKE MICHIGAN
LOWER MICHIGAN
LAKE ONTARIO
LAKE ERIE
ILLINOIS
INDIANA
OHIO

Part 2

The Bridge Builder

Pontifex Maximus

***David Bernard Steinman* (1886-1960) grew up in New York City's *Lower East Side* – one of six children born to Russian-Jewish immigrants. He was raised in the shadow of the *Brooklyn Bridge* (1883). In fact, the bridge's designer: *John Augustus Roebling,* was a childhood hero to him. The late 19th and early 20th century/s were a time of significant bridge construction on the lower *East River*; *Williamsburg Bridge* (1903), *Manhattan Bridge* (1909). From watching these bridges being built as a child, he gained a fascination with bridges. He put himself through both the *City College of New York* (graduating Summa Cum Laude in 1906) and then *Columbia University*, where he completed three additional degrees culminating in a PhD in *Civil Engineering* (his PhD thesis was gased on a steel truss arch design for the *Henry Hudson Bridge*). After teaching at the *University of Idaho* from 1910 to 1914, he returned to NYC to work as a "special assistant" to bridge engineer *Gustav Lindenthal* on the *Hell Gate Bridge* (1917). Another special assistant to Lindenthal was *Othmar H. Ammann* – a brilliant Swiss engineer who would go on to become the Chief Engineer of the *Port of New York Authority* and build six major bridges in NYC during his long career. It was from their mutual experience working on the Hell Gate Bridge under Lindenthal that a life-long rivalry developed between the two great bridge engineers. In 1921, Steinman and *Holton D. Robinson* (1863-1945) formed the firm of *Steinman & Robinson.* Steinman and Robinson later became *Steinman, Boynton, Gronquist & Birdsall*, carrying Steinman's name until it was bought by the *Parsons Corporation* in 1988.**

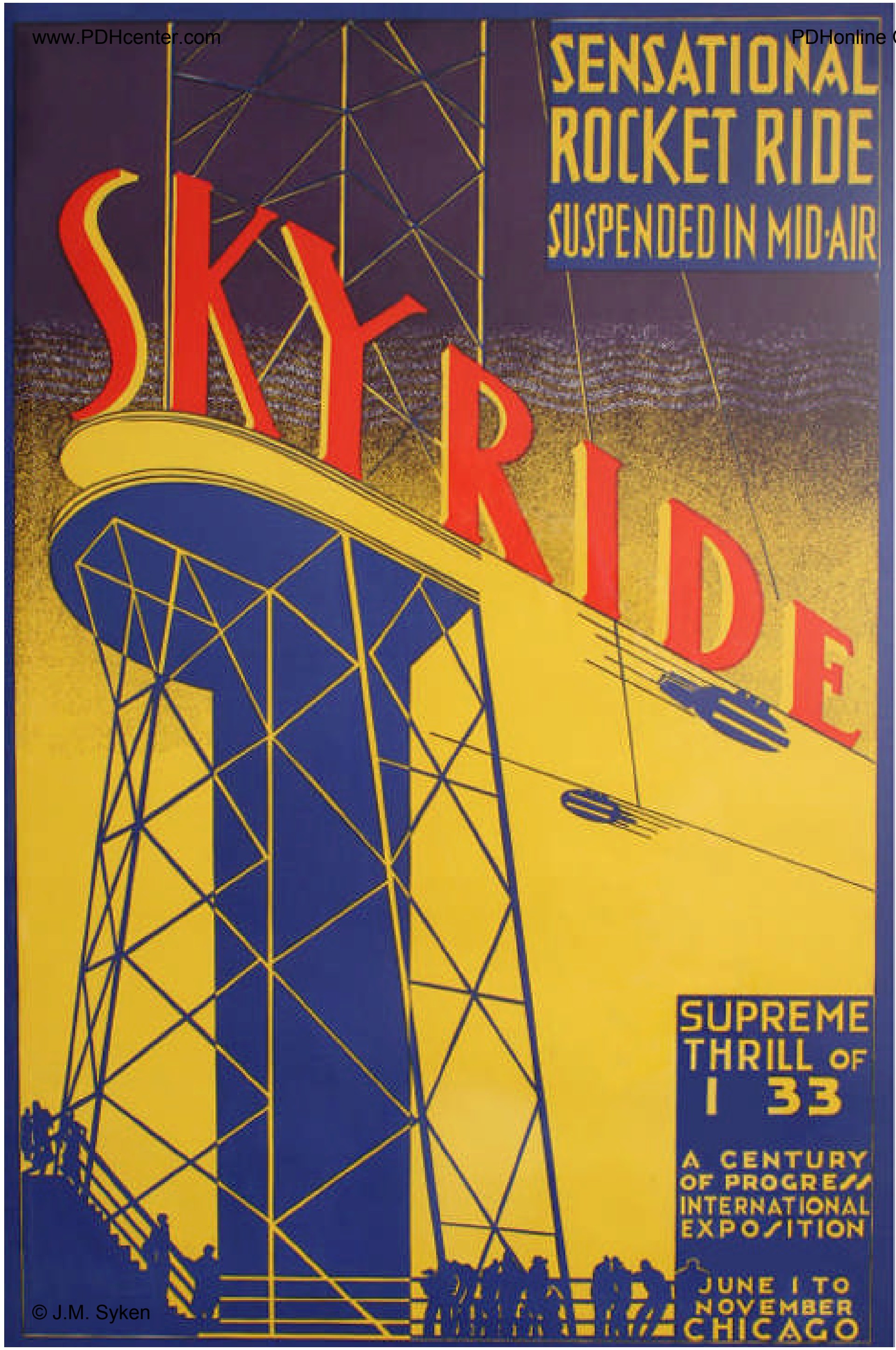
"Steinman, bridge engineering is easy. It's the financial engineering that's hard"

Gustav Lindenthal

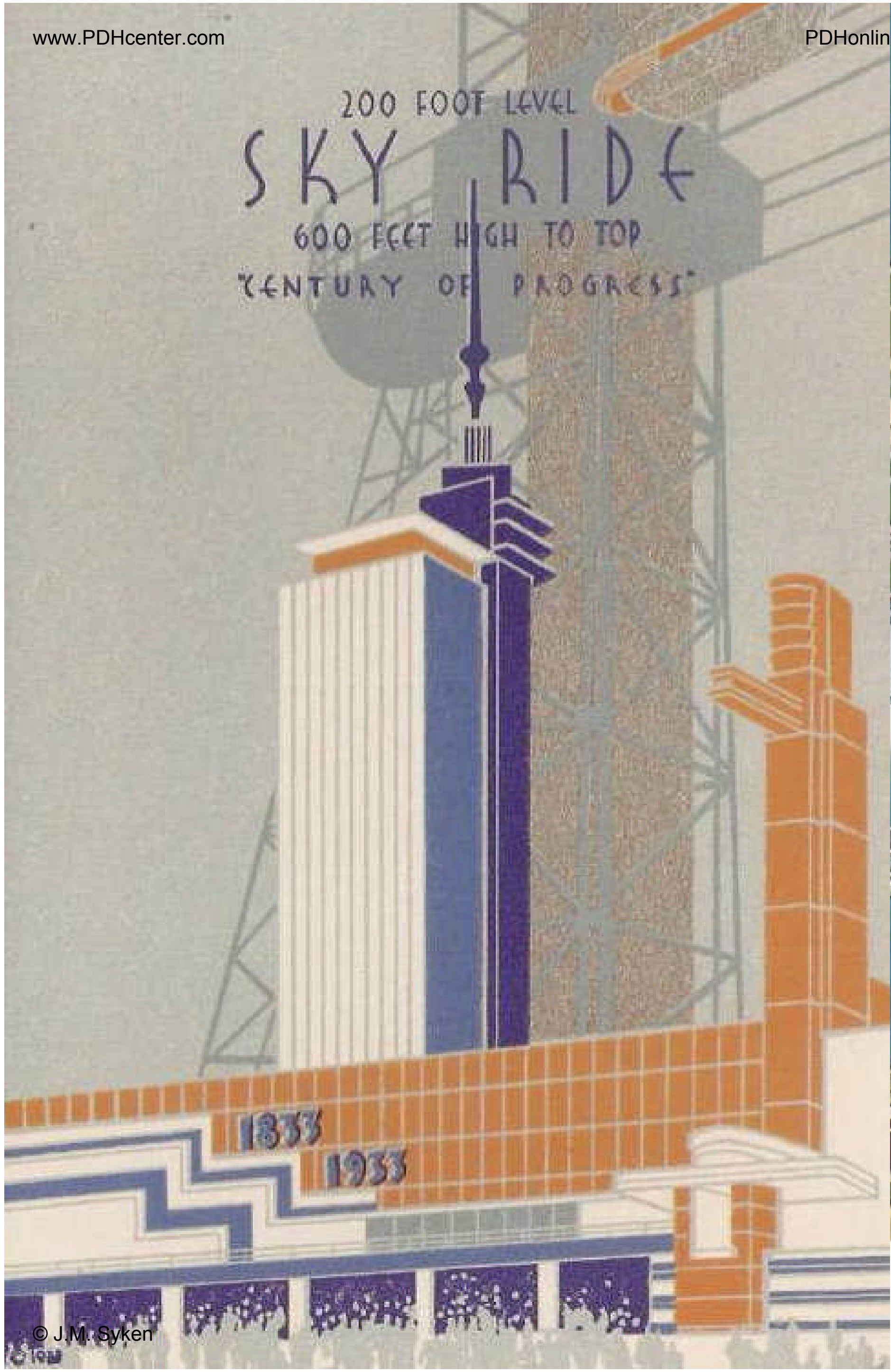
Above: *Hell Gate Arch* (present-day)

Left: the engineering staff pose for photograph near Hell Gate Arch during construction (October 1916). *Gustav Lindenthal* (highlighted) is the large man at center with *D.B. Steinman* to his immediate left. *O.H. Ammann* is to his immediate right.

Steinman was well regarded in the engineering profession and had a reputation for good presentations and for being politically astute. The early 1920s were, in general, a difficult time for bridge construction. Thus, Steinman designed his bridges to be economically (rather than aesthetically) pleasing, without sacrificing structural integrity. A case-in-point was the design for the *Florianopolis Bridge* (a.k.a. Hercilio Luz Bridge) in *Florianopolis, Brazil* (1926). Steinman changed the original plans for the Florianopolis Bridge (above), using eyebar chains as the upper chord of the stiffening truss instead of conventional wire-cable. The new design produced a very stiff bridge with much less material than originally called for. Competing bridge engineers (i.e. *O.H. Ammann*) would, no doubt, have to take Steinman's economical design innovations into account when competing with him. 91



The late 1920s an 1930s were a busy period for *Steinman & Robinson*. His firm was involved in many significant projects including the San Francisco Bay's *Carquinez Strait Bridge* (1927) - at the time the second largest cantilever bridge in the U.S., the *Mount Hope Bridge* and *Grand Mere Suspension Bridge* (both in 1929), the *St. Johns Bridge* and *Waldo-Hancock Bridge* (both in 1931), the *Sky Ride* (poster at left) – a passenger transporter at the *Century of Progress International Exposition* in *Chicago* (1933), the *Henry Hudson Bridge* (1936), the *Marine Parkway Bridge* (1937), the *Wellesley and Hill Islands Bridge*, *Wellesley Island Suspension Bridge* and *Georgina Island Bridge* and part of the *Thousand Islands Bridge System* (all in 1938), the *Deer Isle Bridge*, the *Sullivan-Hutsonville Bridge* (both in 1939).



THE SKY RIDE. VIEW FROM THE WEST TOWER

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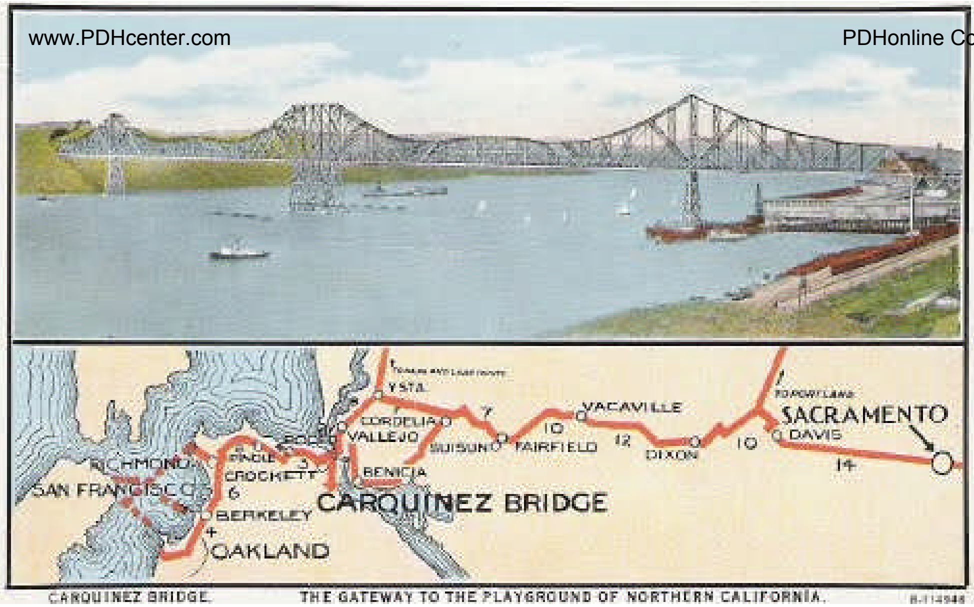
BROTHER CRAWFORD
51284

"…Steinman's strength in the theoretical aspects of bridge engineering and Robinson's practical experience in construction complemented each other, and the office of Robinson and Steinman began obtaining commissions for significant structures…Although Steinman had the opportunity to work on many types of bridges, his technological legacy is almost always associated with suspension bridges. One design innovation developed by Steinman is the use of a center tie to rigidly connect the superstructure to the main cables, as a way of stiffening and stabilizing the superstructure…"

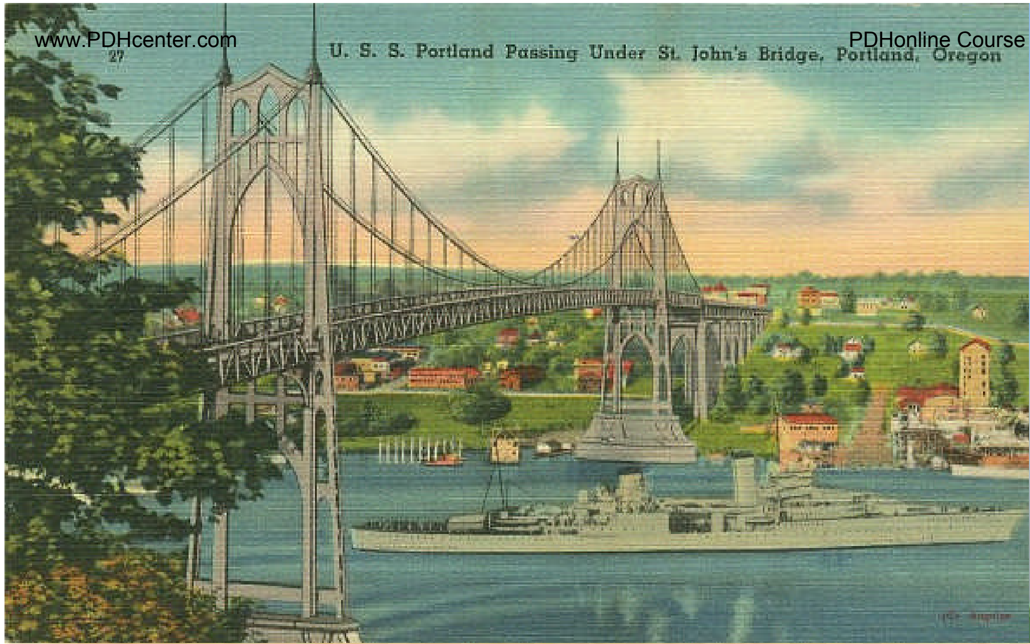
***Maria Grazia Bruschi*, Structural Engineer**



Top Left: ***Carquinez Strait Bridge*** **(San Francisco, CA)**

Top Right: ***Mount Hope Bridge*** **(Newport, RI)**

Left: ***Grand Mere Suspension Bridge*** **(Quebec, Ca)**

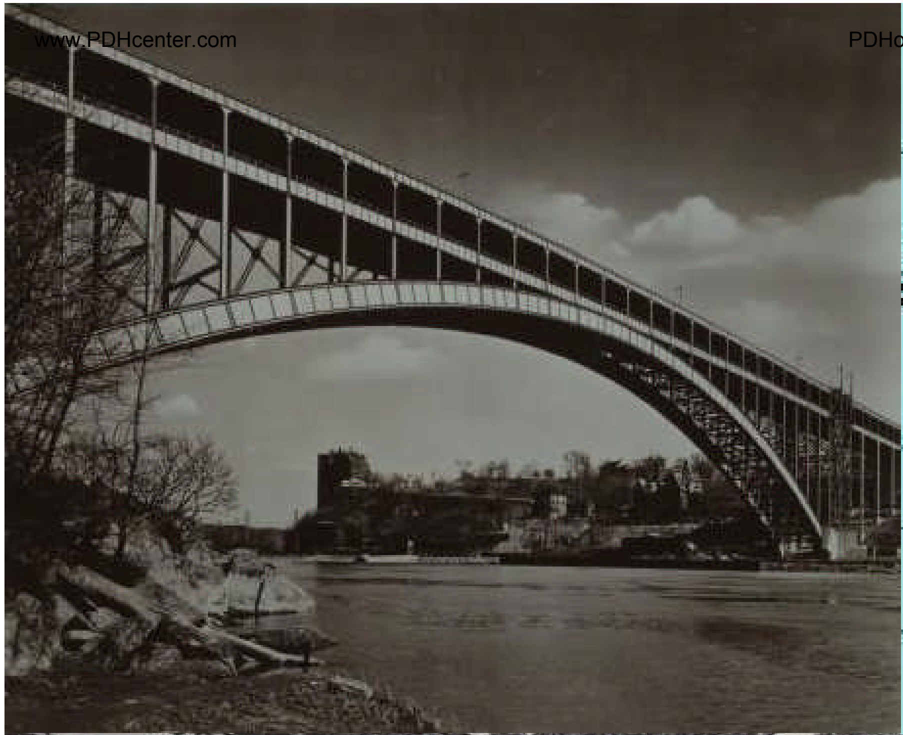


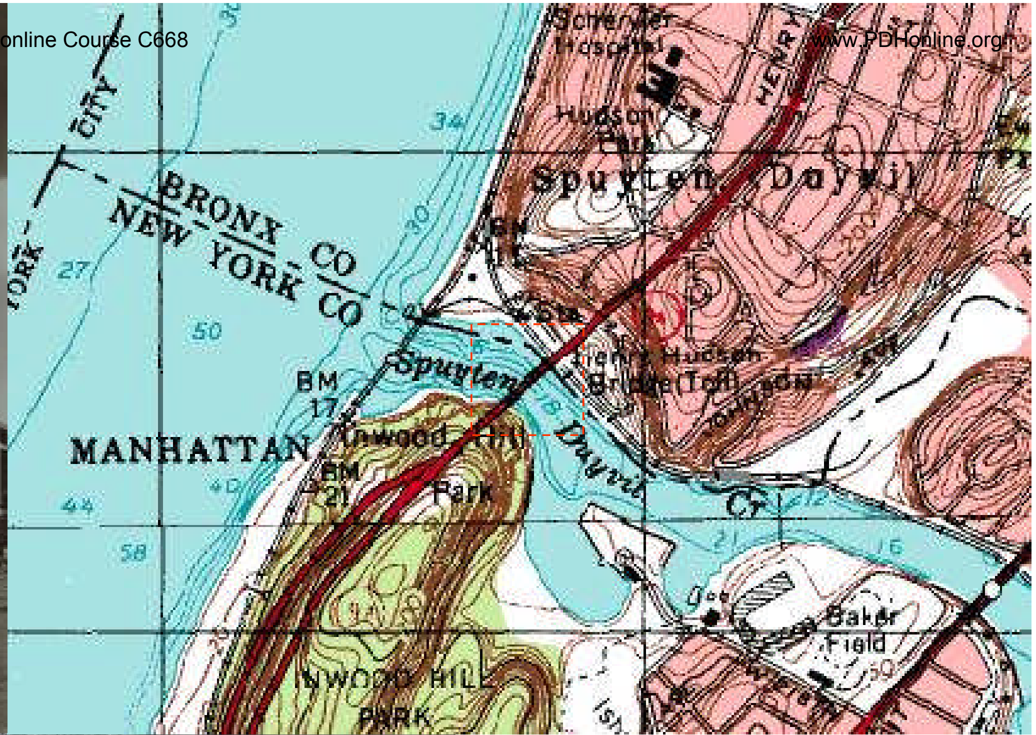
"If you asked me which of the bridges I love best, I believe I would say the St. Johns bridge. I put more of myself into that bridge than any other bridge"

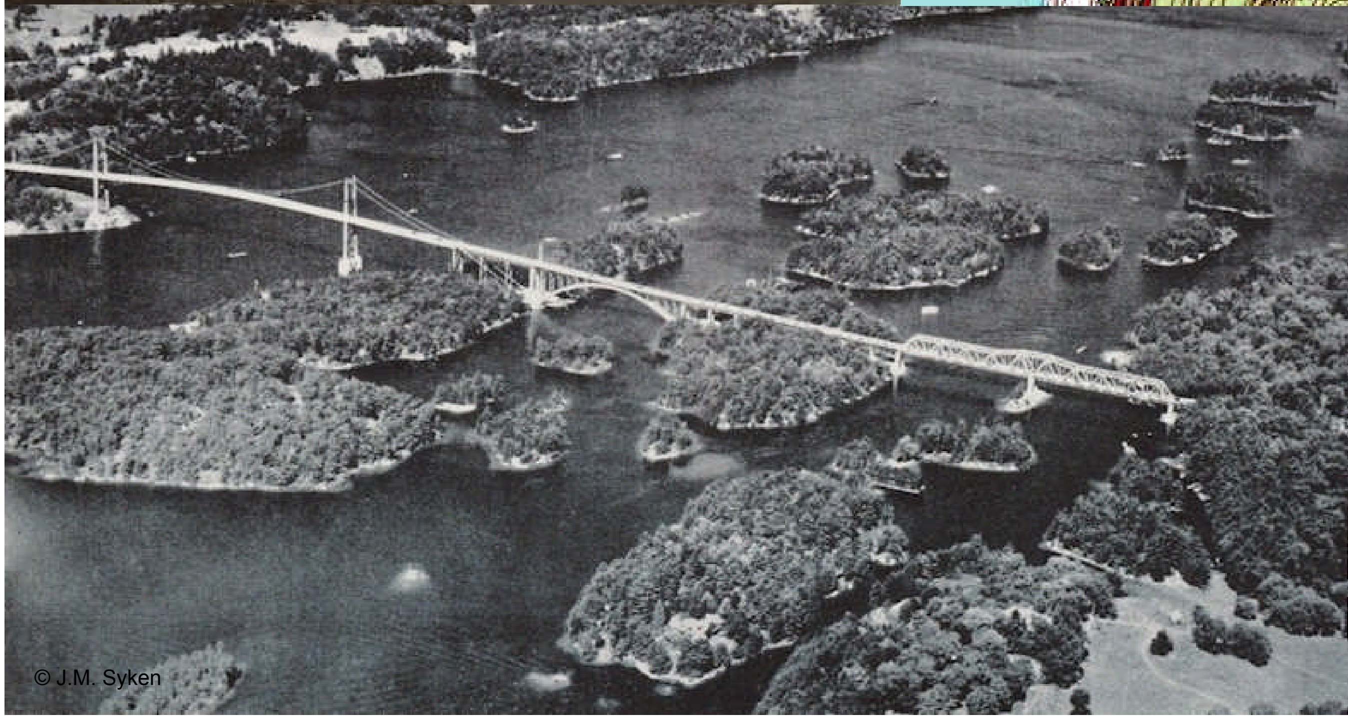
D.B. Stenman

<u>Top L&R</u>: ***St. John's Bridge*** **(Portland, OR)**

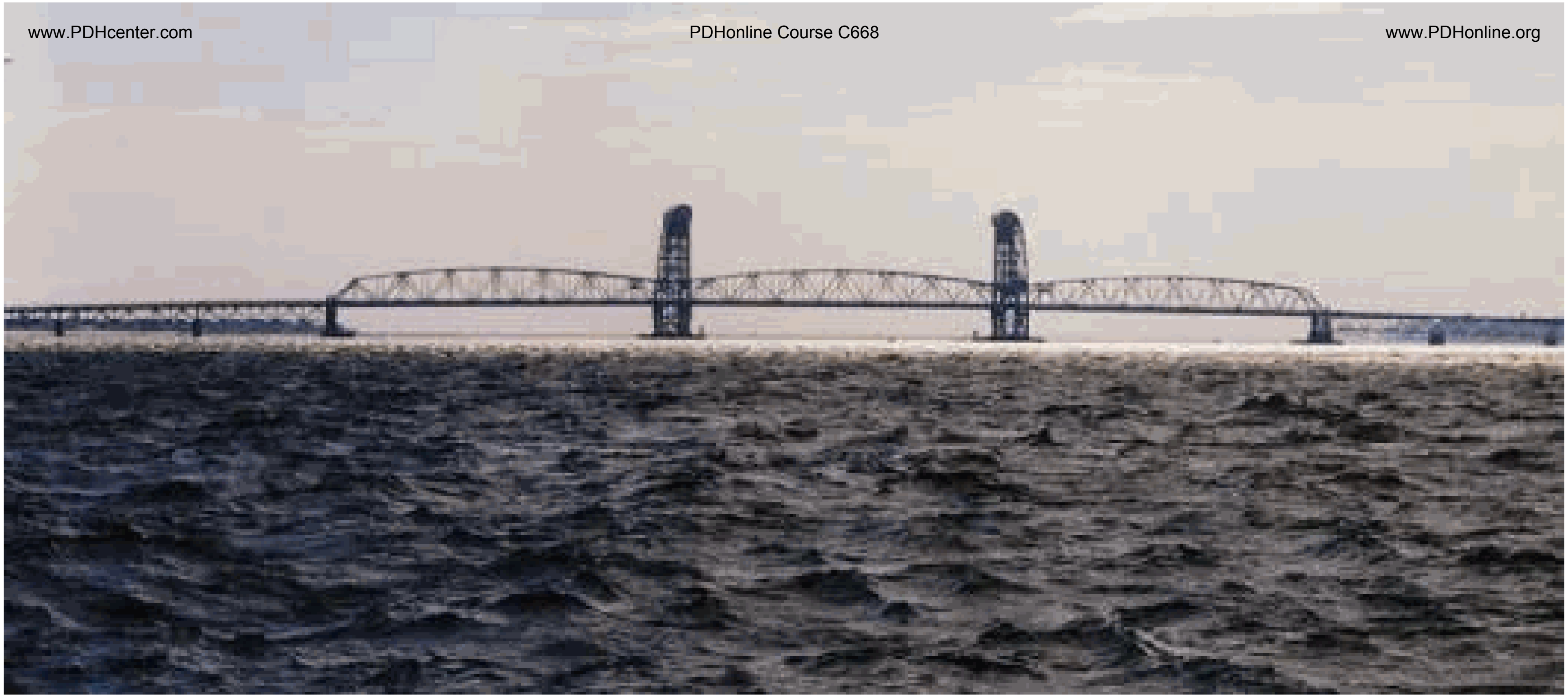
<u>Left</u>: ***Waldo-Hancock Bridge*** **(Bucksport, ME)**



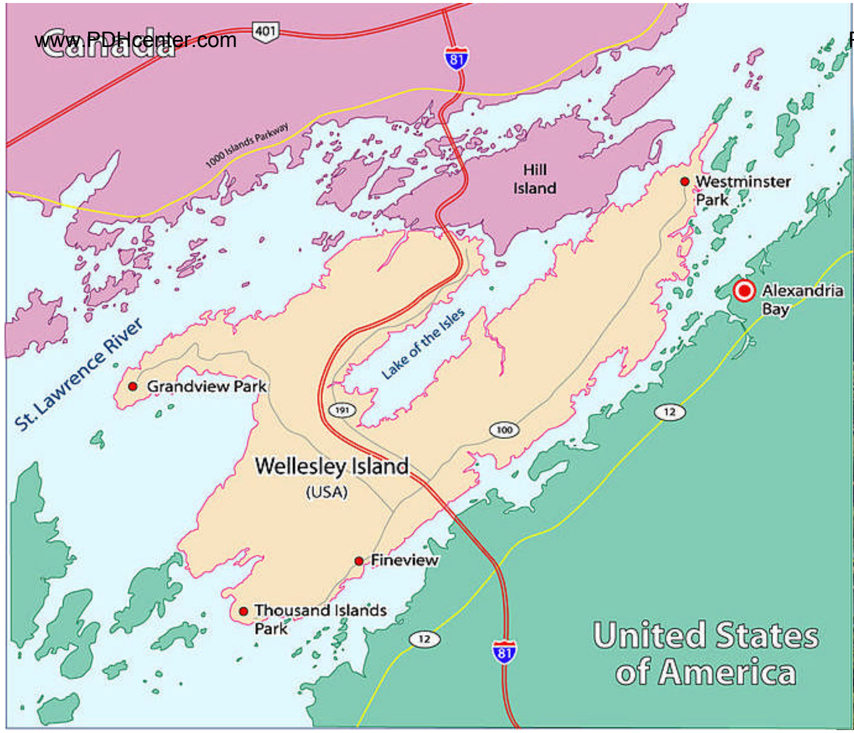




<u>**Top L&R**</u>**:** ***Henry Hudson Bridge*** **(New York City)**
<u>**Left**</u>**:** ***Thousand Islands Bridge System*** **(Ontario, Ca)**



Above: construction of the four-lane *Marine Parkway Bridge* began in June 1936. The bridge consisted of a 540-foot-long center lift truss span, two 540-foot-long side truss spans and two 1,061-foot-long approaches. The 2,000-ton highway lift span, the longest of its type at the time, could be raised 95 feet in two minutes, providing a clearance of 150-feet at mean high water. The steel plate roadway, similar to the surface found on sidewalk gratings, was the first such roadway to be used on a bridge on the east coast. To counter the engineering axiom that lift spans were ugly, the tops of the steel towers were tapered so that they would be flush with the main span when it was lifted. To protect against damage from ice flows and stray vessels, more than 600 Douglas fir trees were driven into the sand and strapped to the bridge piers. The $12 million bridge over *Rockaway Inlet* opened to traffic on July 3rd 1937. For a toll of $0.15, motorists between *Brooklyn* and the *Rockaways* no longer had to travel a circuitous route of as much as thirty miles. In addition to providing easy access to recreational areas, the completion of the bridge fostered the growth of the *Rockaway Peninsula*.



The *Thousand Islands Bridge* is an international bridge system over the *Saint Lawrence River* connecting northern *New York State* with southeastern *Ontario, Canada*. Constructed in 1937 (with additions in 1959), the bridges span the *United States-Canada* border in the middle of the *Thousand Islands* region, from which it derives its name. The bridge is not a single bridge but, rather, a series of five bridges that span parts of the St. Lawrence River, connecting both banks via *Wellesley* and *Hill Island/s*.

<u>Above T&B & Left</u>: *Sedgwick Bridge*, (Deer Island, ME)

<u>Above L&R & Left</u>: the *Hutsonville Bridge* (a.k.a. *Sullivan-Hutsonville Bridge*) connects *Crawford County, Illinois* with *Sullivan County, Indiana* over the *Wabash River* (built in 1939 and replaced in 1988). It was a rare example of the self-anchoring suspension bridge type (above L&R).

The *Kingston–Rhinecliff Bridge* (a.k.a. *George Clinton Memorial Bridge*) is a continuous under-deck truss bridge that carries NY 199 across the *Hudson River* in *New York State* (north of the city of *Kingston* and the hamlet of *Rhinecliff*). Though not complete, It was opened to traffic on February 2nd 1957 as a two-lane (one in each direction) bridge. The formal opening was held on May 11th 1957. 103

In addition to the many bridges that Steinman designed, he also served as a consultant on several projects (i.e. *Brooklyn Bridge* reconfiguration; 1944-1954 – famous photo of Steinman on cable stays at left). Steinman consulted extensively with the proponents of the *Tacoma Narrows Bridge* during the 1920s but ultimately, his design was not selected. He wrote of his frustration with the design that was chosen and predicted its failure. He presented his findings at the 1938 meeting of the structural division of the *American Society of Civil Engineers* (ASCE). In the audience was *Leon Moissieff*, the designer of the bridge (the bridge was under construction at the time). The failure occurred on November 7th 1940 and he wrote that it had a profound impact on his design principles, becoming even more conservative. Steinman designed the *Mackinac Bridge* to withstand winds of 365 mph. It is considered to be his most significant bridge and crowning achievement as a bridge-builder

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CITY OF NEW YORK
ROBERT F. WAGNER
MAYOR
HULAN E. JACK
PRESIDENT, BOROUGH OF MANHATTAN
JOHN CASHMORE
PRESIDENT, BOROUGH OF BROOKLYN
BROOKLYN BRIDGE RECONSTRUCTION
1954
DESIGN AND CONSTRUCTION SUPERVISED BY THE
DEPARTMENT OF PUBLIC WORKS
FREDERICK H. ZURMUHLEN, P.E., R.A.
COMMISSIONER
J. FRANK JOHNSON, P.E.
DIRECTOR, DIVISION OF BRIDGES
D. B. STEINMAN, P.E.
CONSULTING ENGINEER
KLEVENS CORPORATION, CONTRACTORS

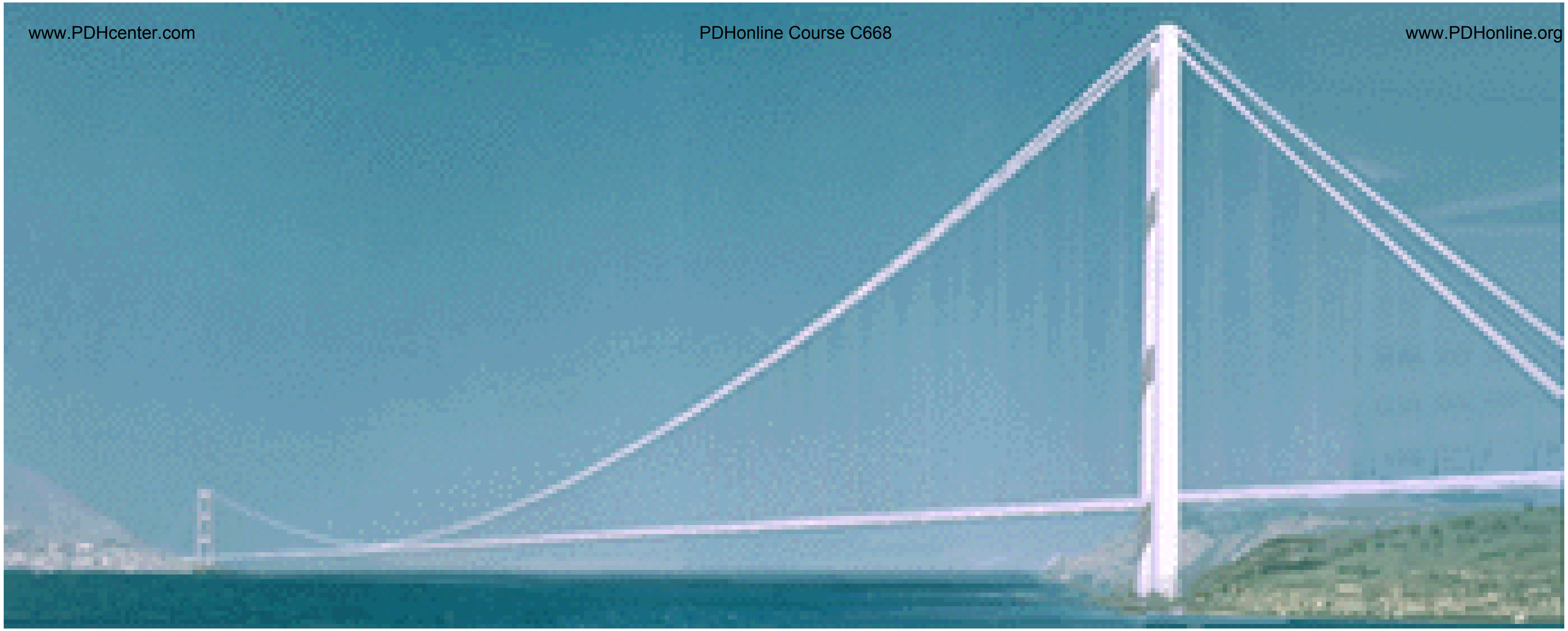
105

Ode to a Bridge

Against the city's gleaming spires,
Above the ships that ply the stream,
A bridge of haunting beauty stands –
Fulfillment of an artist's dream.
From deep beneath the tidal flow
Two granite towers proudly rise
To hold the pendent span aloft –
A harp against the sunset skies.
Each pylon frames, between its shafts
Twin Gothic portals pierced with blue
And crowned with magic laced design
Of lines and curves that Euclid knew.
The silver strands that form the net
Are beaded with the stars of night
Lie jeweled dewdrops that adorn
A spiderweb in morning light.
Between the towers reaching high
A cradle for the stars is swung;
And from this soaring cable curve
A latticework of steel is hung.
Around the bridge in afterglow
The city's lights like fireflies gleam,
And eyes look up to see the span –
A poem stretched across the stream

RE: poem entitled: *Brooklyn Bridge – Nightfall*, by D.B. Steinman

<u>Left</u>: rendering of the never realized *Liberty Bridge* (*New York Harbor*). *David Steinman* proposed a suspension bridge across *The Narrows* in 1926 to be funded by private investors. His "Liberty Bridge" (memorializing WWI casualties) would have had a 4,620-foot clear span and 800-foot tall towers ornamented with Gothic tracery enclosing observation decks, beacon lights, and a clarion of bells. A business syndicate applied to *Congress* for a charter to build and operate the bridge. Congressman *Fiorello H. La Guardia* single-handedly blocked the proposal, stating his opposition to a private corporation profiting from a civic need. Steinman also proposed a 1,524 meter suspension span across the *Straits of Messina* (between *Siciliy* and *Italy*) that was never realized.



"…The Steinman design for the Messina Straits Bridge has been replaced with a design for an even longer span that incorporates later developments in suspension bridge technology, but some of his legacy remains in the current design for a 3,300m span: e.g., in the use of a partially open grid deck to improve aerodynamic performance…"
***Maria Grazia Bruschi*, Structural Engineer**

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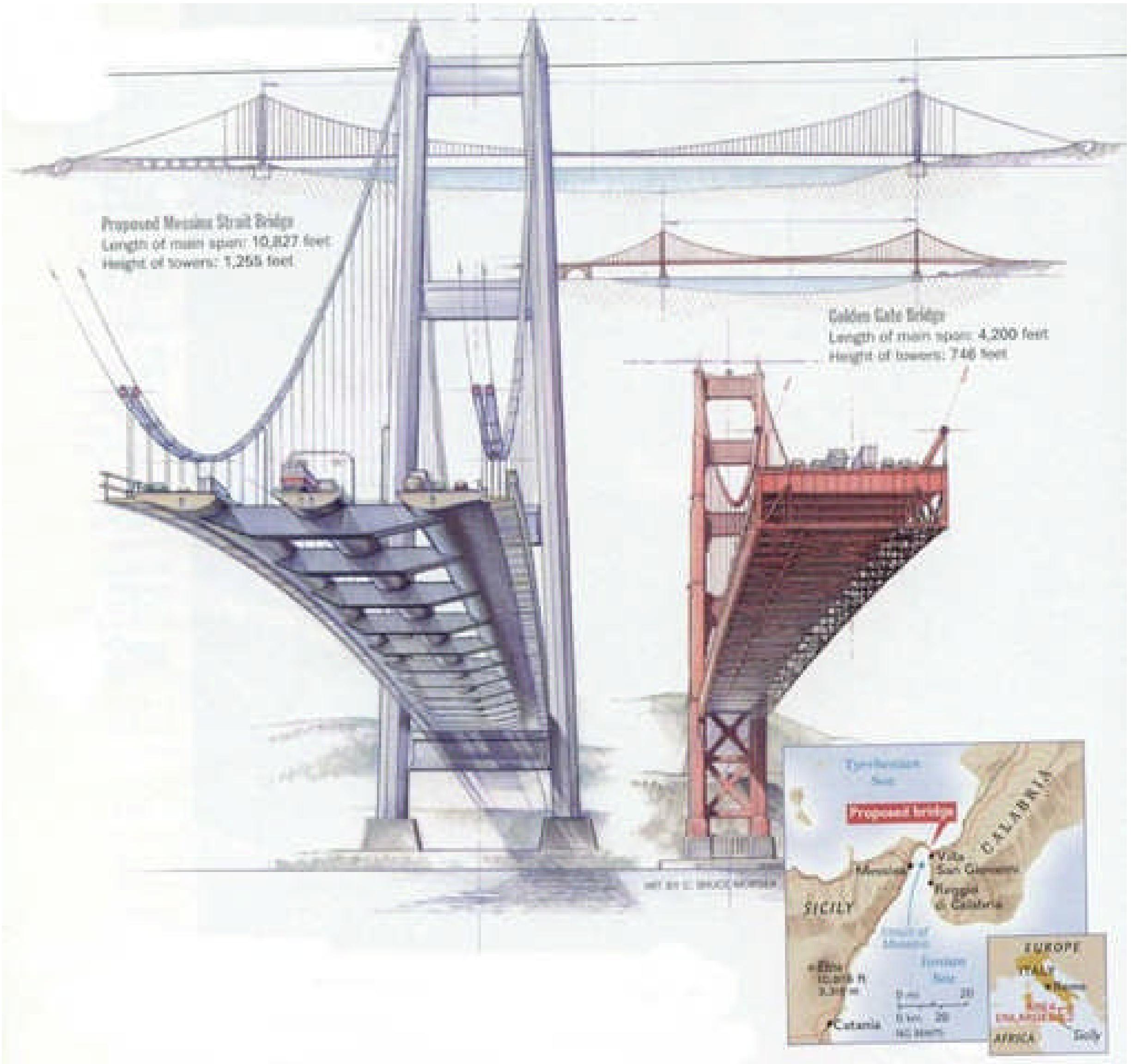
Proposed Messina Strait Bridge
Length of main span: 10,827 feet
Height of towers: 1,255 feet
Golden Gate Bridge
Length of main span: 4,200 feet
Height of towers: 746 feet
Tyrrhenian Sea
Proposed bridge
CALABRIA
Villa San Giovanni
Messina
Reggio di Calabria
SICILY
Strait of Messina
Ionian Sea
Catania
EUROPE
ITALY
Rome
AFRICA
Sicily

In late 1952, Dr. Steinman agreed to prepare plans for bidding purposes with the understanding that he would be paid if and when the bonds were sold. Ultimately, his firm received $3.5 million to design the *Mackinac Bridge*. The design of the *Mackinac Bridge* was directly influenced by the lessons of the first *Tacoma Narrows Bridge* which suffered a catastrophic failure on November 7th 1940 due to instability under dynamic (wind) stresses. Three years after the disaster, *Steinman* published a theoretical analysis of suspension-bridge stability problems. Among his recommendations were the inclusion of deep trusses to stiffen the bridge deck and an open-grid roadway to reduce its wind resistance. In January 1953, Steinman was appointed as the design engineer for the Mackinac Bridge and his recommendations were incorporated into its design. The Mackinac Bridge represented a new level of aerodynamic stability in suspension bridge design and was the first long-span suspension bridge to incorporate specific design features, including a porous deck to manage the forces imposed on it by winds.

The Greatest Bridge in the World

"The Mackinac Bridge is the greatest bridge in the world. Its cost is more than that of the George Washington Bridge and the Golden Gate Bridge combined. The record cost of $99,800,000 is a measure of the magnitude and the difficulty of the project. Both artistically and scientifically, it is outstanding. No effort has been spared to make it the finest, safest, and most beautiful bridge the world has ever seen…"

David B. Steinman

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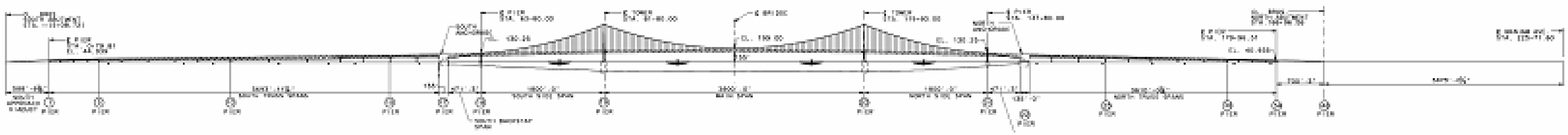

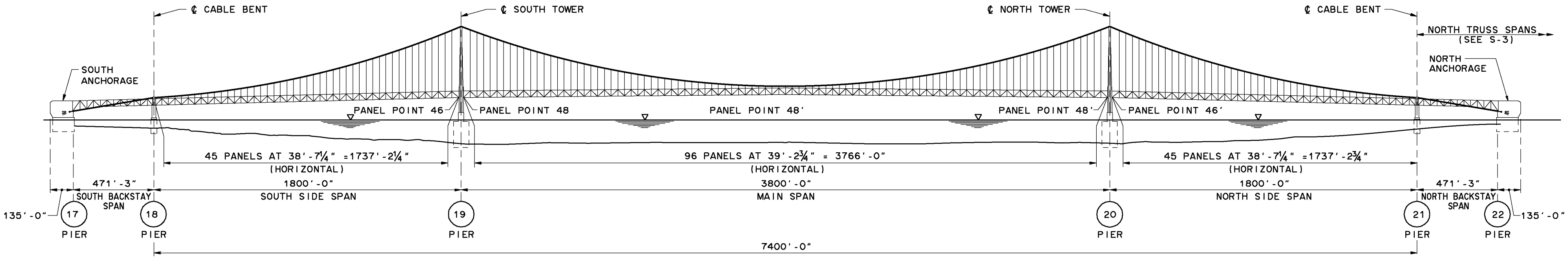

"…The bridge is five miles long. In the middle of the bridge, in the deepest water, spanning a submerged glacial gorge, we have a suspension bridge bigger than the George Washington Bridge, with a length of 8,614 feet from anchorage to anchorage, Mackinac is the longest suspension bridge in the world…"

David B. Steinman

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"…One day during the building of the bridge, Grover Denny, the genial and resourceful construction superintendent on the foundation work, said to me, 'Doctor, I believe that you have made an important mistake in a decimal point.' Startled by this remark, I asked: 'What do you mean, Grover?' To which he replied: 'Doctor, you have been telling people that this bridge is good for a century. But I want to go on record as saying that the bridge will be standing a thousand years from now!'…"

David B. Steinman

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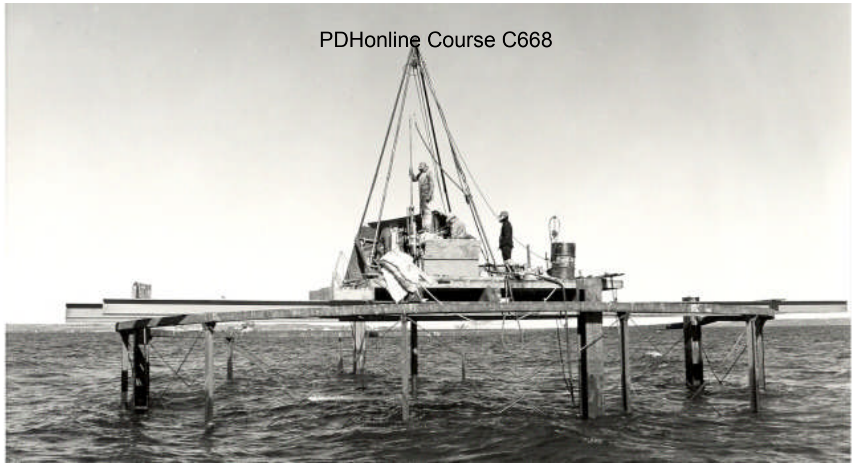


"…Before construction, people said that the rock underlying the Straits, because of the unusual geological formation, could not possibly support the weight of a bridge. To resolve any doubts, outstanding geologists and soil-mechanics authorities were consulted. Exhaustive geological studies, laboratory tests, and 'in-place' load tests on rock under water at the site established, without a doubt, that even the weaker rock under the Straits could safely support more than 60 tons per square foot. This is four or more times greater than the greatest possible load that would be imposed on the rock by the structure, including the combination of dead load, wind load, and ice pressure. The foundations were made large enough and massive enough to keep the maximum possible resultant pressure under 15 tons per square foot on the underlying rock. The geologists, moreover, pointed out that during the past one million years the rock under Mackinac Straits has been preloaded and pretested by the weight of a solid glacier, from one to five miles high, representing a load ten to fifty times greater than the maximum pressure under the bridge foundations…"

David B. Steinman

Above: caption: "Drilling rig and workers making test borings for Pier 11. October 19, 1954"

"…The foundations of the Mackinac Bridge contain more than a million tons of concrete and steel to form the massive piers and anchorages. Three-quarters of the mass is under water, to provide enduring stability. These foundations will be more enduring than the pyr-amids…"

David B. Steinman

<u>Left</u>: caption: "View of Pier 16 (foreground) taken from Pier 17 looking south. November 19, 1955"


© J.M. Syken

"…Because the public had been alarmed by unscientific claims that no structure built by man could withstand the ice pressure at the Straits, I added a further generous margin of safety. According to the most recent engineering literature on the subject, the maximum ice pressure ever obtained in the field is 21,000 pounds per lineal foot. I multiplied this higher figure by five and designed the piers to be ultra-safe for hypothetical, impossible ice pressure of 115,000 pounds per lineal foot. With the maximum possible ice pressure multiplied by five, and the safe foundation pressure divided by four as a basis for design, the combined factor of safety is 20 for the ultra-safe design of the piers against any possible ice pressure. For still further safety against any possibility of ice damage, the concrete of the piers and anchorages is protected by inter-locking steel sheet piling, steel caissons, and wrought iron armor plate…"

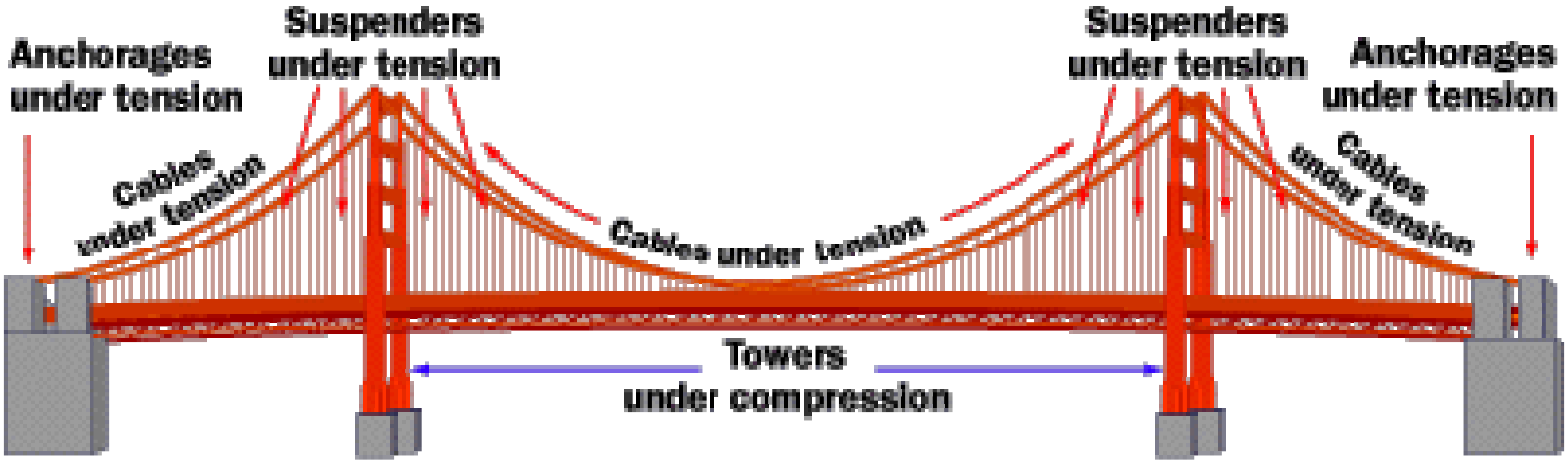
David B. Steinman

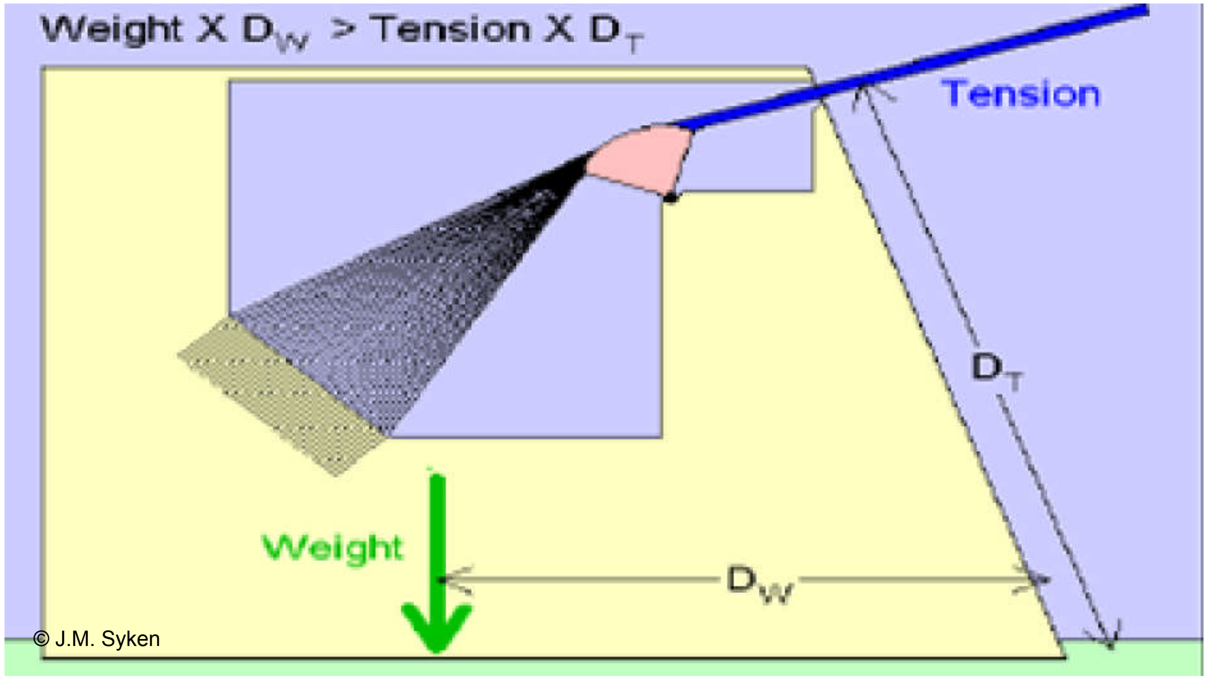
Left: caption: "Erecting Pier 20, Oct. 1955"

"The boat would sink with serious loss of life"

David B. Steinman

RE: his response when asked what would happen if an ore freighter crashed into the bridge





"…The maximum pull of the two cables on the anchorage is 30,000 tons. Each anchorage has a mass of 180,000 tons of concrete and steel, providing a generous safety factor of six against the maximum cable pull…"

David B. Steinman

<u>Above</u>: caption: "Temporary catwalk in place before the start of the construction of the Mackinac Bridge cables." The anchorage is at left in photograph.

