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The Experimental Aluminum House Story

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Ruben A. Gomez, P.E.

1.0 FOREWORD

My mother was born way back in the year 1911 more than one hundred years ago. She had a 6th grade elementary school education because that was all the schooling available in her village; however, she was naturally smart, inquisitive and persistently continued her self-education efforts during all her lifetime. She was full of energies until the age of 80, but then she had a broken hip. Two painful surgeries later and months of physical rehabilitation enabled her to resume a borderline normal life. It was running the year 1992 when I asked her how she felt about her nightmarish experience, she told me: “I only regret that our human bodies are made of such a poor and inferior material”.

“Do you think so?” I replied, and then jokingly asked her without really expecting a meaningful answer: “What kind of material would you rather be made of: concrete, cast iron, steel, wood, stainless steel or aluminum?” Without seeing the humor in it, she hesitated for a moment and then affirmed to my surprise: “Given those choices you have given me, I choose aluminum”; “But why aluminum?” I persisted in my query. “Because aluminum does not rust, it is easy to clean and work with, reasonably strong and yet flexible