© J.M. Syken

"…The public had been irresponsibly told that no structure could resist the force of storms at the Straits. So I made the design ultra-safe against wind pressure, too. The greatest wind velocity ever recorded in the vicinity was 78 miles per hour; this represents a wind of 20 pounds per square foot. I multiplied this force by two and a half, and I designed the bridge to be ultra-safe against a hypothetical, unprecedented wind pressure of 50 pounds per square foot. The crowning feature in the design of the Mackinac Bridge for ultra-safety is its unprecedented achievement of perfect aerodynamic stability. This means absolute security against the initiation or amplification of oscillations which are due to wind, the kind of oscillations ('galloping' and 'twisting') that destroyed the Tacoma Narrows Bridge in 1940…"

David B. Steinman

"…He was an absolutely brilliant man, an absolute genius. He made very convincing presentations, where he was very self-assured and he always had answers to questions. Indeed, he had an ego, but it went with his personna…He did not want to be a party to a bridge that was susceptible to wind. He designed it so that a wind would move Mackinac Island before it would move that bridge…"

Lawrence Rubin

RE: Rubin was appointed Executive Secretary of the *Mackinac Bridge Authority* on June 24th 1950, and supervised the operation and maintenance of the bridge from its opening on November 1st 1957 until his retirement on December 31st 1982

© J.M. Syken

"…The main span at Mackinac is a suspension bridge, which is inherently the safest type of bridge. The stiffening trusses are 38 feet deep, or one-hundreth of the span length. This is 68 percent greater than the corresponding ratio of the Golden Gate Bridge. But even without this generously high depth-ratio, the Mackinac suspension span would have more than ample aerodynamic stability. In fact, by utilizing all of the new knowledge of suspension bridge aerodynamics, particularly my own mathematical and scientific discoveries and inventions, I have made the Mackinac Bridge the most stable suspension bridge, aerodynamically, that has ever been designed…"
David B. Steinman

The *Mackinac Bridge* was the world's first bridge to fully incorporate Steinman's principles of aerodynamic stability. Designing a bridge to cross the *Mackinac Straits* posed three significant challenges:

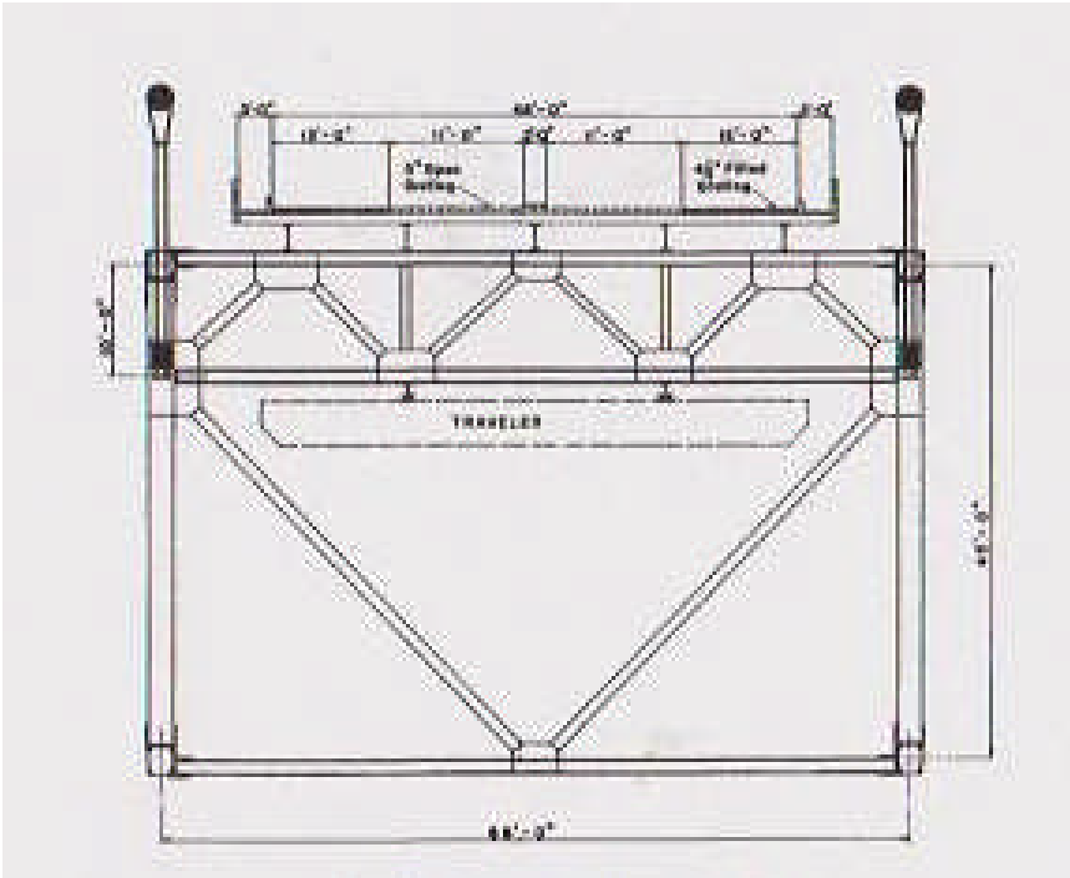
- **High velocity winds**
- **Deep water**
- **Extreme pressures from ice accumulation**

To deal with the wind, Steinman utilized deep, open stiffening trusses in lieu of solid steel (plate girder) trusses (as in the *Tacoma Narrows Bridge*) beneath the roadway. The suspended spans of the Mackinac Bridge contain 186 truss panels in total.

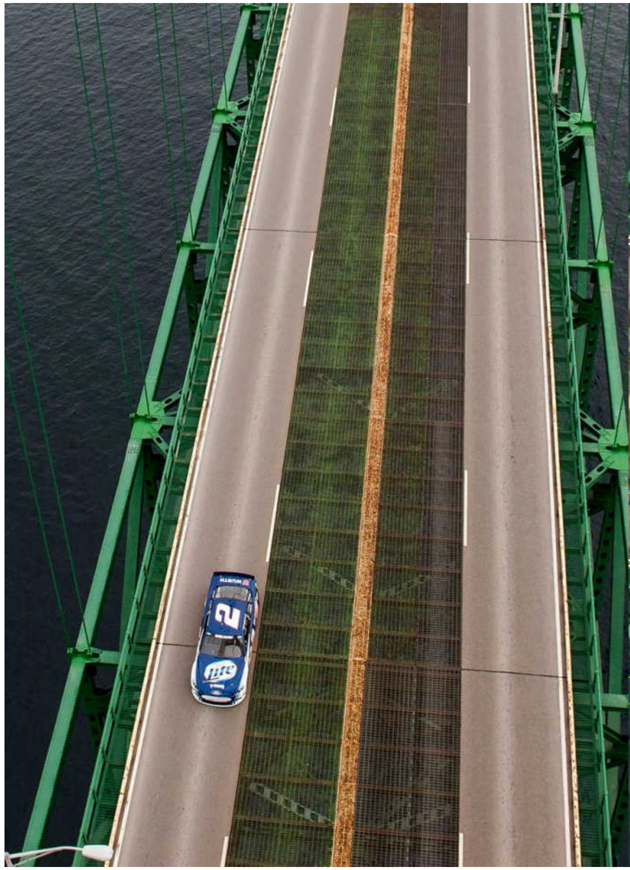
Left: a section of stiffening truss is lifted into place from a barge below

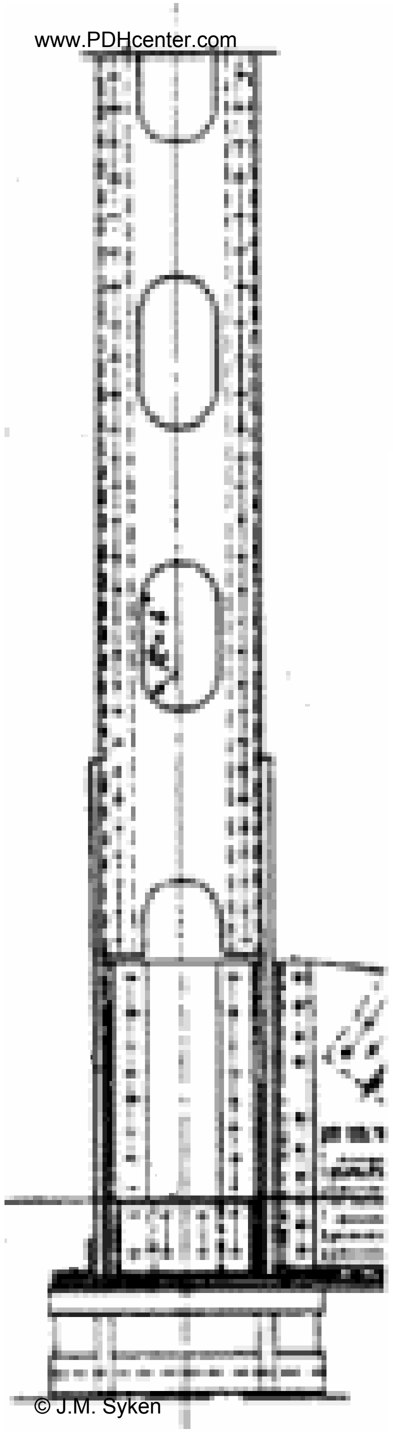
"…This result has been achieved not by spending millions of dollars to build up the structure in weight and stiffness to resist the effects, but by designing the cross-section of the span to eliminate the cause of aerodynamic instability. The vertical and torsional aerodynamic forces which tend to produce oscillations have been eliminated. The basic feature of this high degree of aerodynamic stability is the provision of wide open spaces ten feet wide on each side, the full length of the suspension spans. When you drive over three suspension spans in the central portion of the bridge, you can see the stiffening trusses beyond the edges of the roadway, with the open spaces between them. These open areas constitute the scientific design. They eliminate the closed corners in which pressure concentrations are producible by wind, and they eliminate the solid areas on which such pressure differences would otherwise act to produce oscillations of the span. By this feature alone (the open spaces between roadway and stiffening trusses), the critical wind velocity (the wind velocity at which potential oscillations can start) was increased from 40 miles per hour to 632 miles per hour!…"

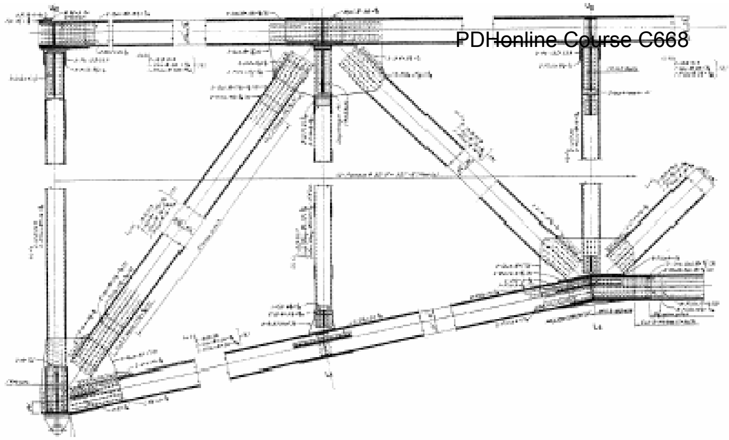
David B. Steinman

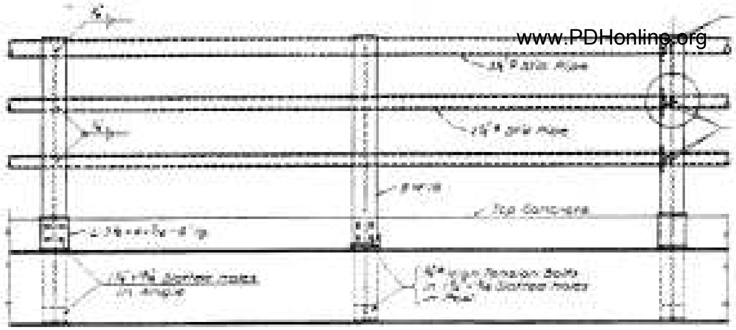


CROSS SECTION — SUSPENDED STRUCTURE

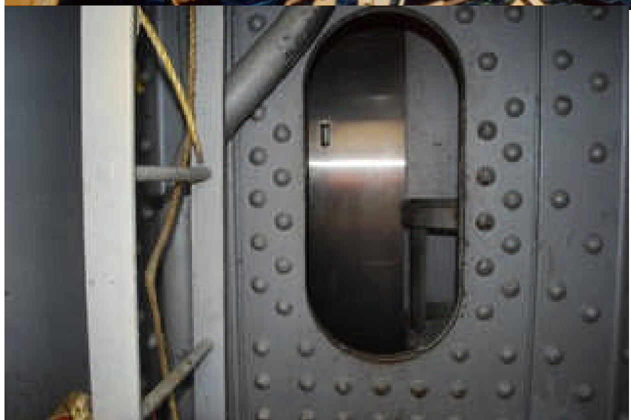








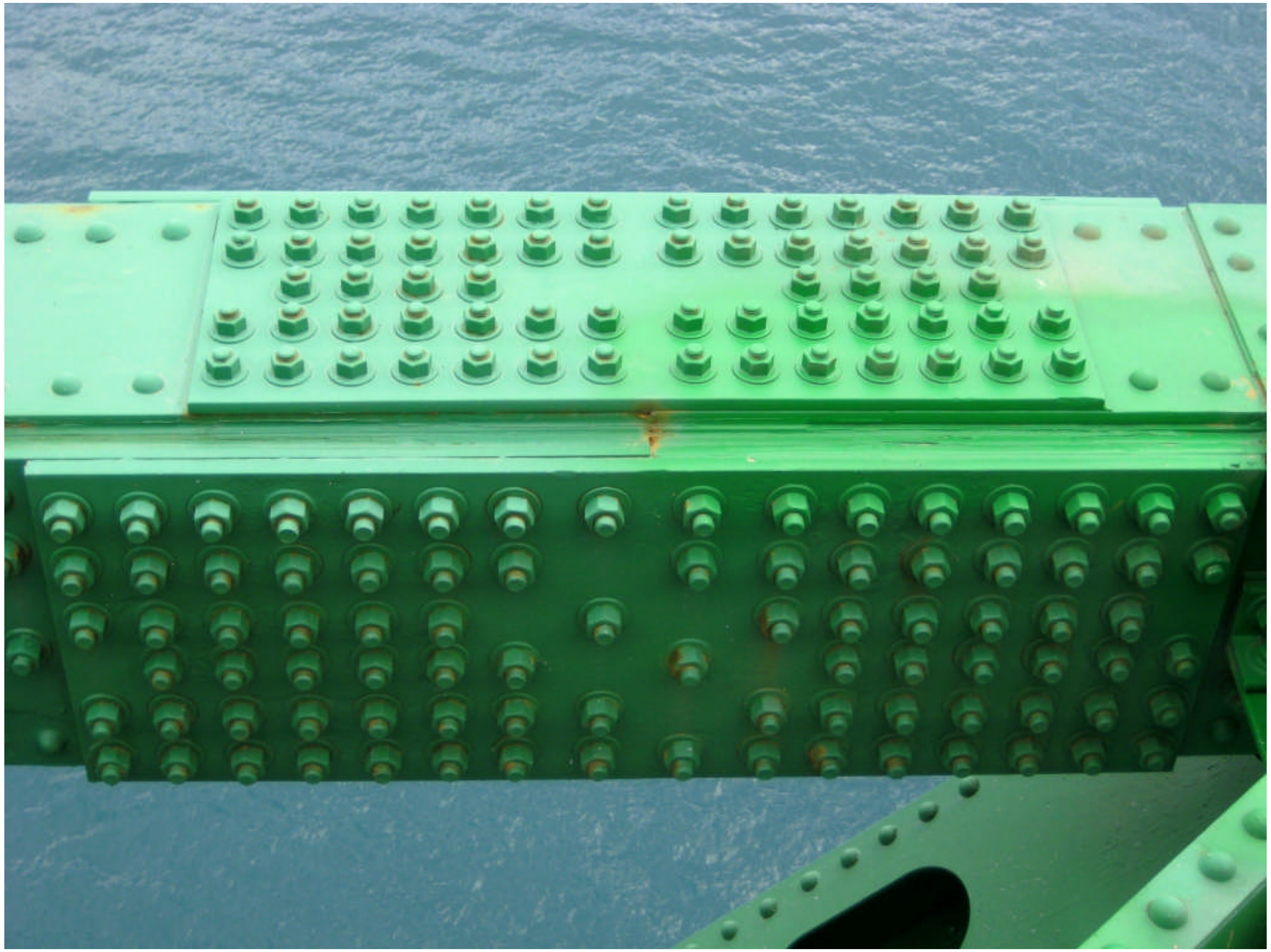
Fully complete by 1958, the Mackinac Bridge's relative youth evidences itself in its simple concrete approach supports, bolted connections on the stiffening trusses and a lack of v-lacing or lattice on any part of the bridge's built-up steel. However, the bridge is old enough that built-up sections were used for larger members (left) and rivets were still used to field assemble them (i.e. the towers). In contrast, most connections on the bridge were bolted as opposed to riveted (i.e. portion of deck truss assembly, above left). There are 4,851,700 rivets and 1,016,600 bolts on the bridge. At the time, the transition from riveted to bolted connections was on-going in the construction industry (by the mid-to-late 1950s most field connections were bolted while fabricated sections still used rivets since the fabricating shops still employed their automatic riveting machines). Guardrails were composed of three steel pipes (above right) with a steel curb in front (the two-directional traffic is also separated 129 **by a steel curb.**



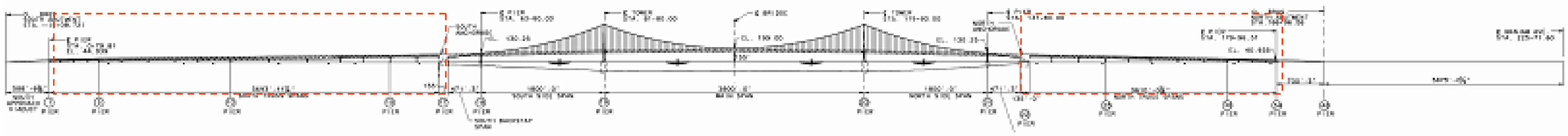
<u>Top Left</u>: caption: “Roadway stringers being assembled in place above the truss section which had been raised near the north anchorage.”

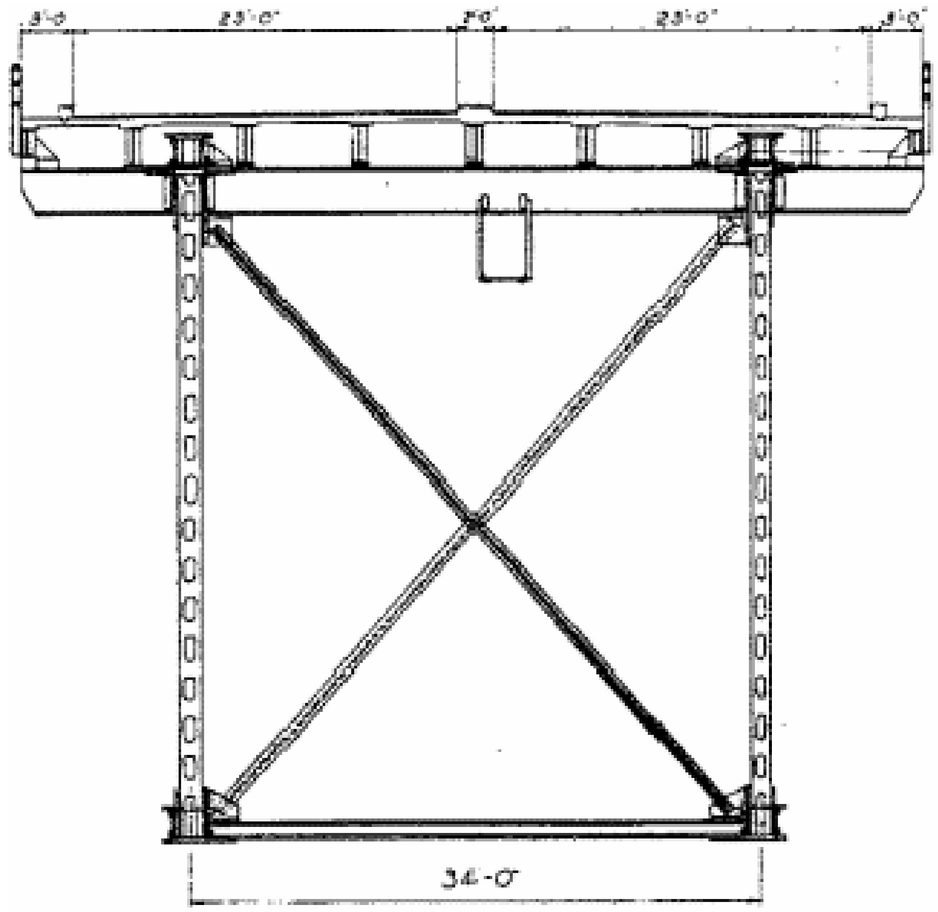
<u>Top Right</u>: caption: “Using a long-handled spanner to secure bolt in splice plate for roadway stringer”

<u>Left T&B</u>: caption: “Riveted connections inside tower leg”



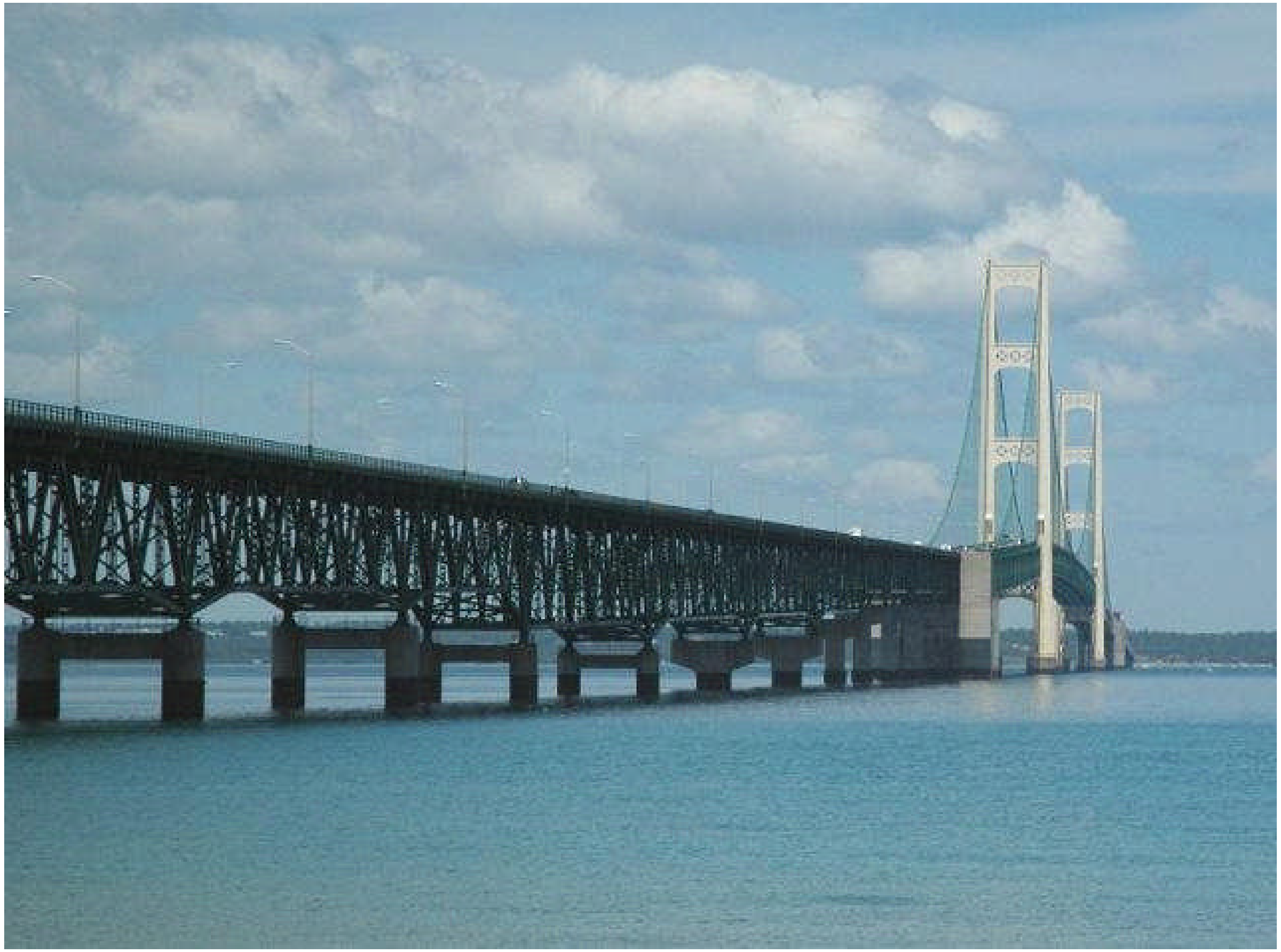
131





Approaches to the bridge are deck trusses (left). The southern deck truss approach (above left) system is longer than the northern deck truss approach system (above right). There is also a significant causeway built of rubble-type stones on the *St. Ignace* (north) side of the bridge. A small steel beam bridge is located at one spot on this causeway. This causeway bridge actually predates the *Mackinac Bridge*, serving the ferry terminal that preceded the bridge.

Left: caption: "Typical cross-section for approach spans"



134

<u>Above</u>: a causeway 4,200-feet long was built from 1939 to 1941 in anticipation of a bridge across the Straits that was delayed due to the outbreak of WWII. Steinman used the existing causeway in his plans for the new bridge realizing a savings of $3 million in construction costs.

To Infinity and Beyond!

"…But I was not satisfied with raising the critical velocity to this fabulous figure. For still further perfection of the aerodynamic stability, I provided the equivalent of a wide opening in the middle of the roadway on the suspension spans. The two outer lanes, each twelve feet wide, are made solid, and the two inner lanes and the central mall, 24 feet wide together, are made of open-grid construction of the safest, most improved type. By this additional feature of aerodynamic design – adding the central opening to the lateral openings previously described, I achieved a further increase in aerodynamic stability and raised the critical wind velocity from 632 miles per hour to a critical wind velocity of infinity!…"

David B. Steinman

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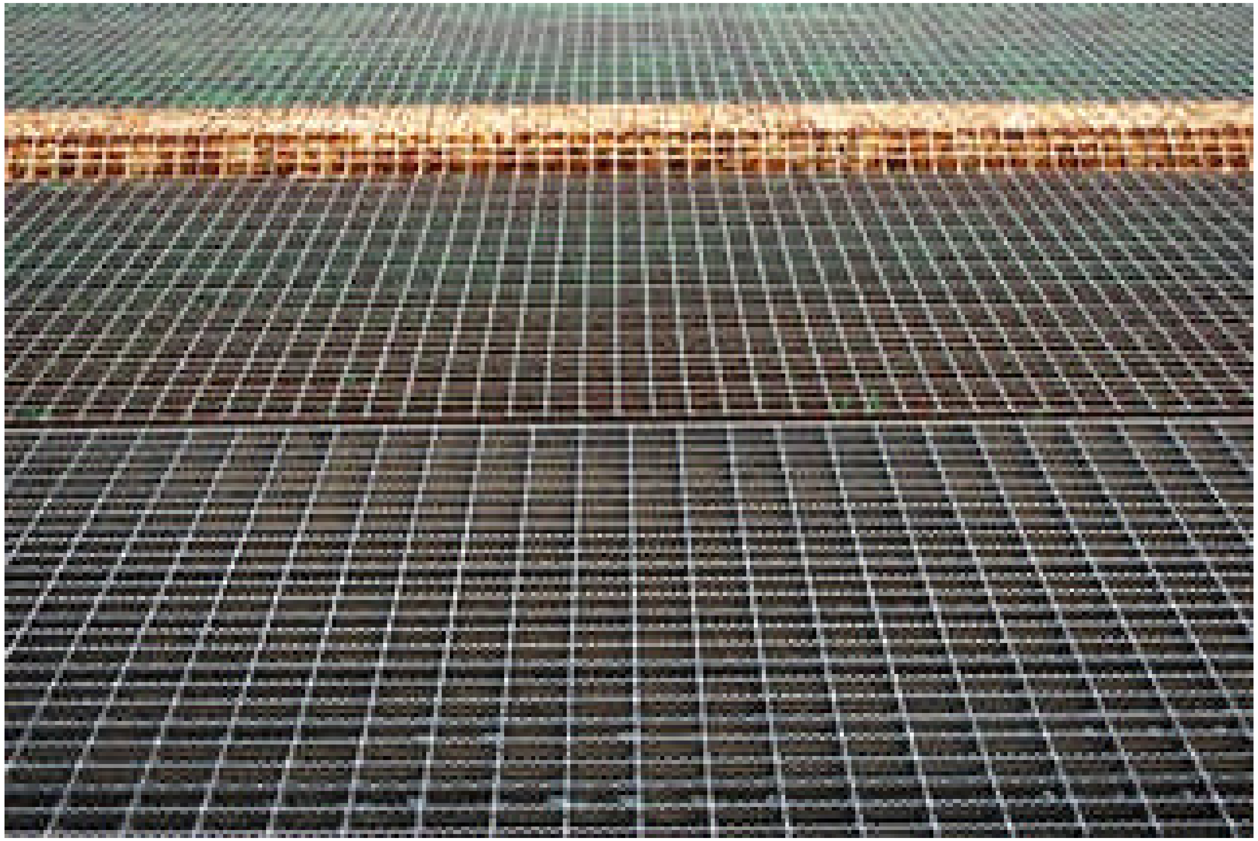
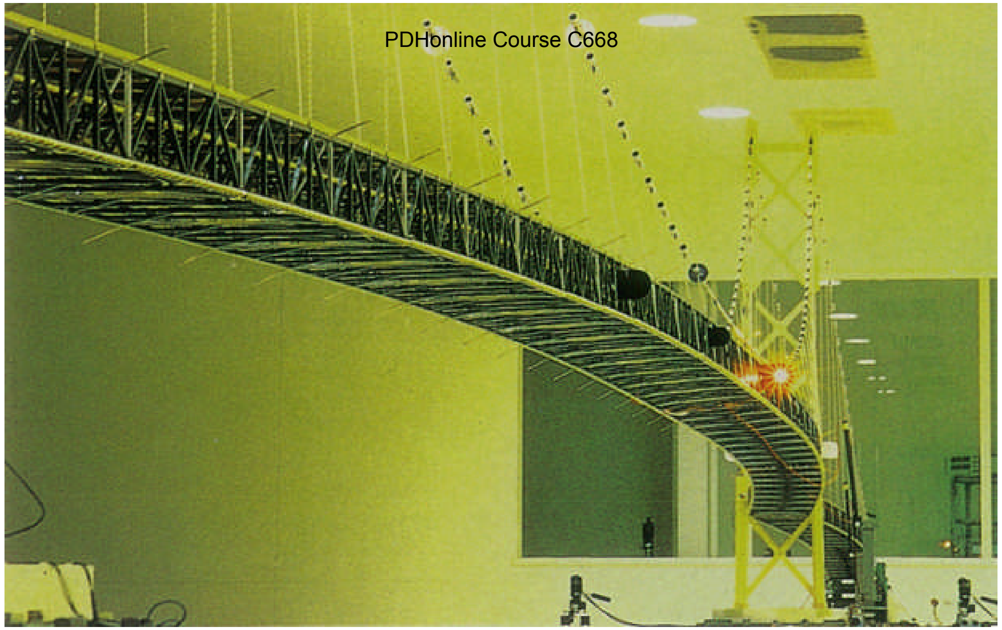




"…These results and conclusions have been independently confirmed by laboratory and wind-tunnel tests on a small-scale and large-scale section-models of the bridge. The wind-tunnel tests show conclusively that the Mackinac Bridge has complete and absolute aerodynamic stability against all types of oscillations (vertical, torsional, and coupled) at all wind velocities and all angles of attack of the wind. The Mackinac Bridge represents the triumph of the new science of suspension bridge aerodynamics. It represents the achievement of a new goal of perfect aerodynamic stability, never before attained or approximated in any prior suspension bridge design. In other large modern suspension bridges, the critical wind velocities range from 30 to 76 miles per hour. In the Mackinac Bridge, the critical wind velocity is infinity…"

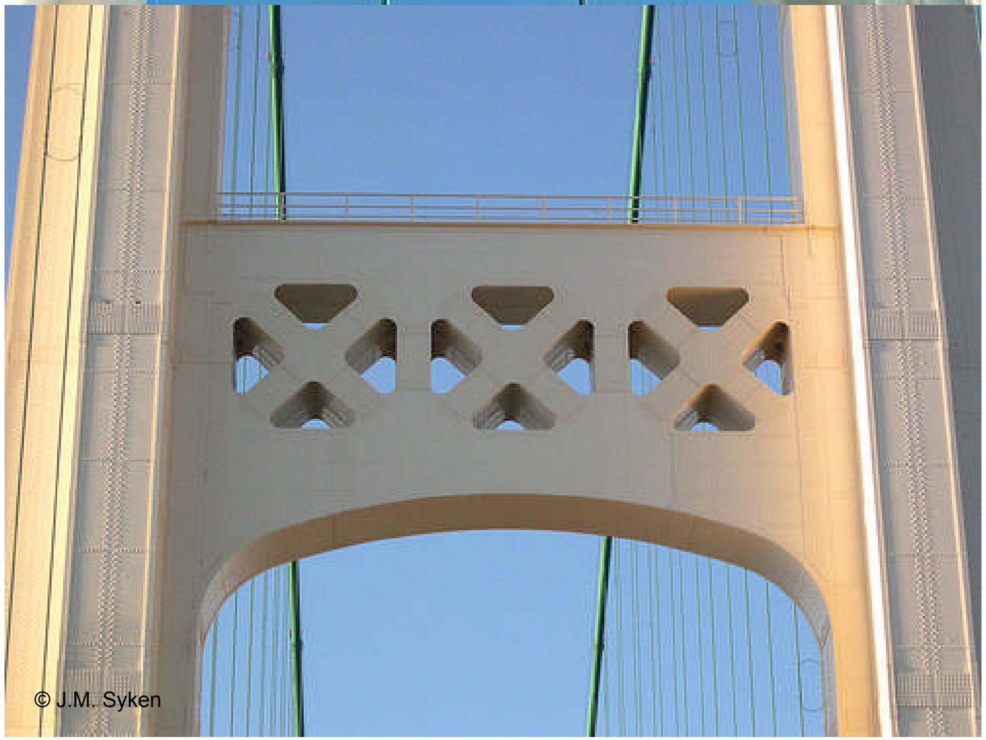
David B. Steinman

Above: a scale model of the *Akashi-Kaikyo Bridge* is subjected to laboratory wind-tunnel tests demonstrating the deflection caused by wind forces 139

A Symphony of Steel and Stone

"…Michigan's bridge is not only a scientific and economic triumph. It is also an artistic achievement. Devoted thought and study were applied to the development of forms, lines, and proportions to produce a structure of outstanding beauty. A suspension bridge is a naturally artistic composition, with the graceful cable curves and the symmetry of the three spans, punctuated by the dominant soaring towers and framed between the two massive, powerful anchorages. There is symmetry about each tower, and over-all symmetry of the three-span ensemble. The lofty towers are architectural compositions of vertical and horizontal lines; and each horizontal member is arched for inflection and pierced for artistic interest and distinction. The design is functional and efficient, actually saving in cost while producing an effect of notable beauty. The suspension span framed by the two lofty towers is 'a harp outstretched against the sky,' 'a net outspread to hold the stars.' The bridge as a whole is a 'symphony in steel and stone,' a poem stretched across the Straits…"

David B. Steinman



"…For the painting of the bridge, I chose a two-color combination – foilage green for the span and cables and ivory for the towers – to express the difference of function (I may be joshed about 'ivory towers')…"

David B. Steinman

__Above__: painting the tower

__Left__: tower struts

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Poetry by Night

"…During the cable stringing, lights were strung along the catwalks for the night work. They were like a necklace of pearls and inspired artists and poets. My suggestion that such illumination of the cables, necessary for construction, be made a permanent installation was enthusiastically adopted. With lights strung along the cables and with flood-lighting at the towers, the beauty of the lines and forms as seen by day will be continued in poetry and magic at night…"

David B. Steinman

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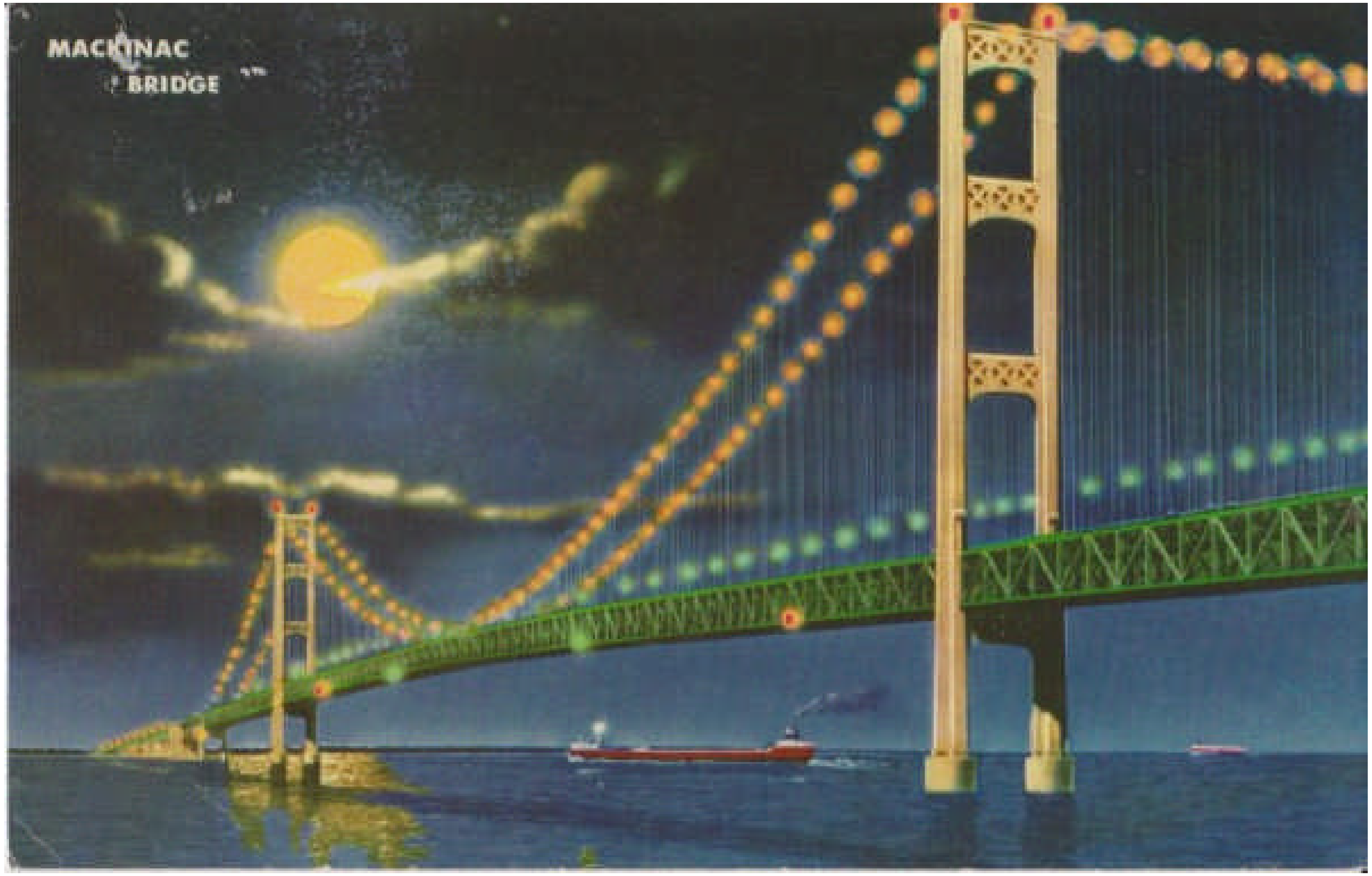
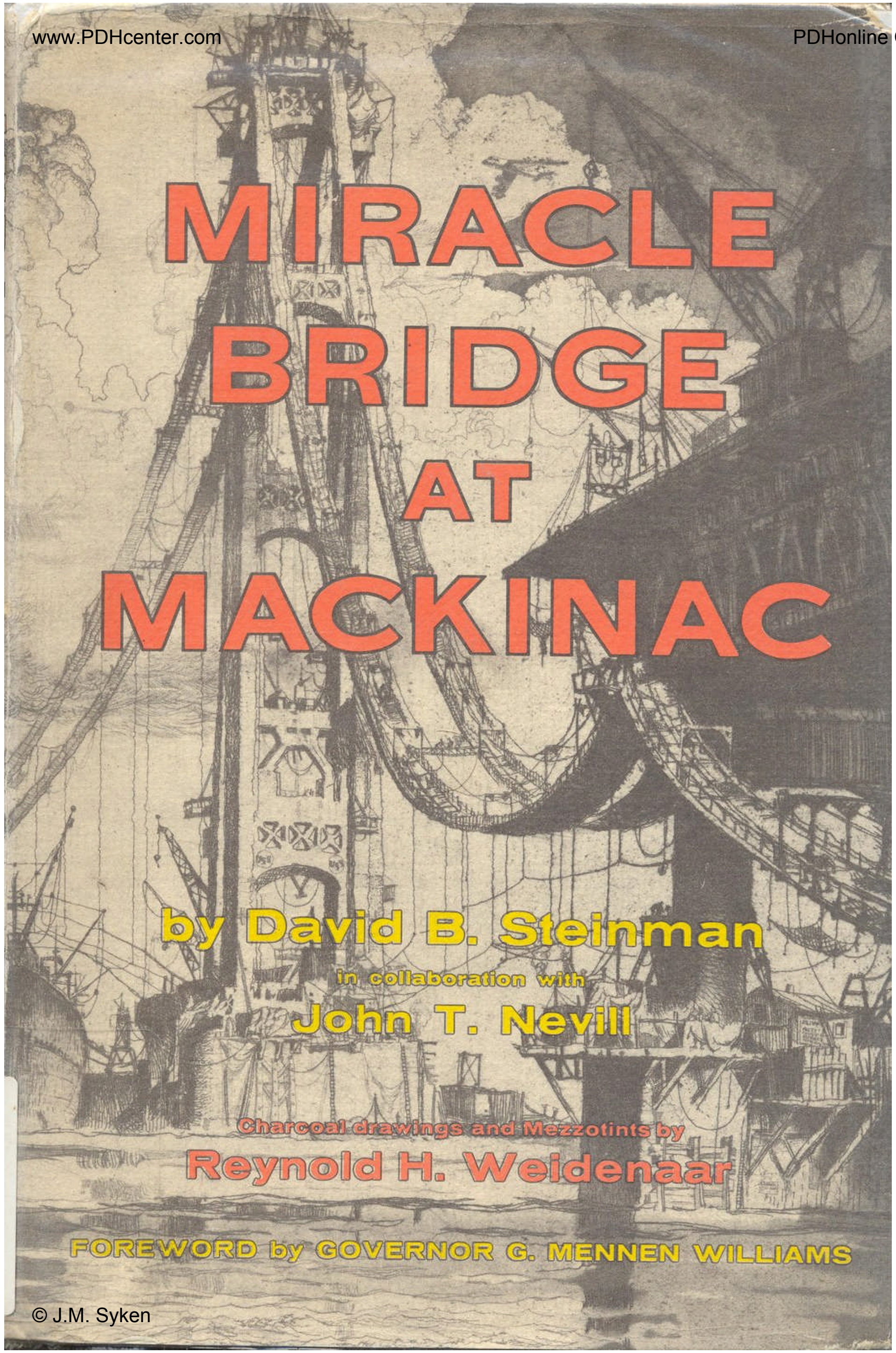

MACKINAC
BRIDGE

It is a Monument

"The Mackinac Bridge is a triumph of science and art. It is a monument – an enduring monument – to vision, faith, and courage. Without the vision, faith, and courage of the people of Michigan – their leaders, their statesmen, their workers – this great bridge could never have been built. Outsoaring gravity and space, it rises from the waves on shining strands to arch across the sky in lofty grace. This is our triumph over ancient fears. A Bridge of Peace, wrought of the dreams of man."

***David B. Steinman* (1887-1961)**

150



"…The Mackinac Bridge is my crowning achievement – the consummation of a life-time dedicated to my chosen profession of bridge engineering. As far back as in 1893, when I was a newsboy selling papers near the Brooklyn Bridge, I told the other newsboys that someday I was going to build bridges like the famous structure that towered majestically above us. They laughed at me. Now I can point to 400 bridges I have built around the world, and to my masterwork - the Mackinac Bridge - the greatest of all. The realization, one after another, of dreams that seemed hopeless leaves me reverent and humble…"

RE: excerpt from D.B. Steinman's book *Miracle Bridge at Mackinac* (left)

Now the towers, mounting skyward,
Reach the heights of airy space.
Hear the rivet-hammers ringing,
Joining steel in strength and grace.

RE: inscription on *Christmas* card (left) sent by Dr. and Mrs. *David B. Steinman* in 1957. The artwork appearing on the card was a mezzotint by *Reynold Weidenaar* entitled "Bridge Builders."

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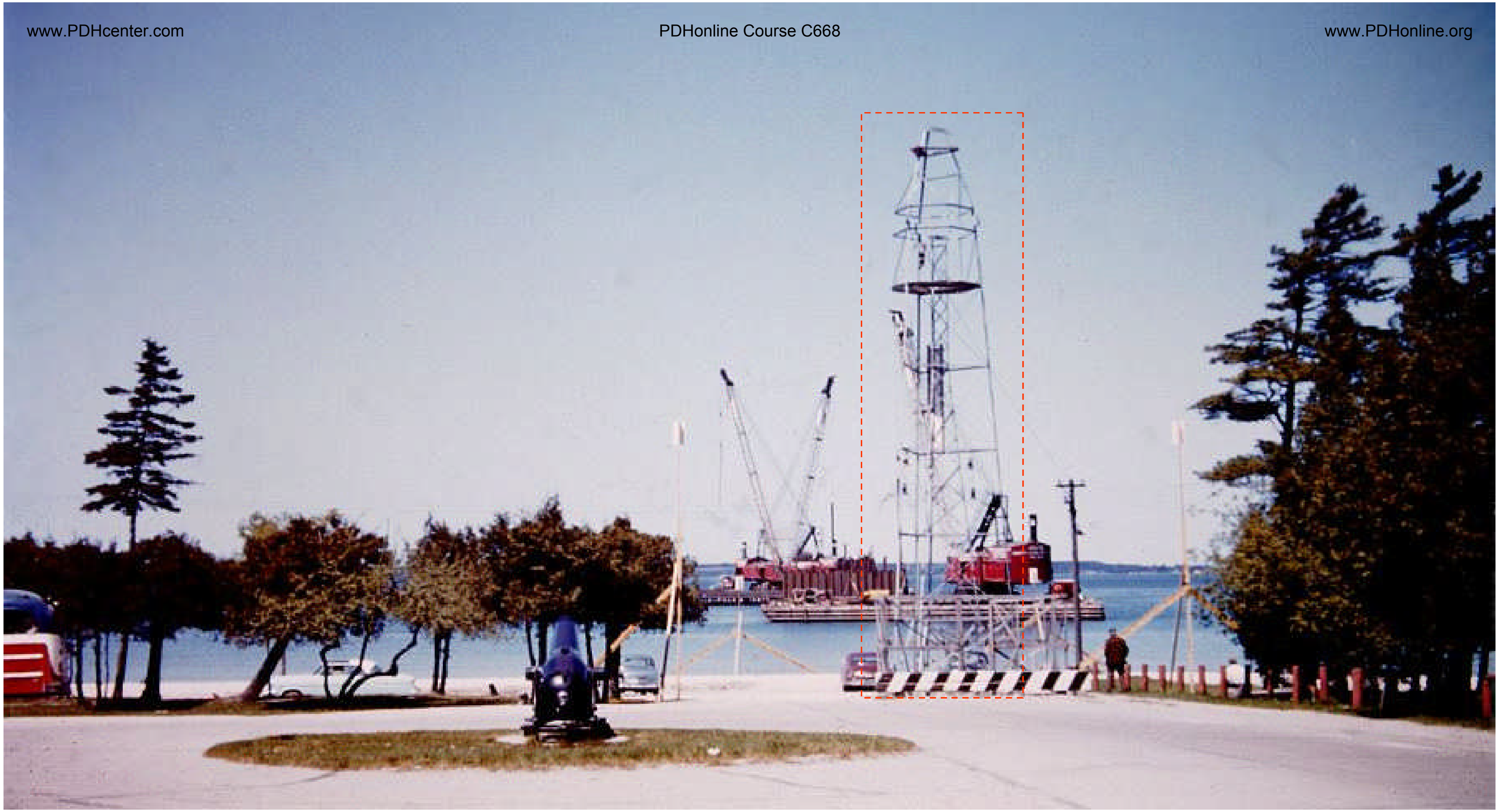
The Bridge That Faith Has Built

"…To a dedicated bridge designer, a bridge is geometry transmitted into poetry and music…the Mackinac Bridge has been a challenge and an opportunity – a challenge to conquer the impossible, to build a bridge that people said couldn't be built; and an opportunity to apply consecrated, scientific, resourceful design to achieve the finest, safest, and most beautiful long-span bridge that the science and art of bridge engineering can create. The Mackinac Bridge represents a triumph over staggering obstacles and difficulties – some man-made and others imposed by nature. We had to overcome the difficulties of legislation and financing in the face of ignorance, skepticism, and prejudice. And we had to conquer the problems of the challenging natural conditions – the magnitude and depth of the crossing, the unique geology of the Straits, and the alleged hazards of ice and tides and storms. The structure has been made generously safe to defy all these natural forces with an unprecedented high margin of safety. Aerodynamically, it is the safest bridge in the world; in fact, it is the first long-span bridge ever designed and built to have perfect assured aerodynamic stability for all wind velocities up to infinity. This result has never before been approached or attained. Finally, my staff and I are proud of our record of building the Mackinac Bridge within our estimate of cost and within our estimate of time. We have generously fulfilled all our promises and commitments. We have kept faith with the Bridge Authority and with the people of Michigan. The Mackinac Bridge may well be called 'The bridge that faith has built.'"
David B. Steinman

Part 3

Season One: 1954

Survey



<u>Above</u>: construction of the *Mackinac Bridge* officially began on May 7th 1954 at what was the parking lot for *Michilimackinac State Park*. The metal structure (highlighted) was one of seven land-based survey towers at fixed locations which were used along with six water-based towers. By sighting along lines from one location to another and by directing surveyors in boats to position themselves where these lines crossed, the location/s of piers was thus determined precisely.

<u>Left</u>: two members of the survey crew on *Survey Tower No. 1* in the *Straits of Mackinac* during the placement of the foundations (October 1954). This tower was one of six triangular survey towers anchored in the Strait; three on each side of the proposed centerline of the bridge.

Mobilization

***Merritt-Chapman & Scott Corp*.**, **a.k.a. "The Black Horse of the Sea," was the premier marine salvage and construction firm in the *United States* well into the late *20th Century,* with world-wide operations. The company was founded in the 1860s by *Israel Merritt*, but many other firms were merged into it over the course of the company's long history. MC&S won a $25,735,600 lump-sum contract with the low bid to build thirty-three marine foundations leading to the mobilization of the largest bridge construction fleet ever assembled up to that time for a peace-time project.**

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<u>Above</u>: caption: "Several MC&S floating cranes (on barges) at work on the construction of the piers for the south-end of the Mackinac Bridge, with Mackinac Island and Bois Blanc Island in the distance. View from southern shore."

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<u>Above</u>: caption: "An MC&S floating crane used in the construction of a *Mackinac Bridge* pier." 162

<u>Above</u>: caption: "Dredging barge and crane (the south anchorage is at left)."

Above: caption: "Barges used for floating superstructure truss panels into position."

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<u>Above</u>: caption: "A marine crane on barge preparing to raise a truss section of the framework into place."

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"The one thing I seem to remember most is the wind. After you go up so high it was just constant. Sometimes you could lean into it, and that helped a little. But that wind screwed up a lot of schedules…We'd have 60 or 70 men coming off the towers waiting for the waves to settle down so they could get the boat close enough. Those times in particular the men and I didn't like that wind."

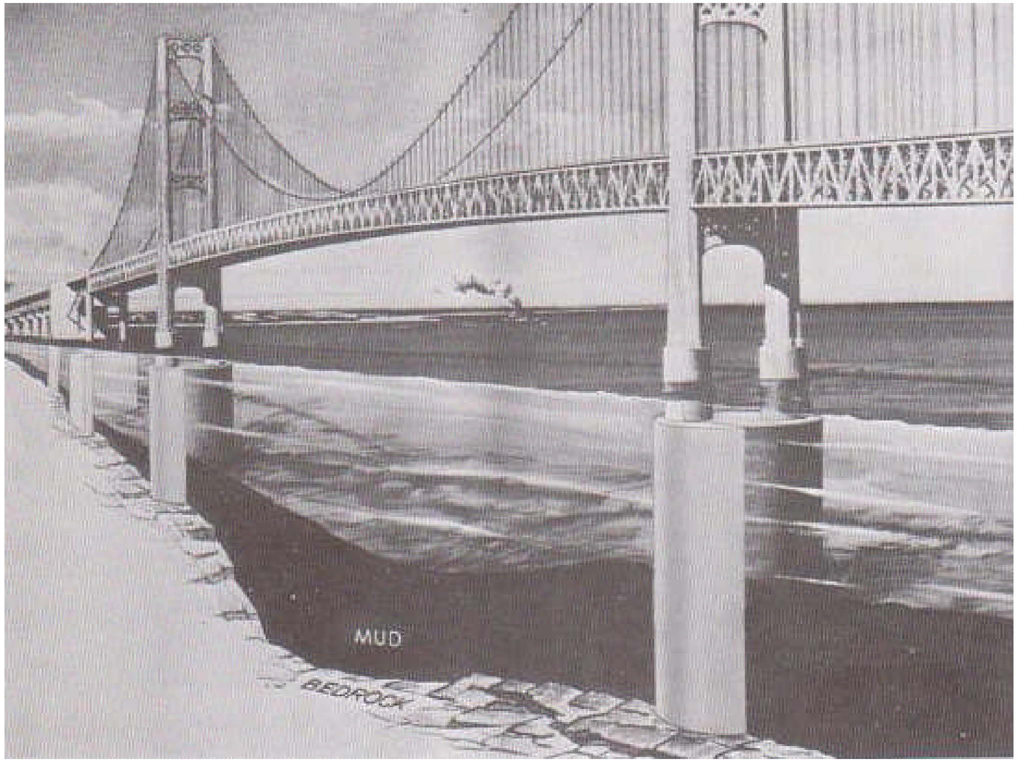
Bill Babinchak, **Ironworker**

<u>Top Left</u>: caption: "American Bridge Division workers preparing to board a personnel boat at shift change from Pier 22. October 19, 1956"

<u>Top Right</u>: caption: "Bridge builders with lunch in hand, electric cap lights lit, and life preservers secure pull away from dock to start another day's work."

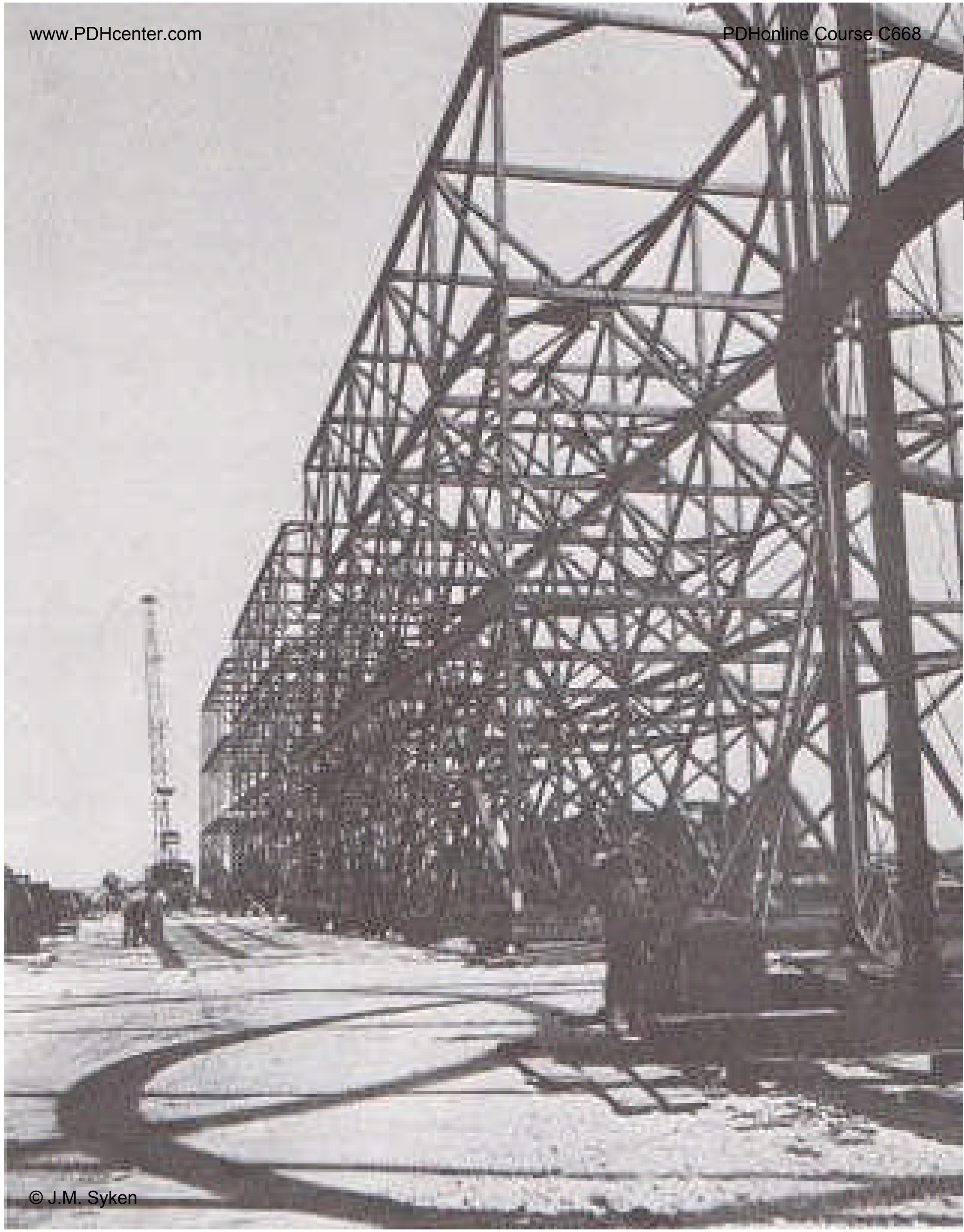
Substructure

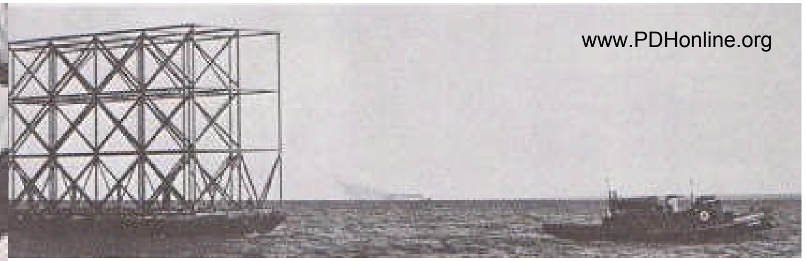
There were two general methods of marine foundation (substructure) construction used for the *Mackinac Bridge*; cofferdams and/or caissons. Of the thirty-three piers required, three of the largest piers; founded on rock more than 100-feet below the surface, were built with caissons. The balance were built using the open cofferdam method. Five of these were cofferdams built on steel piles driven to rock.



Left: caption: "Artist's sketch showing one of the unique features of Mackinac Bridge foundations. All were built from rock up to an elevation of eight feet below the surface excepting the anchorages. From this point up heavily reinforced slender pedestals were erected to support the steel superstructure. This was done to counteract ice, which often troves back and forth through the Straits with the wind. Since the ice is rarely up to three feet thick, it can move around the relatively narrow shafts, while pressure thereon is taken up by the huge heavy foundations."

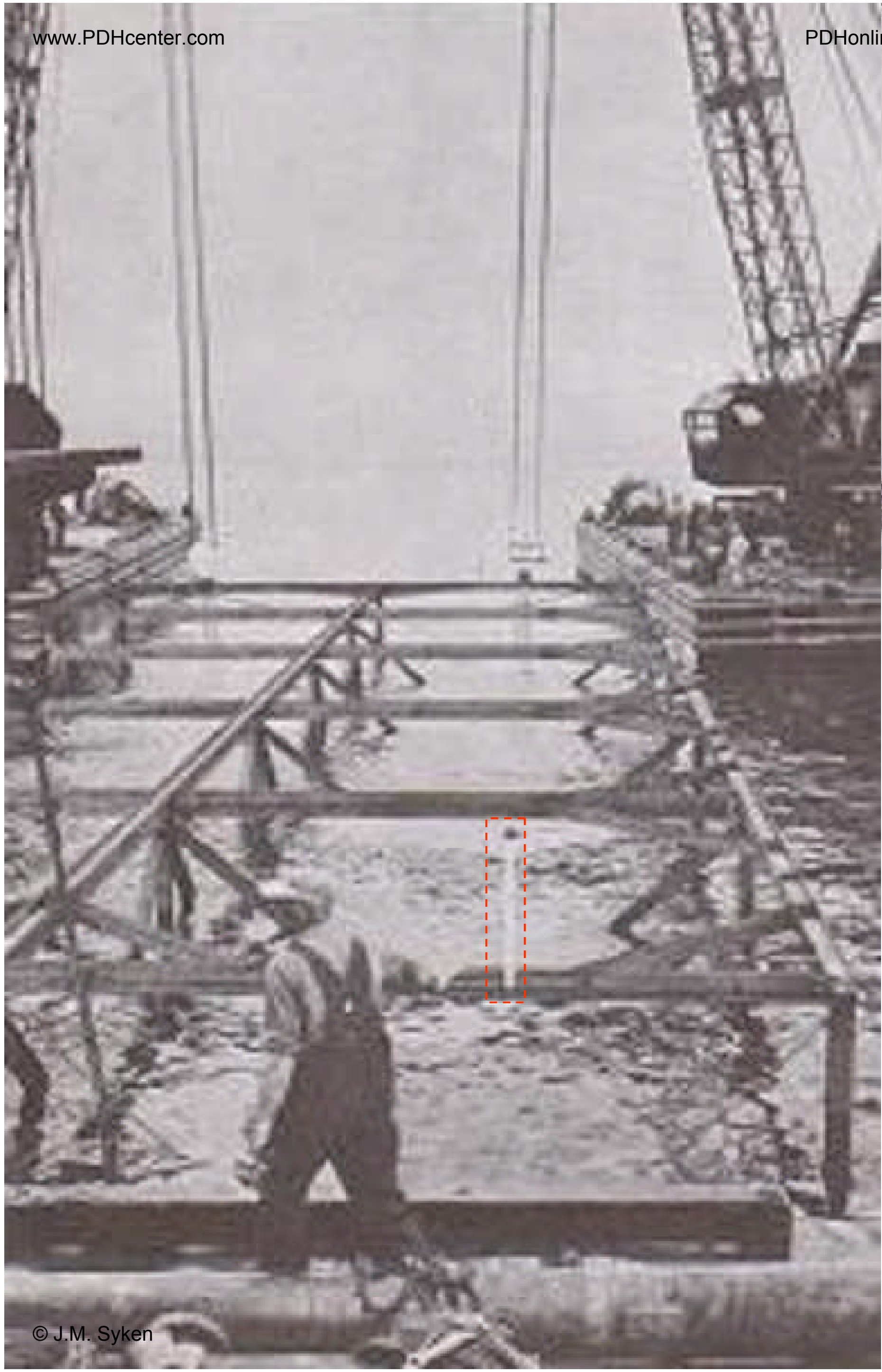
Anchorage Foundations (Piers 17 & 22)

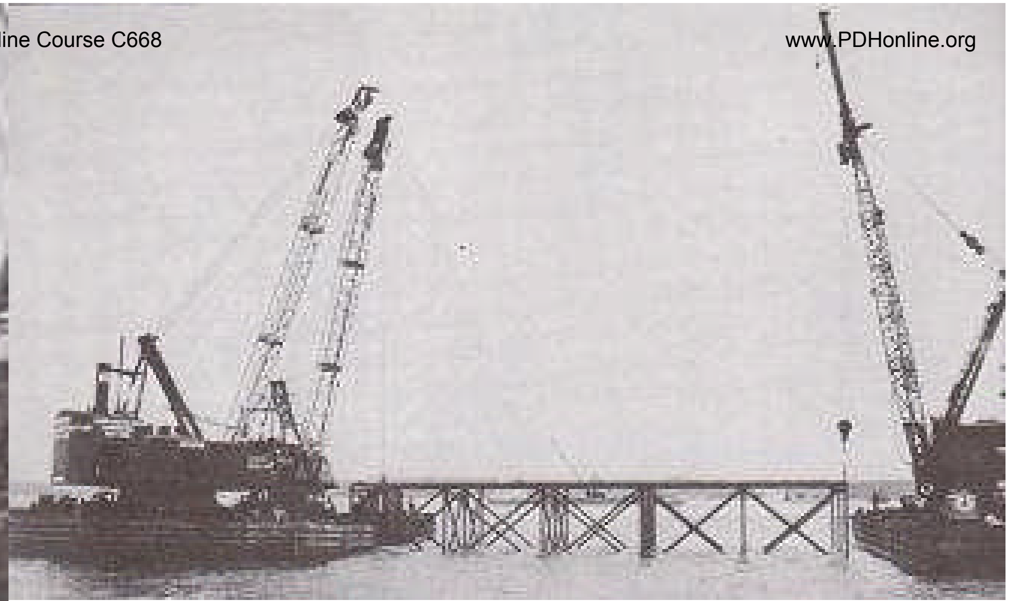




<u>Left</u>: caption: “The two huge foundations in which the cables are anchored measure 115 x 135 feet, about one-third the size of a football field. They are toed into rock more than 90 feet below the surface. The first step in building them required the land construction of three similar steel 106-ton frame-works, 135 x 35 x 75 feet high.”

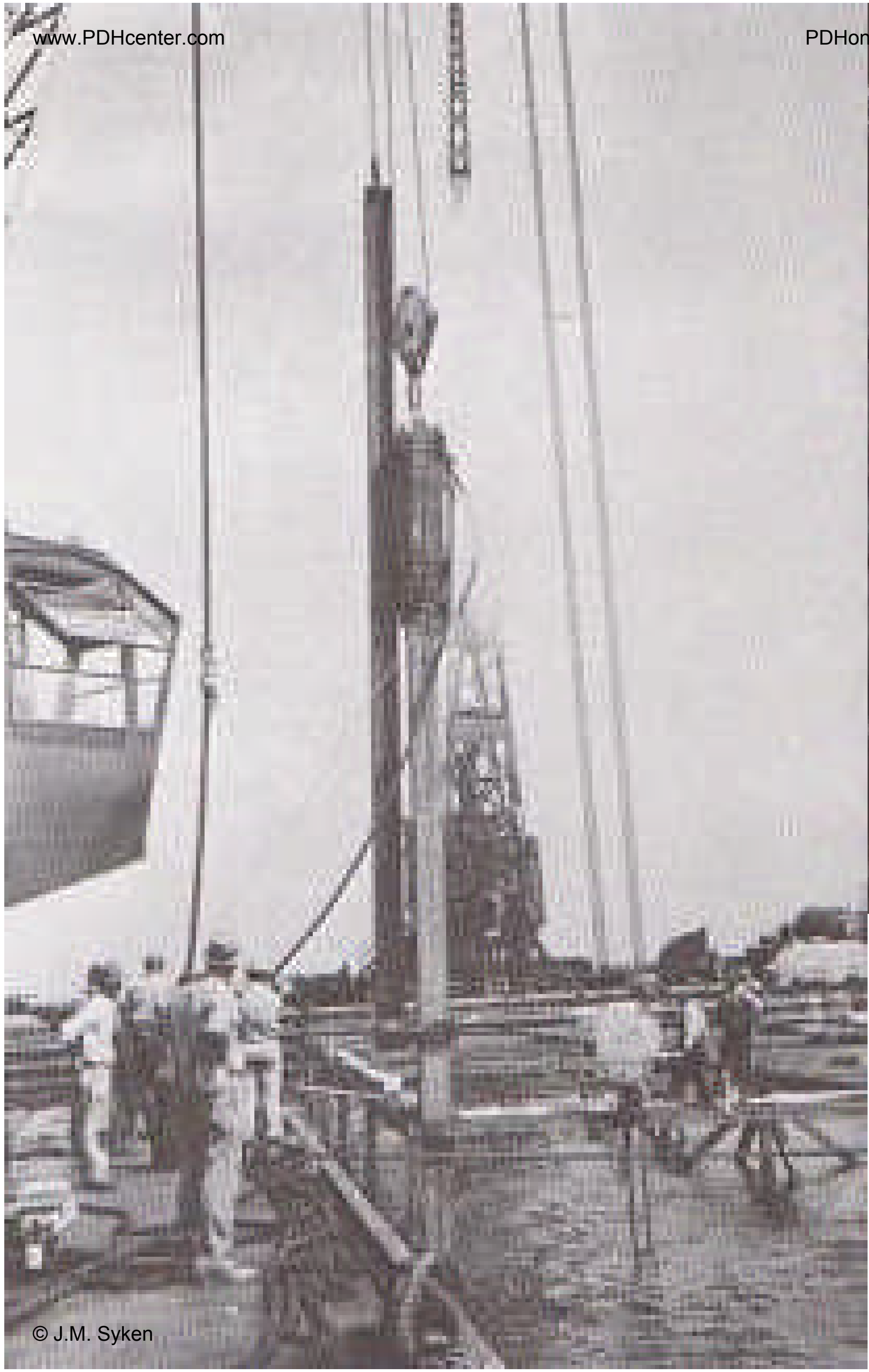
<u>Above</u>: caption: “The first of the three steel frames was loaded aboard a barge and towed to a position pre-selected by the surveyors.”

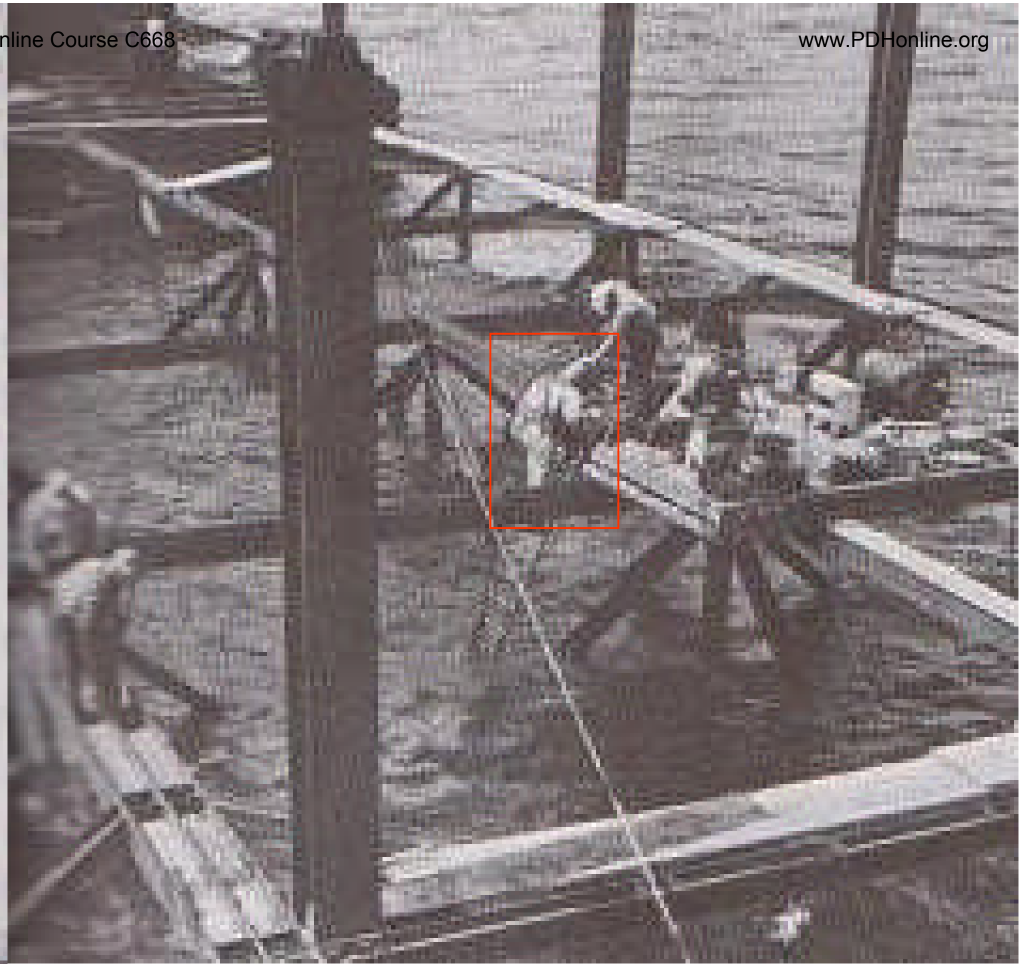




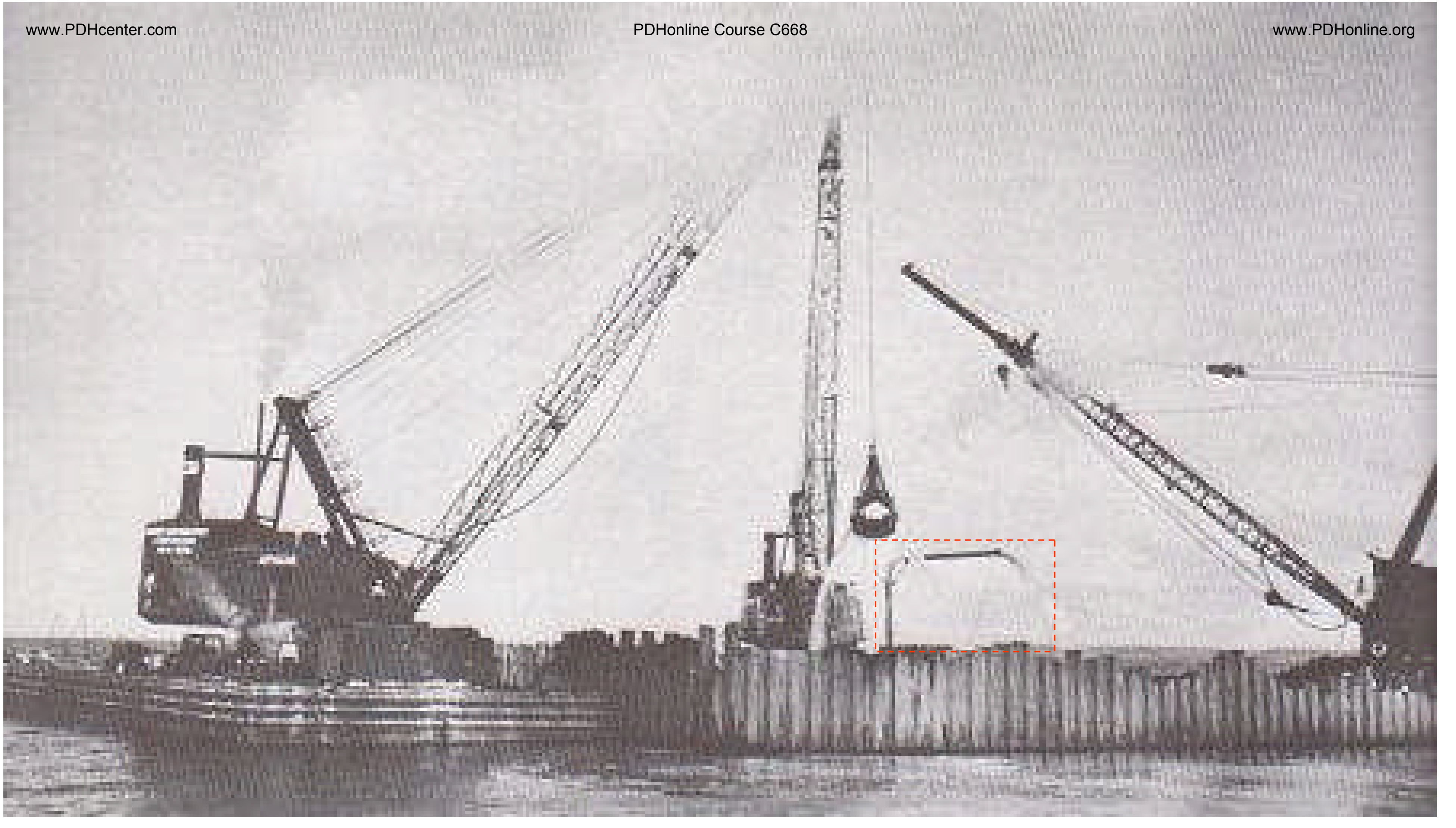
<u>Above</u>: caption: "When in position, the steel frame was picked off the barge by three marine cranes, sometimes called 'whirlies' because they turn a full circle, and gently lowered to the overburden. This is the sand, mud, clay, broken stone and miscellaneous soft material lying under water and above bedrock."

<u>Left</u>: caption: "With surveyors radioing directions (note white sighting rod welded to steel frame) the crane operator/s maneuver the frame into precise position within a tenth of an inch."



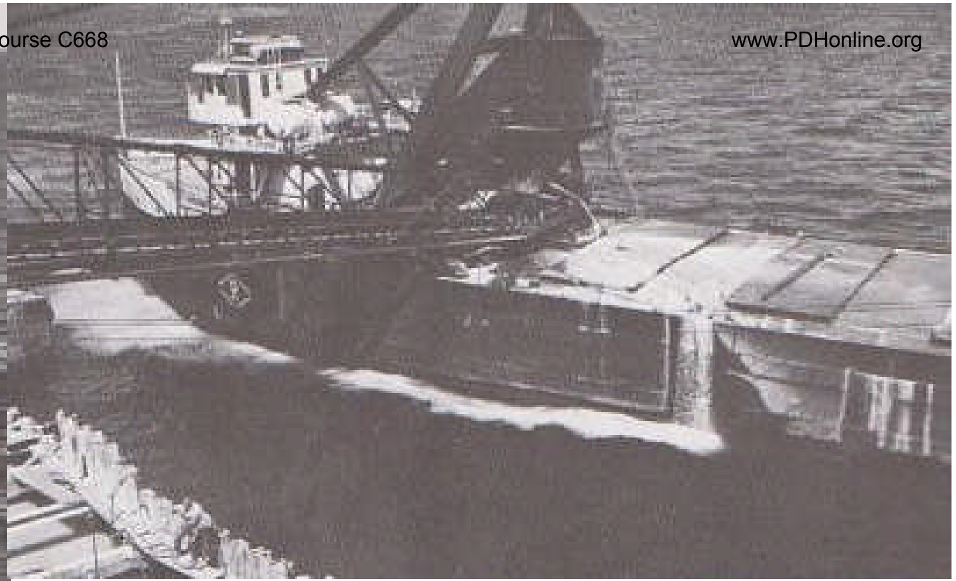


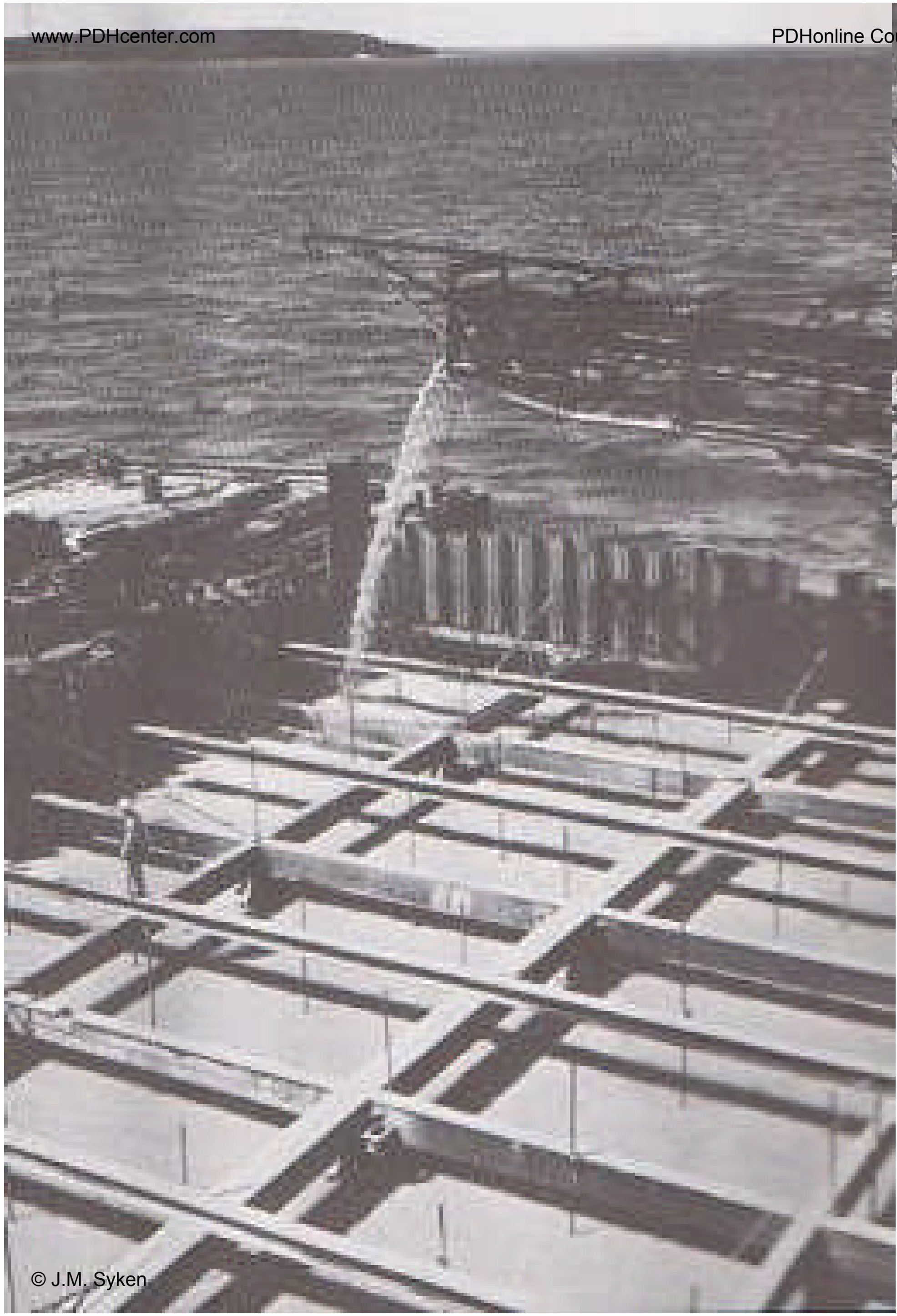
<u>Left:</u> caption: "Once in position, the frame is locked to rock by driving huge spud piles (117 pounds to the lineal foot) through slots in the frame, through the overburden, into bedrock until the pile could no longer be driven (every blow was counted and the depth of penetration it caused was precisely measured).
<u>Above</u>: caption: "When the first of the three steel frames was tied to rock with eight spud piles, the second or middle section of the frame was attached both above the surface and below as a diver descended to perform underwater operation. The procedure was repeated, with the third steel frame completing the entire framework for the foundation."



<u>Above</u>: caption: "Clam-shell buckets, operated from three busy 'whirlies,' dig overburden out of cofferdam, which was not dewatered. A jet (center of picture) removes fine materials in the manner of a vacuum cleaner. All overburden was removed so that only clear blue water remained above bedrock. Since the sheet piles around the cofferdam were all driven to refusal – could be driven no further – their top is irregular, paralleling the irregular contour of the bedrock (Pier 17)."

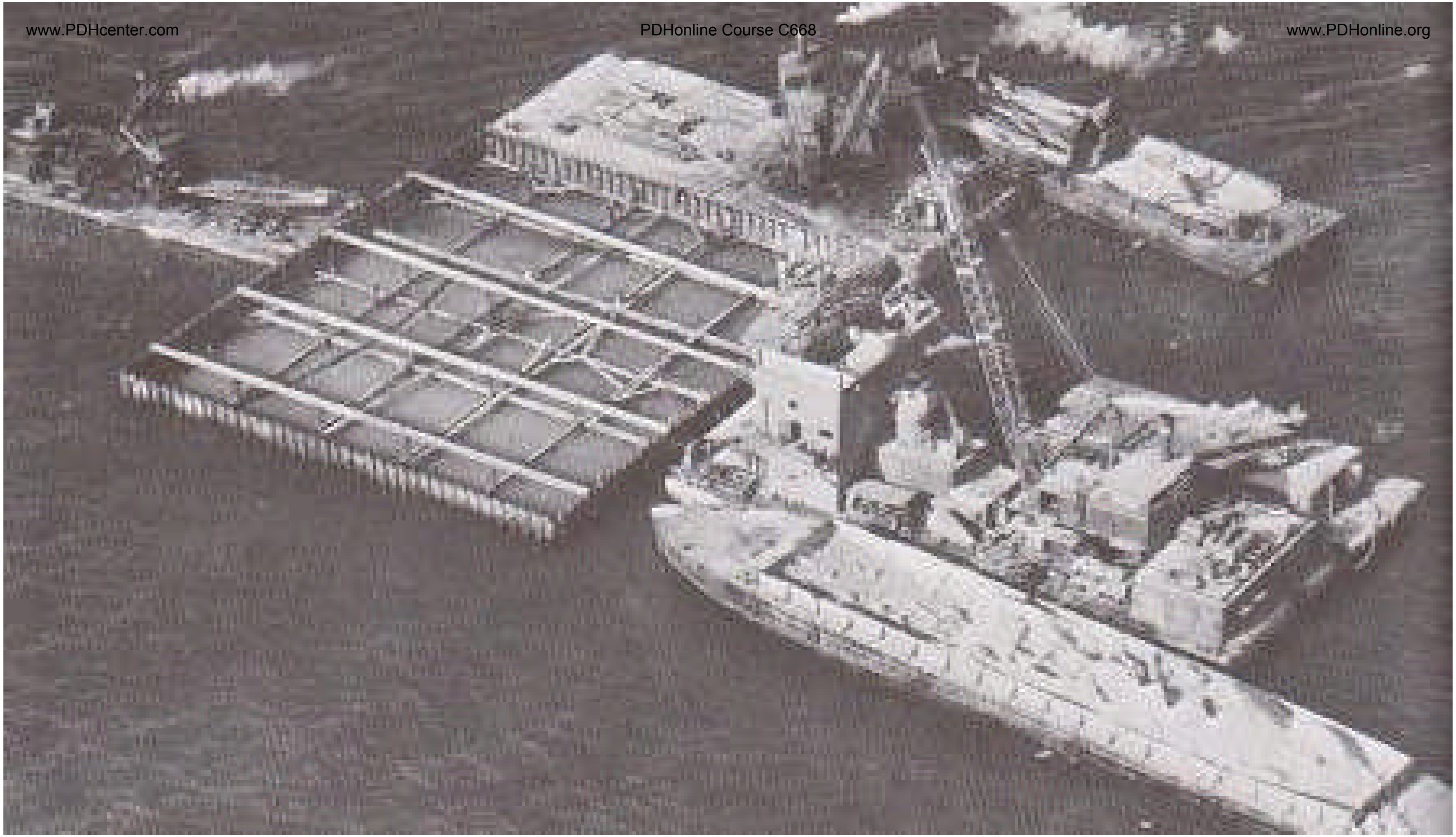
<u>Above</u>: caption: "The aggregates or crushed stone for the Mackinac Bridge foundations had to be specific sizes, hardness and cleanliness (actually washed two or three times to remove fine dust particles). It was quarried, crushed, screened and washed at Drummond Island, about 50 water miles away." 176



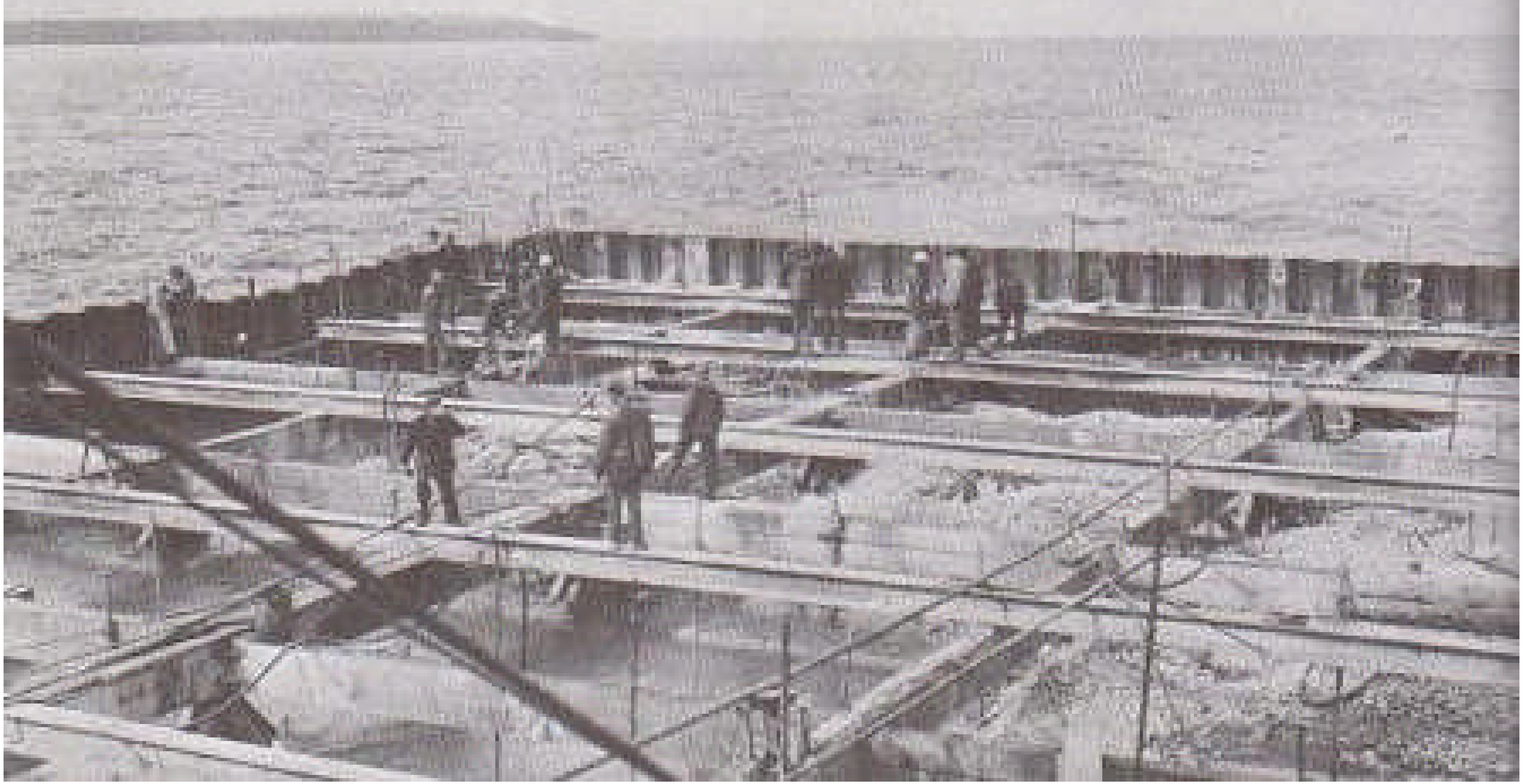


Above: caption: "It was shipped in 12,000-ton self-unloading boats to the bridge site where it was unloaded into the cofferdams in three to four hours."

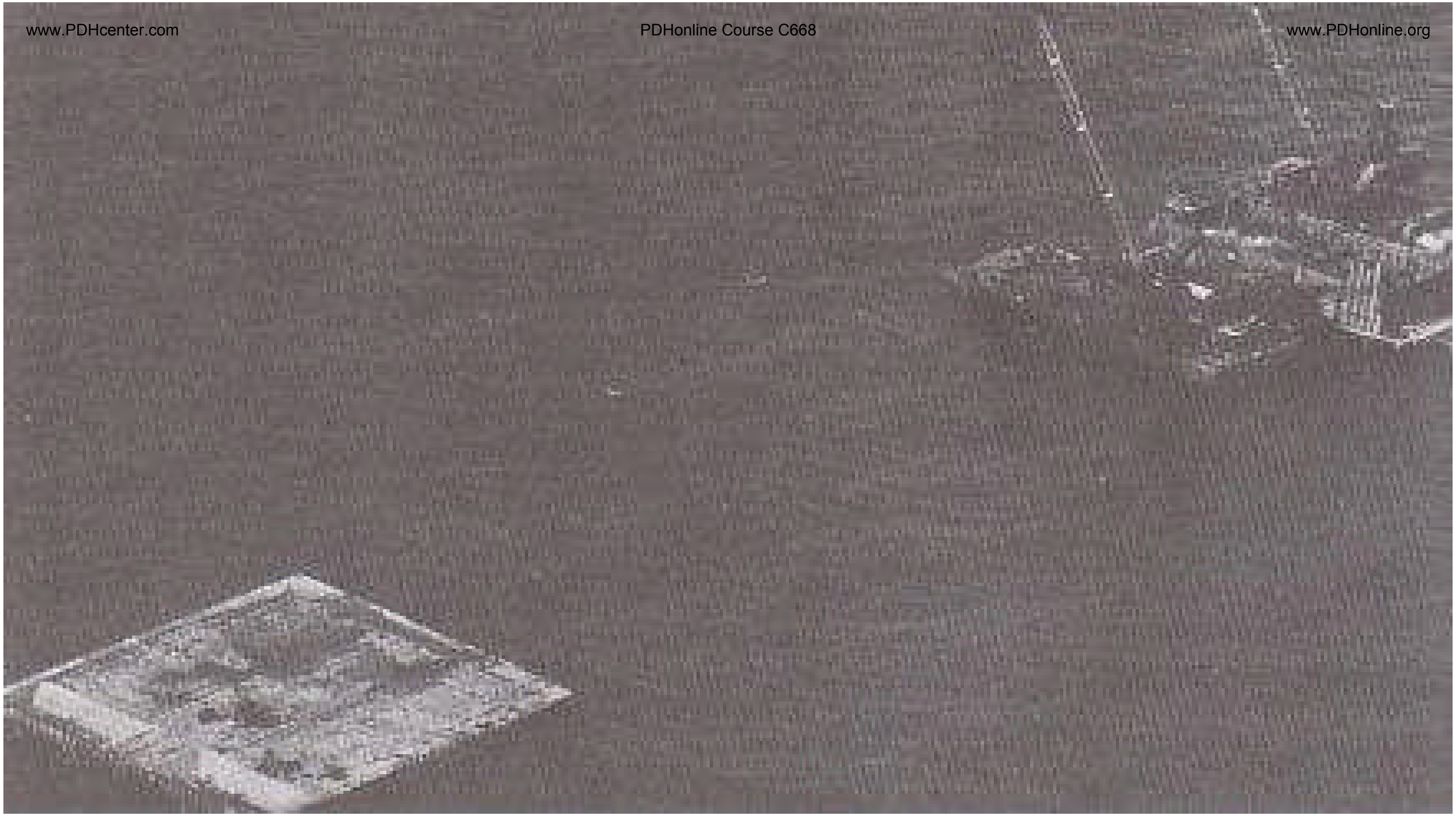
Left: caption: "prior to dumping aggregate into the cofferdam, vertical pipes were installed from the surface to the bottom. These pipes as shown were spaced 20 feet apart and were known as grout pipes."



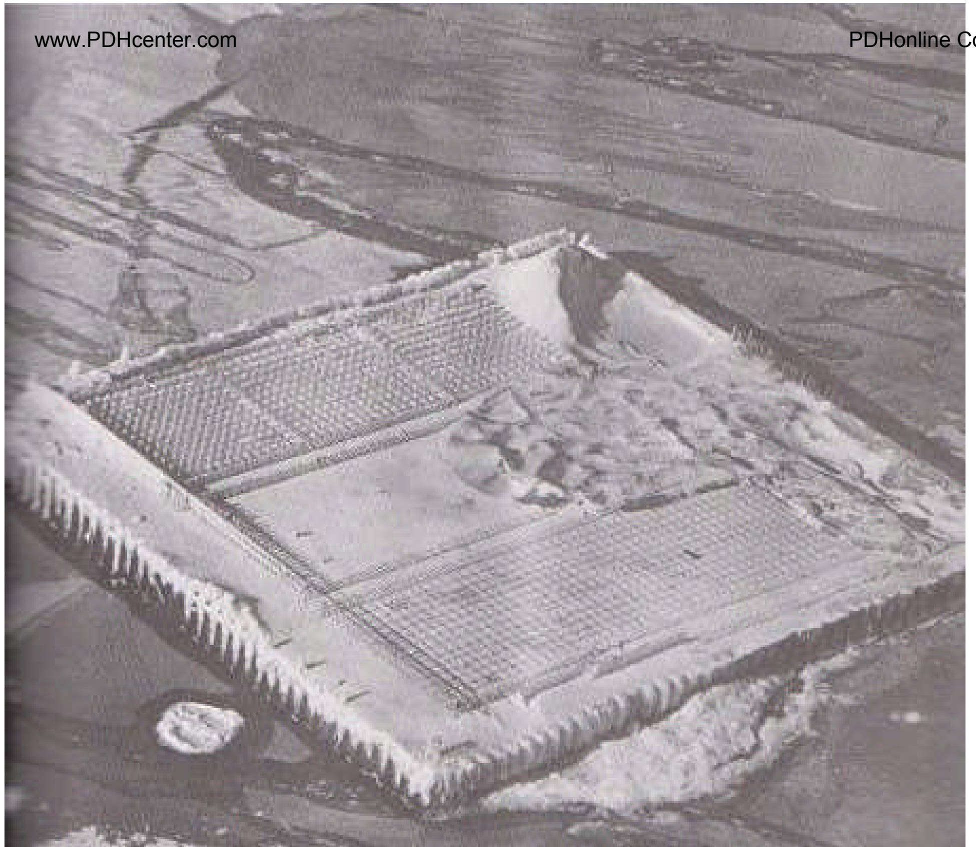
<u>Above</u>: caption: "When a layer of aggregates about 10 feet deep was dumped inside the cofferdam, the four-story high marine grout plant was brought alongside. The plant made grout from cement, sand, fly ash, water and a patented intrusion-aid which gave it a smooth flowability and a pea soup consistency. The mixture was then pumped down the grout pipes to the bottom of the cofferdam where the aggreagates had previously been dumped. About 40% of the area occupied by the aggregate was filled with water. Into this area the grout was pumped displacing the water, completely surrounding the crushed stone and hardening it into solid concrete."



<u>Above</u>: caption: “Before the grout solidified, the grout pipes were pulled up to about two feet below the surface of the crushed stone. Then more aggregate was dumped into the cofferdam, more grout was pumped in and the operation was repeated until the foundation reached the surface as shown.”



<u>Above</u>: caption: "An aerial view of the south anchorage, Pier 17, as it appeared in October, 1954; 85,000 tons of concrete and steel from the rock bottom of the Straits 90 feet below the surface to 10 feet above. To the right, foundation of Pier 18, caisson construction." 180



<u>**Top**</u>**: caption: “By January, 1955, winter had completely shut down all work on Pier 17 and all other foundations as well.”**

<u>**Bottom**</u>**: caption: “View of the top of the south cable anchorage foundation (Pier 17) after the two-inch steel dowels for connecting up with the superstructure had been installed (January 1955). This surface was eventually concreted smooth and buried under 45,000 tons of concrete and steel in which the cables were anchored.”**

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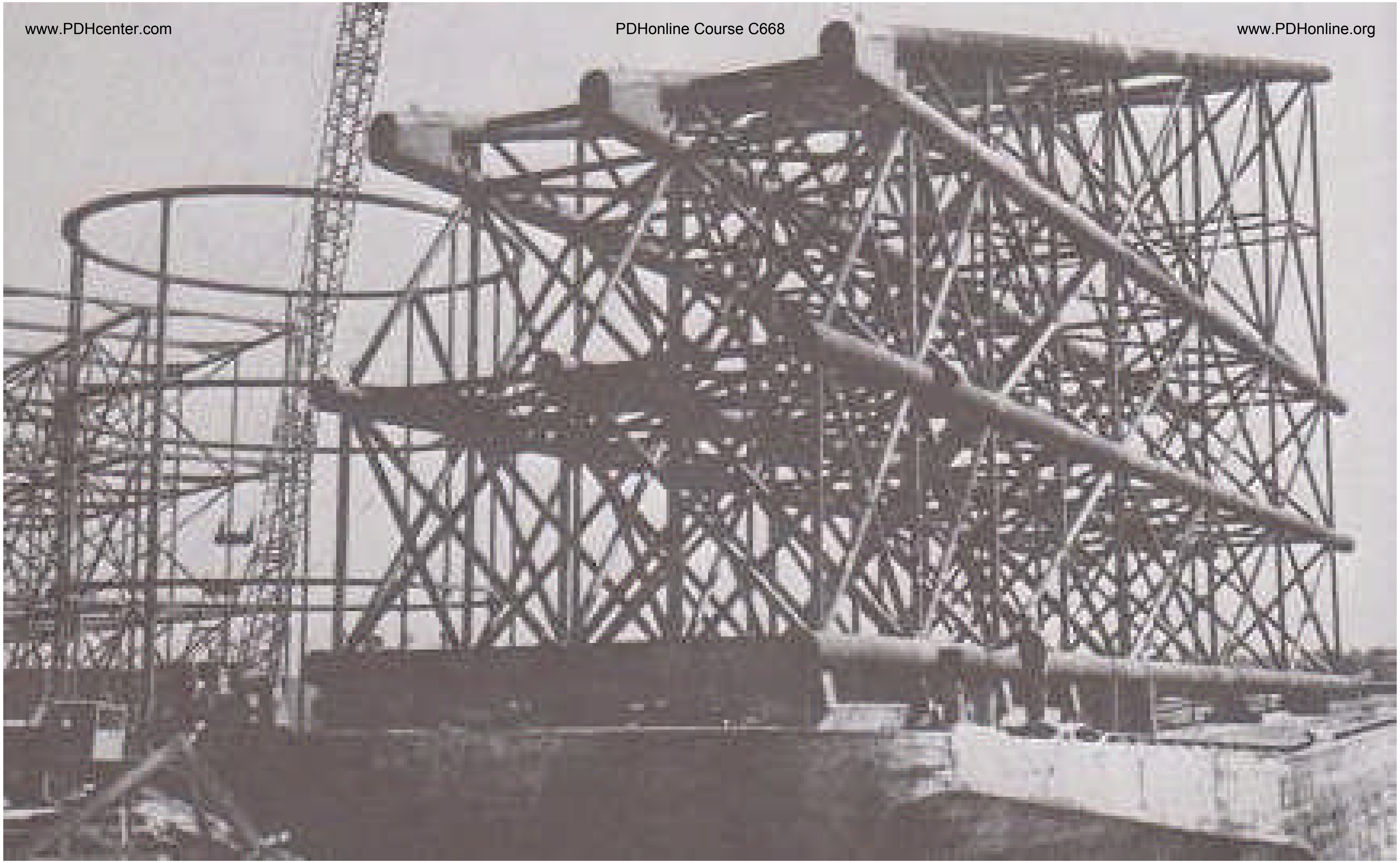
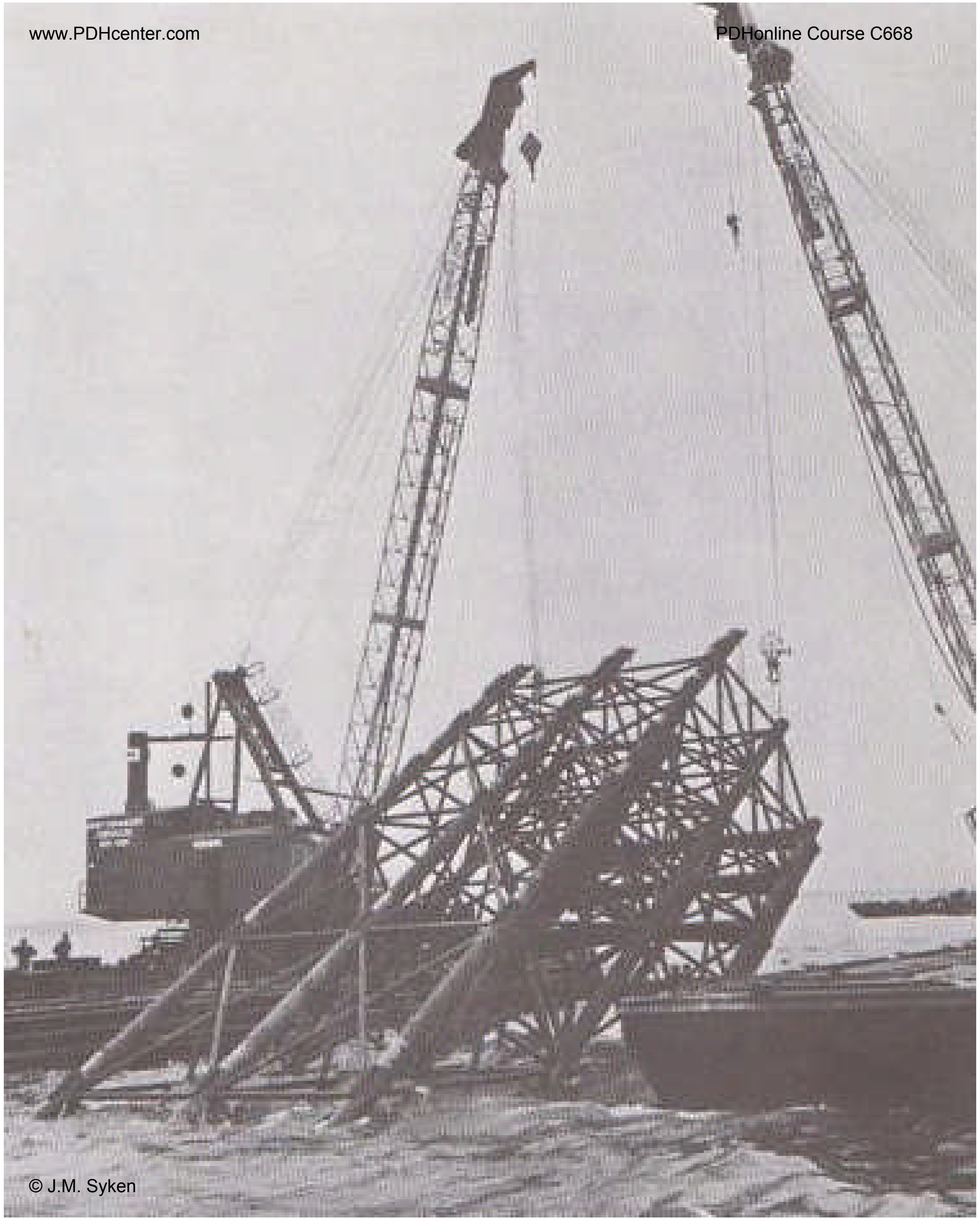
Tower Foundations
(Piers 19 & 20)

While the two anchorages (a.k.a. Pier/s 17 and 22) were under construction in 1954, MC&S was simultaneously constructing two enormous foundations upon which the two main towers would rest (a.k.a. Pier/s 19 and 20). Two smaller cable-bent piers; one a caisson, the other a pair of cofferdams, were under construction in 1954. The tower foundations would be toed into solid rock more than 200-feet below the surface of the Straits at a distance more than two miles from either shore.



<u>Above</u>: caption: "Loaded on a barge, here is one of the four parts of a corral – not to hold horses, but to hold a huge double-walled circular steel can. The structure, shown lying on its side, is made up of 20-inch pipes held together with six-inch pipe bracing (Pier 19)."



Left: caption: "Three of the four caisson corral units were lowered to overburden. Through their 20-inch pipes heavy piles were driven to rock. Concrete was pumped into the pipes for additional strength. Next, the caisson was towed into position flush against the three units of the corral already anch-ored. Then the fourth side was installed. Thus the huge caisson was held in position while being lowered to the bottom, despite wind and high water. All movements were directed by surveyors from triangulation towers."

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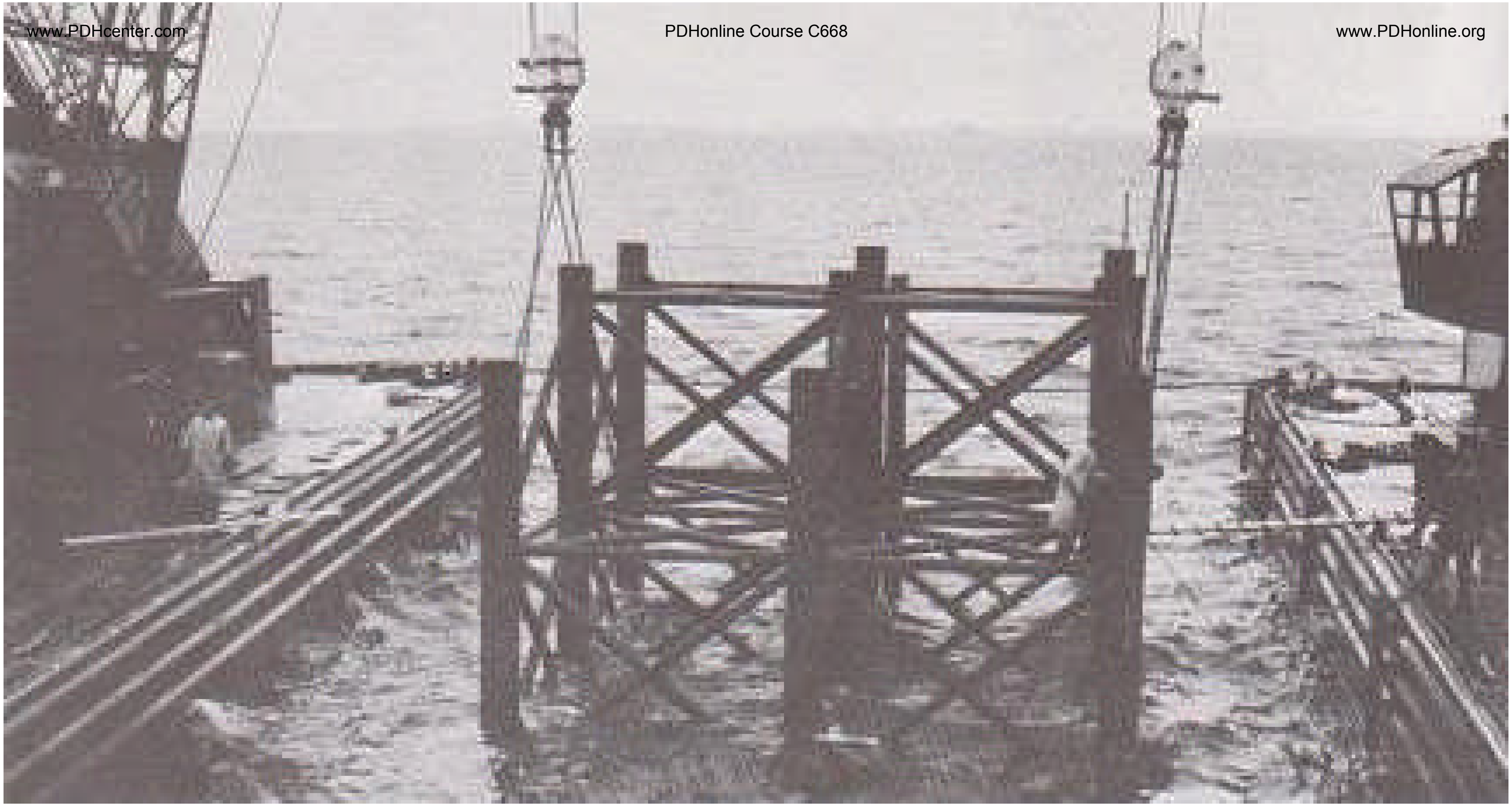
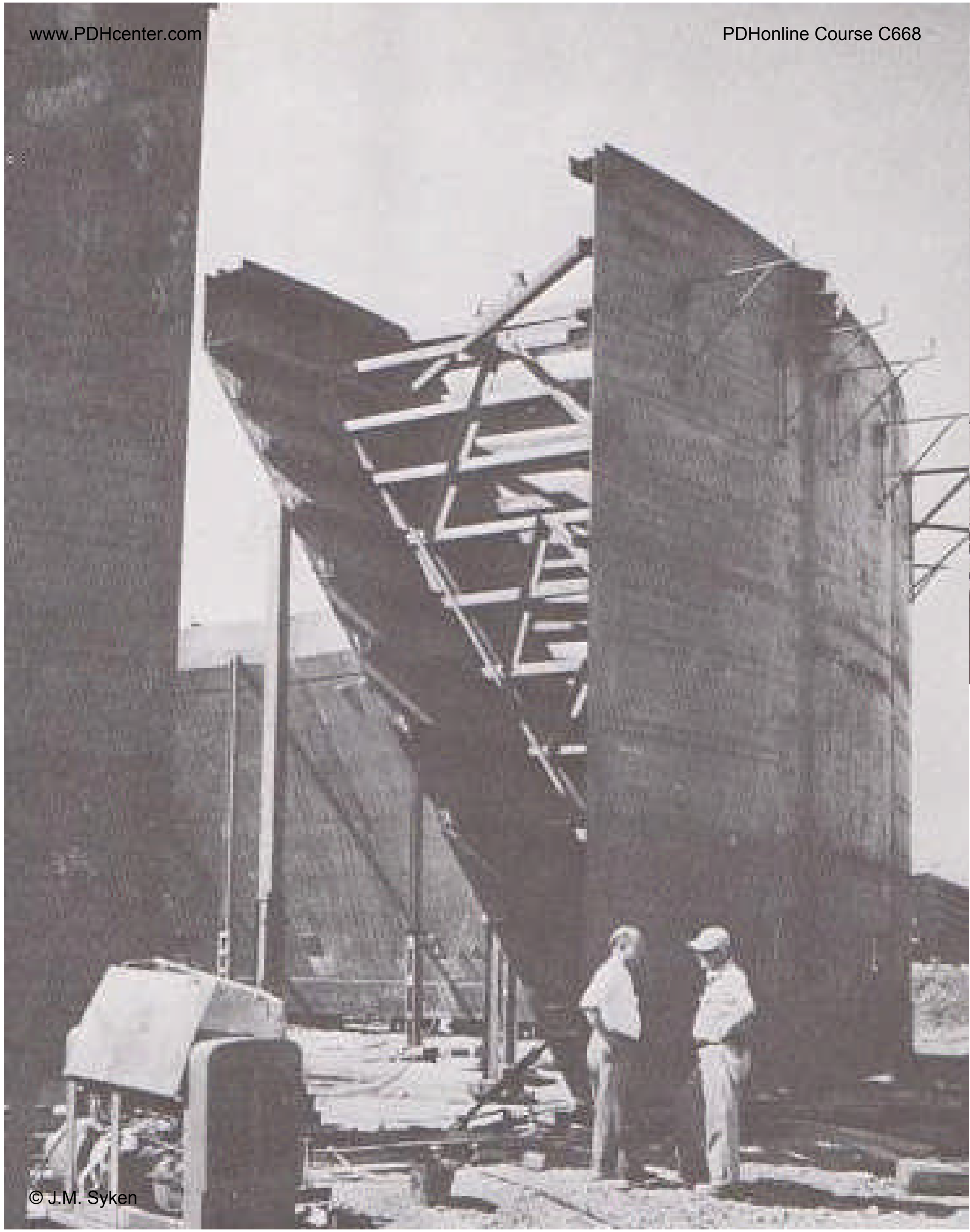
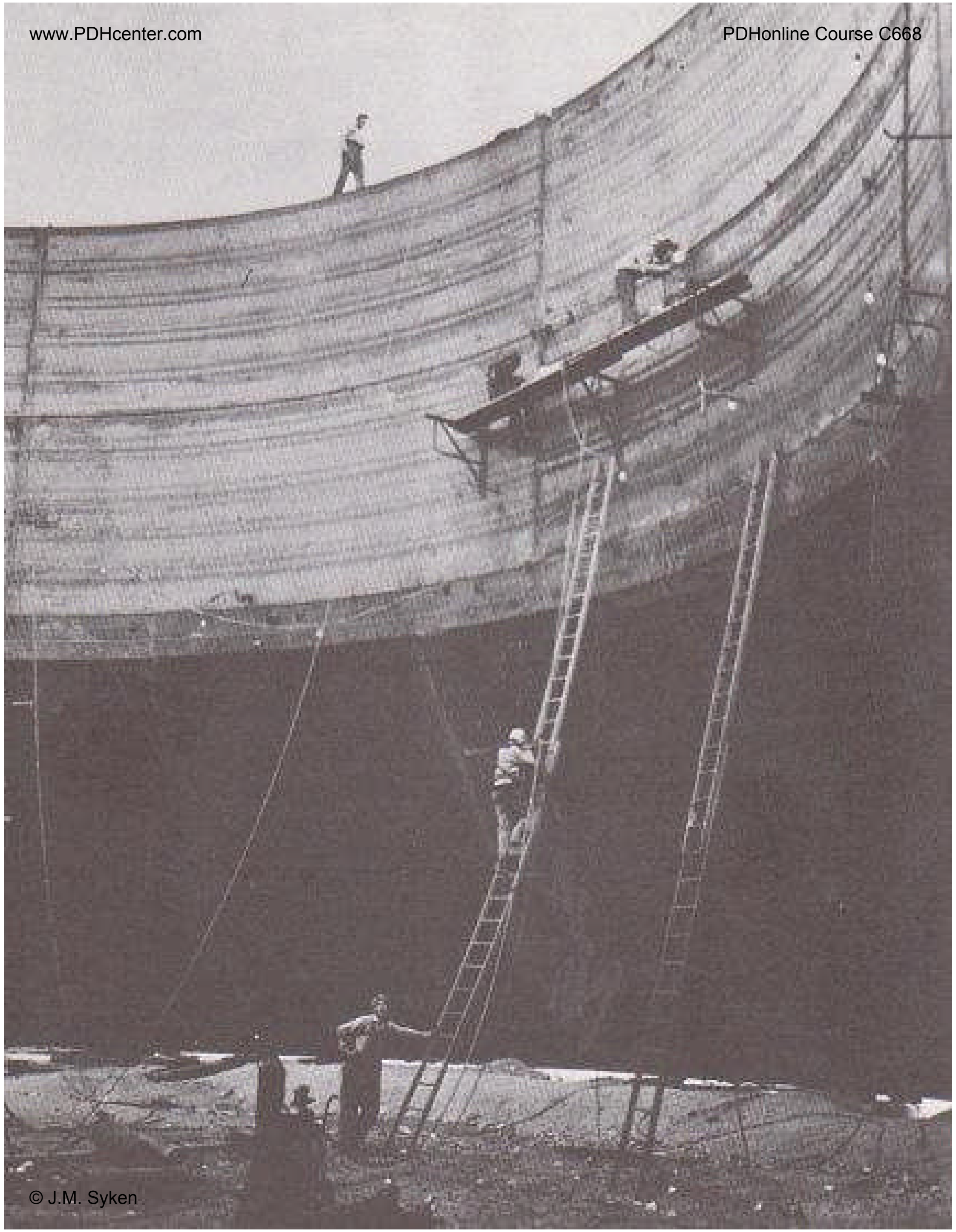


<u>Above</u>: caption: "With the caisson guide (one side of the corral) resting on the bottom, workmen unhitch the block and tackle connected to the derricks which lowered the huge clumsy framework precisely into position." 186

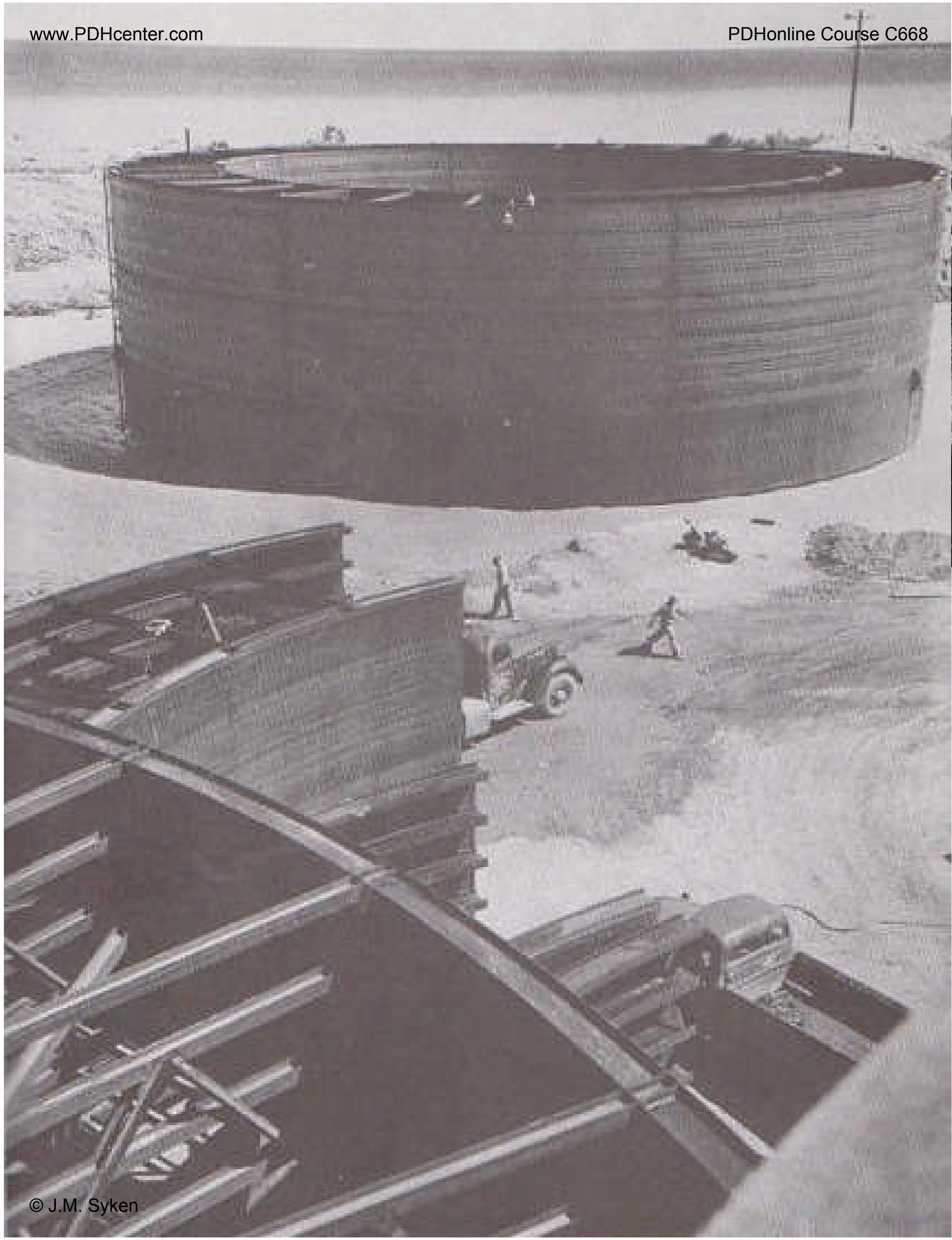


<u>Above</u>: caption: "A close-up of two of the four corral units showing 20-inch pipes with spud piles inside. These were driven to rock to anchor the framework sufficiently to contain the caisson."

<u>Left</u>: caption: "The two caissons (French, meaning box, usually for artillery) were assembled on land at Rockport, Michigan, 90 miles from the Straits. Shown here is the incomplete bottom section. Note how the inside wall tapers to the outer wall to form a cutting edge."

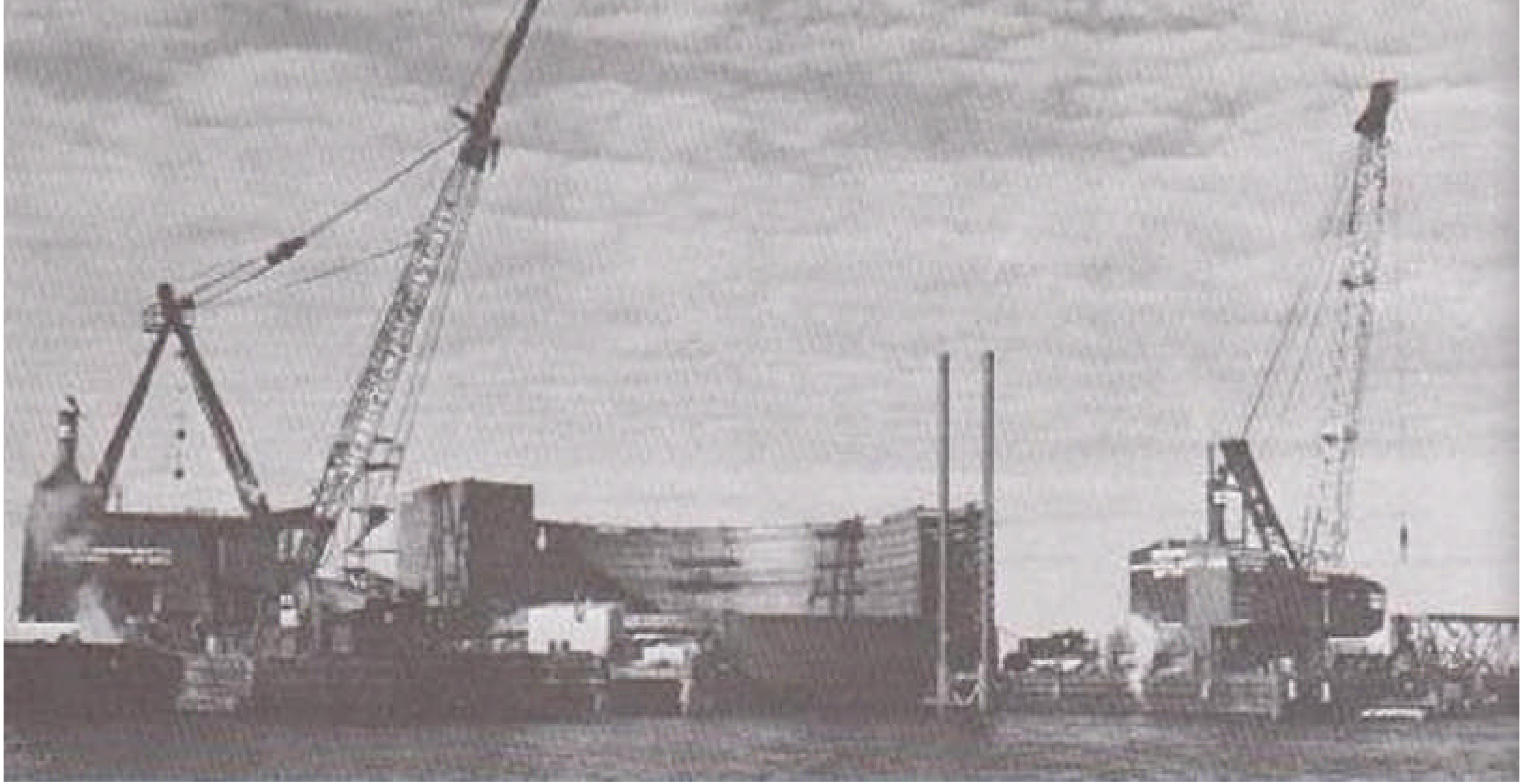


Left: caption: "Inside the caisson, welders sealed all parts so that it became watertight between the walls. These were then divided into eight watertight compartments (Pier 20)."



<u>Above</u>: caption: "Caisson for the north main tower foundation afloat at Wiltse Brothers Shipyard near Alpena. August 31, 1954"

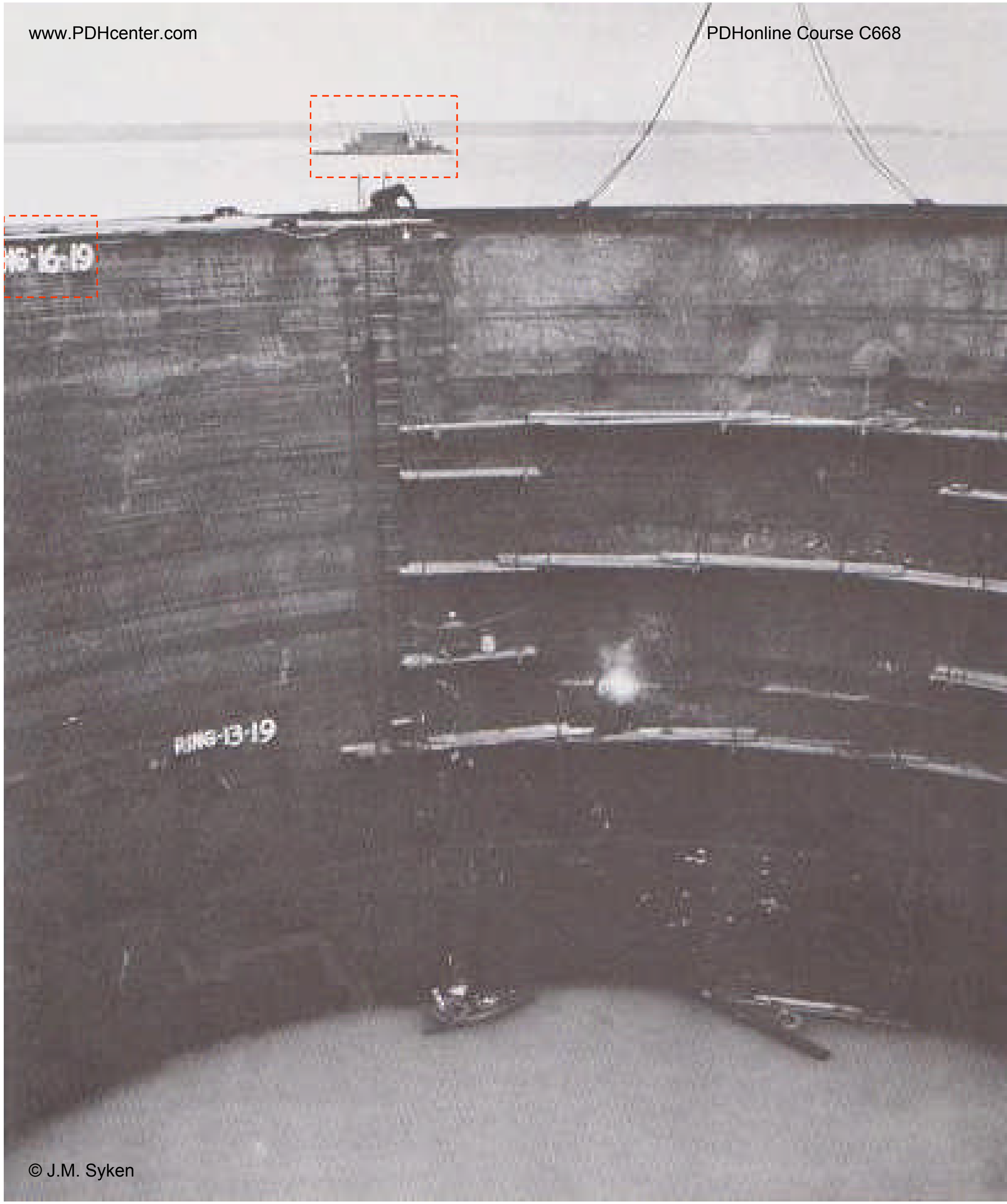
<u>Left</u>: caption: "When the caisson was built to a height of 44 feet (116 feet in diameter) a channel was dug from Lake Huron to the caisson, flooding the area beneath it. Being buoyant, the caisson could then be lowered into Lake Huron and 90 miles northwest to the Straits of Mackinac."

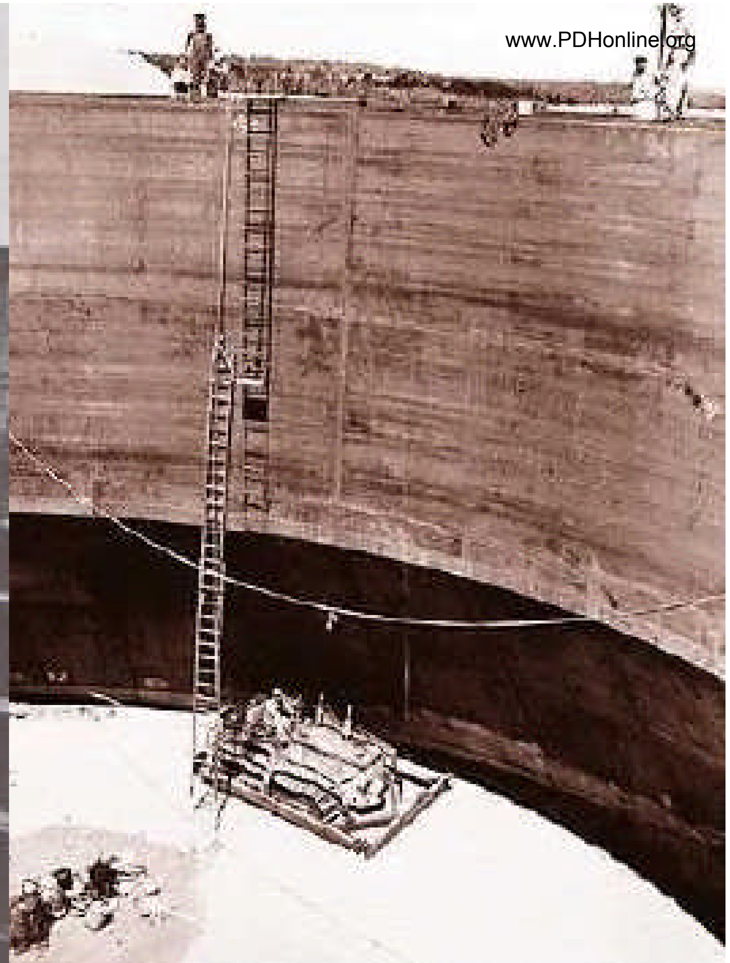


<u>Above</u>: caption: "Once in position the process of sinking the caissons began. This was accomplished by dumping rock aggregates into the space between the two circular steel walls. Acting as ballast, the stone caused the caisson to sink, and another double-walled ring of steel was added to the top as shown (Pier 19)."

Above: caption: **"Soon the stone-loaded caisson reached the overburden. To penetrate this area 'whirlies' with clam-shell buckets dug out the overburden out of the center (digging well) of the caisson. This reduced resistance against the cutting edge of the tapering wall at the bottom of the caisson (weighted with stone) forcing the overburden toward the center of the digging well - just like a giant cookie-cutter. The overburden was dumped outside the caisson. (Pier 20, North tower foundation, Oct. 29, 1954)."**

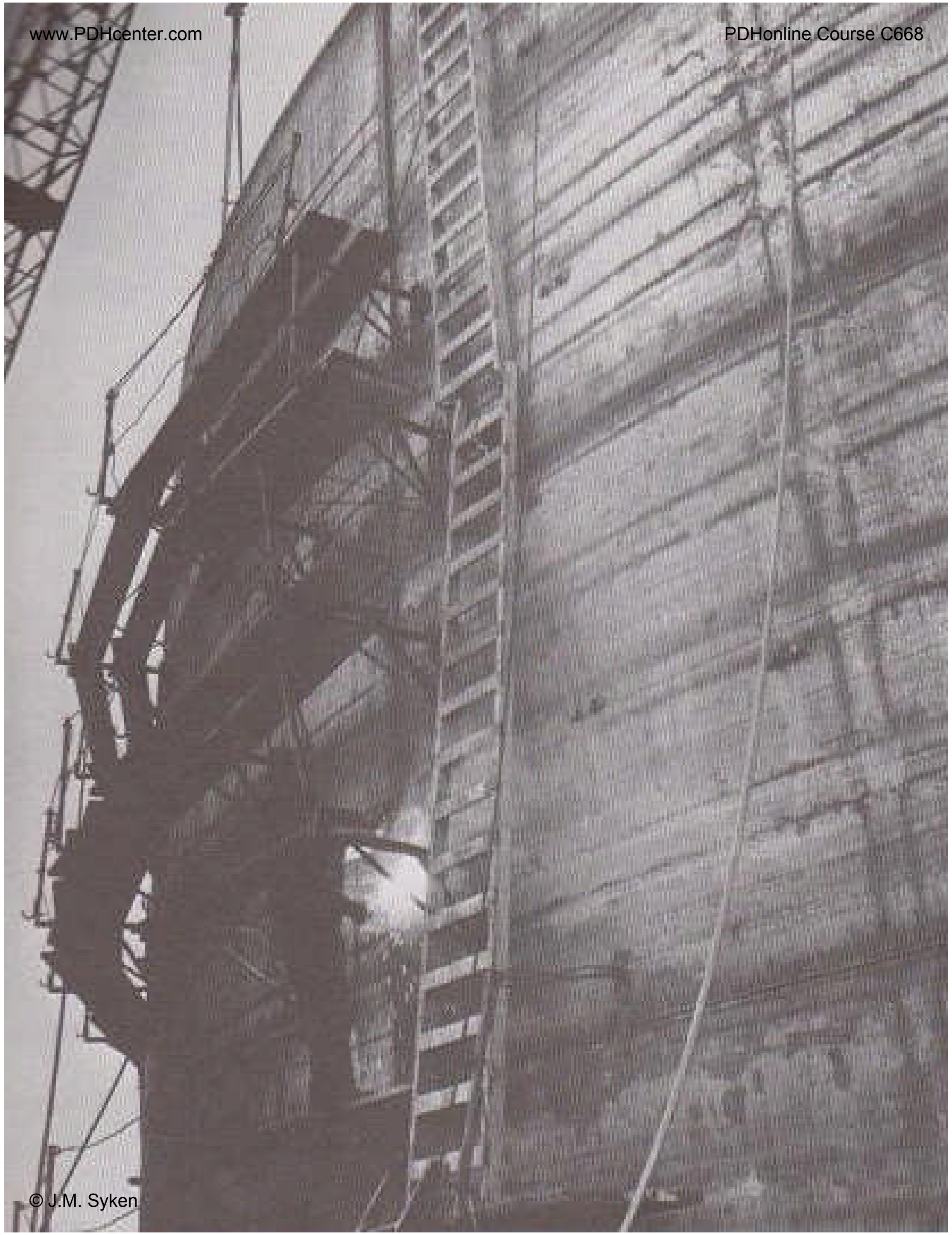
191



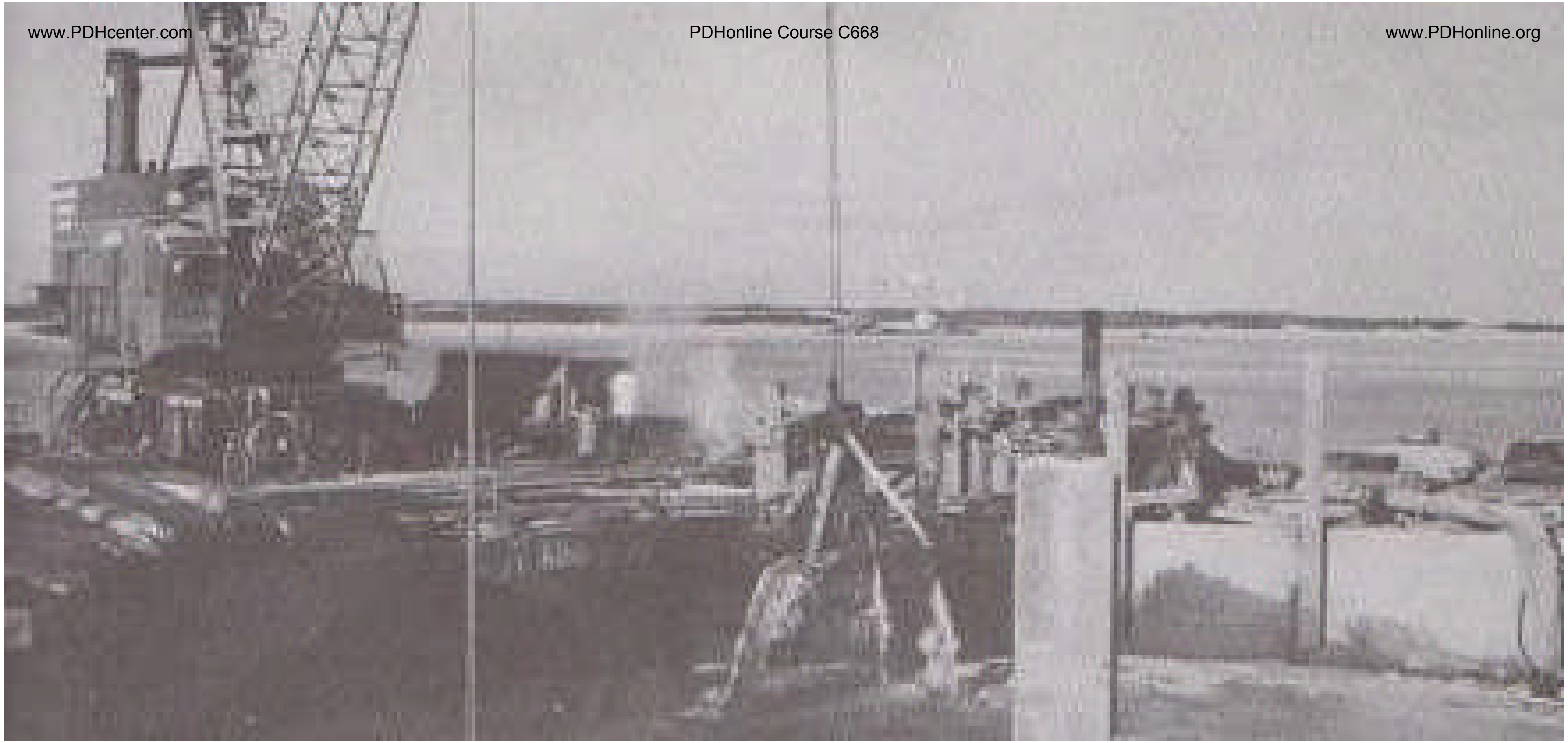


<u>Left</u>: caption: “Inside the caisson, the bottom of which was about 50 feet from bedrock, workmen welded the double-walled ring of steel. ‘Ring 16-19’ identifies the sixteenth high stage of steel for Pier 19. Pier 20 is in the distance.”

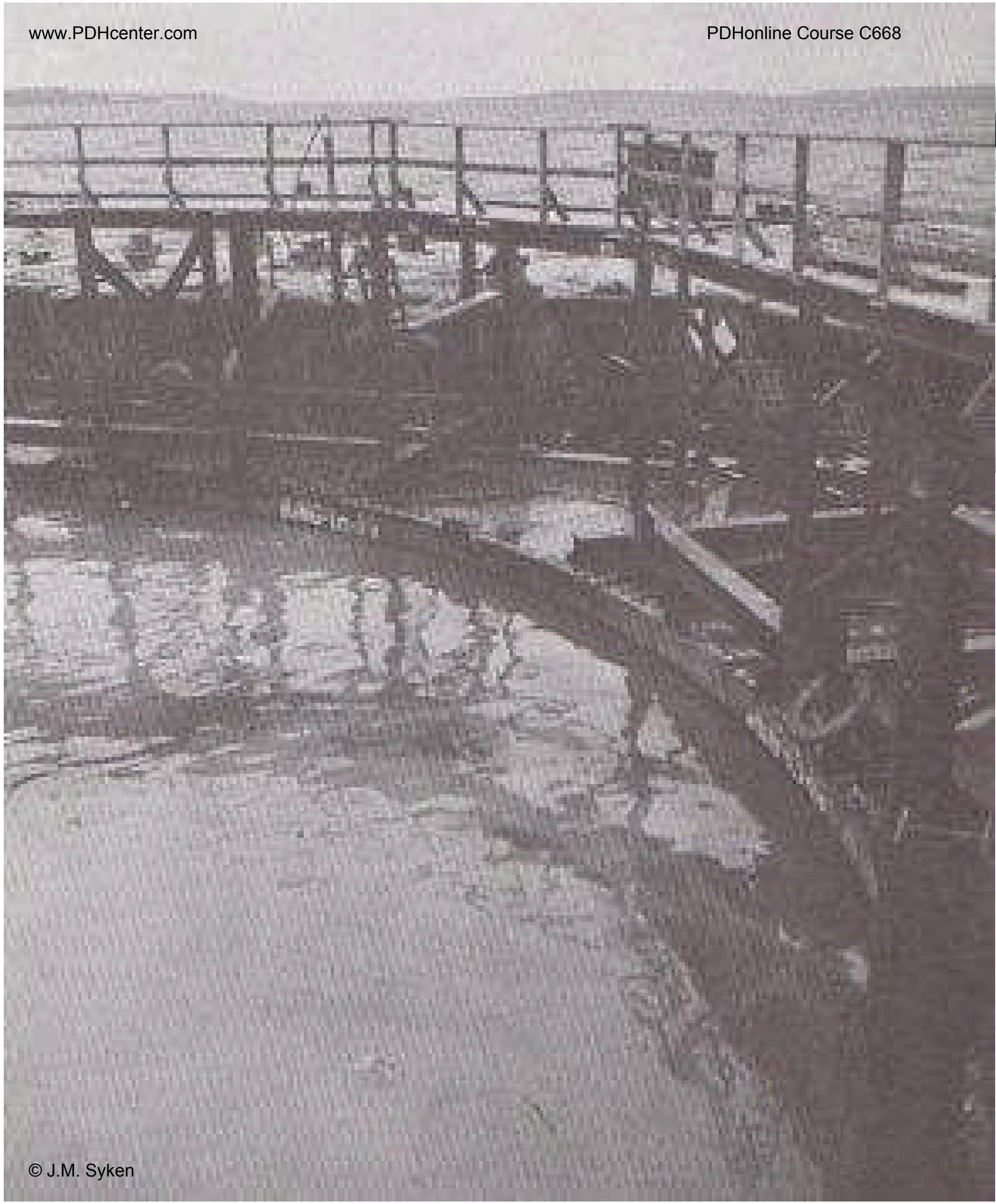
<u>Above</u>: caption: “A Caterpillar tractor levels the stone within the caisson.”



<u>Left</u>: caption: "Outside, the caisson men on three stories of scaffolding raced against winter to complete the driving of the caisson to bedrock. This photograph was taken on November 26, 1954."



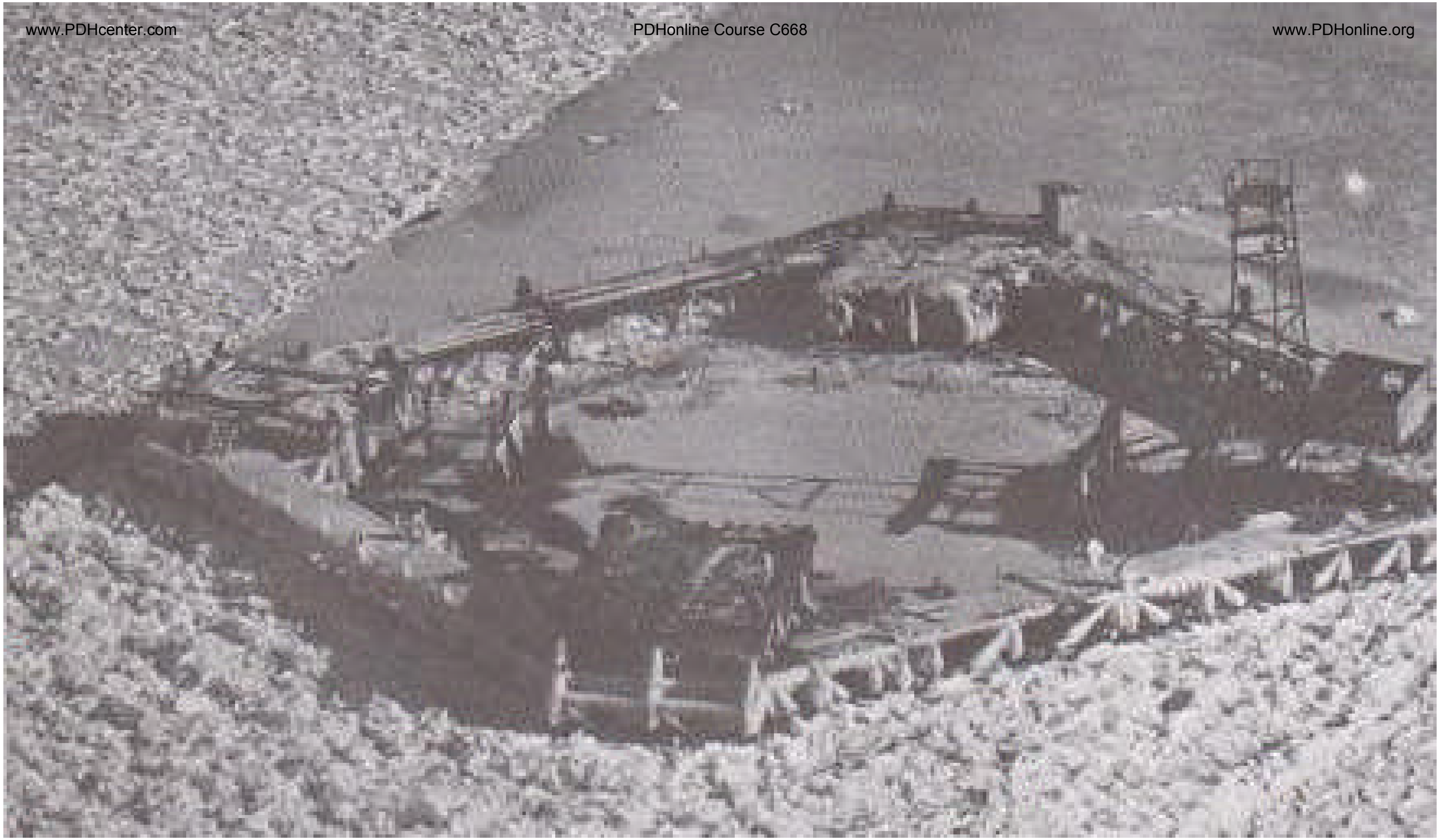
<u>Above</u>: caption: "The caisson bottom was about six feet from bedrock four days before Christmas, 1954. The driving was extremely difficult then, with penetration averaging only a few inches per day. Steam as well as explosives were required to break away boulders and other obstructing materials nearly 200 feet below the surface (Pier 19)."



__Above__: caption: "Mackinac Bridge site from the northwest after the first construction season. In the foreground there are materials stockpiled on the causeway. Foundations are in place for Piers 22, 21, 20, 19, 18, and 17. January 18, 1955."

__Left__: caption: "The caisson was nearly founded in early January, 1955, as ice began to form in the Straits. Winter was late that year and work did not shut down until January 14, 1955."

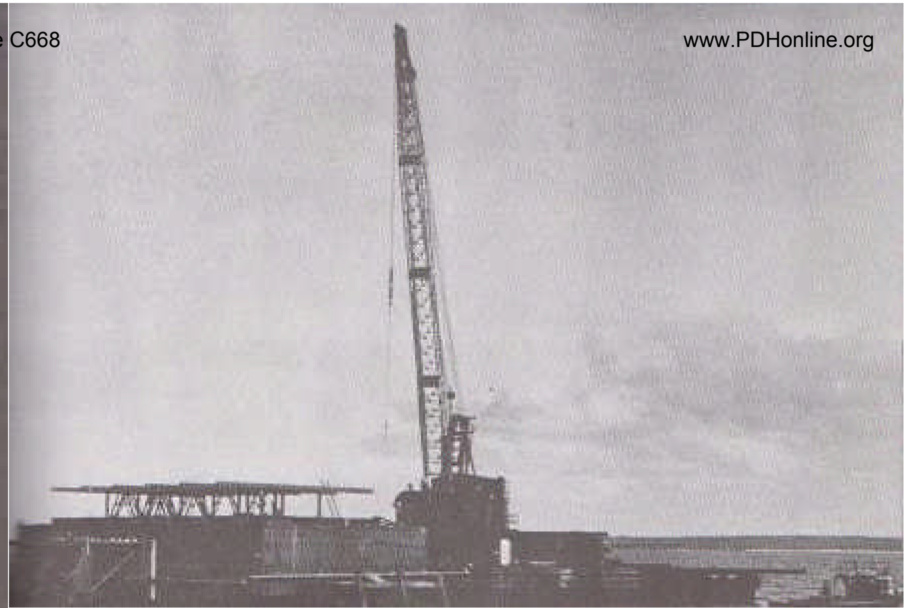
195



<u>Above</u>: caption: "Crinkled ice makes an attractive pattern around the caisson still protected by four corral units and the work platforms connecting them. Wind has piled ice up against one side of caisson while the opposite side is clear (upper right of picture)."

South Cable-Bent Foundation (Pier 18)

Along with the foundations for the two main bridge towers, the foundation for the south cable-bent tower (Pier 18) was also built using a caisson. However, rather than having a circular configuration, Pier 18 had an overall rectangular shape. As such, rather than have a single digging well, it had a total of twenty-one; three rows of seven each nine-feet in diameter (the wells were circular). This allowed for increased control during the sinking operation.



<u>Left</u>: caption: “The Pier 18 caisson, 44 x 92 feet, was assembled at Toledo to a height of 38 feet. It was towed to the Straits, positioned in its corral, and the process of driving it to rock bottom was the same as for the circular caisson. Here another lift of digging wells and wall is being welded to the top of the caisson.”

<u>Above</u>: caption: “The function of the corral is shown clearly in this picture of Pier 18 caisson. In view are two of the four units which anchor the caisson in place against wind, current and boat bumping.”

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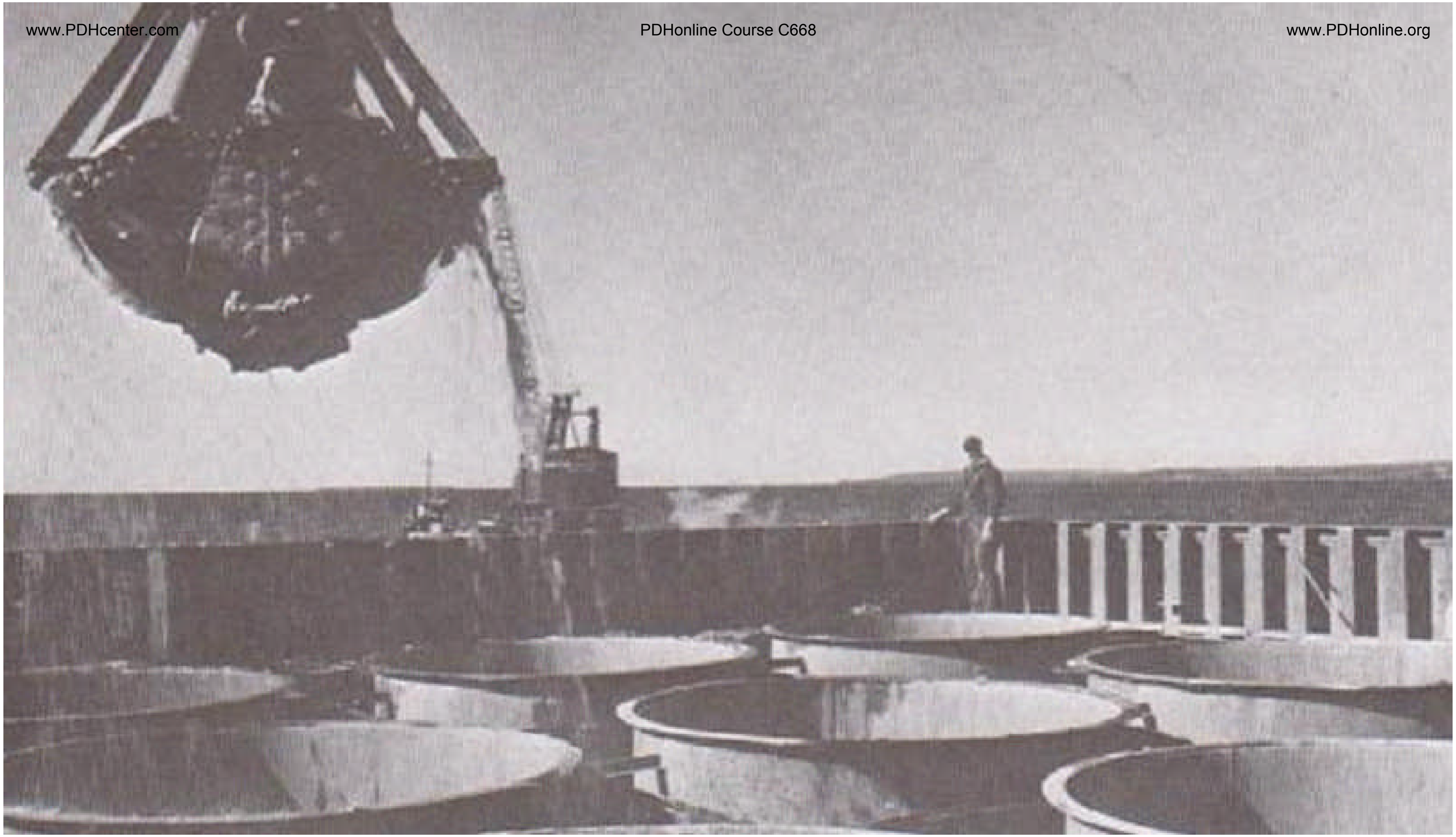
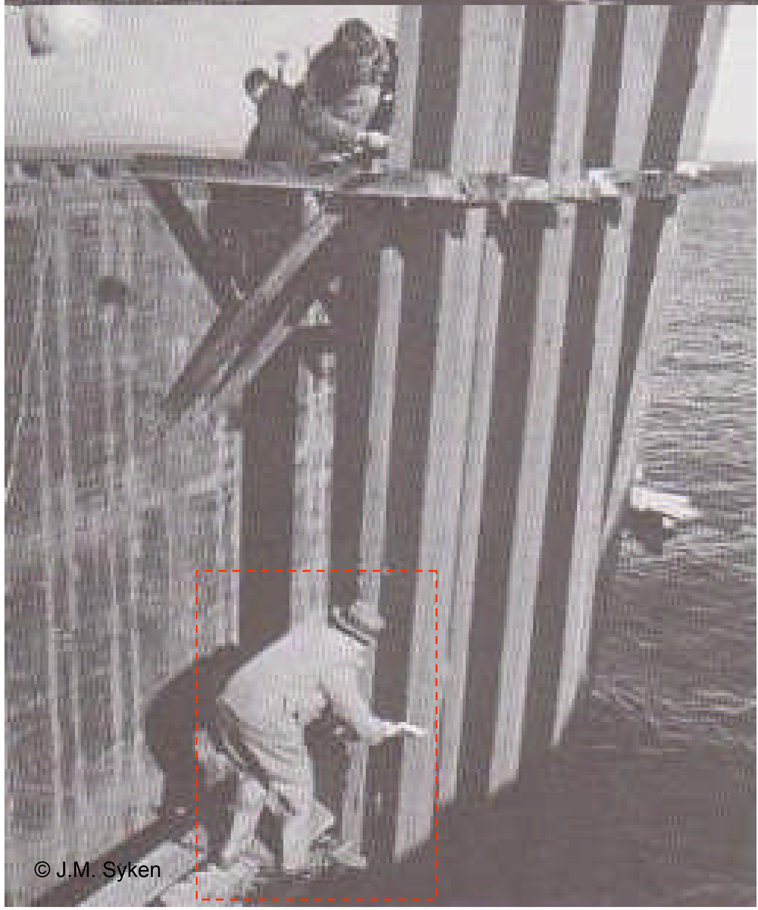
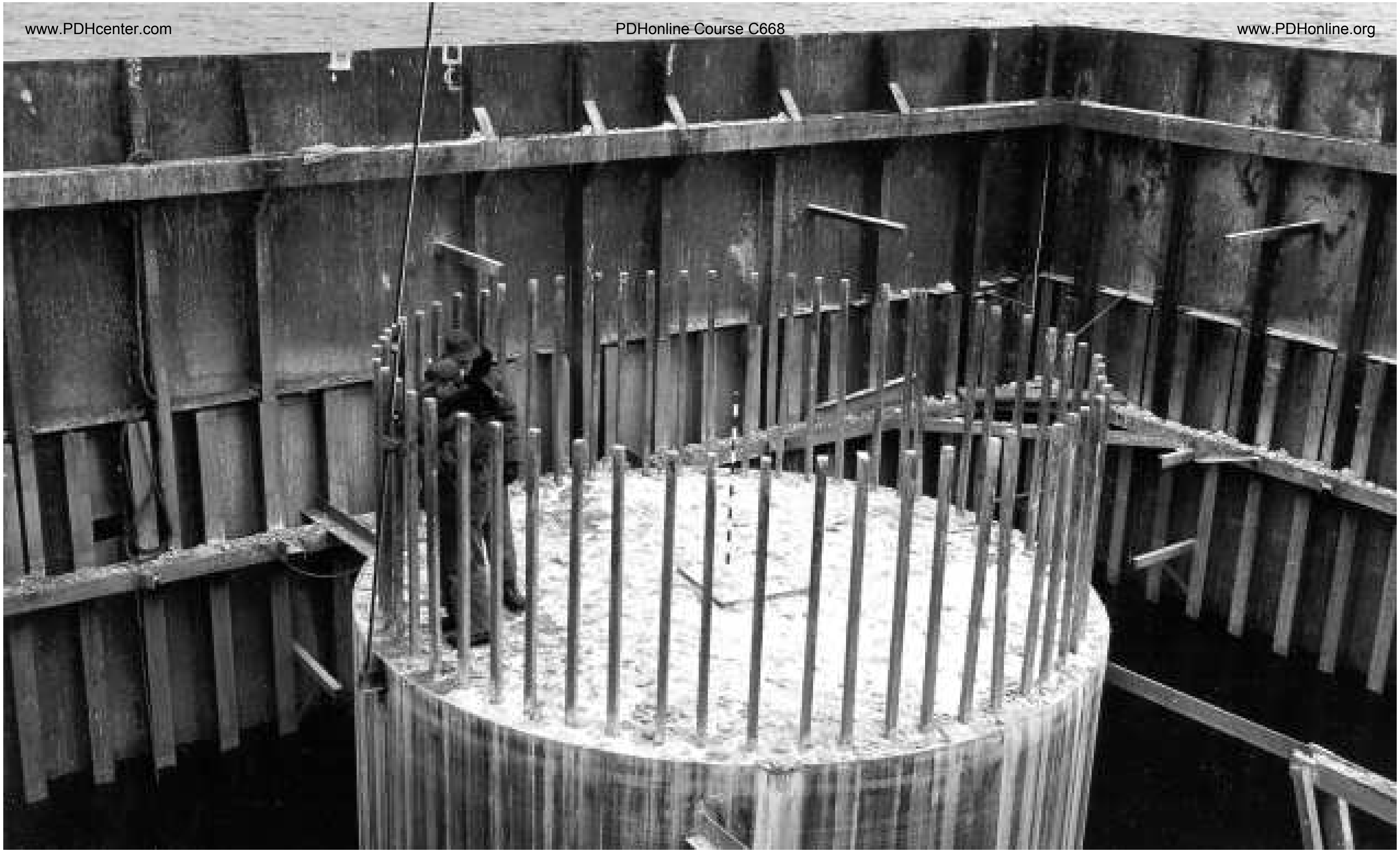


<u>Above</u>: caption: "The cutting edge of the caisson is nearly 100 feet below the surface and penetrating through overburden as clamshells dig it out from under through the 21 digging wells."

200



<u>Left</u>: caption: "Driving the caisson for Pier 18 to rock gave the engineers and contractors a real scare when one of the inspectors discovered on a frostbitten midnight that the caisson was tilting. Piles were quickly driven to rock against the tilted side to prevent further distortion. Then the process of righting the caisson was undertaken by concentrating the loading and digging on the high side of the caisson. Here an engineer measures the angle of skew in support piles."
<u>Above</u>: caption: "With caisson for Pier 18 founded in rock, it was solidly concreted the same way as were the anchorage foundations, except that the concrete was discontinued eight feet below the surface. Two pedestals, 16 feet in diameter, with reinforcing rods sticking out, were built on top of the foundation, which is still in its corral as winter shows signs of closing in."



Above: caption: "When the rectangular caisson for the south cable bent pier was finally anchored on rock at the bottom of the Straits, the rectangular form was cut off at 8 feet below the surface. The two circular concrete towers surrounded by wrought-iron were constructed from eight feet below the surface to ten feet above it. In the spring of 1955, steel towers were erected for a height of about ninety feet above the concrete foundations. December 1, 1954."

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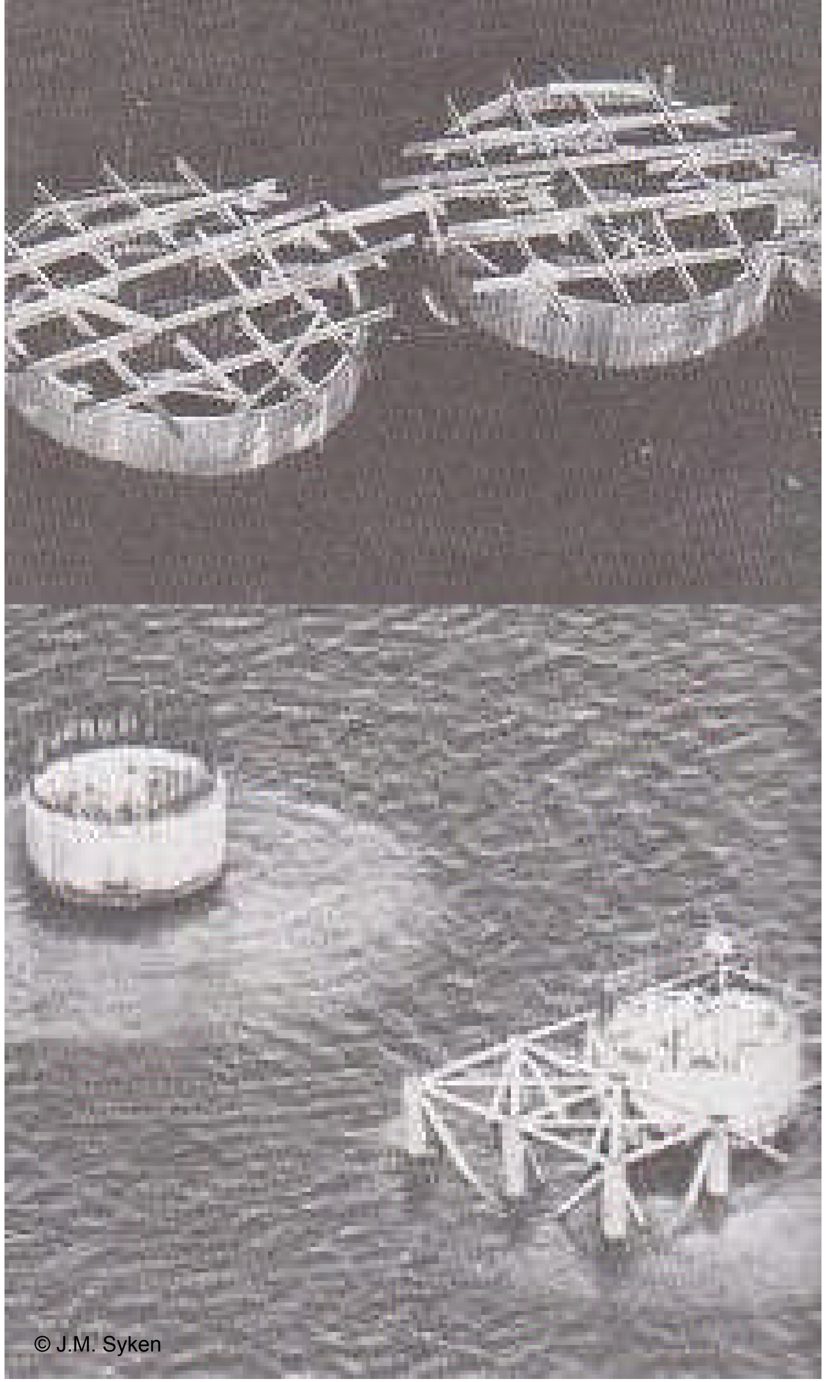
North Cable-Bent Foundation
(Pier 21)

The sixth and last foundation undertaken in 1954 was for Pier 21 – the north cable-bent tower. Comprised of a pair of circular cofferdams 50-feet in diameter founded on rock only 65-feet below the surface of the Straits, it was comparatively easy as compared to the other bridge foundation work performed that year.

Left: caption: "The steel framework for one of the pair of coffer-dams took shape on land at St. Ignace. One of the units for a caisson corral is in the background."

<u>Left</u>: caption: "The framework, swung aboard a barge, is transported to proper position in the Straits. It is 75 feet high and 50 feet in diameter."

<u>Above</u>: caption: "When the twin steel frames were in position, sheet piling was driven to rock all around their outside circumference. Then followed the same procedure for filling them with concrete as was applied in concreting the anchorages."



<u>Top</u>: caption: "When the foundations were concreted to a height of eight feet below the surface, they were mounted with pedestals sixteen feet in diameter. These in turn were filled with reinforcing rods."

<u>Bottom</u>: caption: "The sheet piling was cut off eight feet below the surface. Here the real foundations are clearly revealed under water."

Above: caption: "Winter wrote 'finis' to construction for the first season, but the contractors did not give up without a struggle. Men chopping ice away to get out on the job November 17, 1954. They did not quit operations until January 14, 1955."

Left: caption: "Late in 1954 looking north over the Starits showing the six important foundations undertaken in 1954. More important, they dramatize the physical line of the bridge, which up to that time had been largely a dream. Note the causeway jutting into the Straits, upper left, built in 1941."

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Part 4

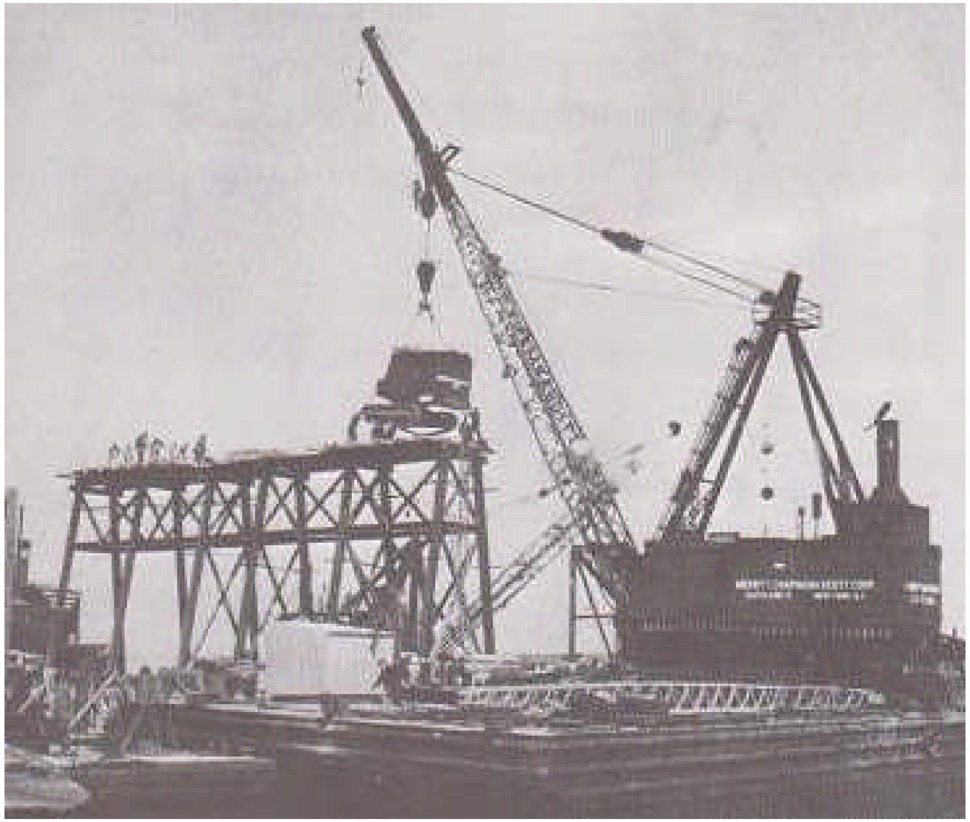
Season Two: 1955

Of the one million tons of concrete and steel in the *Mackinac Bridge*, three-quarters or 750K tons is sub-aqueous (sub-merged). The first season saw the creation of six of the most critical bridge foundations – a pair each for the:

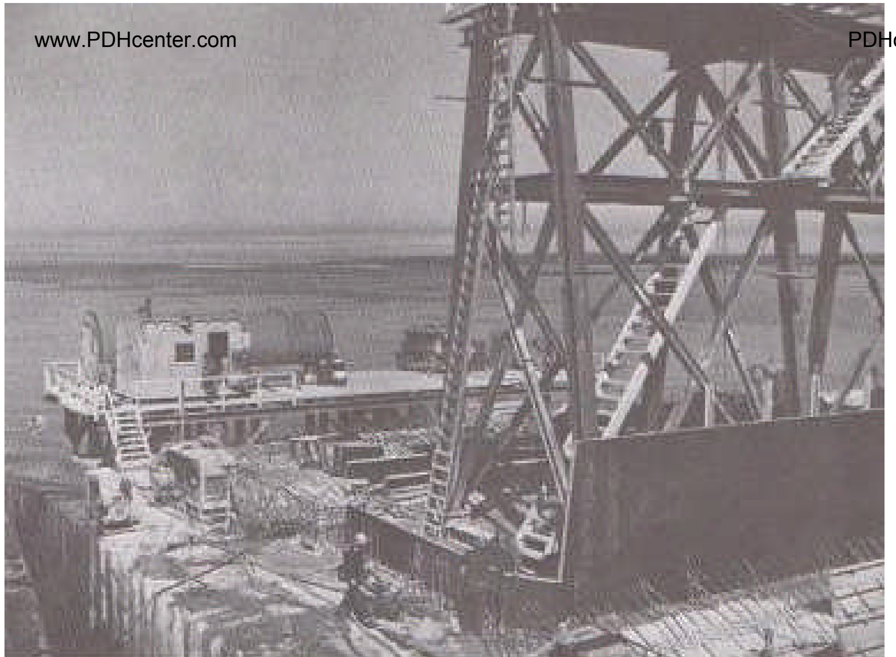
- **Towers**
- **Cable-bents**
- **Anchorages**

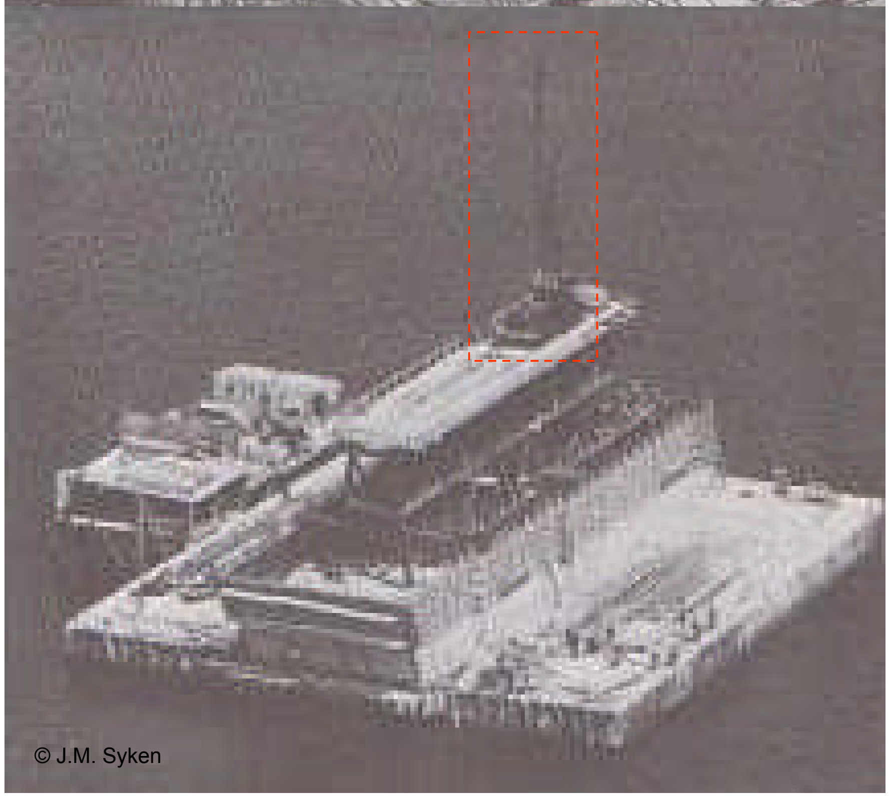
In contrast, the second season (1955) would see the superstructure rise from above the surface of the Straits.

Anchor Blocks
(Piers 17 & 22)



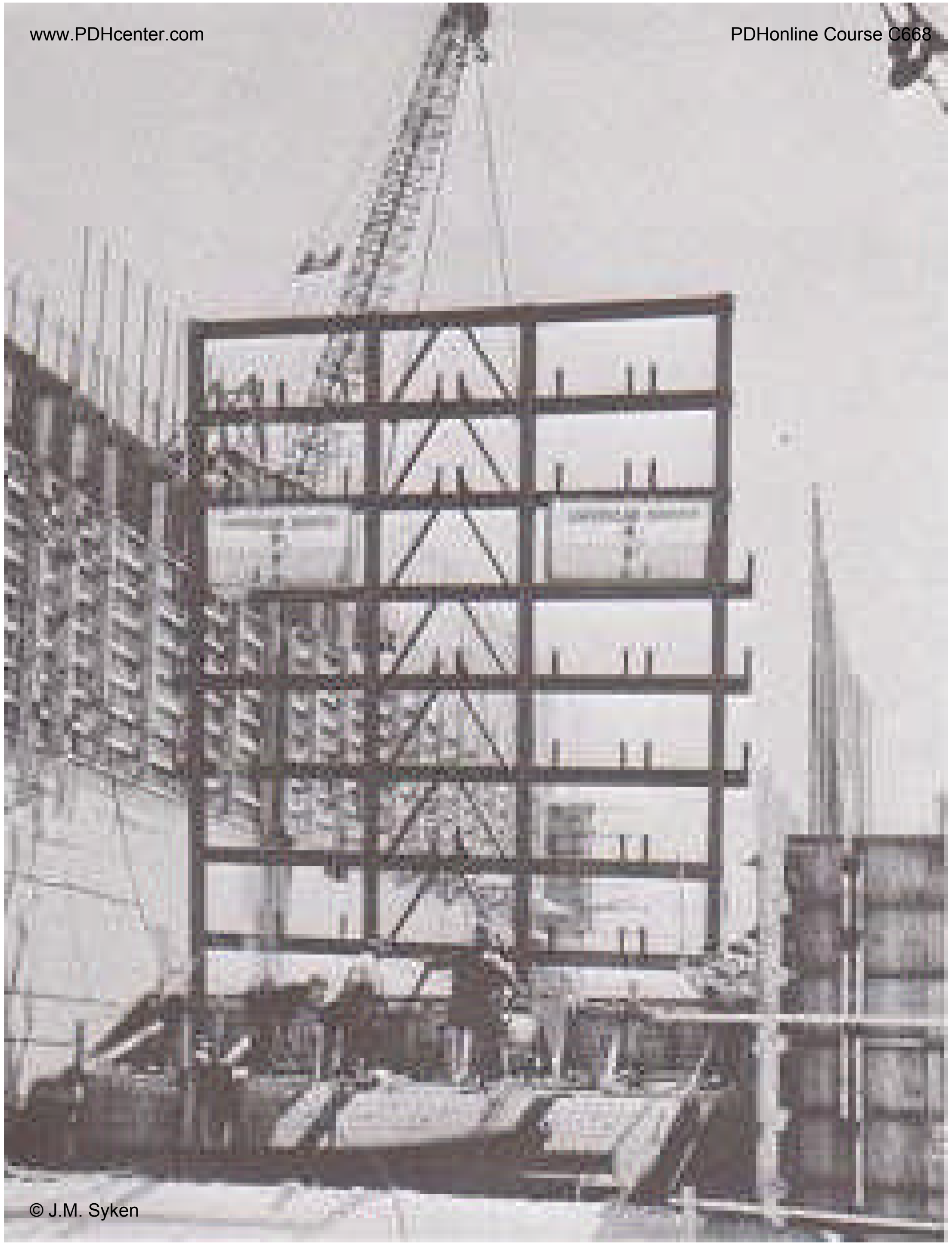
Left: caption: "As soon as the ice was sufficiently broken up so that marine equipment could navigate, Merritt-Chapman and Scott built a 50-foot high trestle on top of each anchor foundation (not visible) and then raised a crane to the top of the trestle to facilitate the handling of materials."





<u>Top</u>: caption: "Next came the erecting of forms to hold the concrete that would hold the steel that would hold the cables that would hold the suspension bridge."

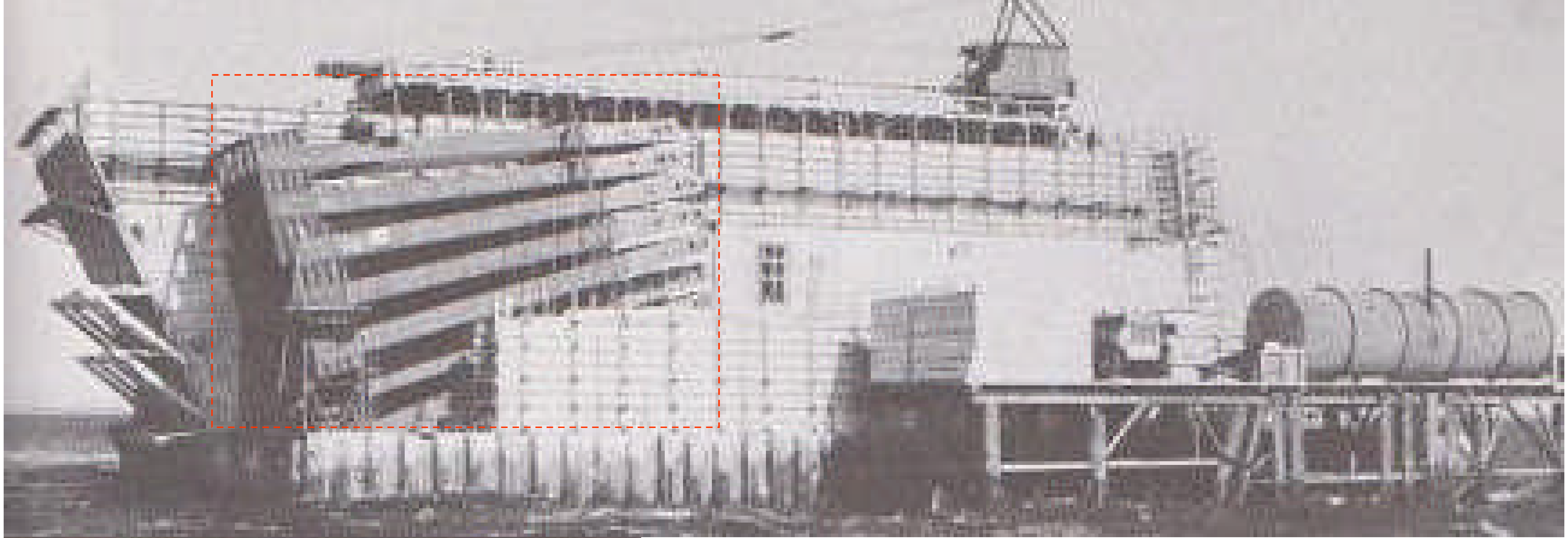
<u>Bottom</u>: caption: "An overall view showing rising center walls of anchor block superstructure and crane trestle about half buried in concrete. The story goes that the first crane operator assigned to this job quit as soon as he saw the perch on which he had to work."

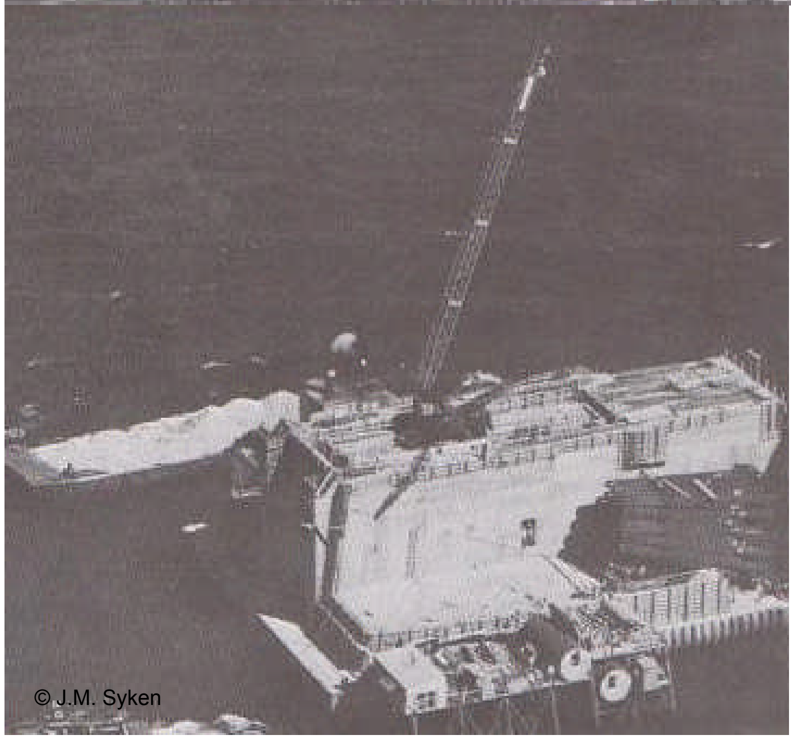


<u>Left</u>: caption: **“This three-story high chunk of steel is called an ‘Anchor Bar Support Frame,’ and that is just what it does: support the anchor bars (Pier 22).”**

214

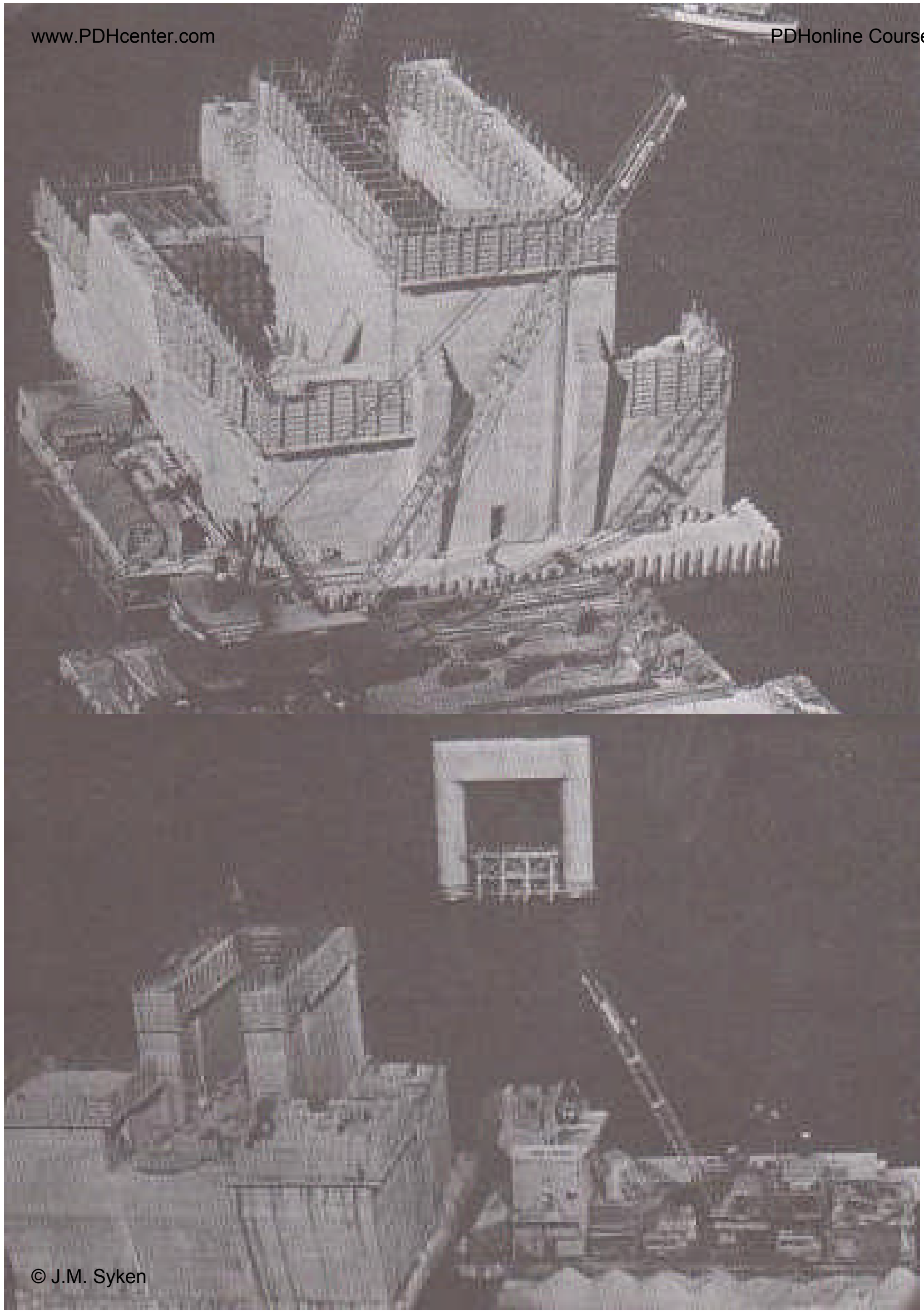
<u>Left</u>: caption: "The American Bridge Division of the U.S. Steel Corporation erecting the first steel in their $44,532,900 contract for the Mackinac Bridge superstructure. This first steel, consisting of anchor bars, is all buried in concrete."





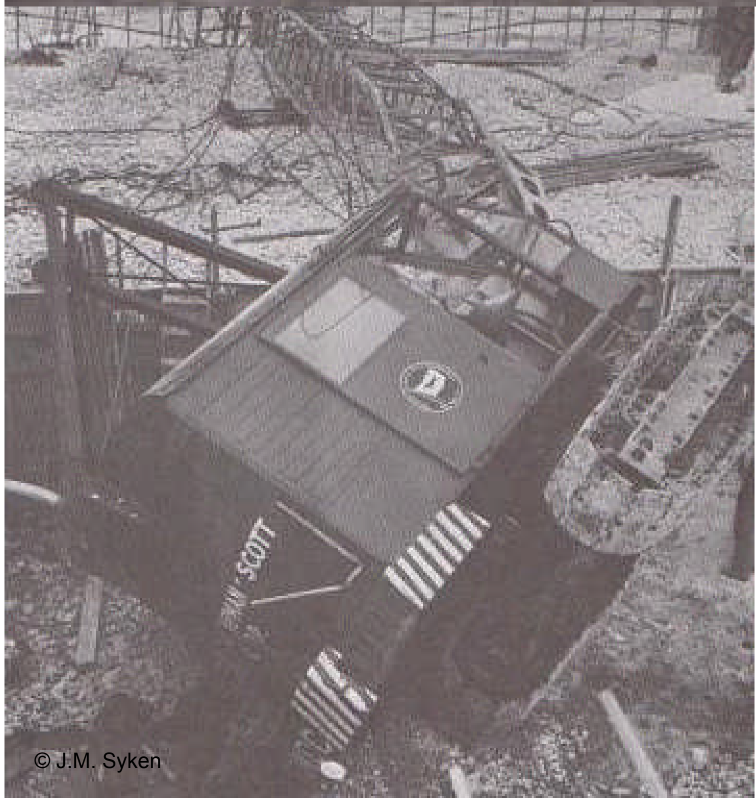
<u>Above</u>: caption: "All the anchor bars are in place. To them will be attached additional links around which the individual wires making up the cables will be looped. Note the height of the center wall almost up to the top of the trestle (Pier 22)."

<u>Left</u>: caption: "Another view of the anchor block and the eye-bars dramatizes their function as they are huddled together forming a strong compact group designed to resist the 30,000-ton pull of the cables (Pier 17)." 216



<u>**Top**</u>**: caption: “As the 1955 summer wore on the superstructure continued upward, burying the anchor bars and the trestle and gradually taking on some appearance of its function (Pier 22).”**

<u>**Bottom**</u>**: caption: “When winter approached, the anchor bars were solidly concreted in place. The boom of the crane is barely visible as walls around it nearly reach their full height of 118 feet (Piers 17 and 18).”**

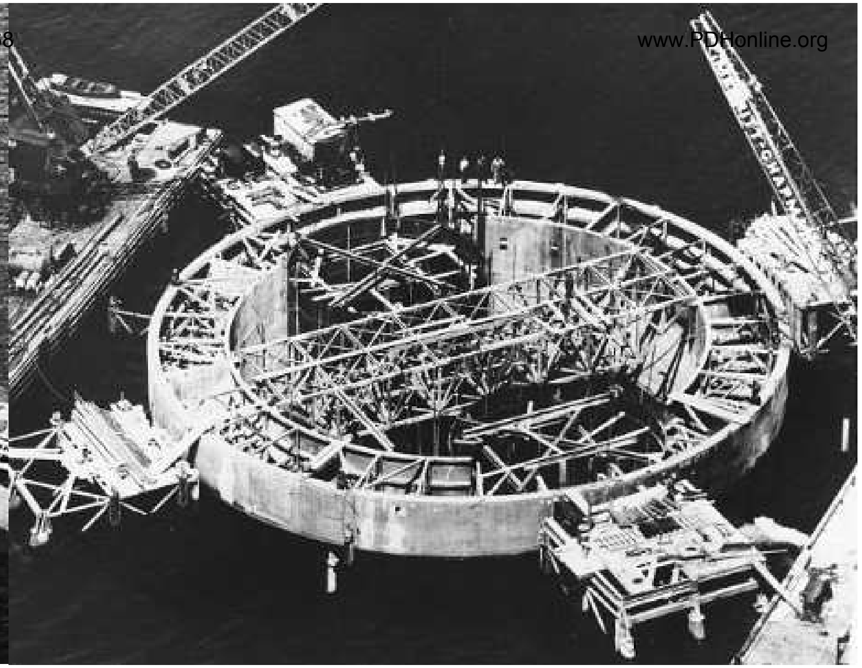


<u>Left</u>: caption: "These were days to try the durability of the strongest men and equipment as well. The men usually proved more durable. Here, a piece of tough equipment lies, wounded, on its side as it tried to buck a gust of wind with too large a load."

<u>Above</u>: caption: "Another manhandled piece of equipment that buckled under a misplaced load. The ancient ore carrier *Wolverine* was used to store sand. Too much got into too little an area and the fatigued steel quit. Believe it or not, after the sand was unloaded she straightened out and with minor repairs was back in floating service again."

Main Tower/s Superstructure (Piers 19 & 20)

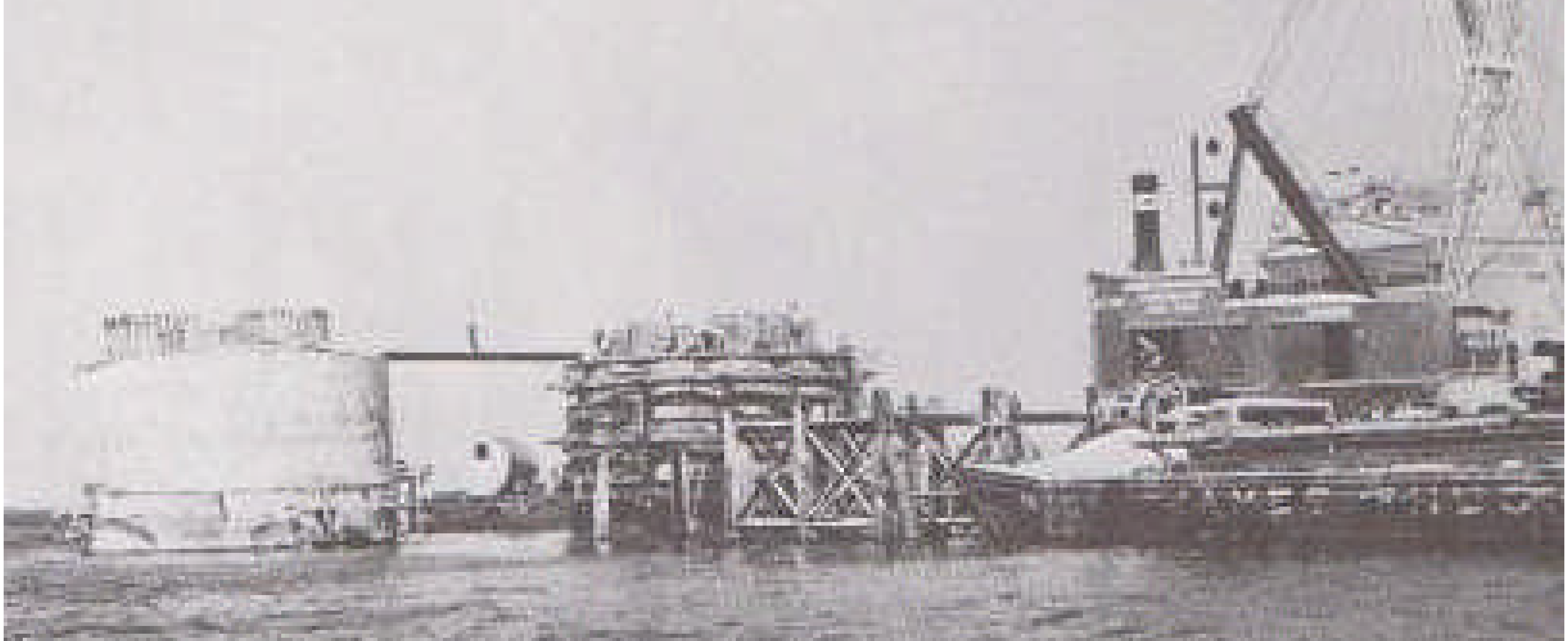
<u>Above</u>: caption: "As with the anchor blocks work resumed on the main tower foundations as soon as the ice melted. Notwithstanding the fears of the faint-hearted who were certain the bridge work would never stand the Straits ice, there was no ice damage whatsoever. Here is one of the incomplete caisson foundations. A twin-walled steel can without concrete reinforcing challenged the winter's worst. And when spring came. Inspection revealed that these caissons came through unscathed (Pier 19)."

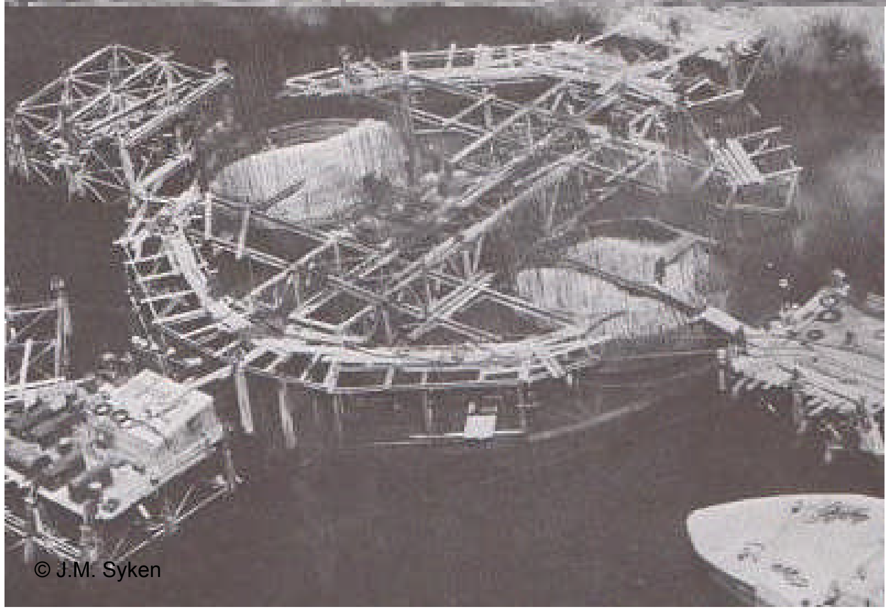


Left: caption: "The versatility of the self-unloaders of the Bradley Transportation fleet is shown in this photo of the Irvin L. Clymer unloading limestone into a caisson that formed the foundation for one of the towers of the Mackinac Bridge. Cement was being pumped in simultaneously to fill the caisson with concrete."

Right: caption: "The month of May, 1955, is one not easily forgotten. Closed out by the winter before, the caissons for the main tower foundations were left un-concreted and somewhat behind schedule. When work resumed in the spring of 1955, the concreting began, and during the 31 days of a pleasant, mild, dry May 103,000 cubic yards of concrete were poured into Mackinac Bridge foundations, setting a new record for underwater consolidation of concrete (Pier 20)."

221



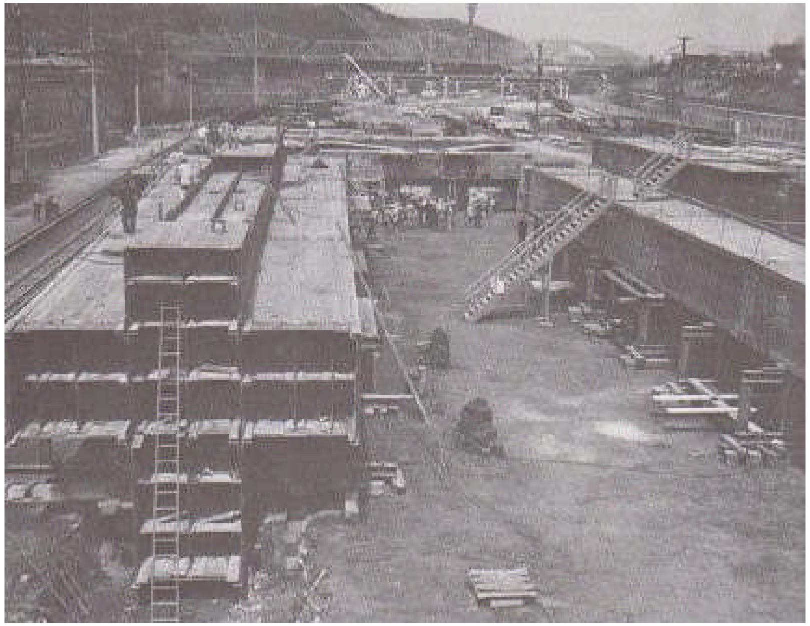


<u>Left</u>: caption: “Notwithstanding its hodge-podge appearance, this is really an orderly construction scene. Around the outside of the center are the four corral units still being used as work platforms. They no longer hold the caisson in place. Not only is the caisson founded on rock, but it is filled with concrete. Inside the center circle are two smaller circles, 38 feet in diameter. They are the pedestals that will arise from the foundation eight feet below the surface (Pier 19).”

<u>Above</u>: caption: “The two pedestals on top of the foundation are 25 feet above the water surface. The bolts embedded 20 feet in these concrete pedestals were sticking up ready to grab hold of the steel for the towers.”

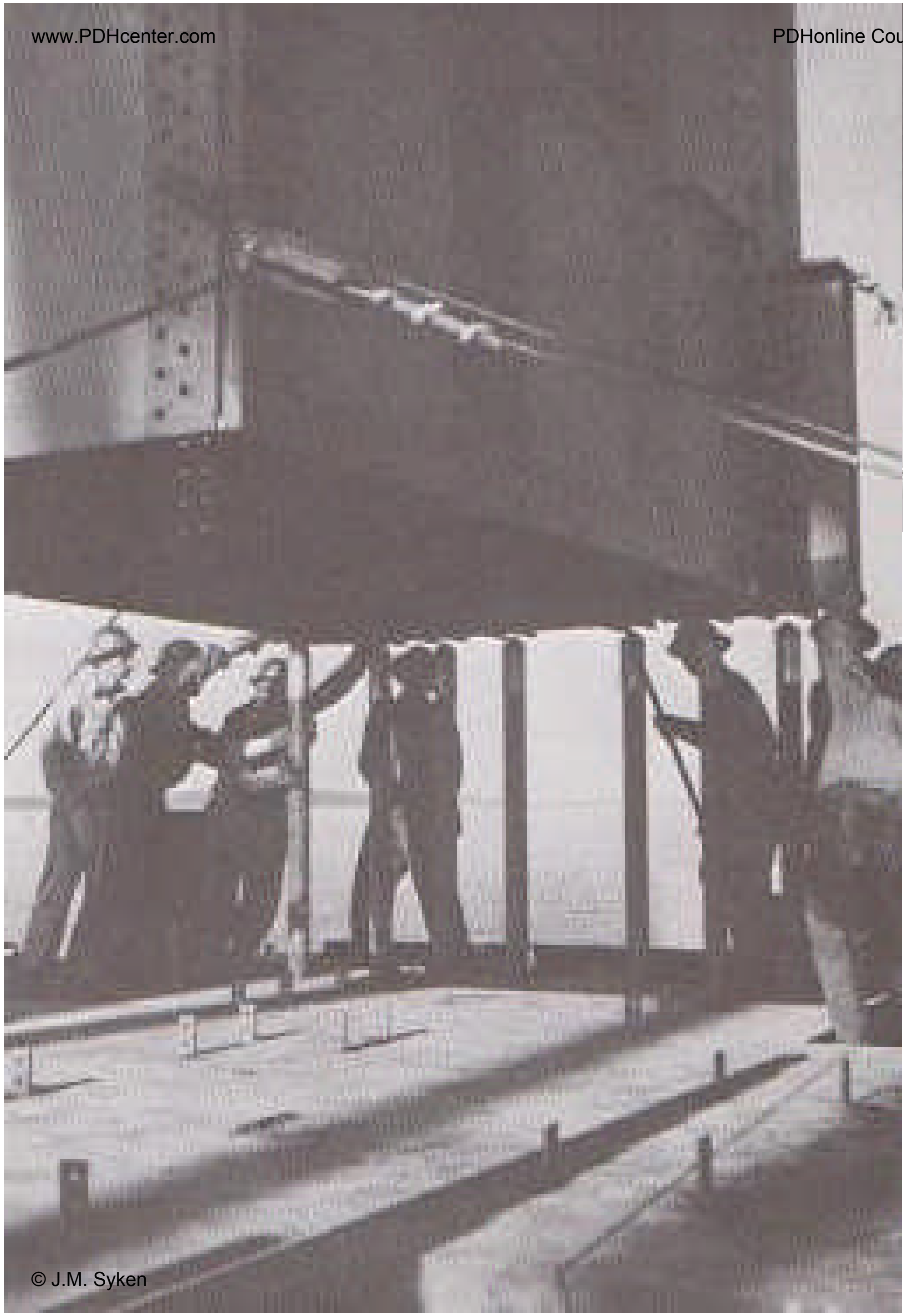
222

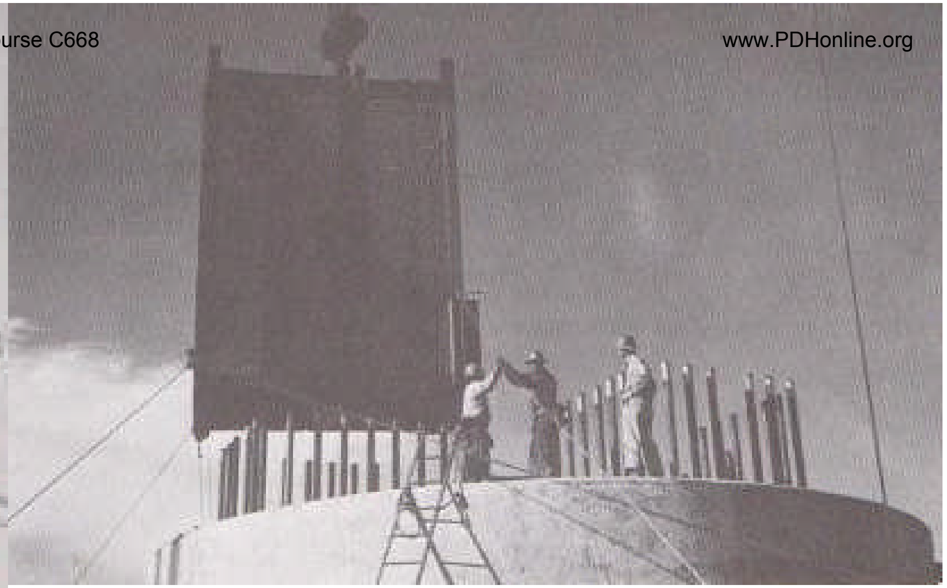
<u>Left</u>: caption: "Crane carefully lowers tower base plate into position."
<u>Above</u>: caption: "Finally came the day when actual tower erection could begin. The first piece was hardly impressive, a base plate just four inches high, though it weighed 13 tons."



Left: caption: "Meanwhile the towers were not only being fabricated but were being built – horizontally instead of vertically – some 500 miles from the Straits of Mackinac. At Ambridge, Pennsylvania, the towers were laid out on the ground and drift-pinned together to see if all parts fit properly. This picture showing the bottom section provides a clue to their enormous size."

224





<u>Above</u>: caption: "Next came the actual tower section weighing 40 tons and representing the bottom 16 feet of a tower that rises 552 feet above the surface."

<u>Left</u>: caption: "Engineers, pushers and journeymen steel and ironworkers prod and push until the giant sections fit properly over the bolts which will secure it and 6,500 additional tons of tower steel to the pedestal, which in turn is connected to the foundation that goes down more than 200 feet to rock."

<u>Above</u>: caption: “North Mackinac Bridge tower. Placing steel section, 2nd tier, west leg. July 5, 1955”
<u>Left</u>: caption: “Erecting the creeper derrick on the south tower of the Mackinac Bridge. As soon as three tiers of steel on each tower leg were erected, the creeper crane was attached. July 28, 1955.”

Left: caption: “Using the creeper derrick to erect the fourth tier of the Mackinac Bridge north tower. This ingenious device mounted with a boom raised steel and climbed up the steel it raised. August 9, 1955.”

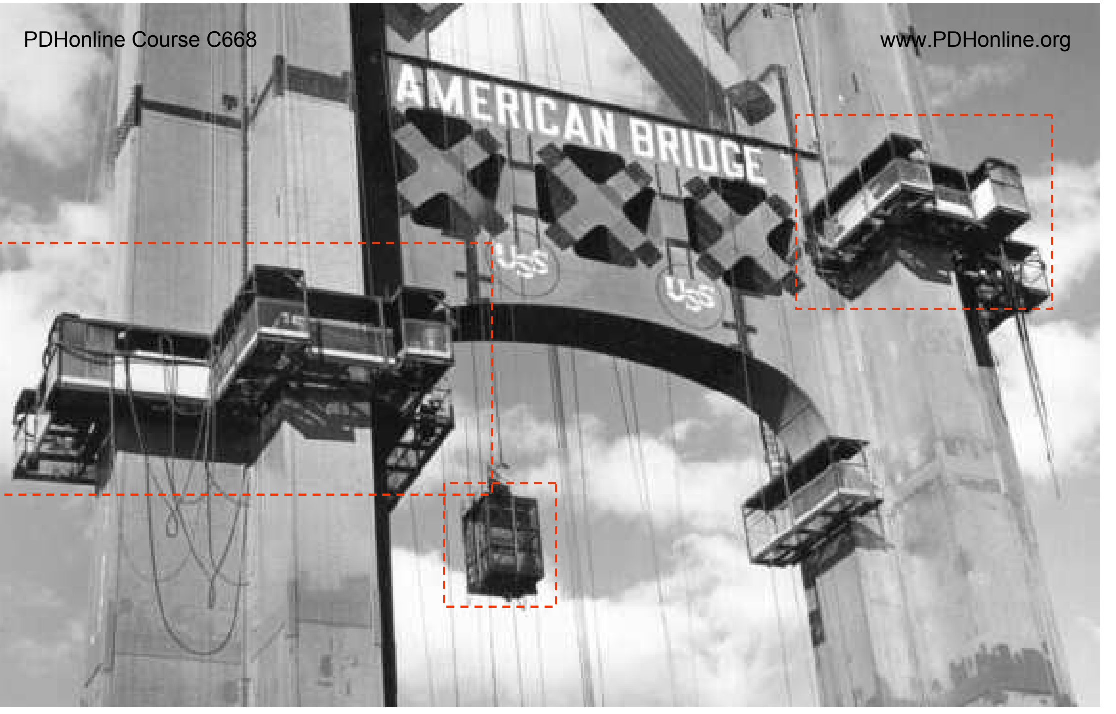
"I ran rivet crews, and I was a supervisor. I worked on the bridge from 1954-56. It was all tough work. I worked handrail detail on the top of the towers. The heights either bother you or they don't, and working up there never really bothered me…"

Bill Babinchak, **Ironworker Foreman (a.k.a. "Pusher")**

<u>Above & Left</u>: caption: "Sections were bolted together temporarily as riveters patiently worked away on the 6,000,000 rivets designed to hold the towers together."

228

<u>Above</u>: caption: "This is in mid-summer 1955 and steel workers are assembling the two prefabricated main Mackinac Bridge towers."



"My first day on the job there were about 20 of us who were in an elevator going up the north tower to our worksites. When we were about 300 feet up, the wind got a hold of us and blew the cab out of the guide pullies. There were guide pullies on each side and, one suspended in the center which moved it up and down. We were swinging like a pendulum. We grabbed for the cables and finally got us back in the cable and we all got safely onto the tower. People who say they weren't scared working on that bridge are lying. One guy who was in that elevator wanted down. He had it."

Don Horne, **Ironworker**

Above: caption: "Close-up reveals riveter's cages attached to the legs of the north tower and personnel elevator. On windy days it was often blown out of its guide lines. October 14, 1955."

Left: caption: "Creeper crane sets steel section onto tower leg. After 14 weeks the tower approached the 420-foot mark."

Working on the Edge

© J.M. Syken

"I didn't realize the significance or the value of working on the bridge at the time, I guess you get a little perspective with age. My dad was a pipe fitter, and he told me at the time, 'you don't know how lucky you are. I wish I could work on it.' As I look back on that time, it was exciting and challenging working on the edge. I never worked tied off. There was danger…but it was extremely exciting. Now, as I look at it through the eyes of a person who is 61 years old, I can look back and say 'whew.'"

Joe Oldeck **– 21yo bridge ironworker (in 1957)**

"…something almost erased my mind. I was headfirst in the drum, up to my armpits, and that rivet knocked me out cold. My hard hat shattered like a windshield, and it put me in the hospital for two weeks. I have no lasting effects from getting hit, and I still have wonderful, great memories of working on that job."

Clarence Kraft, **Riveter**

<u>Above</u>: caption: "Inside the tower were the men who backed the rivets driven from the outside. Their only light came from flashlights and the miner's lamps attached to their safety helmets."

<u>Left</u>: caption: "Rivet gang's 'hammerman' (left) and 'bucker-up' (right, emerging from access panel)"

<u>Top</u>: caption: "The Straits could be rough even during the construction. Here waves and spray more than 40 feet high pound fruitlessly against the Mackinac Bridge towers and foundations."

<u>Bottom</u>: caption: "View of south anchorage Pier 17, Pier 18, south tower and north tower from the southwest. September 28, 1955."

"…was trying to get out of someone else's way…He was only three or four feet from me when he fell, and we weren't tied off at that time. I saw an air hose that supplied a pneumatic gun looped right below us, and I saw he was falling toward a diagonal (a piece of iron). So I pulled on that air hose, and he fell into it and it changed his direction just enough so that he only brushed the iron, and he fell maybe 80 feet into the water…I don't know, I may have saved the man's life, everything happened so fast. No one else was looking at me, and I never talked to anybody about what happened. I never met the worker who fell."

***Richard Brown,* Ironworker**

RE: the fall of a fellow ironworker. The man drifted in the straits for a while before being picked up by a nearby boat, suffering only a broken leg. After the incident, rescue boats were permanently on-station below the bridge.

Left: caption: "Both towers completely erected."
Above: caption: "Here is what happened when a rivet fell off the tower onto the deck of one of the boats."

<u>Left</u>: caption: “Tower fully erected (though not fully riveted) with 80 foot booms to handle materials atop.”

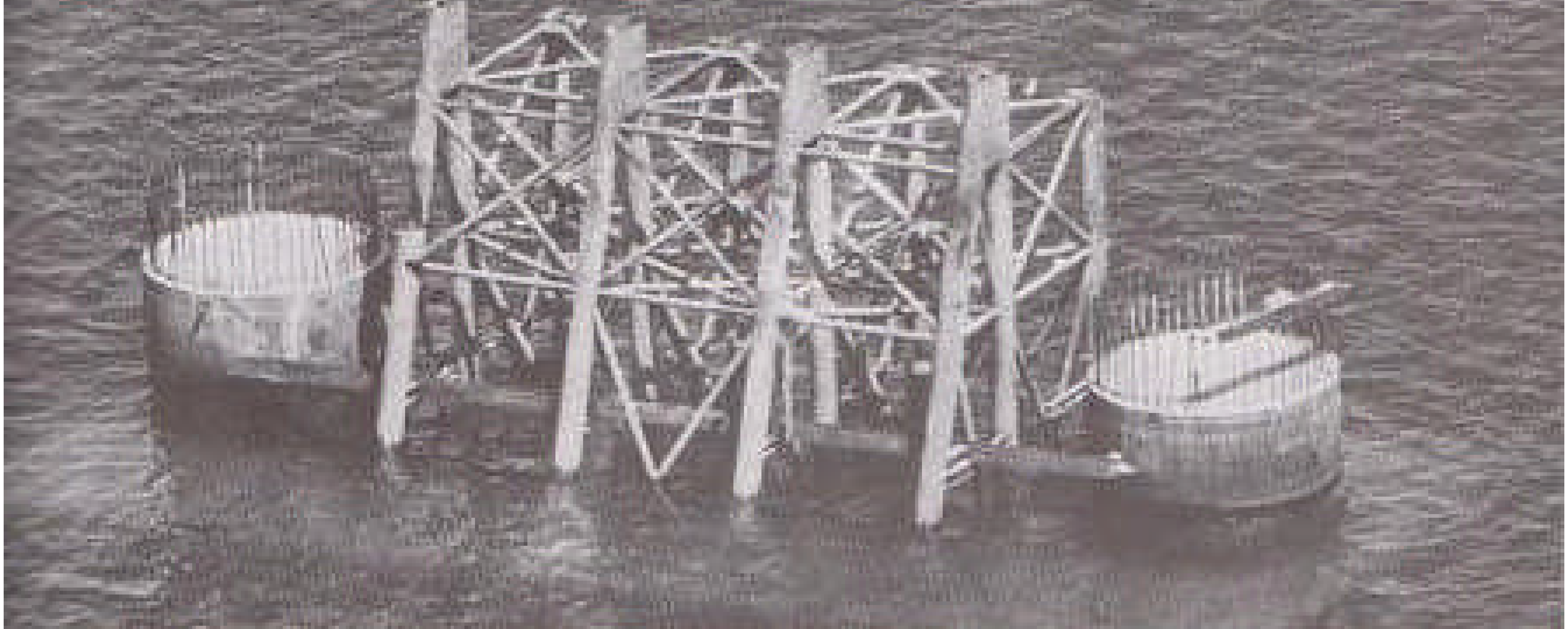
<u>Above</u>: caption: “Finally, on October 22, 1955 the first topmost piece of steel was erected, and according to tradition Old Glory waved proudly with the men who put it there, 552 feet above the Straits.”

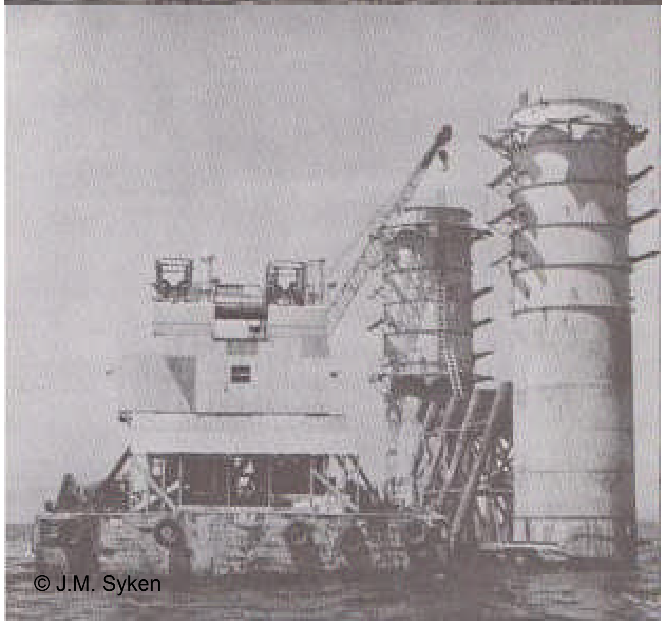
"American Bridge was a very good company to work for. They came out with all the safety equipment before any other company, and they came out with it before OSHA even existed. They supplied the men with hard hats, safety belts, and tools that were designed to improve safety."

***John* "Reds" *Kelly -* one of seven *American Bridge* superintendents on the Mackinac Bridge**

Though the erection of the two soaring towers was the main event of the 1955 season, there was other less glamorous but nonetheless important work going on elsewhere. Besides the anchor blocks, the superstructure for the cable-bent piers was erected. Additionally, twenty-seven pier foundations for the approaches were constructed. As winter closed in on season two, two huge backstays were floated into position as well.

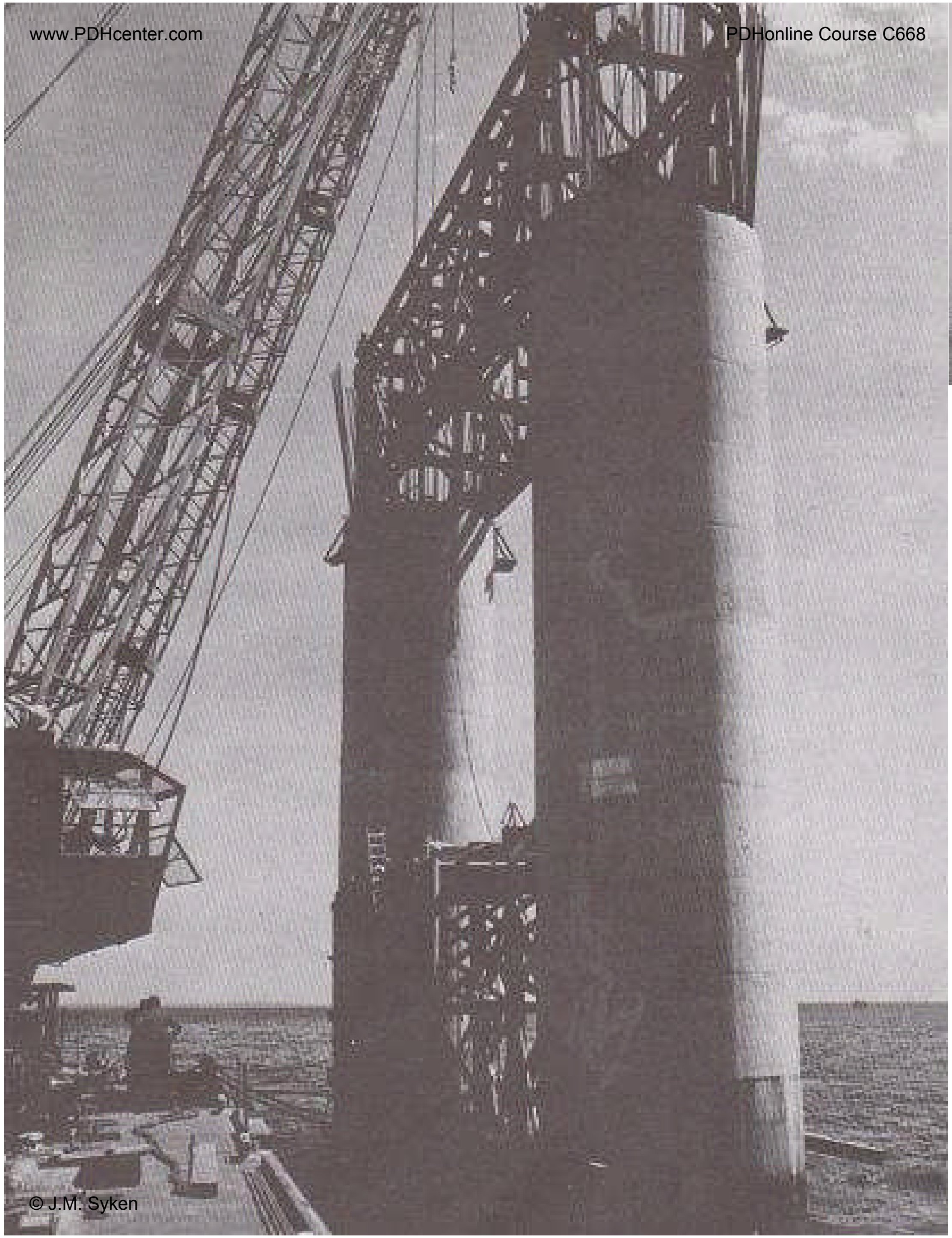
North & South Cable-Bent Superstructure (Piers 18 & 21)

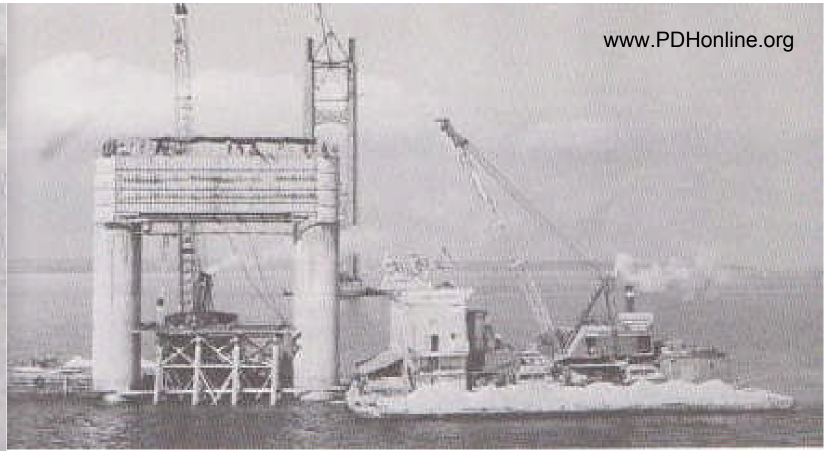




Above: caption: "The south cable-bent foundation Pier 18, caisson construction founded on rock 130 feet below the surface, was ready for its superstructure early in 1955. A piece of corral unit was placed on the foundation between pedestals as a work platform."

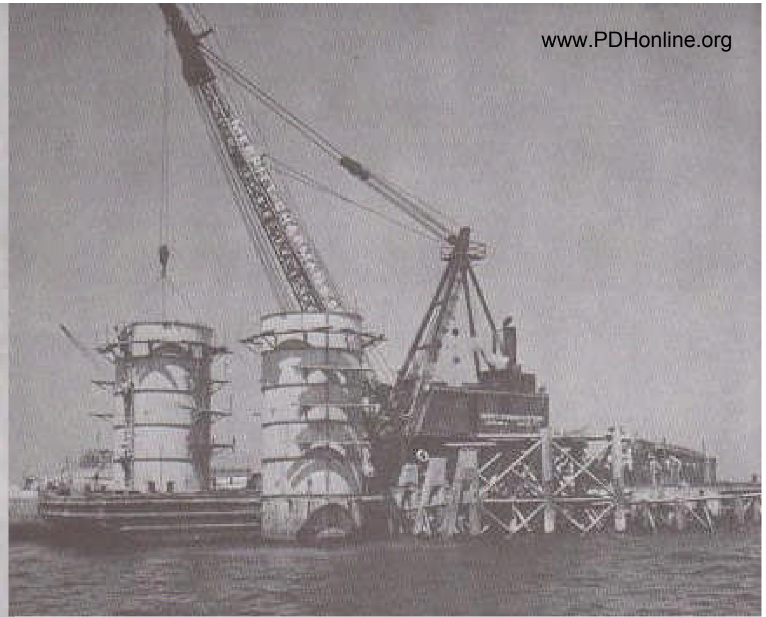
Left: caption: "Circular forms 16 feet in diameter were filled with concrete at regular stages to build twin towers that look like silos."





Left: caption: "A massive steel arch was raised to the top of the concrete towers and made a bridge connecting them." Above: caption: "Forms were built around the arch frame, and they were filled with concrete."

242

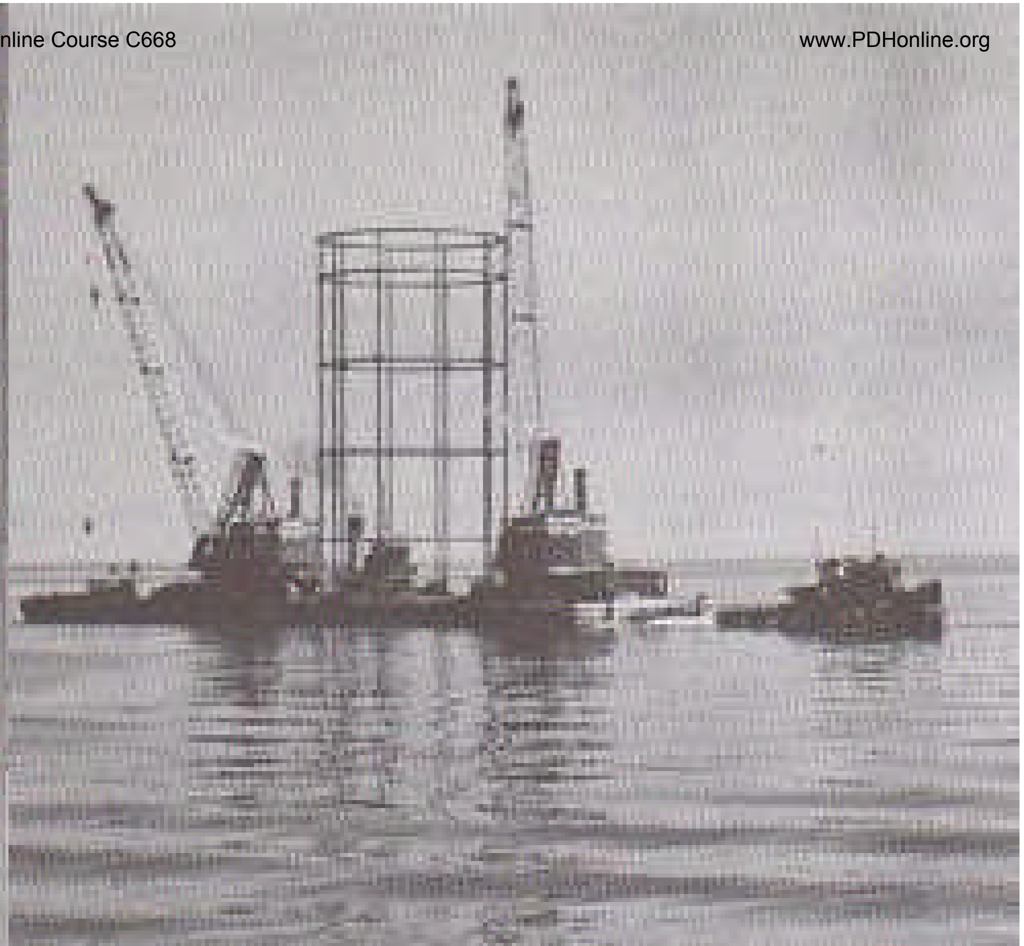


<u>Left</u>: caption: “Steel towers, over which cables did eventually bend as they swept down from towers toward the anchorages, were erected on top of the concrete superstructure.”
<u>Above</u>: caption: “The super-structure construction on the south cable-bent was duplicated on the north cable-bent Pier 21. Only their foundations were different. In this picture the derrick was preparing to lift an empty form off the barge onto the pedestal at the extreme right.”

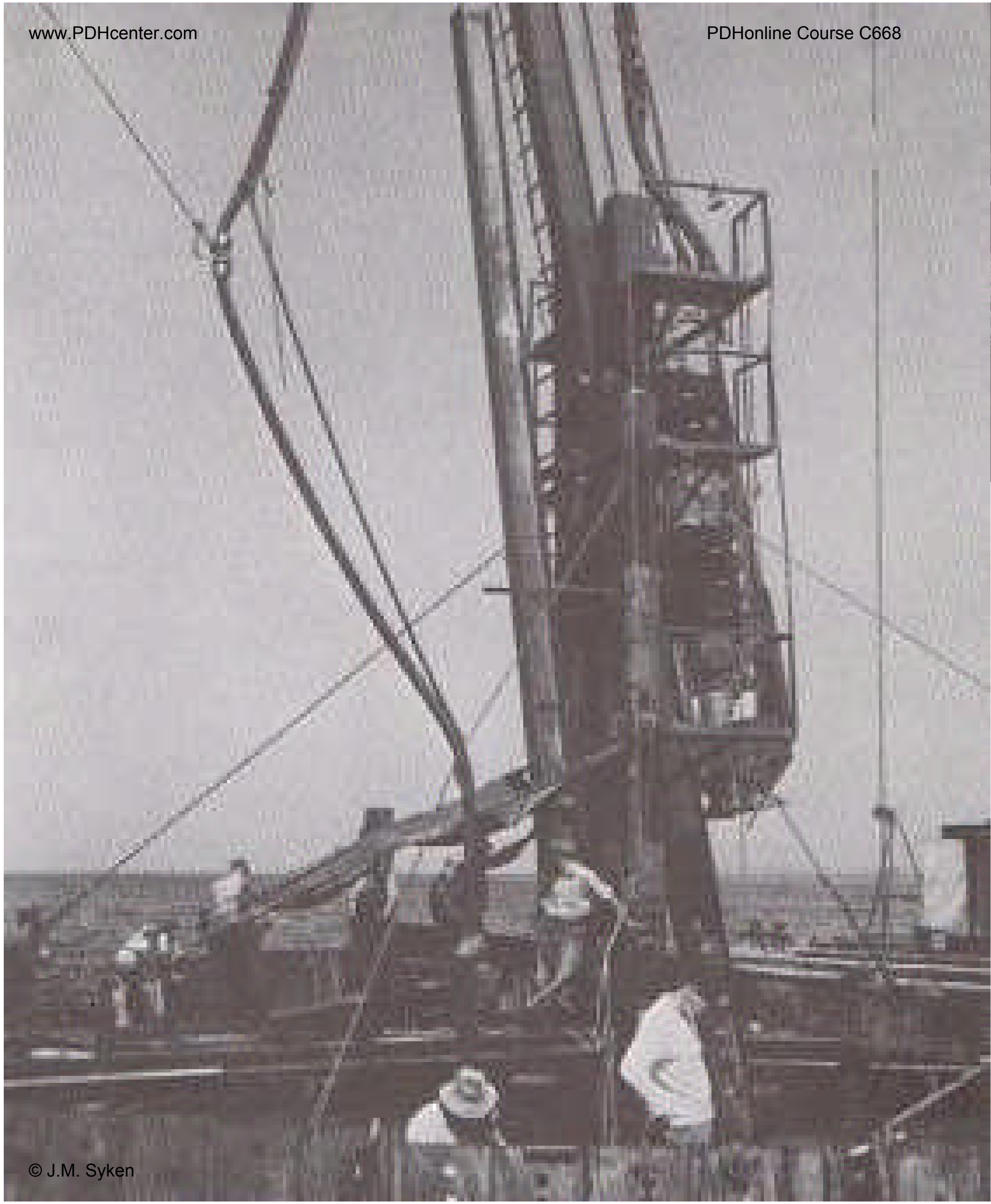
243

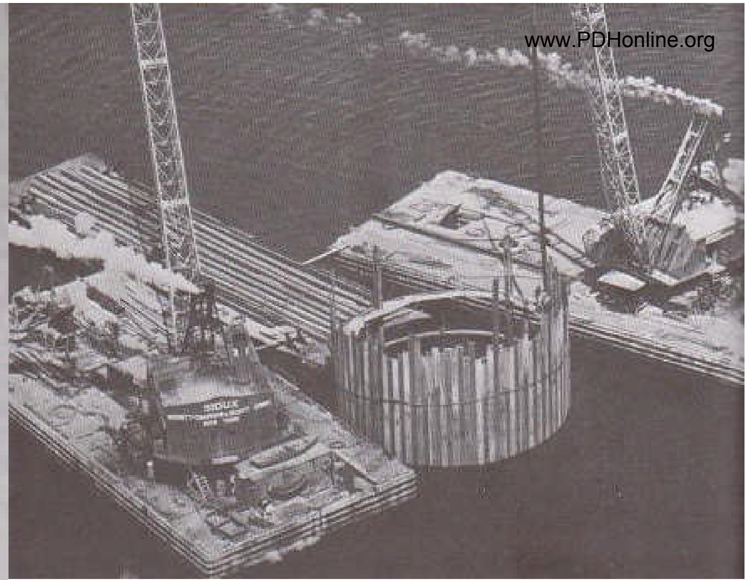
Approach Piers

The balance of marine foundations (27 of them) were of cofferdam construction. However, five of these foundations were built in an area where rock was comparatively deep for the size of the required foundation. Efficiency dictated that these cofferdams be built on steel spud piles driven through the overburden to rock. Piles had to be driven at angles to provide a wide supporting base.



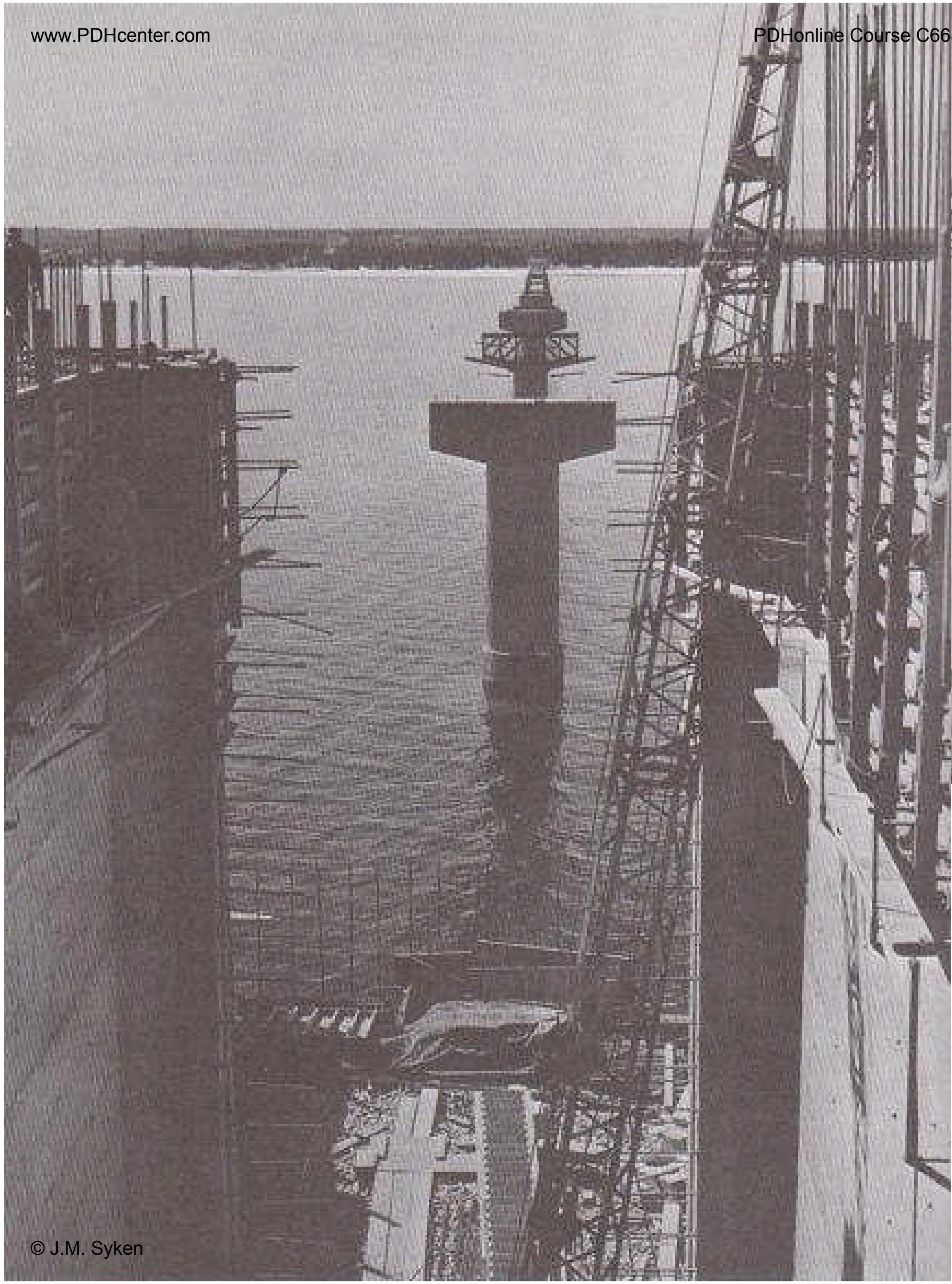
<u>Left</u>: caption: "The steel framework 90 feet high for one of the five cofferdams on spud piles was erected on land."
<u>Above</u>: caption: "It was obviously a beautiful calm day, that May 15, 1955, when the framework was towed past the former ferry docks to its position in the Straits." 247

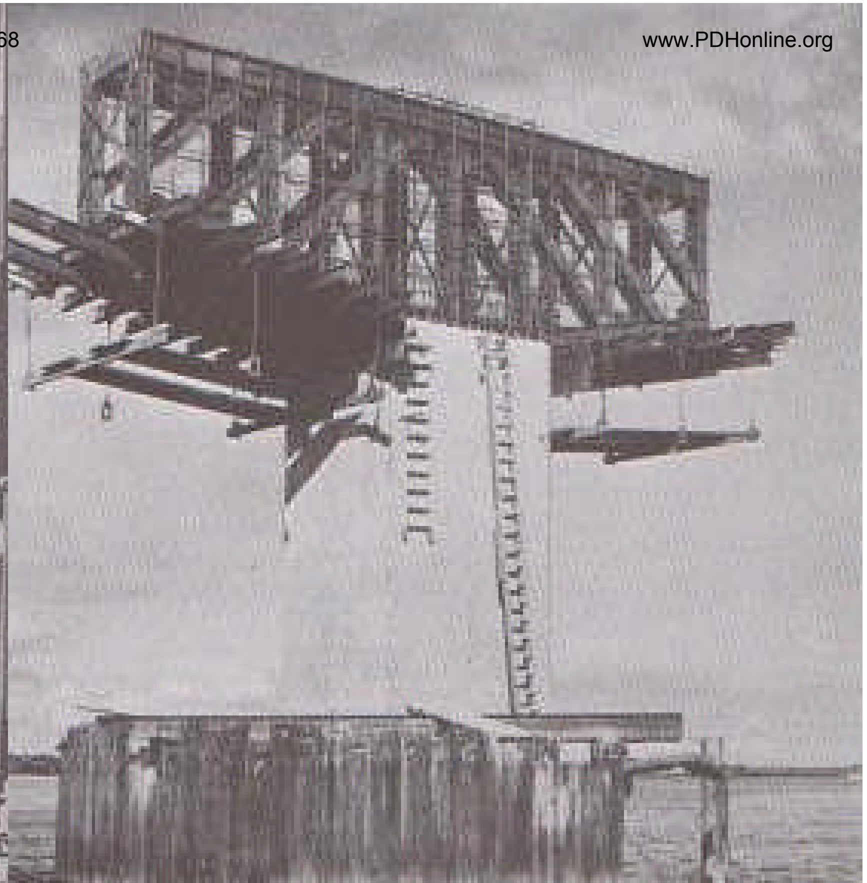




Above: caption: "Once in position, sheet piling was driven all around the framework, but not to bedrock or refusal, because a different method was being used on this foundation."

Left: caption: "Steel H-beam piles, 96 of them, were driven inside the cofferdam to rock and refusal. Many of them were battered (driven on angle as shown here) to provide a wider and thereby stronger base to hold the concrete load to be placed within (Pier 11)."





<u>Above</u>: caption: "A single shaft of concrete emerged from the 50-foot diameter foundation lurking eight feet below water. A hammerhead frame (sometimes called elephant ears) was placed on top of the shaft. Forms were built around the frame and it was completely encased in concrete (Pier 26)."

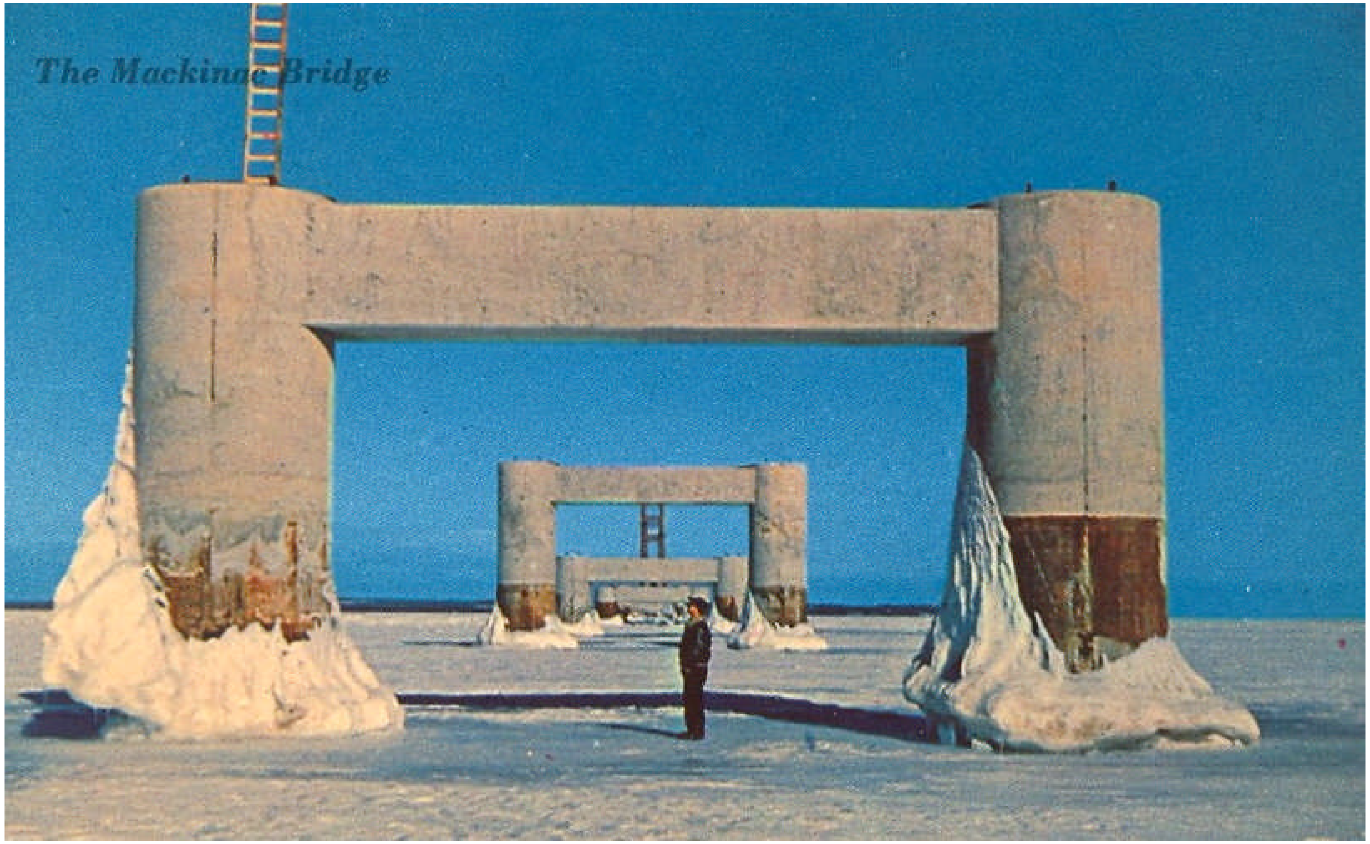
<u>Left</u>: caption: "South from the south anchorage, 16 foundations come into view, one exactly behind the other as straight as an arrow (Piers 1-16)."

<u>Above</u>: caption: "Also south from the end of the causeway at St. Ignace, the north foundations, 11 of them, line up to form stepping stones across the straits."

<u>Left</u>: caption: "Looking south from the top of the south tower. October 26, 1955."

<u>**Above**</u>**: caption: “Cofferdam approach piers under construction. Notice the automobile ferries in the background with the black smoke coming from the coal fired engines.”**

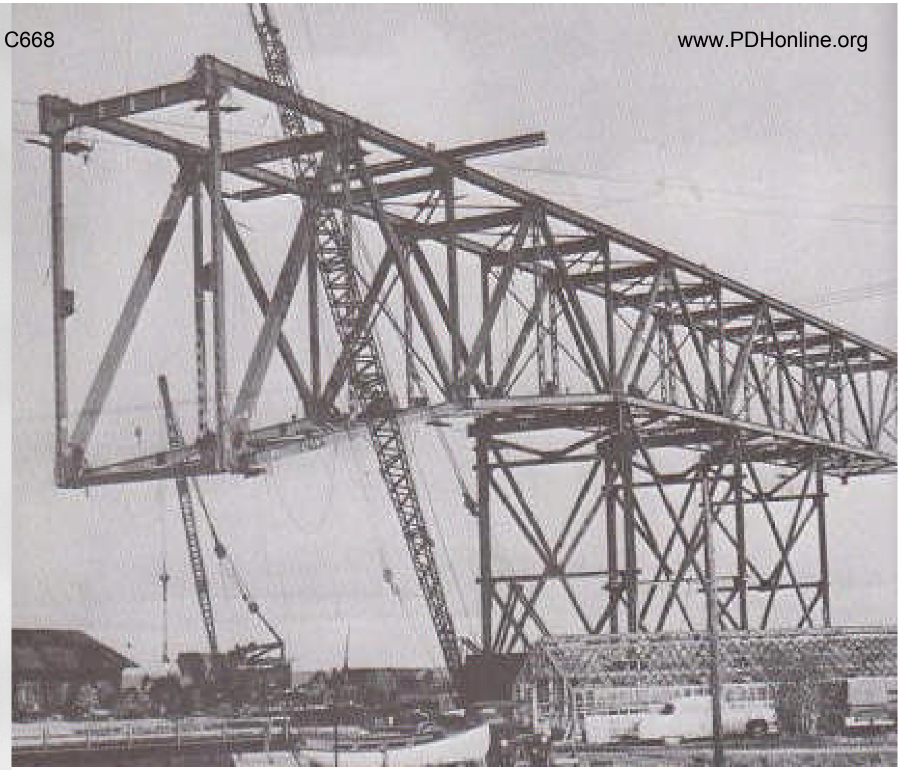
<u>Above</u>: caption: "Mackinac Bridge pier construction nearly complete. Note formwork for connecting beam for the pier in foreground (near shore.)"


The Mackinac Bridge

256

Backstay/s

The placing of the backstays (a.k.a. “side-spans”) rivaled the towers’ construction for the boldness of the undertaking. The backstay/s were horizontal stiffening trusses designed to support the road deck between the anchor blocks and the cable-bent/s. Two barges were lashed together and a falsework constructed to support each side span which weighed 720 tons and was 472-feet long. Top-heavy, they could only be towed into position during calm weather.

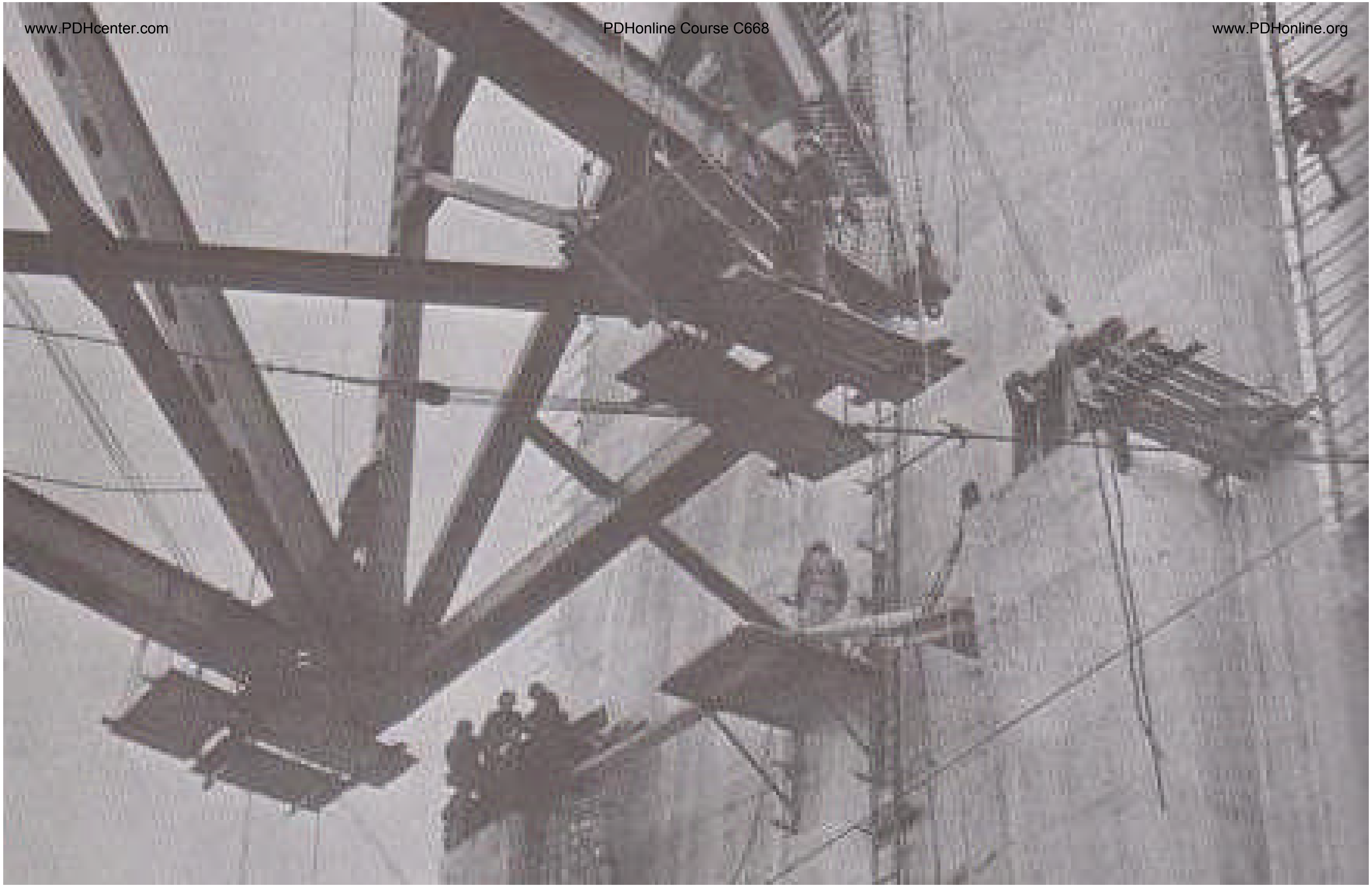


<u>Above</u>: caption: "November 10, 1955, the south backstay span was just about ready for launching, but the weather wasn't. On the sixteenth, a blizzard with winds gusting up to 76 miles per hour nearly toppled the span."

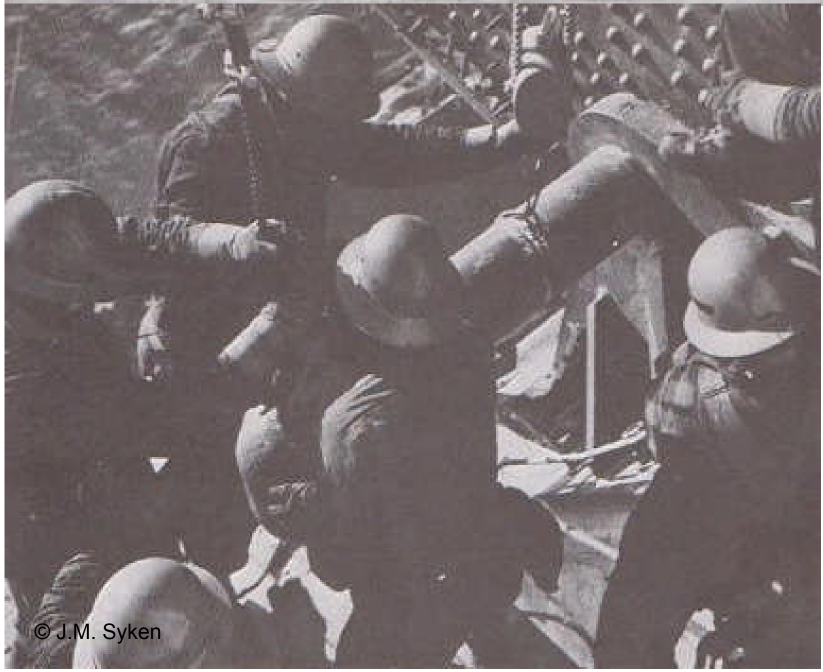
<u>Left</u>: caption: "On Nov. 19, 1955, the Straits were calm enough to tow the backstay into position."

<u>Above</u>: caption: "On the nineteenth, the Straits were calm and thumbs crossed hoping and praying the weather would remain calm, the contractors ordered 'operation backstay span.'"

<u>Left</u>: caption: "With tugs pulling and pushing and winches wheezing with taught wire ropes, the backstay was slowly babied into position."

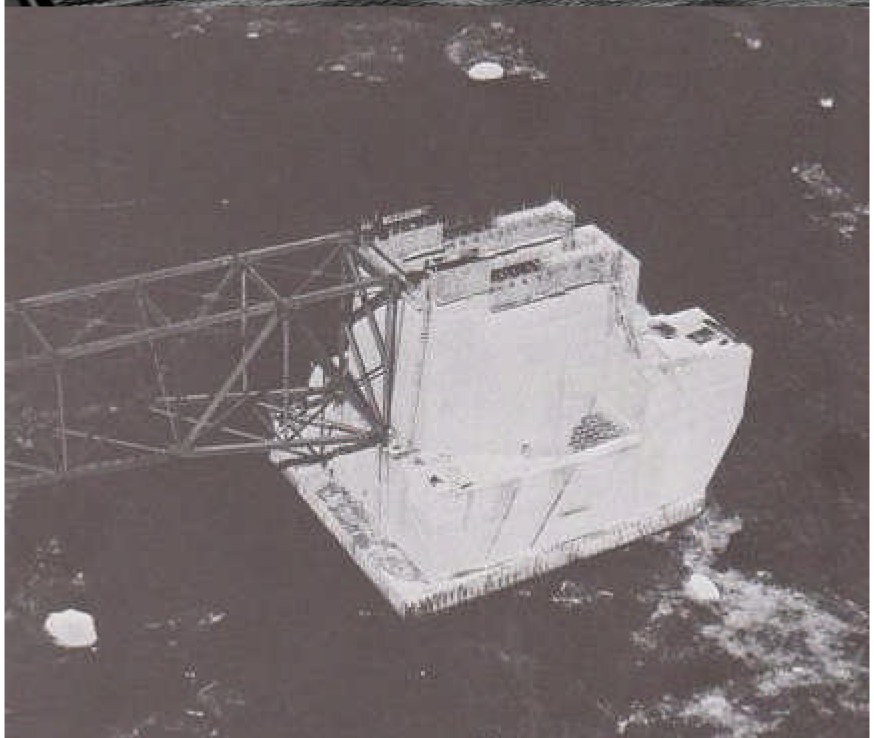


<u>Above</u>: caption: "A close-up shows there were about six feet to go before the backstay span lined up with the steel shoe into which it would eventually fit."



<u>Left</u>: caption: "The holes in the span were flush with the holes in the shoe and a 500-pound pin was rammed into these holes to secure the backstay to the anchorage."

<u>Above</u>: caption: "Pinned to the anchorage, left, and sitting firmly on steel shoes on the cable-bent, right, the backstay span was made clear of the falsework when the barges on which it was built were flooded and consequently lowered, so that they, along with the falsework, could be towed out from under the span."



<u>Top</u>: caption: "North backstay span under tow to site. December 18, 1955."

<u>Bottom</u>: caption: Exactly the same operation was performed on December 18, 1955 to place the north backstay span, shown here with the north anchor block as winter weather moved in (Pier 22)."

<u>Above</u>: caption: “The Mackinac Bridge towers are complete and the first two truss sections (backstays) are in place at the two anchorages. This is very late in the 1955 work season or early in 1956.”

<u>Above</u>: caption: “Mackinac Bridge construction goes on hold during the winter of 1955-56.”

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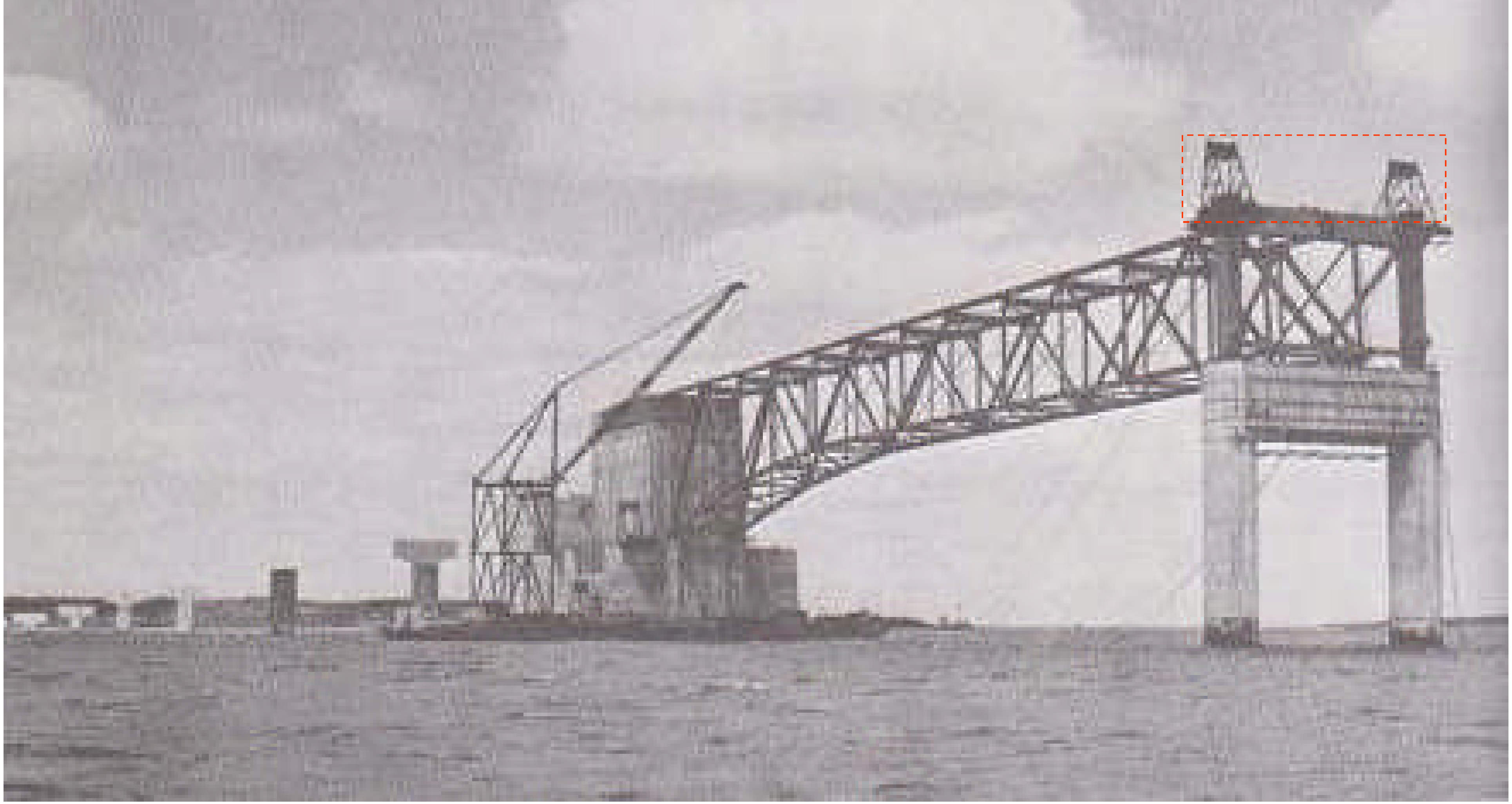
Part 5

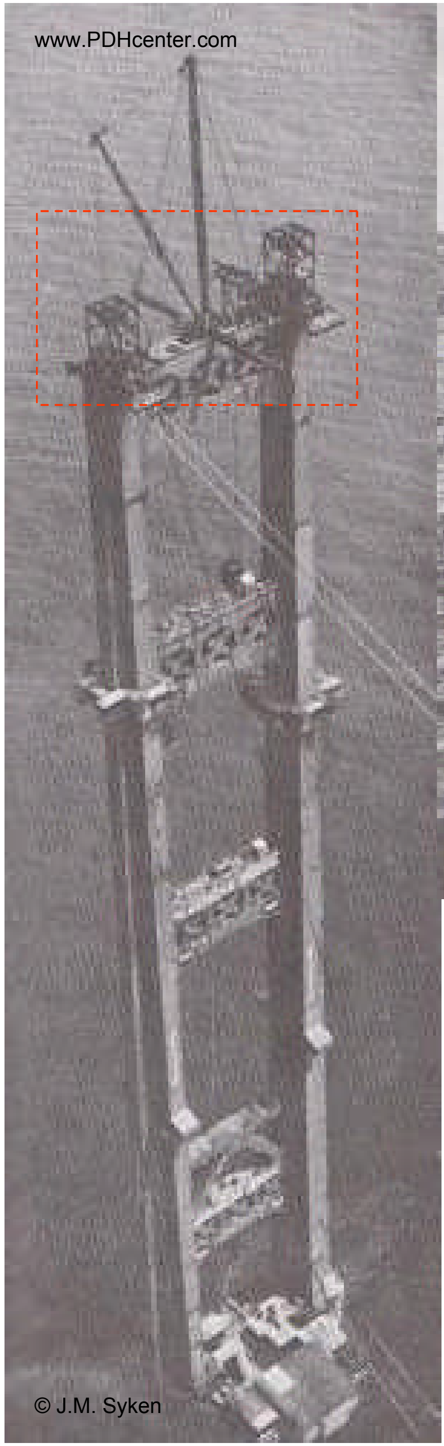
Season Three: 1956

Of all phases of construction, aerial cable-spinning aroused the greatest curiosity and interest from the public-at-large and was the highlight of season three. Once begun, the spinning of the two cables had to be completed on schedule since unfinished cables could not be left exposed to the elements during winter above the Straits. Considered the most dangerous aspect of constructing a suspension bridge, both cables were completed in record time; seventy-eight working days. Also in 1956, truss spans for the approaches were erected atop their piers starting from each shore along with the partial paving of the roadways atop these spans.

Catwalk Construction



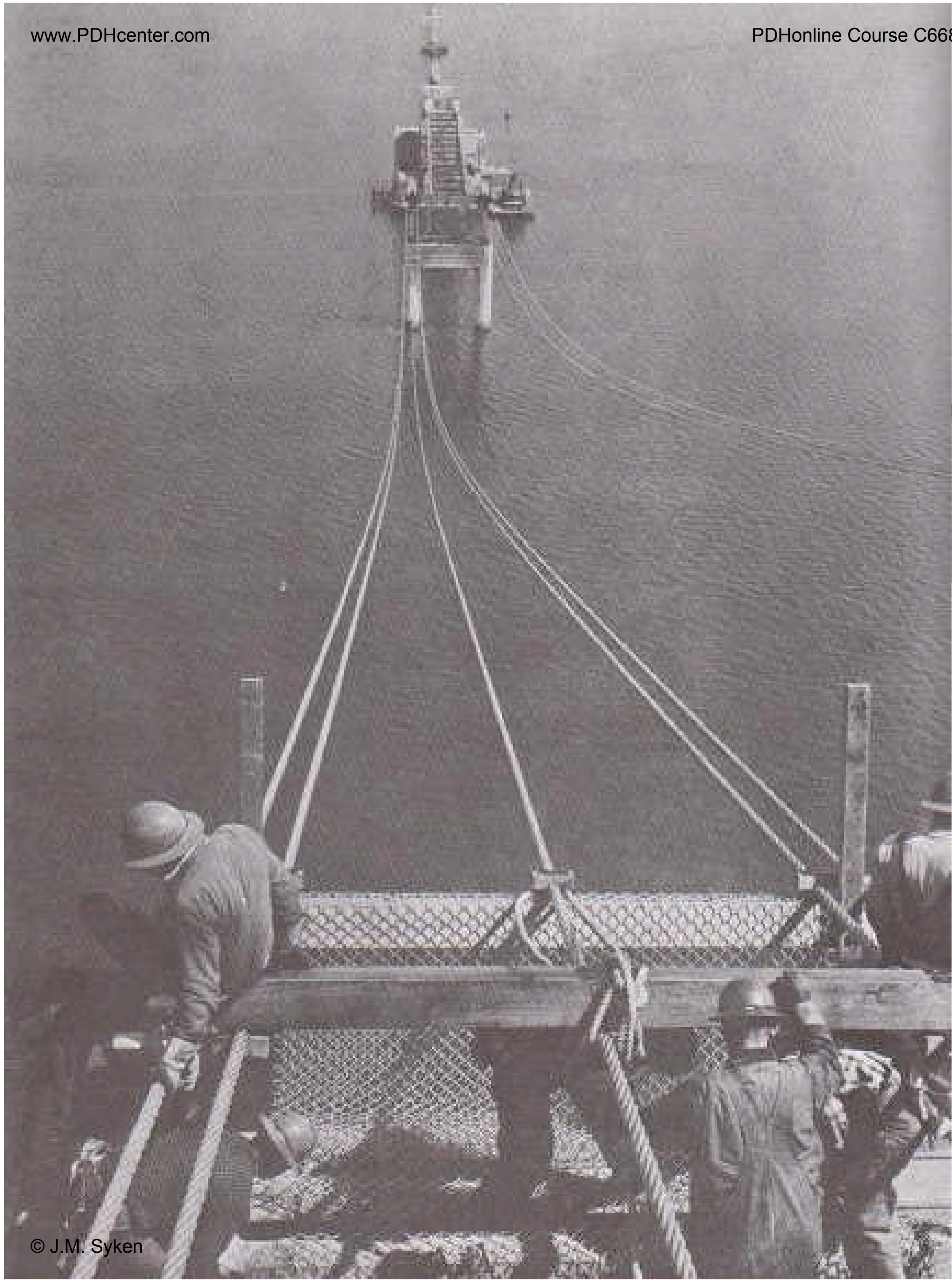
<u>Above</u>: caption: "In order to spin the cable there had to be a catwalk (a.k.a. "Footbridge") on which the cable spinners could work. In order to build a catwalk there had to be wire ropes to support it, five for each catwalk, raised from one anchor block over the tower tops to the other anchor block following the same curve and contour that the cables would eventually take. Here the wire ropes were started from the anchorage to the cable-bent (Piers 21 and 22)."



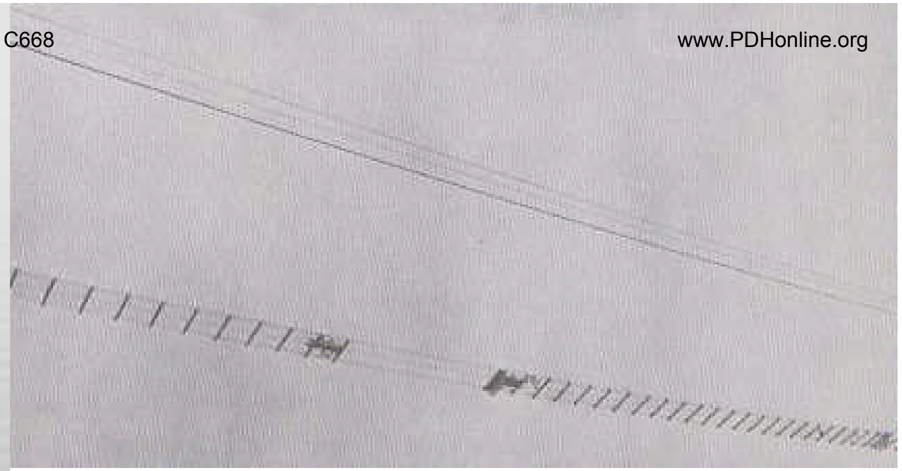
<u>Above Left</u>: caption: "Wire rope was unreeled from a barge towed across the Straits. Rope was two and one-quarter inches in diameter. After serving as catwalk support it was re-employed later to hold up the suspension span."

<u>Left</u>: caption: "The ropes were pulled over the tops of the tower. Note the huge steel frameworks and platforms built on top of the tower to take care of the equipment and operations necessary for cable spinning."

<u>Above Right</u>: caption: "Workers attaching first catwalk rope to the top of the south tower. May 23, 1956." 271



<u>Left</u>: caption: "With the wire rope in place, the next job was to slide the cyclone wire fence, which was really the catwalk, down the wire rope from the tops of the towers toward the cable-bents and toward the center of the main span."
<u>Above</u>: caption: "Careful to stay centered, the workmen jumped up and down to help pay-out the cyclone fence through the five wire rope supports."



<u>Left</u>: caption: "Slowly but surely accordion wrapped sections of cyclone fence unfolded and slid gently down the wire ropes."
<u>Above</u>: caption: "Coming down from each tower in opposite directions toward the center of the main span, the catwalks were nearly joined together."

273

<u>Top</u>: caption: "Workers are placing a winch on the catwalk. The winch was a motor-driven hoisting machine used to pull the sections of the temporary catwalk into position. June 6, 1956."

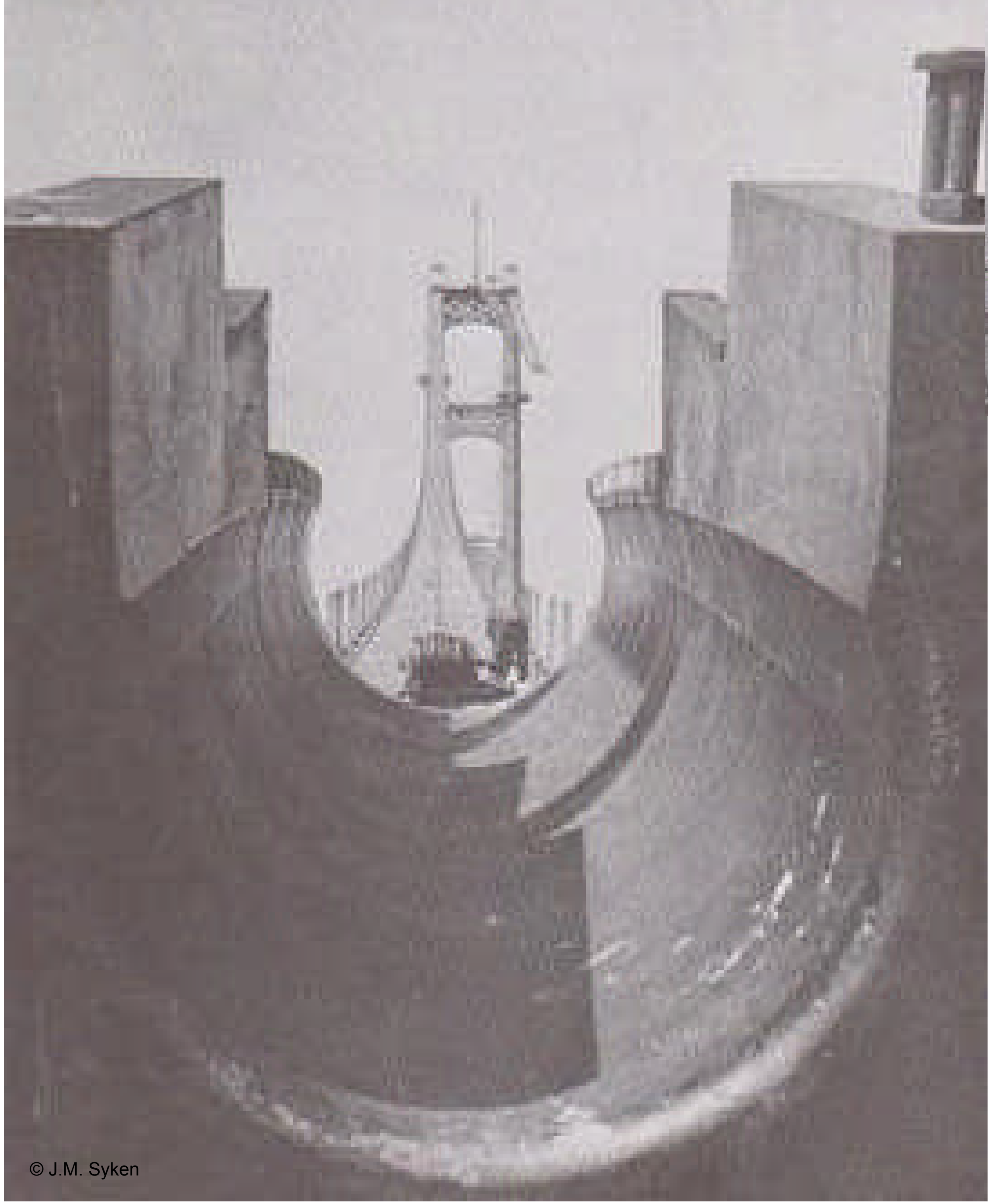
<u>Bottom</u>: caption: "Erecting the east catwalk between the north and south towers. June 15, 1956."

274

Top: caption: "Bridgemen had to do all the hand work and detailed work that went into making the catwalk a safe and useful platform on which to work."

Bottom: caption: "Bridge workers were pleased to have their picture taken as they joined hands in the center of the main span 190 feet above water, signifying that the cyclone fence catwalk had been connected from anchor-age to anchorage."

<u>Left</u>: caption: "Catwalk spanning over the 762-foot tall tower; 210-feet below the water line and 552-feet above."
<u>Right</u>: caption: " Catwalk spanning between tower, left, and cable-bent, right."



<u>Left</u>: caption: "Looking through the 13-ton cast iron saddle in which the 12,580 cable wires will be held, one can see the completed catwalk ahead, and the incomplete one to the right of center."

<u>Above</u>: caption: "Wood cleats were wired to the fence floor to secure safer walking on the catwalk. Handrails were erected and steel trusses connected the catwalks for additional stead-iness and sturdiness." 278

<u>Top</u>: caption: "Temporary catwalk in place before the start of the construction of the bridge cables. Construction of these catwalks was very hazardous and two Bridge workers fell to their deaths during their construction."

<u>Bottom</u>: caption: "Looking up at the backstay span (left) and catwalk (right) from the anchorage towards the cable-bent pier."

280

<u>Left</u>: caption: "Storm guys were attached to the catwalk securing it to the towers and the anchor blocks to help resist high winds and storms. The billowing sails of the yacht below complement the curves of the catwalk and highlight the strong winds present in the Straits."

<u>Above</u>: caption: "A Great Lakes freighter passes under the growing Mackinac Bridge."

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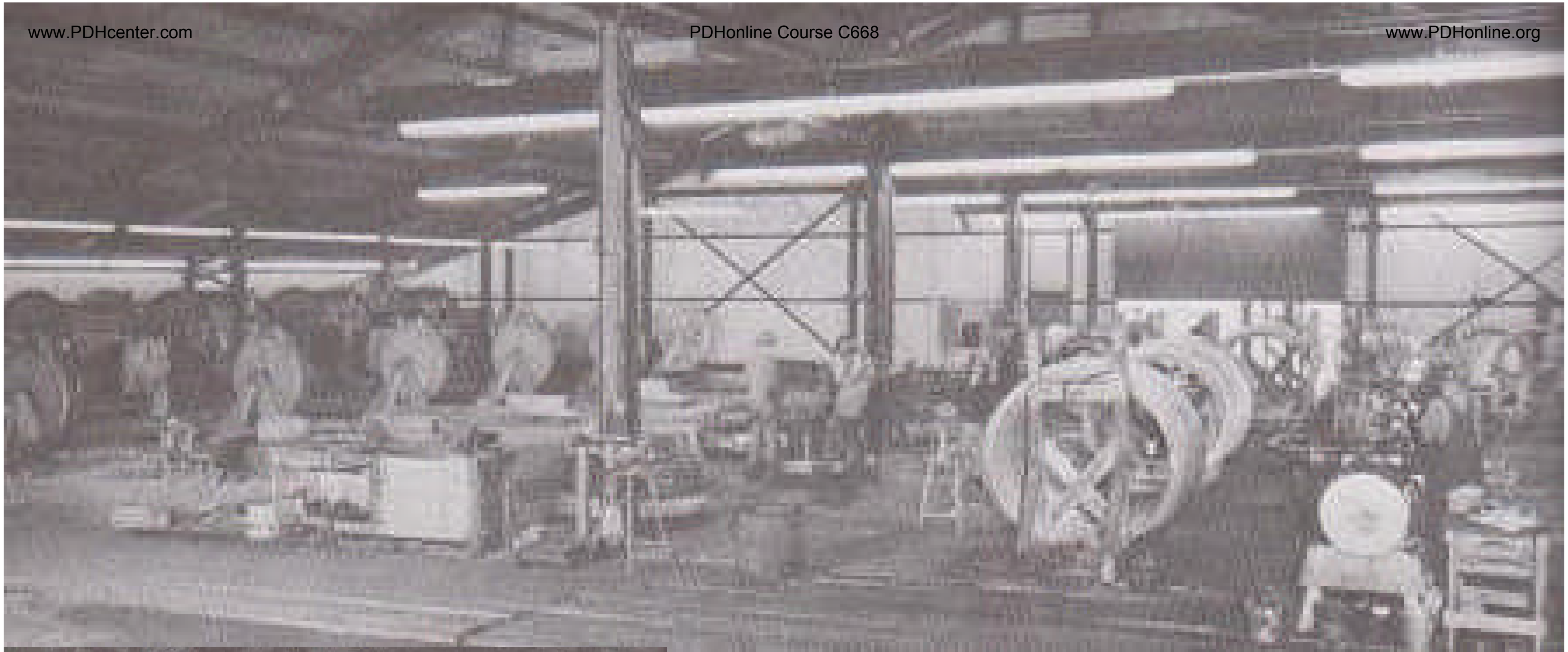
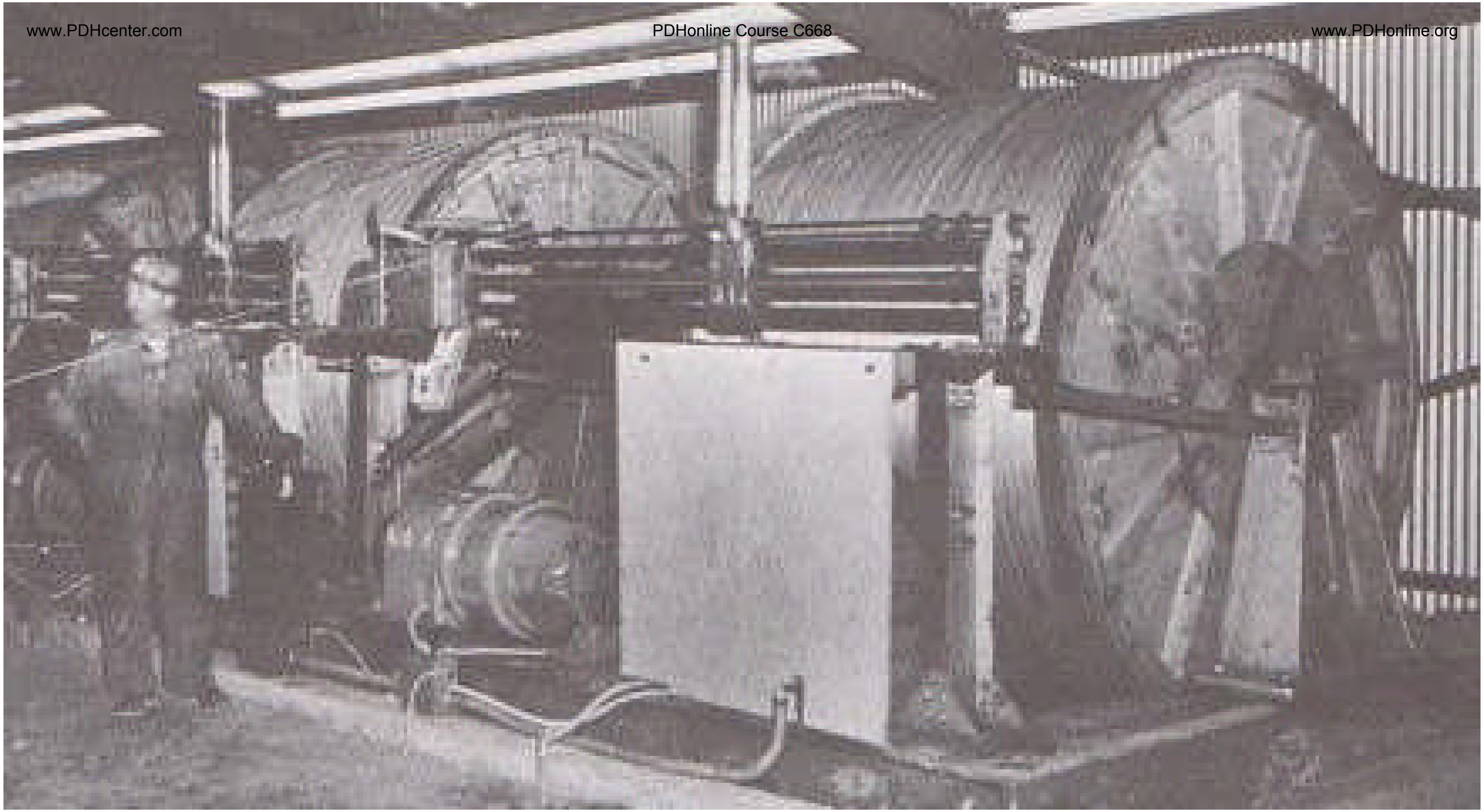
Aerial Cable-Spinning



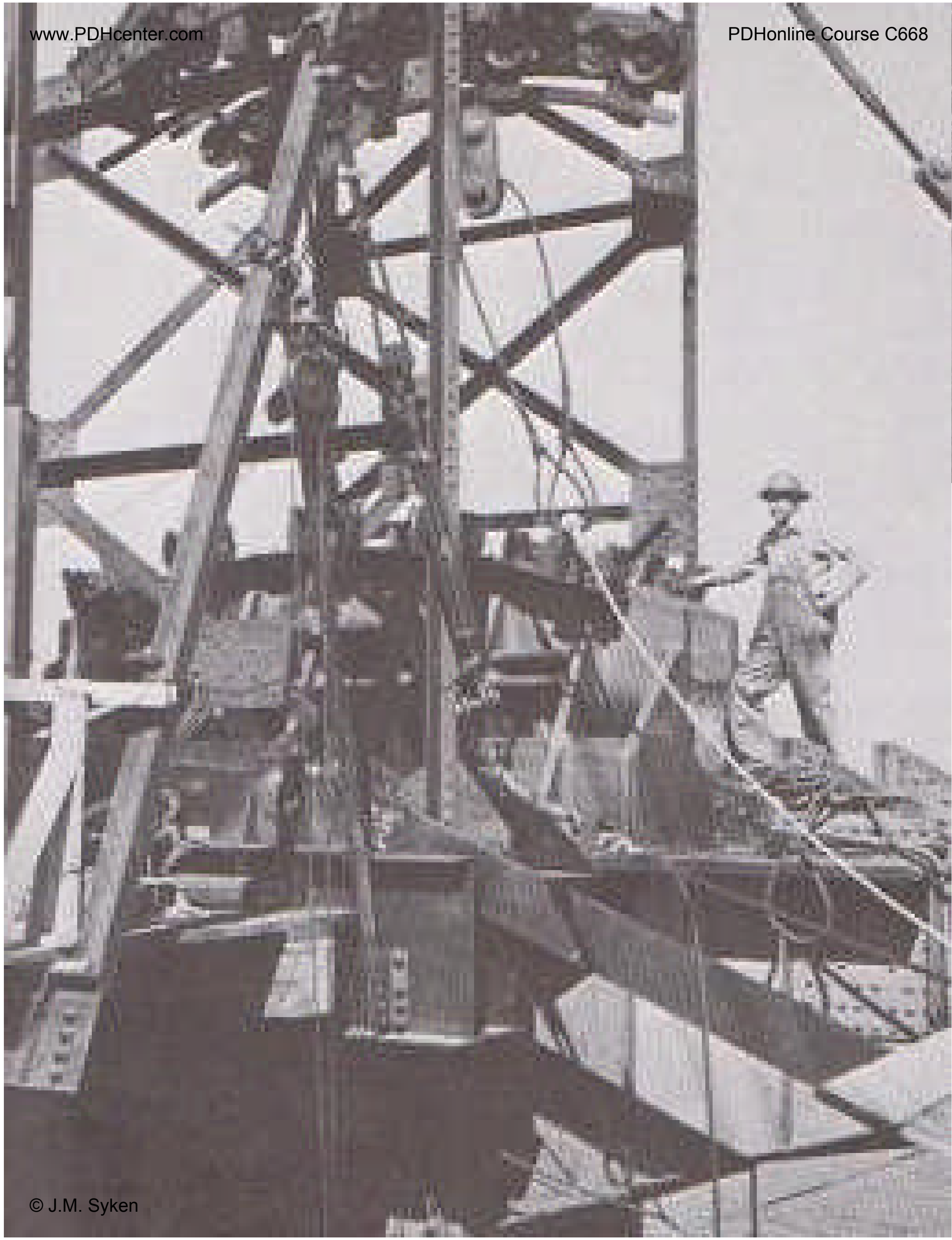
<u>Above</u>: caption: "Beginning in 1955, 55,500 coils of steel wire for the cables had been shipped for storage to Sault Ste. Marie, Michigan. Buildings were specially erected to store these coils prior to their being rolled onto reels."

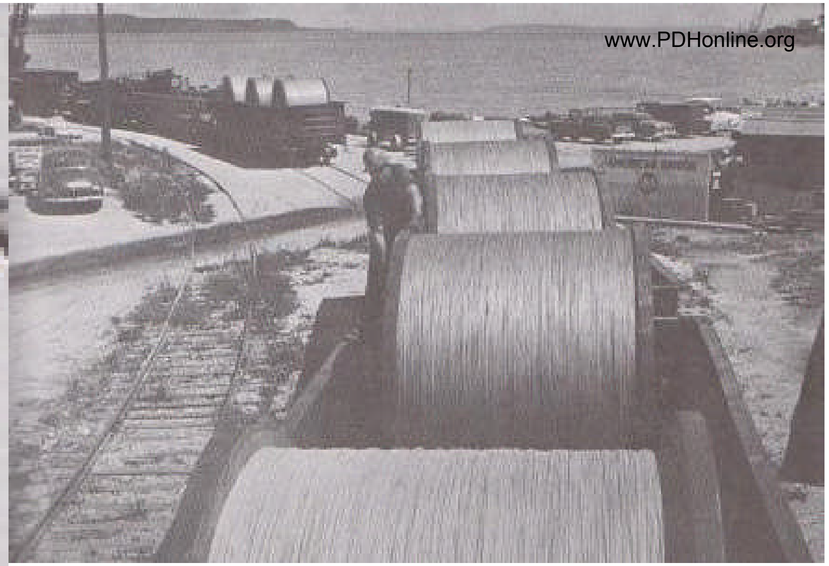
<u>Left</u>: caption: "In the reeling building, the coils were spliced and wound automatically under precisely measured tension on to huge drums."



<u>Above</u>: caption: “Each reel weighed 16 tons and contained approximately 320,000 feet of wire. The wire was much stiffer than its appearance would indicate and was O.192 inches in diameter – about as thick as a lead pencil.”

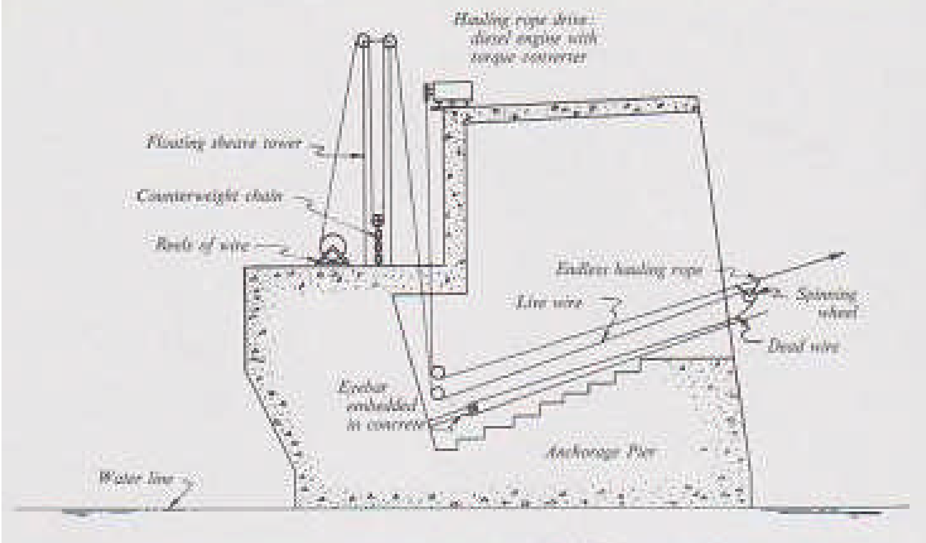
285

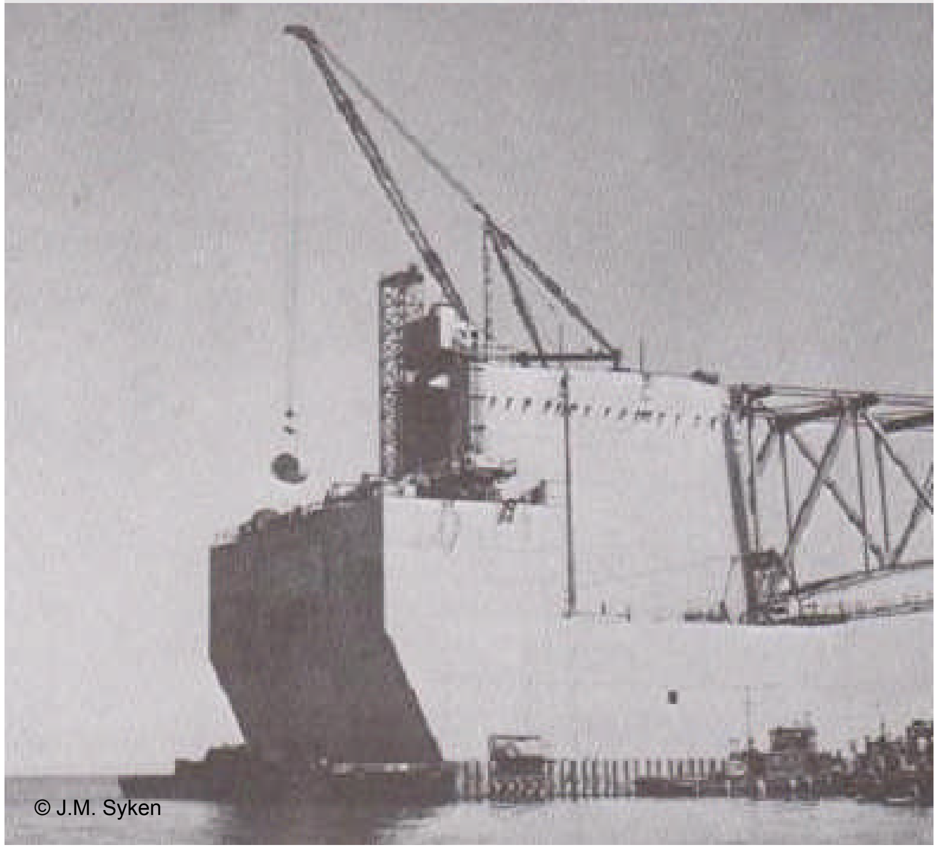




<u>Above</u>: caption: "Logistics required that a large stockpile of wire already on reels be ready before cable spinning began. These reels were shipped by rail to the Straits from the Soo. Empty reels had to be rewound as soon as they were returned so that the cable spinning would not be delayed."

<u>Left</u>: caption: "A close-up of some of the machinery mounted atop the towers to take care of the cable spinning."





<u>Top</u>: caption: "Diagram shows the key parts of cable spinning, which is a very simple process and misleading since there is no spinning, braiding or twisting involved."

<u>Bottom</u>: caption: "Derrick raises 16 tons of cable wire onto huge anchorage spinning platform."

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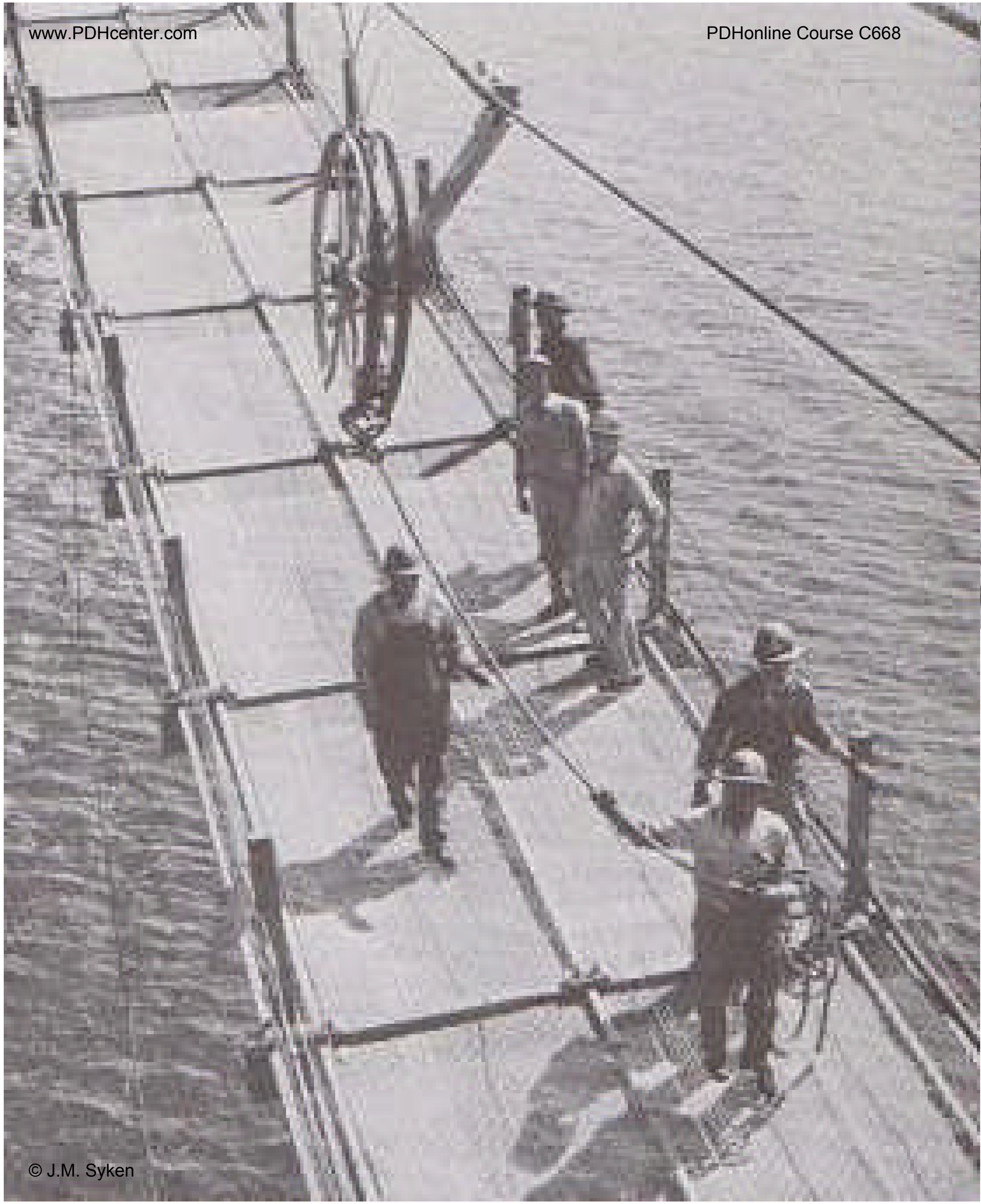

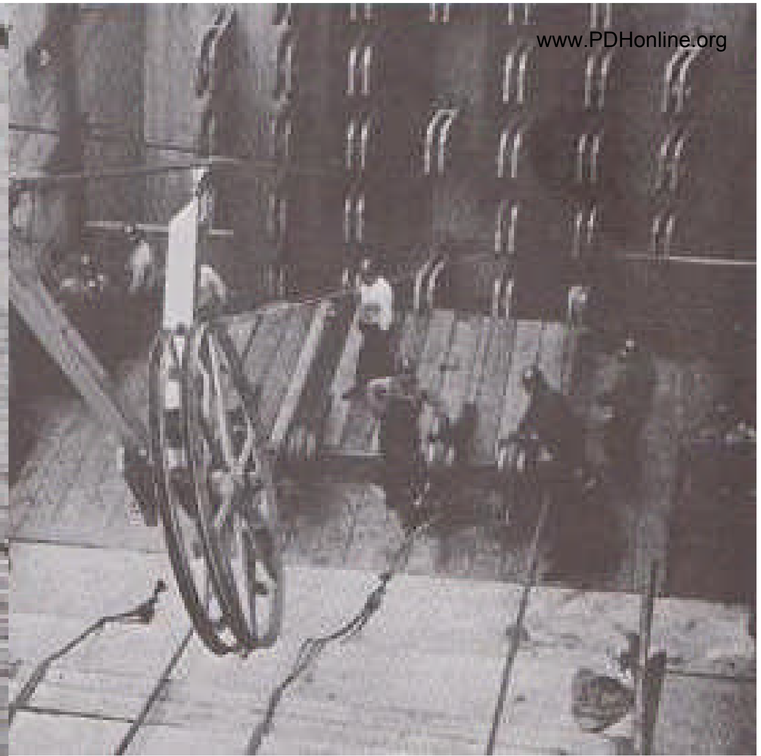

<u>Left</u>: caption: "A bridgeman walks the double-grooved spinning wheel from anchorage to ascertain that it is properly working before the machinery is pressed into action."

<u>Above</u>: caption: "The first four wires are pulled out from the north anchor block on their 12-minute trip up and down the two towers to the south anchor block." 288

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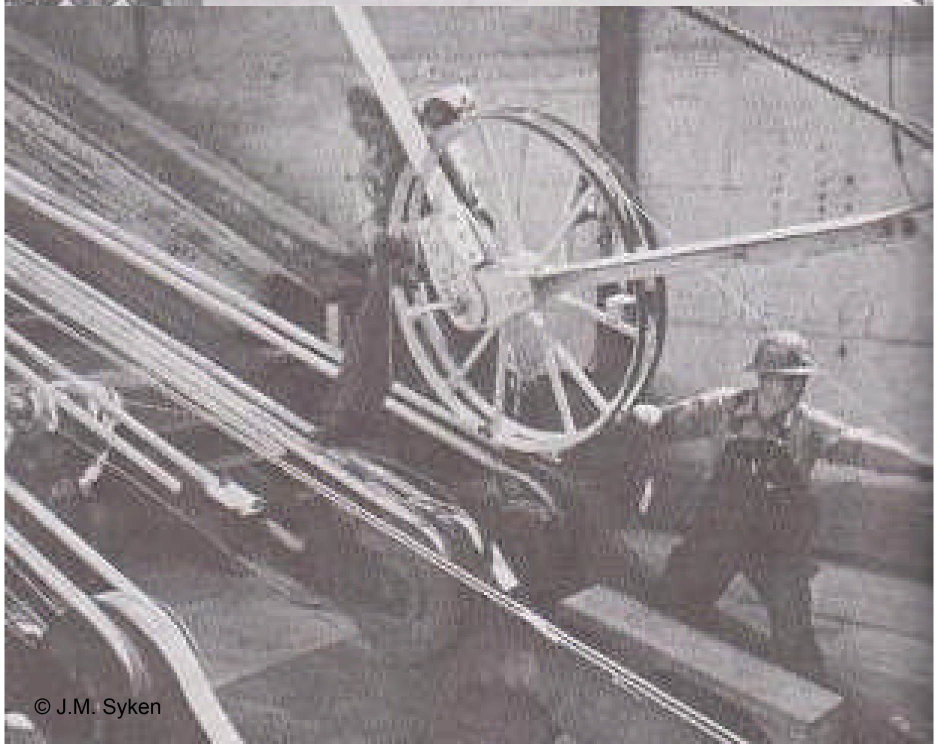

<u>Top</u>: caption: “Moving down from the top of the tower, the spinning wheel laid down four wires to be included in a strand of 340 wires. Thirty-seven strands make up the 24.25-inch cable.”

<u>Bottom</u>: caption: “As soon as the spinning wheel arrived at the anchor block the four wires it carried from the opposite side were slipped around strand shoes (lower left and center) and four wires from the reel on this anchor block were looped over the wheel and it was sent on its way.”

<u>Above</u>: caption: “Temporary catwalk with cable under construction.”

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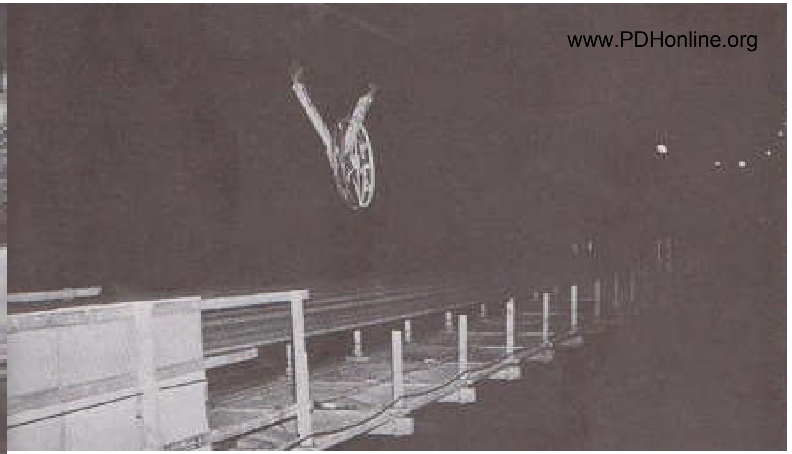
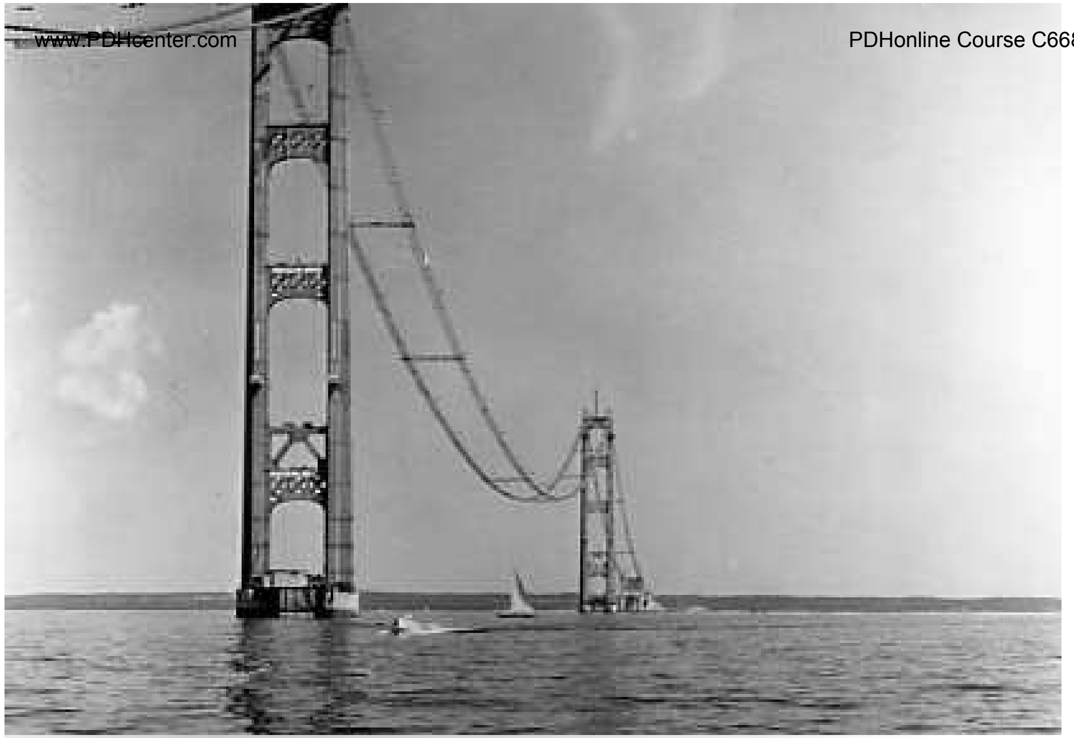
<u>Above</u>: caption: "Since there were two spinning wheels operating simultaneously in opposite directions, they would meet exactly in the middle. When their trips were completed eight wires had been added to the cables."

<u>Left</u>: caption: "Each and every wire pulled across the suspension span was individually adjusted. Strands of wires were adjusted usually at night when the temperature was constant and the wires not likely to contract or expand depending on the location of the sun."



<u>Left</u>: caption: "While spinning was taking place on one cable, bridgemen adjusted, squeezed and handled the strands on the other."
<u>Above</u>: caption: "Cable spinning was carried on in two ten-hour shifts so long as weather permitted."

<u>Above</u>: caption: "With the cable spinning only a few days from completion, one of U.S. Steel's (USS) ore ships saluted the cable spinners as it passed under the bridge. Most probably, this ship and others like it carried ore that went into fabricating the steel[294] **for the bridge."**

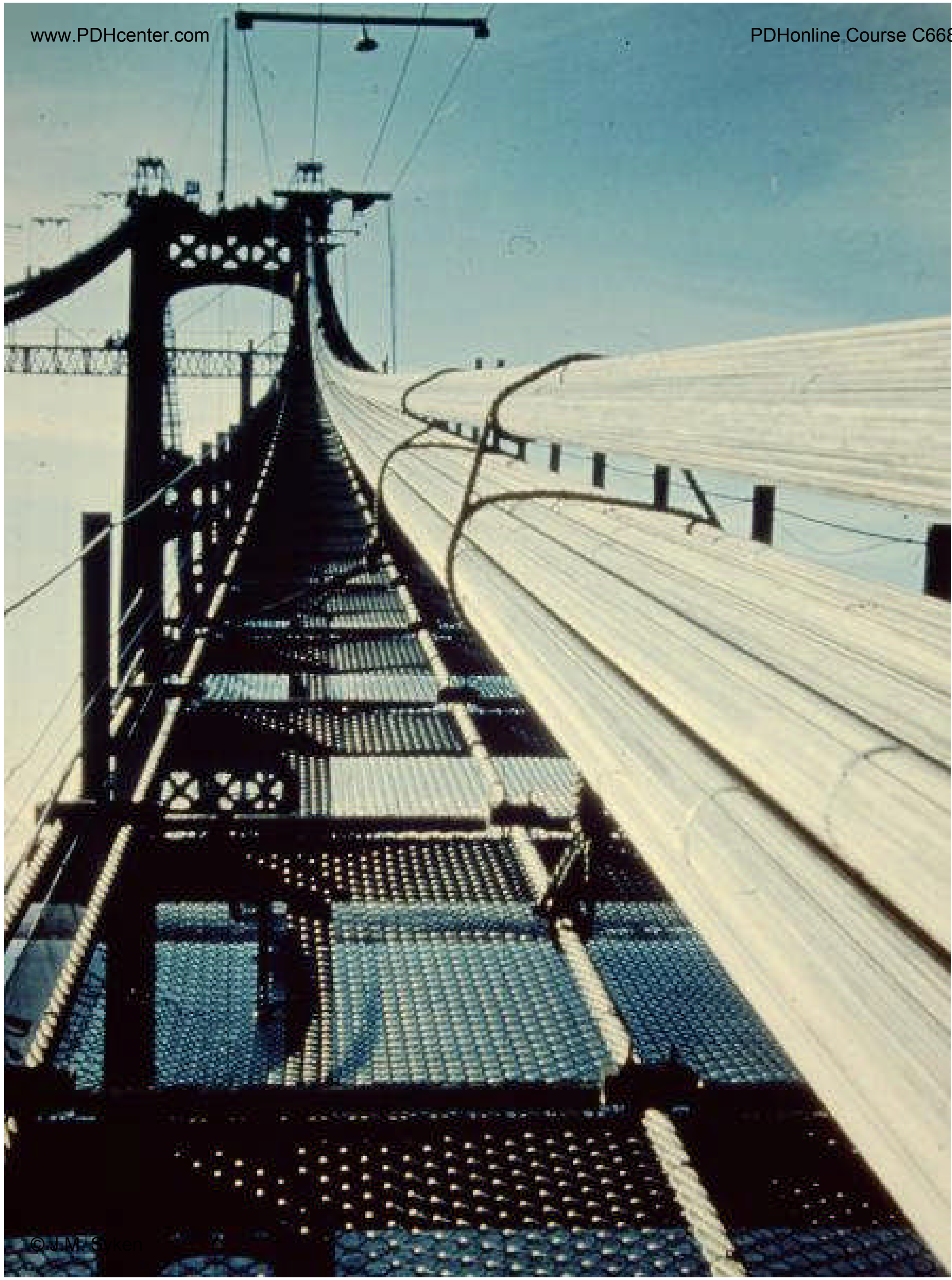


"The fog was blowing down below, and you really couldn't see much. Then, halfway up the catwalk, we cleared the fog. It was almost as if you could walk on the clouds. It was just beautiful, it was really something."

***Joe Oldeck,* Ironworker**

"One thing about the Mackinac Bridge, there were nothing but top-notch men on the job. If they weren't doing the job, they were gone the next day. I made some life-long friends on that job. And American Bridge really took care of us. They got us all the top-notch equipment that we needed."

***Mike Gleason,* Ironworker**



<u>Left</u>: caption: “The cable construction continues with the wire bound temporarily tog-ether.”

<u>Above</u>: caption: “The finished cable strands form a hexagonal configuration until compacting into a round configuration with a 24.25-inch diameter.”

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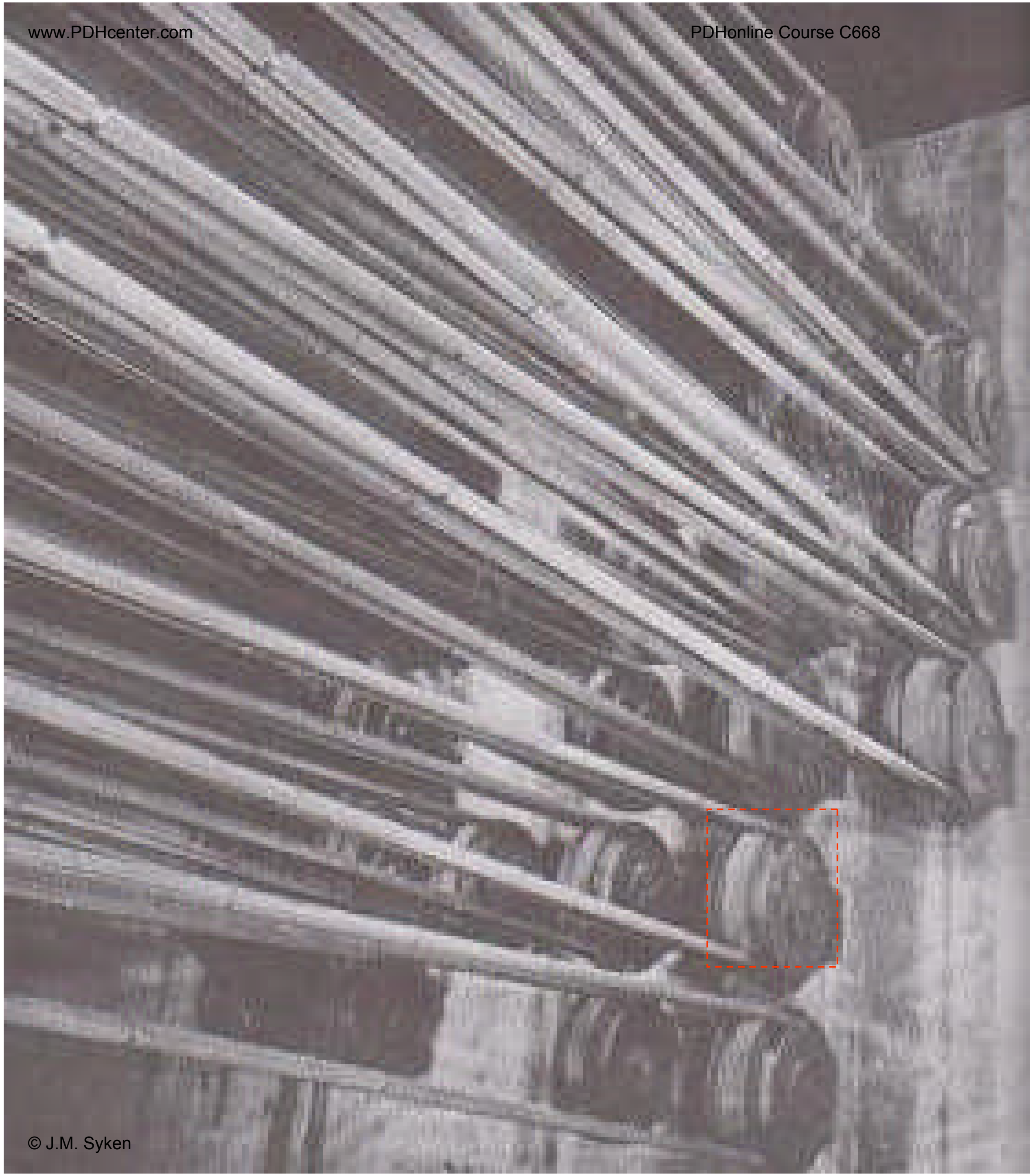


Left: caption: "When the cable spinning was complete the strand shoes around which the wire was wound were attached with steel pins to the ends of the deeply embedded eye-bars protruding from the face of the mass of concrete, similar to the manner by which the links of a bicycle chain are held together."

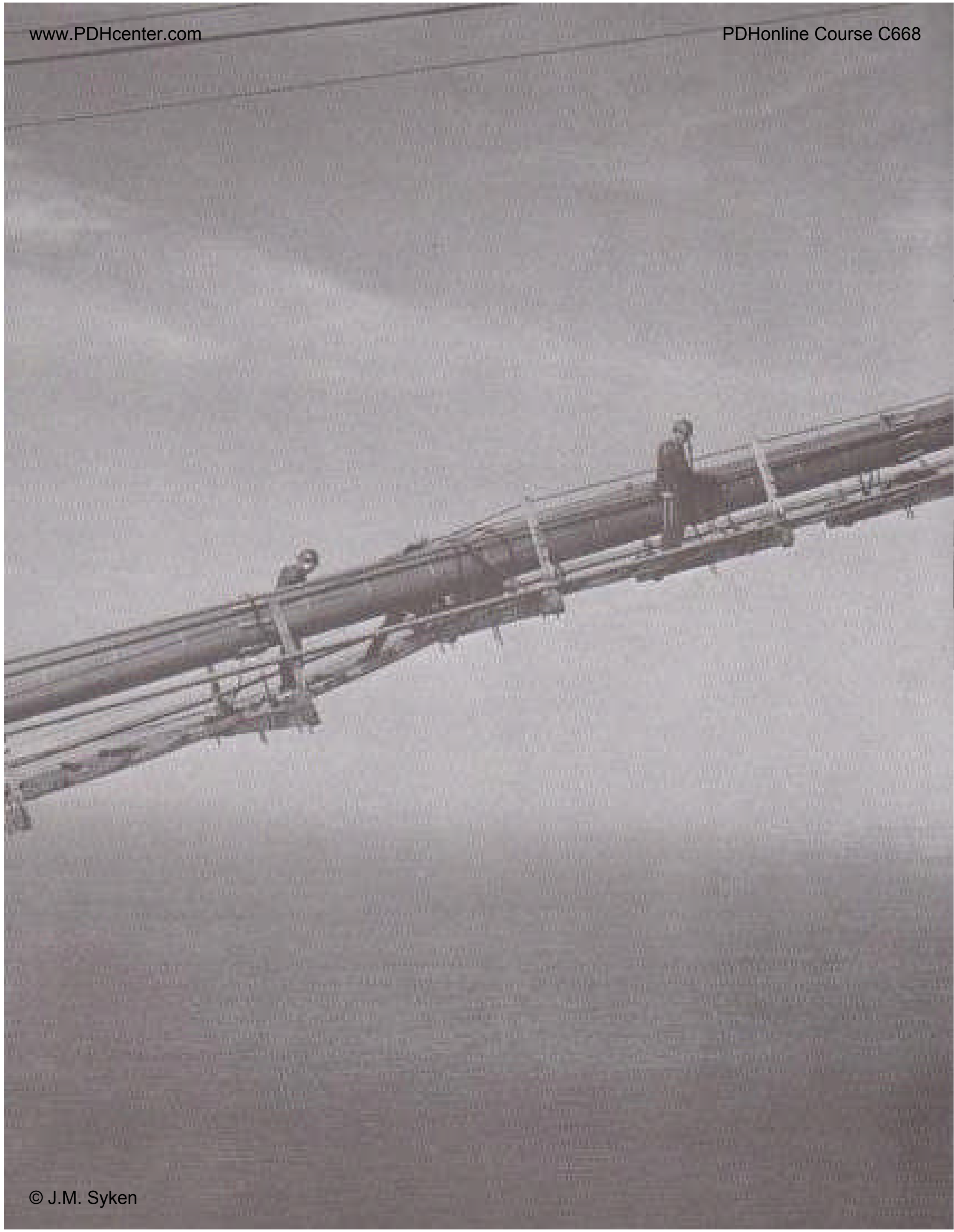
Above: caption: "As seen from above, suspension cable enters cable anchorage"

Cable Compacting

<u>Top Left</u>: caption: "Thirty-seven strands of 340 wires each were compressed into a circular shape and bound with stainless steel straps to form the 24.25-inch diameter."

<u>Top Right</u>: caption: "These workers are placing temporary bands during compacting of the east cable near the top of the south tower. October 20, 1956"

<u>Left</u>: caption: "Engineers carefully measured the diameter of the east cable to make sure it was properly compacted. The photograph was taken near the top of the south tower on October 20, 1956."



<u>Above & Left</u>: caption: "As soon as the cable was compressed and banded the catwalk was attached to it. The wire ropes which originally supported the catwalk were removed and sent to Trenton, N.J., for stretching, cutting and cupping into the precise lengths for use to hold up the suspended span."

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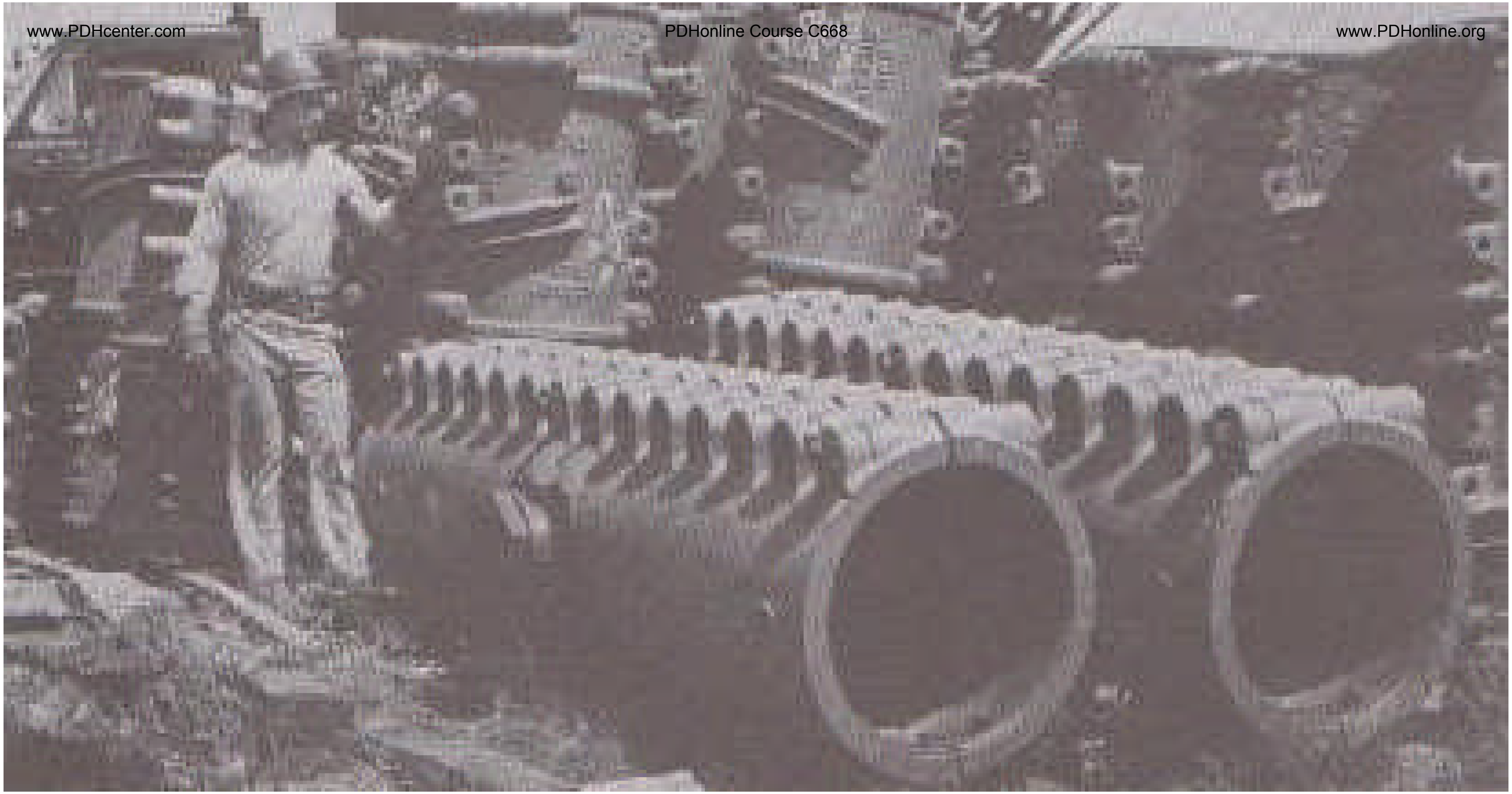
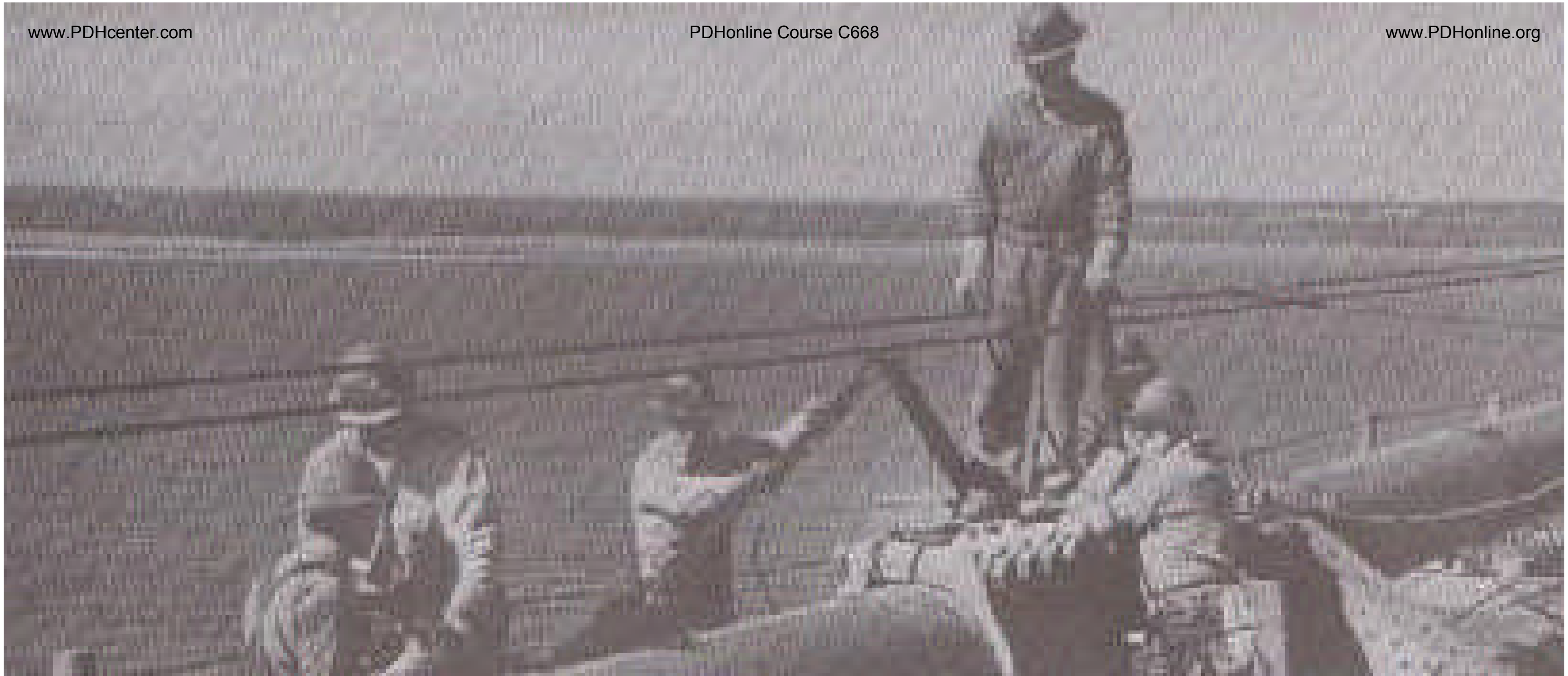


<u>Above</u>: caption: "Cable bands or clamps which hold the cable compact and cradle the suspender ropes which loop over them, connecting the suspended bridge with the cable. The center cable bands are in the foreground." 302



<u>Above</u>: caption: "Bridgemen work the ratchet that pulls the wrench that tightens the center cable clamp. They are working on the catwalk 190 feet above water."
<u>Left</u>: caption: "November 10, 1956 and bridgeman fights freezing temperatures as well as snow and ice to tighten cable clamps 500 feet above the Straits."

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<u>Above</u>: caption: "Finally winter closed in, but the cables were securely in place and a key operation in the construction of the bridge was completed on schedule."

<u>Left</u>: caption: "Late winter view looking south from the top of the north tower. March 4, 1957."

Truss Spans

At the same time the aerial cable-spinning was on-going, twenty-seven truss spans – some almost 600-feet long, for the approaches to the suspension span were being erected. In their own right, they were considerable bridges. Upstaged by the cable-spinning operation and considering the unpredictable wind and weather of the Straits, the erection of the many truss spans without incident was a noteworthy accomplishment.

<u>Above</u>: caption: "Mackinac Bridge truss spans being assembled on shore before being towed into position and raised into place."

Above: caption: "Construction began from the causeway on the St. Ignace (north) side of the Straits in a southerly direction in mid-May 1956. The truss sections were floated into position then topped with the roadway stringers which can be seen atop the three center sections." 308

<u>**Left**</u>**: caption: "Falsework had to be erected between distant piers to support the truss span until all the steel was 'hooked up,' connecting one permanent pier to the next."**

<u>**Above**</u>**: caption: "Moving more of the Mackinac Bridge superstructure into position."**

<u>Above</u>: caption: "Simultaneous lifting of three lateral beams during erection of the span between Piers 23 and 22. May 2, 1957."

<u>Left</u>: caption: "While machinery does most of the heavy lifting, truss erection was, for the most part, a 'hands-on' job. The final movements of every connection were made by hand and all drift pins as well as steel bolts had to be individually inserted and tightened."

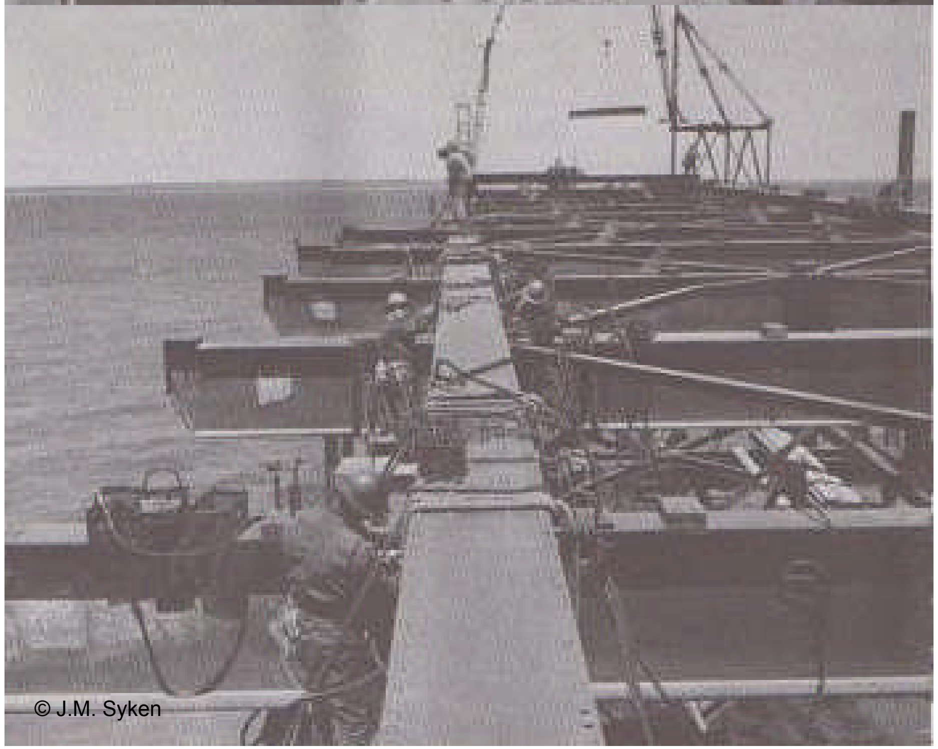
310

<u>Above</u>: caption: "Truss span construction starting out from Mackinaw City (south side)."

<u>Left</u>: caption: "From Mackinaw City, steel truss erection moved northward from Pier 1 to Pier 2. April 24, 1956."

<u>Top</u>: caption: "Placing the first section of the bridge superstructure on the piers on the south side of the Mackinac Bridge"

<u>Bottom</u>: caption: "The foot of the Mackinac Bridge on the Mackinac City side. The main entrance to the Colonial Fort was later built next to the cement pier on the right."



Top: caption: "Bridgemen tightening high tension steel bolts used for all truss span connections. Meter in torque wrench must be carefully observed to make sure that a bolt is neither too tight nor too loose. Every bolt was inspected."

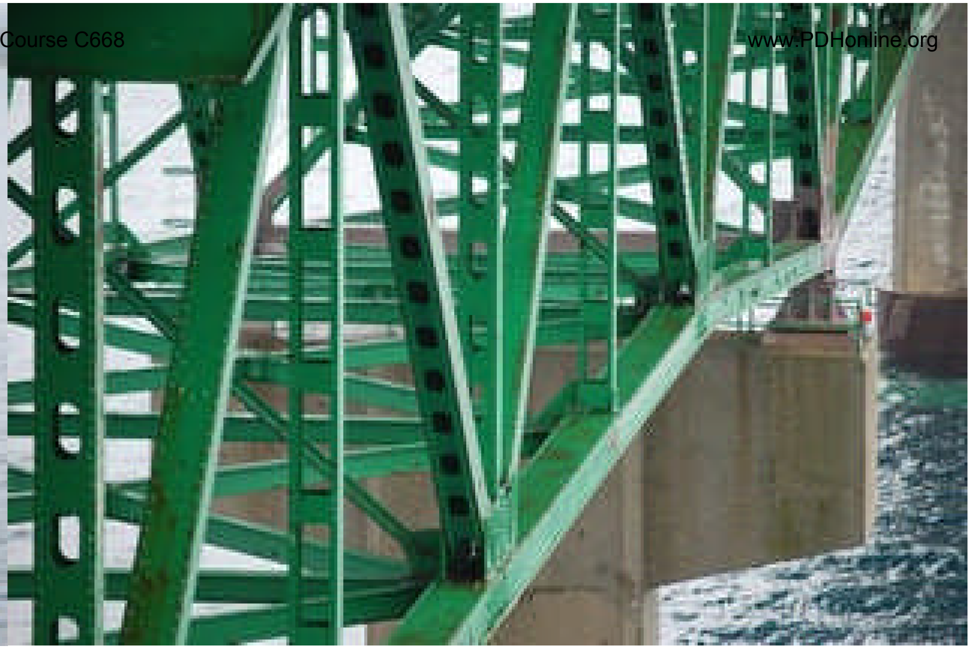
Bottom: caption: "A close-up of truss work construction showing some of the operations. From the shore, it often appeared nothing was going on but a close examination of this photograph will reveal eleven bridgemen at work."

<u>Above</u>: caption: "Hundreds of visitors watched and photographed the Mackinac Bridge construction each day."

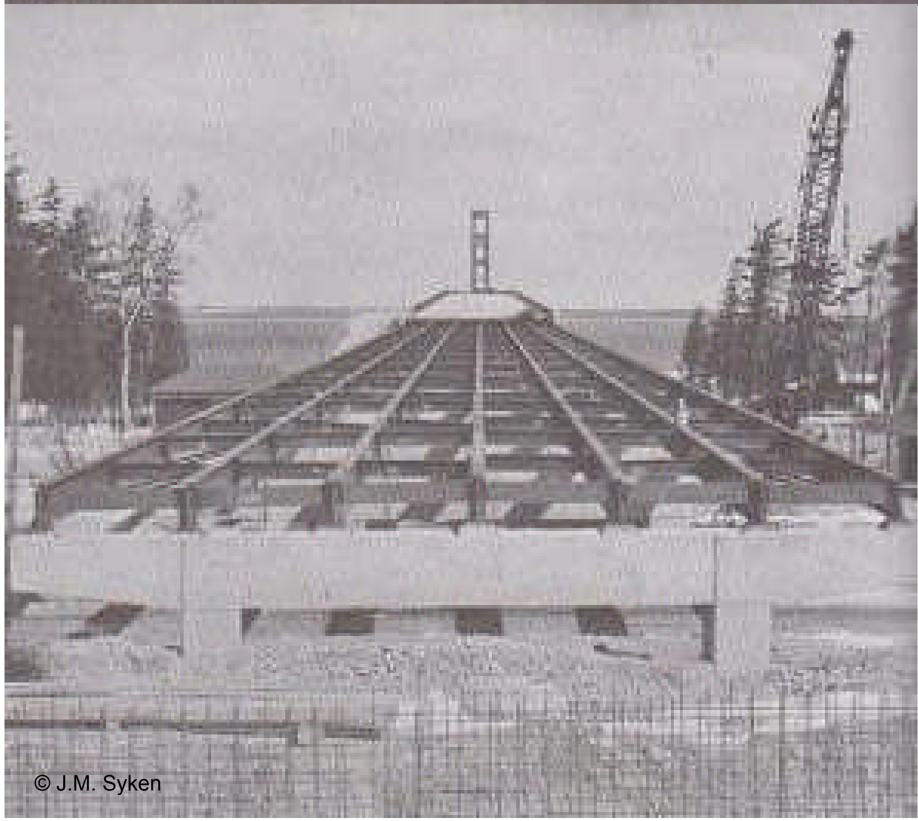
<u>Above</u>: caption: "Mackinac Bridge from the air on Labor Day in 1956. Fort Michilimackinac is at the lower left and Old Mackinac Point Lighthouse is at the right. The lighthouse was decommissioned in 1957 when the lights on the Mackinac Bridge made it no longer necessary. It is a museum today."

<u>Left</u>: caption: "By October 1956 the truss span erection had reached out to Pier 12 some 3,749 feet north of the Mackinaw City shore. Note that the road deck construction is underway."

317



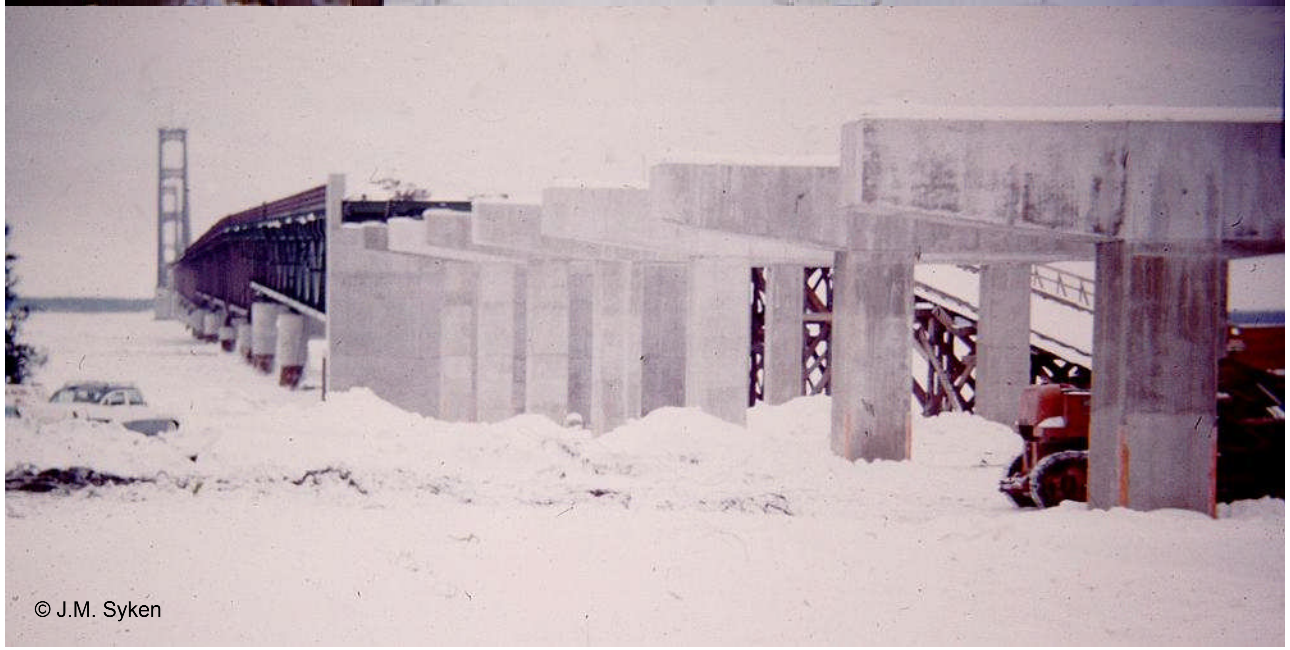
<u>Top L&R</u>: caption: "Truss bridge sections sit on top of piers"
<u>Left</u>: caption: "As seen from above, support for truss section of bridge at concrete cable anchorage"



<u>Above</u>: caption: "On the north side the connection from the bridge deck to the causeway level was started with the completion of 14 bents on which steel and roadway would be built."

<u>Left</u>: caption: "On the south side the connection between the bridge deck at Pier 1 south to the new interstate highway was accomplished by 14 bents on which steel was erected."

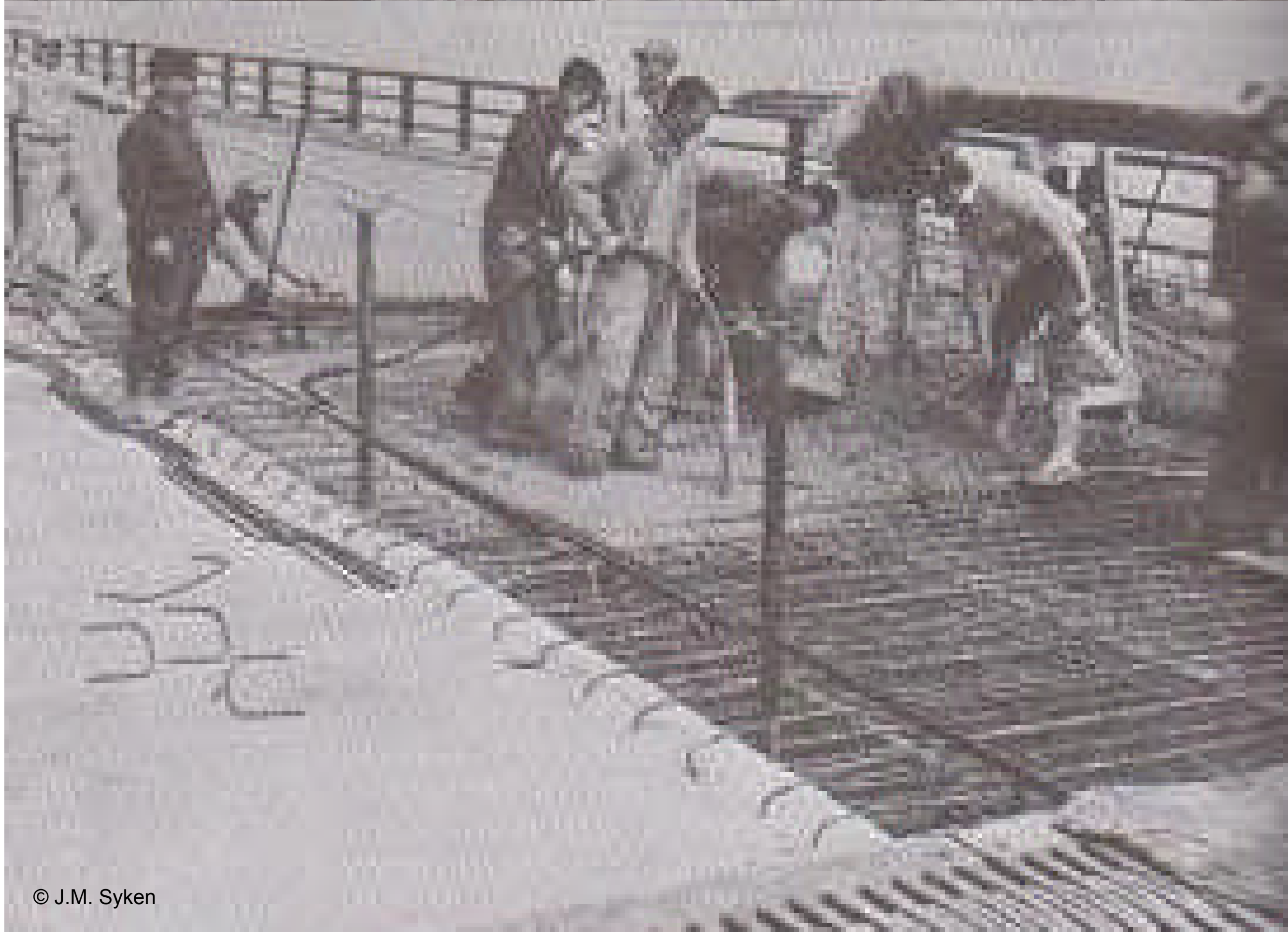
<u>Above</u>: caption: “Construction of the south approach to the Mackinac Bridge. Old Mackinac Point Lighthouse can be seen at the lower left and the Michigan Central Railroad roundhouse with the tall smokestack at the upper left.”



<u>Top</u>: caption: "Construction of the Mackinac Bridge approach where the Fort Michilimackinac parking lot is today"
<u>Bottom</u>: caption: "The wooden ramp at the right was used to drive onto the Mackinac Bridge before the approach was built."

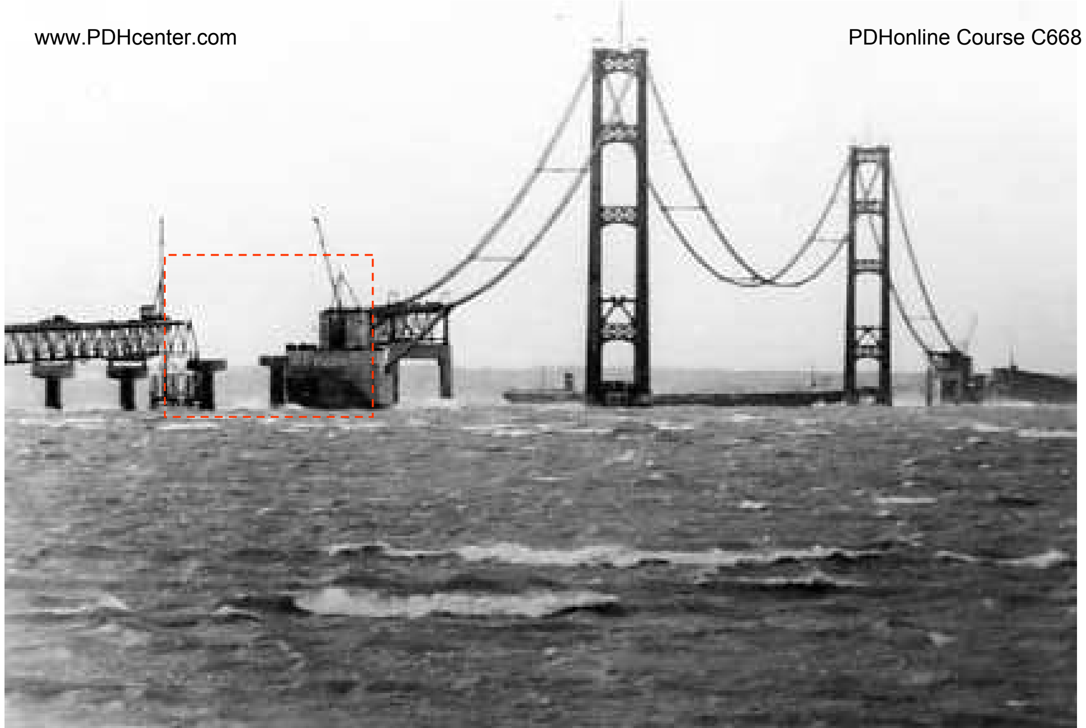
Season three's construction schedule called for paving of the road deck from the shore half-way to the anchor block/s. Seemingly a straight-forward task, it had to be done under difficult and crowded conditions and as compared to paving a grade level highway, it was a substantial challenge. This was recognized in the fact that many local contractors chose not to bid on the job.

<u>Above</u>: caption: "Deck work got underway on the north side in early August 1956. Six inches of concrete, plenty of reinforcing steel, topped with two inches of asphaltic concrete, commonly known as blacktop."
<u>Left</u>: caption: "Pavers leveled off concrete as a foreman was about to signal the man operating the Georgia Buggy to dump another load." 324



<u>Above</u>: caption: “Whereas concrete was conveyed to the pavers with trucks or Georgia buggies on the north side, the south side contractor used a pump-crete machine. This could pump concrete through a pipe about 1,100 feet, thus eliminating wheeled conveyances.”
<u>Left</u>: caption: “Concrete pours out of the pump-crete pipe to fill the forms for paving the deck on the south side. Note the expansion dam in foreground.”

325



<u>Left T&B</u>: caption: "Contractors were confident that they would erect the steel to connect Michigan's two peninsulas before the end of 1956, but the weather did not cooperate and work had to be stopped in late December. About 1,800 feet of four lane road deck was completed on the north side before winter called a halt to paving operations. Just 325 feet short of the mark on both sides of the Strait, the work would be resumed in the spring of 1957. Note the gap/s between the anchor block/s and the truss span/s."

<u>Above</u>: caption: "As the work is suspended for the winter of 1956-57, the bridge roadway is nearly complete up to the two anchorages." 327

Part 6

Season Four: 1957

At the end of the third construction season, it appeared that completing the bridge by the scheduled opening day of November 1st 1957 would be impossible. There was still many things to do, not least of which was raising the suspended span along with concreting and paving operations after it was in-place. Additionally, the anchor blocks had to be filled with concrete to their full height of 118-feet, the two cables had to be wrapped with a fine galvanized wire, lighting needed to installed, the superstructure painted, ancillary facilities such as the toll plaza and administration building needed to be constructed and paving operations for the truss spans (leftover from season three) needed to be completed.

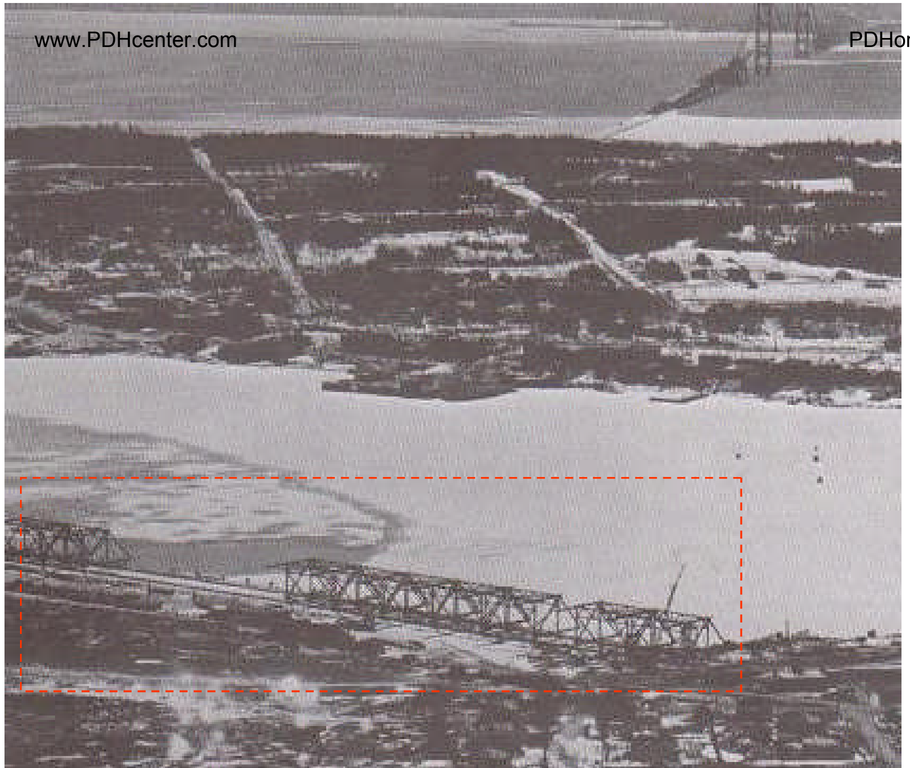
Suspenders

<u>Above</u>: caption: "The wire rope which in 1956 had been used to support the catwalk had been shipped back from Trenton in carefully cut lengths wound on reels. Each individual wire rope was marked for a precise position on the cable from where it would hang to hold a portion of the suspended span."

<u>Left</u>: caption: "The job of raising these wire ropes was begun by positioning a barge directly under the cable band over which the wire rope would loop and then pulling it up off the barge to the cable band."

<u>Above</u>: caption: "A bridge worker nudges the steel socket in which the end of the suspender rope is buried on its way down so that the rope will hang in equal lengths from the cable where it has been looped around the cable band."
<u>Left</u>: caption: "Bridgeman slides down suspender to tighten clamp during installation of the two and one-quarter inch wire rope. He is securely tied to the catwalk, about 500 feet above the water." 332

Suspended Span



<u>Top</u>: caption: “Meanwhile, back in St. Ignace dock, the superstructure contractors were assembling portions of the suspended span. This work went on all during the winter of 1956-57.”

<u>Bottom</u>: caption: “The sections, about 120 feet long and 40 feet high, were assembled on tracks so that they could be rolled down toward the shore where barges would be ready to receive them as soon as the ice went out from the Straits.”

<u>Left</u>: caption: suspender ropes in-place awaiting truss sections."

<u>Above</u>: caption: "With nearly all the suspender ropes hanging from the cable the suspended spans adjacent to the towers were cantilevered out and attached to the suspender ropes. The sockets at the ends of the suspenders were used for attaching the suspenders to the suspended span."

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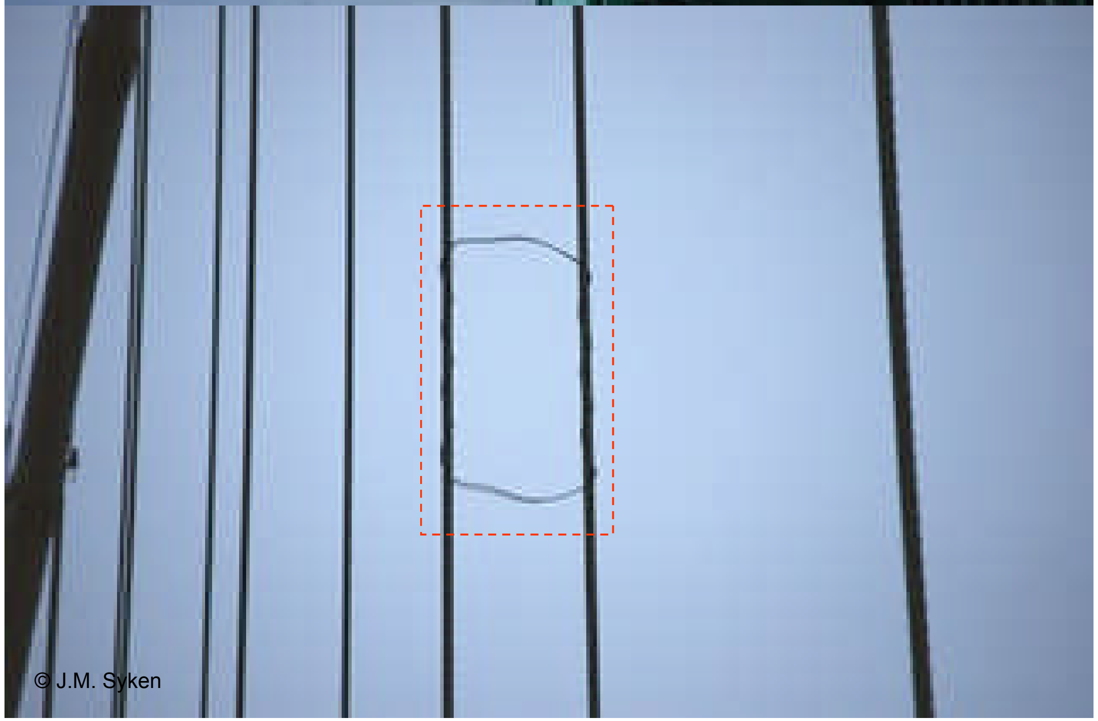
<u>Top</u>: caption: "The first of these suspended portions was towed into position on June 5, 1957. Block and tackle were attached at four points and upon signal from the super-intendent the delicate process of raising the section was begun."

<u>Bottom</u>: caption: "Preparing to lift suspended roadway truss section into position. June 20, 1957."

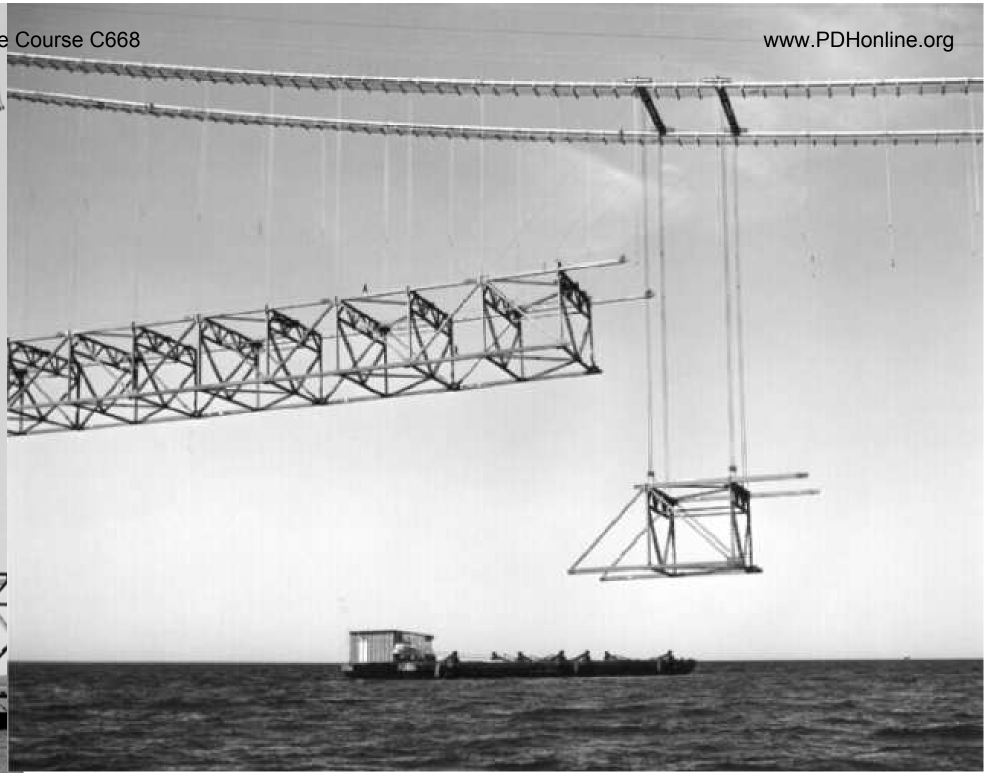
<u>Top Left</u>: caption: “Vertical cables are attached to beam which supports bridge deck system.”

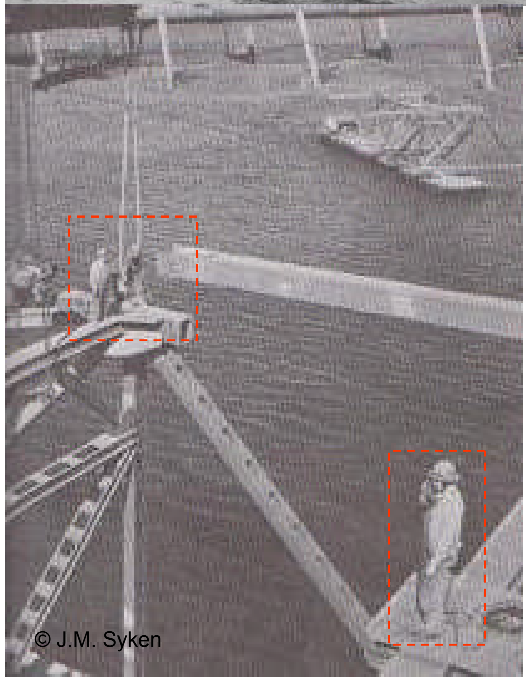
<u>Top Right</u>: caption: “Vertical wires suspend bridge deck from suspension cables.”

<u>Left</u>: caption: “Connection of vertical cable to bridge deck system”



<u>Top</u>: caption: "Bridge cable as seen from top of anchorage"
<u>Bottom</u>: caption: "Horiz-ontal wires between cables keep cables from hitting each other during strong winds."





<u>Top Left</u>: caption: The stiffening truss sections had to be raised on a carefully calculated schedule so that the weight on the cables did not get out of balance. Because the suspended portion of the bridge did not take its final shape until all the weight had been placed on it, the contour of the partially erected suspension bridge seems completely distorted."

<u>Top Right</u>: caption: "Lifting a suspended span stiffening truss unit from a barge to its center span position. June 20, 1957."

<u>Left</u>: caption: "The signal man 'talks' the stiffening truss into position as bridgemen wait on it ready to insert the drift pins as soon as the key holes between units are matched."

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"People who have written about the bridge have used the most colorful people to make their point that iron workers were hell-raisers…They talked to the hardest drinkers and gamblers, and people come away with the impression that that's how everybody was. It made good copy, but most of us just did our job, and went home at the end of the day…There's a certain cameraderie among bridge-men. You know your life depends on the other people who are up there with you every day. They truly are your brothers, and I've stayed close with a lot of them…It was dangerous work, and some days you just had the feeling that it wasn't your day. You could walk off and no one would say anything. It happened to me once: One morning I got that feeling, and I told the boss that today wasn't the day. He said 'OK' and that was the end of it."
Clifford Mumby, **Ironworker**

"I was working on the bridge, and just about everybody else and all the tools had been sent back…I knew that bridge, and I knew it was the last rivet. Hell yeah, I enjoyed driving that last one."
John Tisron, **Ironworker**

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<u>Top L&R</u>: caption: "Finally, by July 22, 1957, all but three of the stiffening truss sections had been raised: two at each cable-bent and one huge section in the center."

<u>Left</u>: caption: "As soon as the vertical stiffening truss was completely erected bridgemen laid in about 80 feet of deck on each side of each tower. Using this as a work platform a 40-ton crane was raised to the deck."

"When we got to the last section in the middle, no one could believe it. We figured it would be close, but it was perfect. They put the last section into place, and they just stuck the pins in there, there was no adjustment necessary. It just showed how sharp those engineers were."
Jim Parker, **Ironworker**

<u>Top Left</u>: caption: "The breeze was brisk and the water rough despite the presence of some 75 news correspondents who came to witness the raising of the center section. Due to unsympathetic weather it was not accomplished until nearly dark."

<u>Top Right</u>: caption: "Just about 40 more feet to go and bridgemen will bolt the center section of the stiffening truss to the already erected portions extending toward the middle, and Mackinac Bridge steel will be connected."

<u>Left</u>: caption: "A close-up of the lifting strut, which was moved down the cable and secured in position over each cable band in order to lift each stiffening truss section straight up to where the suspender rope was waiting to receive it."

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Bridge Deck

<u>Left</u>: caption: "Work progressed rather rapidly on the construction of the steel bridge deck. It had been designed for rapid installation and the design was paying off in August as the scheduled opening date was only three months away."

<u>Above</u>: caption: "American Bridge Division crane lifts a roadway stringer into position as other bridgemen install curbs, railing, and put finishing touches on the roadway grating. August 27, 1957." 351

<u>Above</u>: caption: "Open grid grating was used for the inside center lanes of the bridge, and steel forms for holding light-weight concrete were installed for the outside lanes. The center of the picture shows a Ross Carrier transporting five huge stringers over newly installed deck to the place where they will be strung out on the stiffening trusses ."

<u>Left</u>: caption: "Roadway stringers in-place ready to receive grating" 352

<u>Left</u>: caption: "On September 9 the last section of the center grid deck at the north end of the suspension span was lowered into position. On September 10 the last section of the center deck grid at the south end of the suspended span was lowered into position."
<u>Above</u>: caption: "All during October bridgemen welded more than a million connections to permanently attach the open grating portion of the roadway to the floor beams on which they rested."

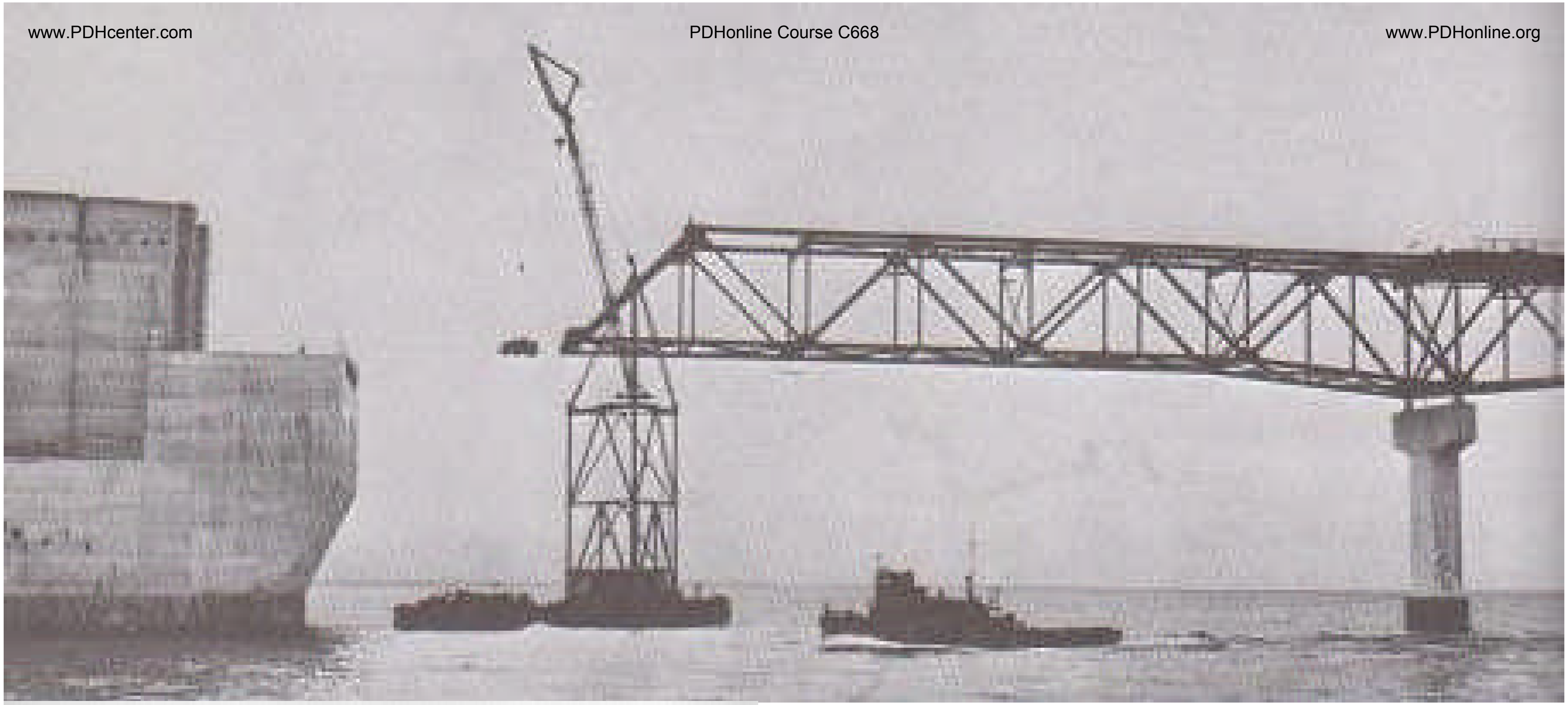
353

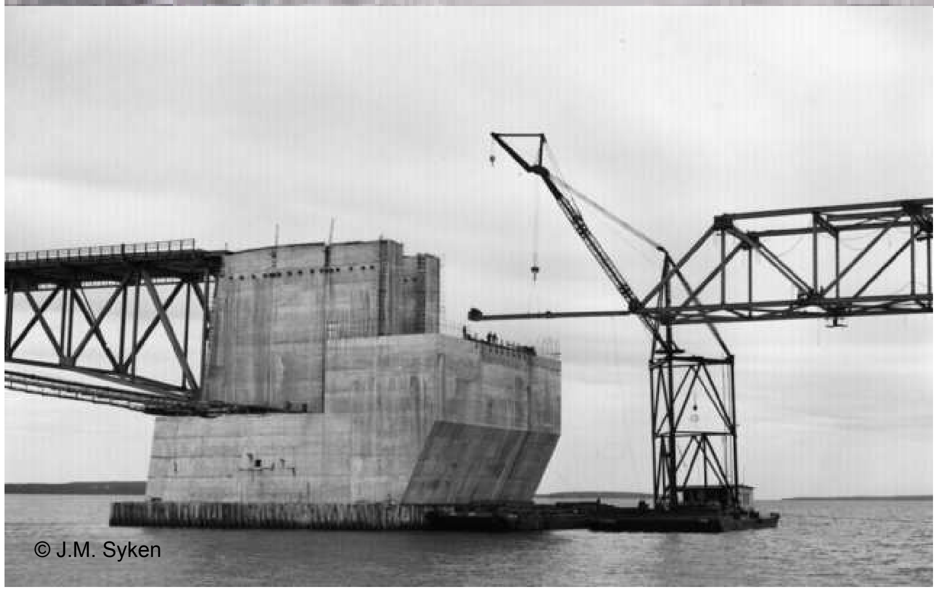
<u>Above</u>: caption: "Paving of the suspended span roadway began in mid-September as lightweight concrete was poured into the steel form of the outer lanes."
<u>Left</u>: caption: "By early September 1957 the road on the suspended bridge extended nearly all the way from each tower to the center."

<u>Above</u>: caption: "The Mackinac Bridge roadway is complete" 355

Anchor Block & Truss Span Completion

While work progressed steadily on the suspended span, the pouring of 25K cubic yards of concrete to complete the anchorage/s superstructure also had to be completed in 1957. First though, the remaining 325-feet of steel truss span on either side of each anchorage had to be erected and the road deck/s brought into the anchor block/s.





<u>Above</u>: caption: "At the outset of 1957 construction season the previous year's unfinished work was completed when the truss spans were carried all the way to the anchor blocks, thus completing a steel structure across the Straits."

<u>Left</u>: caption: "Lowering the first steel chord connection from the truss span to the rear wall of the south anchorage (Pier 17). This marked the first time there was a continuous steel bridge across the Straits. May 17, 1957."

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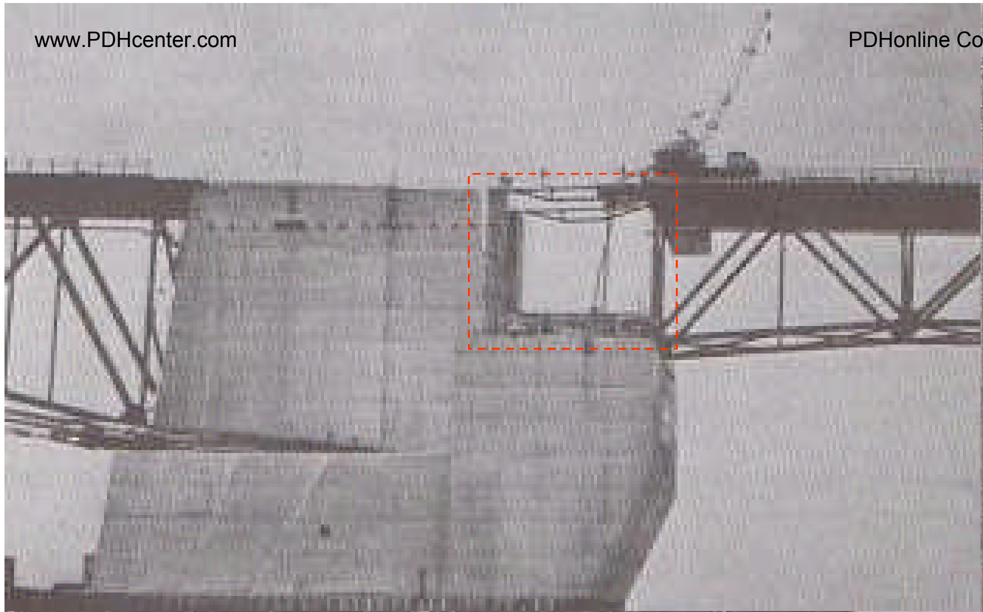
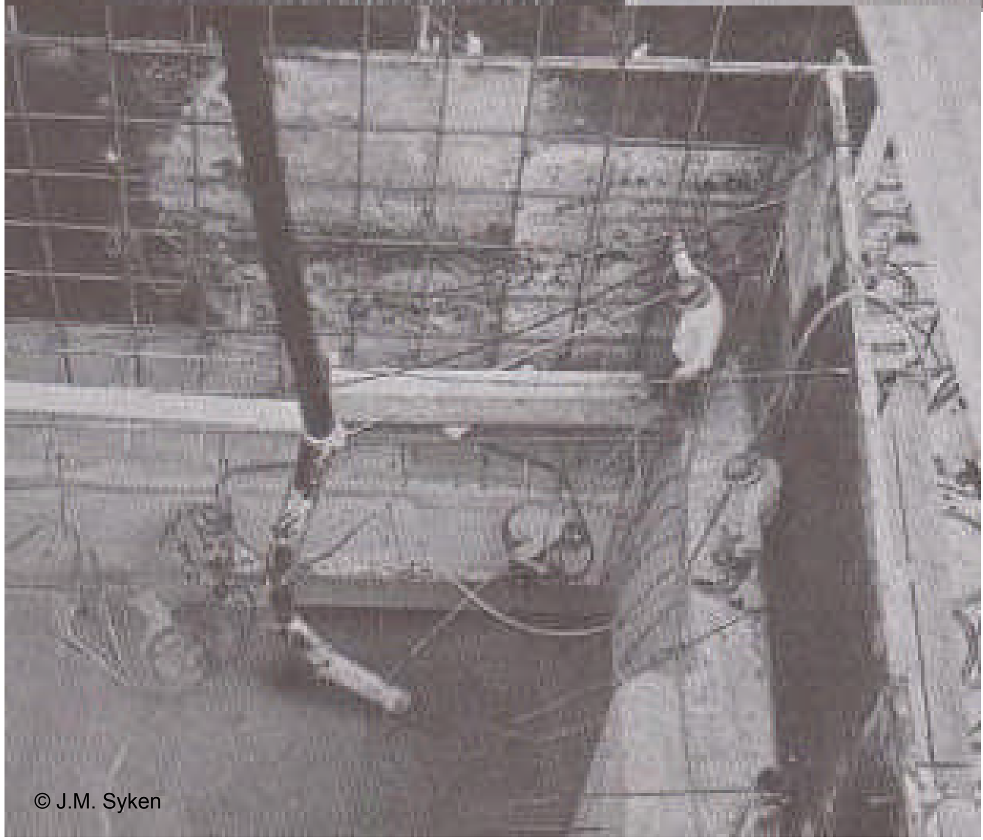
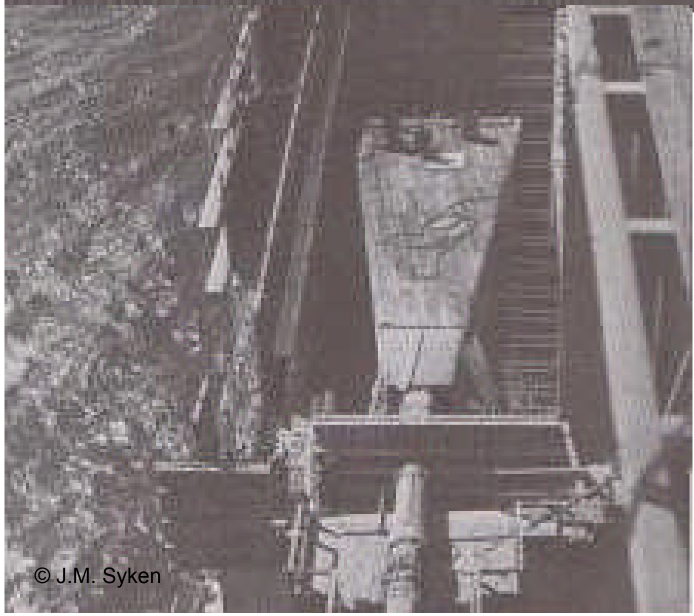


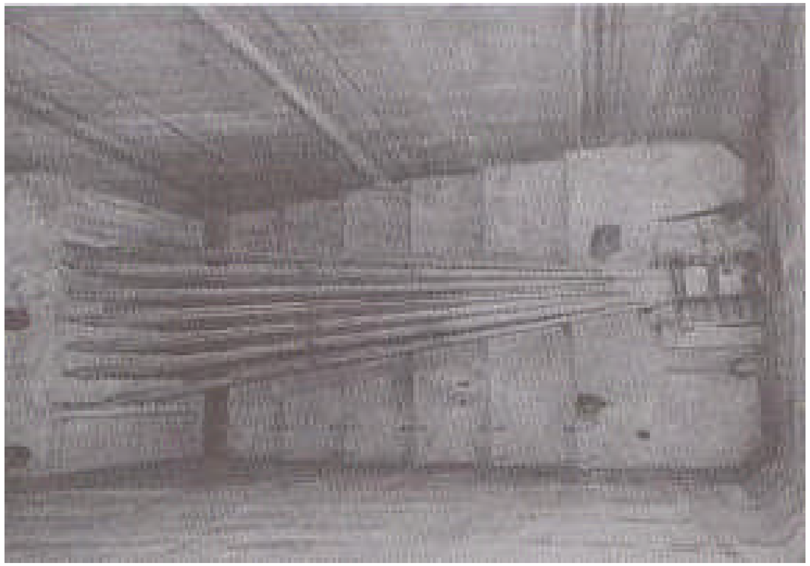


<u>Top Left</u>: caption: "There was still one more huge and critical job to be done, and that involved completion of the anchor block. Solid concrete had to be poured into the rear third of this block while the walls around the cable splay areas had to be raised to deck level. Here, on July 10, MC&S built two foot bridges from the approach span roadway to the completed wall of the anchor block, 118 feet high (Pier 22)."
<u>Top Right</u>: caption: "By early August the rear portion of the anchor blocks had been raised to their full height and the walling-in process had begun."
<u>Left</u>: caption: "An interesting and unusual device, known as an 'elephant trunk' was used to direct concrete from the top of the block to the area some 60 feet below."



<u>Left</u>: caption: "Here the cables splayed out for connections with the strand shoes. They were covered with huge planks against damage from fire and falling materials. In late August the walls around this splay area began to rise."

<u>Above</u>: caption: "The deck of the anchor block was made up of 13-ton slabs of reinforced, pre-cast concrete. These were poured during the summer but were not placed until the walls were completed in late October."



Left: caption: "By the end of October the cable splay area chamber was complete. The cable enters the anchor block, at right, through the cable saddle. The multiple strands of the cable then disperse, like the roots of a tree. Looped around a strand shoe, each cable strand is securely attached to an exposed end of a deeply embedded eyebar, left."

Truss Deck Paving Completion

<u>Above</u>: caption: "Deck contractors pulled out all the stops to complete the concrete roadway all the way out to the cable-bents where the steel and lightweight concrete roadway begins."

<u>Left</u>: caption: "Thornton Construction Co. workmen covering the concrete deck on the north approach with two inches of asphalt. October 1, 1957."

365

<u>Above</u>: caption: "As the south end of the Mackinac Bridge was finished, Mackinaw City residents would occasionally drive out onto the bridge to look at the work in progress. It was usually done on the weekends when the workers were not present."

366

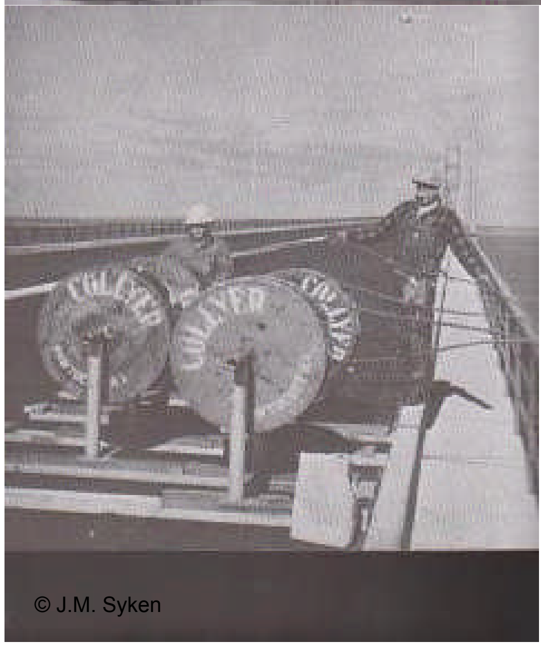
By summer's end, there was only two months left to complete the suspended span including:

- **Paving operations;**
- **Cable wrapping;**
- **Lighting installation;**
- **Superstructure painting**

Above: caption: "While all the work on the roadway was going on, men were strung out overhead on eight sections of the cable applying red lead paste and wrapping thin steel wire as tightly as possible around the cable to provide protection against the elements."

<u>Above</u>: caption: "It wasn't until the end of October, just before the bridge opening, that the blacktop paver finally finished laying asphaltic concrete over the lightweight concrete on the outside lanes of the suspension span."

<u>Left</u>: "An electrician attends to one of the cable light stand-ards. Note how he is 'tied-on' with two hooks.



<u>Above</u>: caption: "Also during the 1957 season the Authority's Administration Building was completed. The facing of the building is Drummond dolomite stone, the same as that used in the bridge foundation."
<u>Left</u>: "During the 1957 season the electrical contractor installed hundreds of miles of cable, 248 light standards, and more than 70 navigation lights as well as aerial beacons to complete the electrical requirements."

370

"I fell a couple of times, and I got scared a couple of times, but I grew to enjoy the work…on the port side of one of the towers, we missed a section about 400 feet up, so I had to go way up in a block and tackle with a seat suspended from it. I didn't like going up in that seat, and it got worse when the wind started blowing. The wind got a hold of me and blew me out from the tower about 15 feet, then it spun me around and around. Oh, I was afraid. My biggest fear was that it would blow me back against the tower against my back, but I was lucky, I went back in feet first, and I was able to hang on. I remember that I smoked an entire three-inch cigar while I was trying to get my line unraveled. I eventually got the job done."

***Omar Breyer*, Painter**

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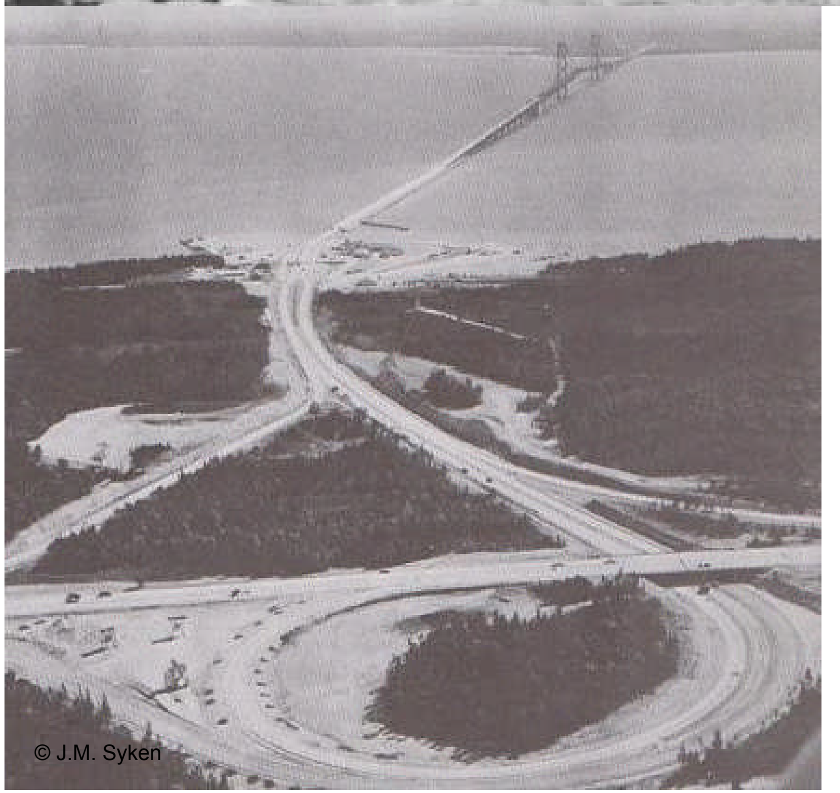

<u>Above</u>: caption: "The Mackinac Bridge Authority toll plaza is designed to acc-ommodate nine toll booths and ten lanes of traffic. Under extreme conditions five lanes of traffic in a given direction can be moved through the toll booths. The initial toll for a passenger car was $3.25 each way."

<u>Left</u>: caption: "The Michigan State Highway Department completed in 1957 and work began in 1956 to provide modern divided-lane highway approaches and connections from existing highways to the bridge."

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In Memoriam

© J.M. Syken

"I talked to him 15 minutes before he died… I went to his funeral, and I realized that I was working on that bridge when three people were killed. I could have gone back to work, but after Jim's death, I lost all interest."

Ellsworth **"Elly"** ***Stewart,*** **Welder**

RE: recalling the death of his best friend welder *James LeSarge,* on October 10th 1954. During the course of the construction of the *Mackinac Bridge*, five workmen lost their lives. One man died in a diving accident, another fell in a caisson while welding (LeSarge), one man fell into the Straits and drowned and two men fell from a temporary catwalk near the top of north tower. As well, there have been add-itional deaths of bridge maintenance workers in the intervening years.

Left: bridge workers' memorial 375

<u>Above</u>: caption: “The Mackinac Bridge looks complete in late 1957, but the auto ferries are still running, so it has not opened. This ferry is either the City of Munising or the City of Petoskey. They could each haul 105 cars.”

Part 7

At Long Last

Michigan United

"Mighty Bridge Unifies Michigan"

Kalamazoo Gazette, November 1st 1957

RE: across the state, newspapers agreed that the opening of the *Mackinac Bridge* was cause for a great celebration. With the bridge ready for traffic, but fearing inclement autumn weather at the Straits, officials decided to have an official *opening* on November 1st 1957, but an official *dedication* in late June 1958. Ironically, the weather on the first day of November (preceded by two days of rain and fog) was sunny and pleasant. However, the weather in late June was so cold and wet (with six-foot waves in the Straits) that some of the events were shortened or canceled altogether. The media hailed the completion of the Mackinac Bridge as Michigan's biggest historical event in 100 years. On November 1st, after paying the $3.25 toll (taken symbolically by former U.S. Senator *Prentiss Brown*, chairman of the *Mackinac Bridge Authority*), Governor *G. Mennen Williams* crossed the bridge (driven in a car by Mrs. Williams because the governor had forgotten his driver's license). Then cars lined up for one mile on both sides of the Straits. In his opening day remarks, Governor Williams predicted that the bridge would add $100 million annually to the state's tourist trade and praised the fact that at last *Michigan* was to be one state; geographically, economically, politically and culturally.

<u>Left</u>: caption: “November 1, 1957. Left-to-right: State Highway Commissioner John Mackie, bridge designer David Steinman, Governor G. Mennen Williams, Prentiss Brown, former Governor Murray Van Wagoner, Sault Ste. Marie businessman George Osborn, William Cochran and Lawrence Rubin.”
<u>Right</u>: caption: Governor G. Mennen Williams and Dr. David B. Steinman with family. Governor Gerhard Mennen Williams (nicknamed “Soapy”) served as Michigan’s forty-first governor for twelve years and was instrumental in bringing the construction of the Mackinac Bridge to fruition. He began the tradition of the annual Mackinac Bridge Walk on Labor Day in 1958.” 380

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To Whom Shall it be Dedicated?

"We will dedicate the Mackinac Bridge on Saturday. But to whom shall it be dedicated? A slim, serene span – glad of its grace, superb in its strength, proud of its power to unite. A marvelous, utilitarian monument made by men with the skills God put into their hand, with the vision he put into their minds, with the spirit he puts into their hearts. But a monument to whom? To What? It is a monument to many men, many things. Any or all the dedications would be graciously received. It could be dedicated to men. Men who dreamed…It could be dedicated to the five workmen who gave their lives to string steel across the choppy waters that delayed, for decades, the progress of the vast upper peninsula…It could be dedicated to them – the soldiers of construction. It could be dedicated to progress – to the idea that one must go forward, or wither and die. It could be dedicated to freedom – to the idea that the five-mile epic poem in the medium of steel could only have been built by men who were free…It will be dedicated to the people of the State of Michigan and the United States of America…"

Detroit Free Press

RE: excerpt from an editorial concerning the upcoming official *Mackinac Bridge* dedication which was held on June 28th 1958

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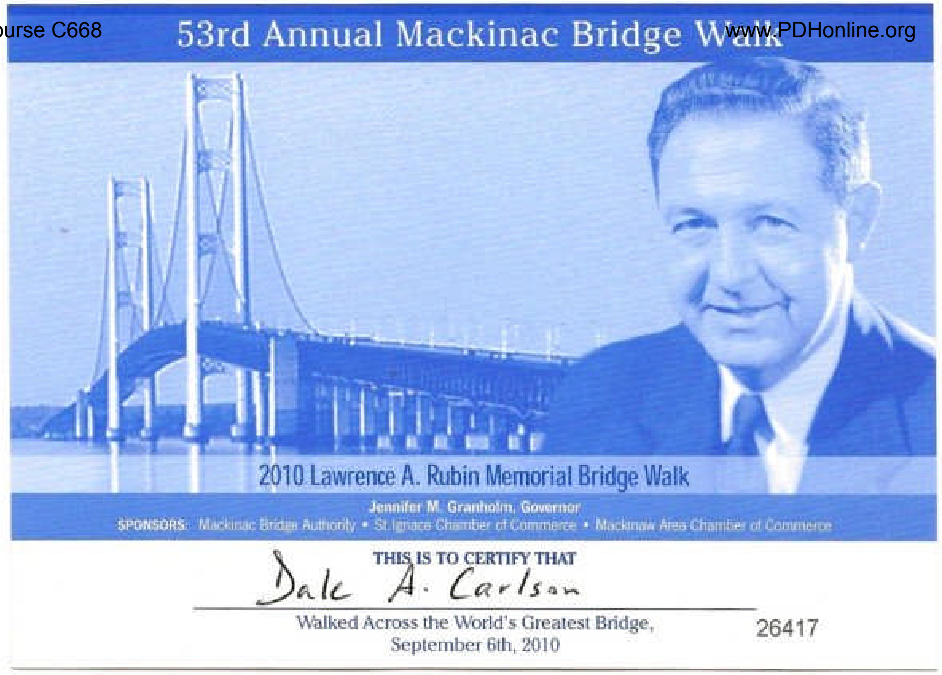
Bridge Walk



On *Labor Day*, the *Mackinac Bridge Authority* opens up the "Mighty Mac" to pedestrian traffic for the annual "Mackinac Bridge Walk." The Bridge Walk allows bridge enthusiasts to get a close-up look at one of the world's great bridges.

Gephyrophobia

"The Mackinac Bridge in Michigan spans five miles and is one of the longest suspension bridges in the world with the roadway soaring more than 200 feet over Lake Michigan. The bridge's dimensions provide stunning views of the surrounding landscape, but those vistas can be stomach-churning for people with gephyrophobia, or an abnormal fear of crossing bridges. Between 1,200 to 1,400 calls are made every year to the bridge's Drivers Assistance Program that provides motorists with a crew member to drive them across if they're too afraid to drive themselves…Dr. Frank Schneier, a professor of clinical psychiatry at Columbia University and research psychiatrist at the New York State Psychiatric Institute, said many people who are afraid to cross bridges are also suffering from agoraphobia, an anxiety disorder triggered by a fear of feeling trapped. 'They have intense anxiety symptoms or panic attacks,' Schneier said. 'It's not so much the idea that bridges are going to collapse. It's that they are places you can't escape from'…'There are techniques that can help people overcome these kinds of fears,' Schneier said, citing therapy and anti-anxiety mediation as options for drivers to ease their worries. But for those who haven't conquered their fear of crossing the Mackinac Bridge, the Driver's Assistance Program is another option. Bob Sweeney, the secretary of the Mackinac Bridge, said phone booths on either side of the bridge allow motorists the chance to call the program. Some even use it during their commute to and from work. 'There's a truck driver, who comes once month,' Sweeney said. 'He gets into a sleeper behind the cab and lays down for the whole trip under a blanket. It's amazing.' Only one crew member is available during the night shift, so a toll operator has to pitch in and drive a second car that picks up the crew member for the return trip to the opposite side of the bridge…"

Good Morning America**, May 25th 2013**

Monitoring the Mighty Mac

"The purpose of monitoring the Mackinac Bridge is to get a solid mathematical representation of its natural movement while it is still relatively young and in good health. Once the bridge has been mathematically modeled, it can be observed over time and space to ensure that the bridge is acting as it was originally designed."

***Brian Dollman-Jersey*, Supervising Surveyor for the MDOT Design Survey Section (December 2007)**

"…To monitor the motions of the "Mighty Mac" as it is known, six Leica Geosystems GX1230 GPS receivers were positioned on and near the bridge. Two receivers were positioned atop the two primary bridge towers and two receivers were located on the mid-span. The other two receivers were placed on solid ground (one on the St. Ignace side and one on the Mackinac City side) to serve as static bases. The high-precision receivers can log many weeks of continuous one-second data using 1 gigabyte Compact Flash cards. Data for this test was collected every second for eight days. The four strategic locations for the receivers were chosen so as to best measure daily repeated motions from expansion and contraction due to winds that are regularly present on the Straights of Mackinac. Due to the five-mile length of the bridge, GPS is currently the only technology capable of measuring absolute positioning in real-time to the accuracy necessary to procure the measurements required for the mathematical modeling of the bridge. Data was stored locally on high-capacity Compact Flash cards on each of the Leica receivers, enabling eight full days of one-second data to be recorded…"

***Michael Olson,* PE**

"…Upon recovery of the six receivers after the test was completed, data was backed up and delivered to General Positioning LLC…The firm processed the GPS data using PAGERS, a modified version of the National Geodetic Survey (NGS) PAGES software. PAGES computes the precise Navstar satellite orbits and processes OPUS (Online Positioning User Service) data; developed by General Positioning LLC, PAGERS is specifically designed for monitoring civil construction work such as that done on bridges, dams and buildings. PAGERS software simultaneously processes kinematic (moving) and static GPS data to solve in real-time or post processes the status of the moving antennae of interest. When integrated with additional General Positioning LLC Web-based software, PAGERS can provide critical data to potential dangerous situations and assist in rapid assessment in the event that one has occurred. Further, when routine maintenance has been performed on a structure such as a bridge, engineers can evaluate the effect of the changes with regards to the 'normal' bridge movement…"

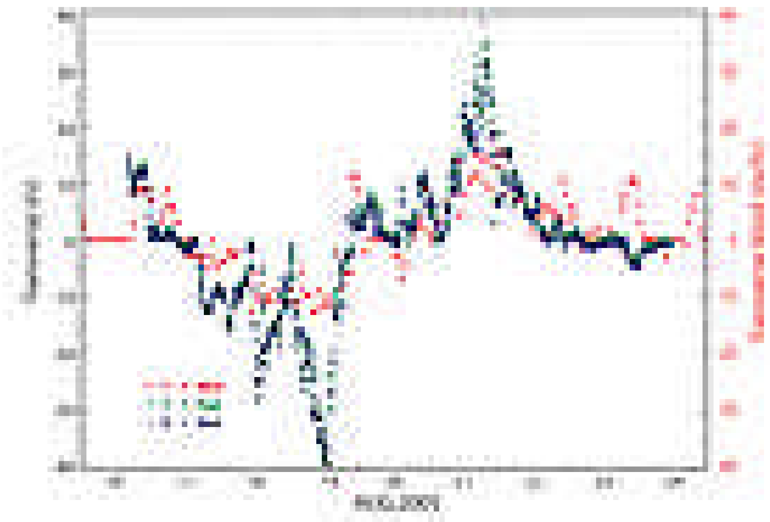
***Michael Olson,* PE**

<u>Top</u>: caption: "Two receivers on either side of the bridge served as static bases and logged many weeks of continuous one-second data using one gigabyte Compact Flash cards"

<u>Bottom</u>: caption: "One of six Leica GPS receivers was positioned atop the north tower for the monitoring test"

"…Meteorological data for this experiment, such as wind speed and direction and temperature, were taken from the Sault Ste. Marie Automated Surface Observing Site collectively operated by the National Weather Service, the Federal Aviation Administration and the Department of Defense. The GPS results revealed that movement of the towers and bridge deck span strongly correlated to changes in temperature and wind. With a wind speed of 13 mph, the bridge deck moved in excess of 3 feet. The results also show the bridge deck sagging as it warms and expands with the air temperature, and similarly, the motions of the towers as the entire bridge warms and cools or as the deck swings with the wind. Such observations are valuable for ongoing maintenance and are essential for modeling the motions of any bridge. They also demonstrated that GPS technology is reliable and easily adaptable for continuous real-time or near real-time, hands-off operation…"

***Michael Olson,* PE**

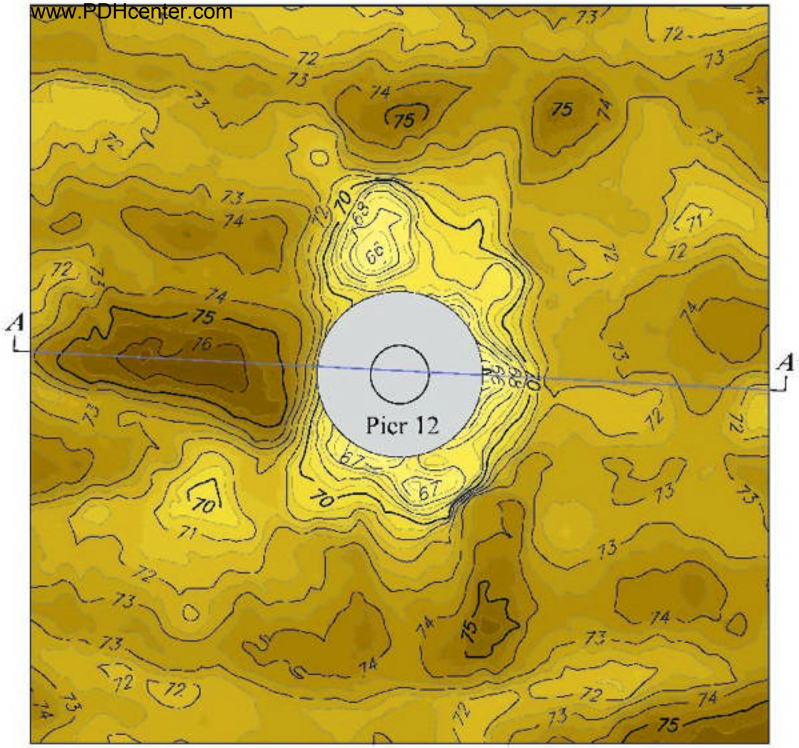


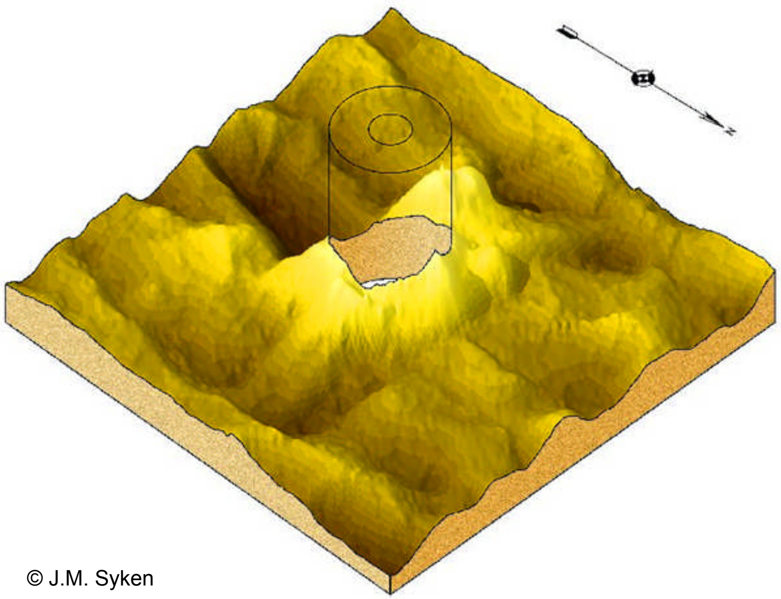
Left: caption: “The GPS results revealed that movement of the towers and bridge deck span strongly correlated to changes in temperature and wind. The estimated minus a priori, transverse coordinate differences for the east deck are shown in green and for the west deck in blue. The transverse wind speed is shown in red.”

"We are very excited to consider the possibility that we will be able to remotely monitor the bridge's behavior as it goes though changes in temperature, wind events and loading from traffic and construction equipment. GPS units strategically placed on the bridge will be a big part of our total health monitoring game plan."

***Kim Nowack*, PE - Chief Engineer of the *Mackinac Bridge Authority* (MBA)**

Scour Mitigation

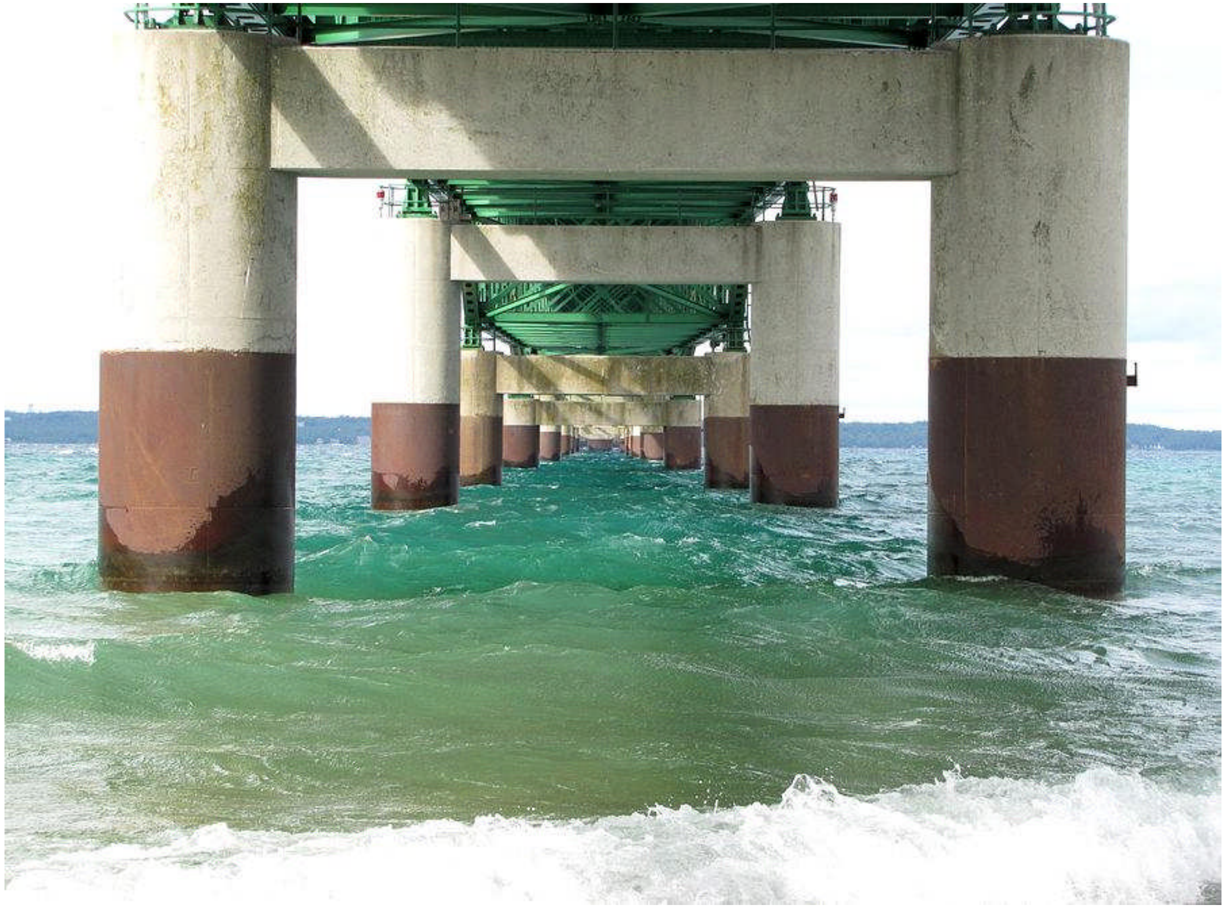


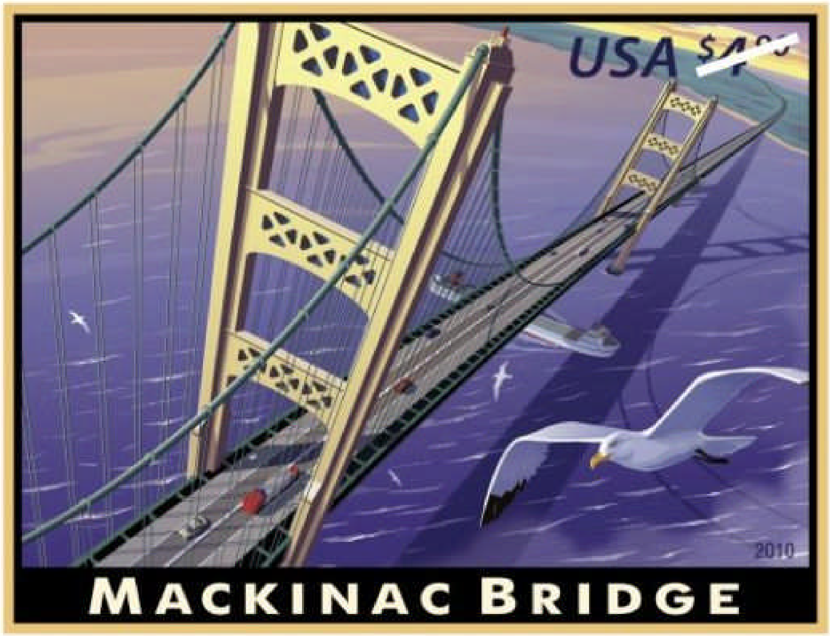


Ocean Surveys Inc. conducted an ultra high resolution multi-beam hydrographic survey of the lakebed adjacent to thirty _Mackinac Bridge_ piers to generate an extremely detailed _Digital Terrain Model_ (DTM) for the purpose of identifying and detailing scour activity. Data deliverables included contoured plan, isometric and profile presentations.

<u>Top</u>: caption: "Plan view depth contour presentation of area adjacent to Pier 12"

<u>Bottom</u>: caption: "Isometric presentation of bottom morphology adjacent to Pier 12"





"The U.S. Postal Service honors the Mackinac Bridge in Michigan as the subject of its 2010 Priority Mail stamp…The bridge, nicknamed 'Mighty Mac,' connects the two peninsulas of Michigan. The longest suspension bridge in the Western Hemisphere, the Mackinac extends from Mackinaw City at the south end to St. Ignace on the north side. Opened in 1957, the Mackinac Bridge cost nearly 100 million dollars and took over three years to complete. The sturdy five-mile bridge is designed to support 38,486 tons and can move up to 35 feet in high winds. Artist Dan Cosgrove used several panoramic photographs of the Mackinac Bridge to create the stamp artwork, which features seagulls flying around the two towers and a large ship passing underneath…"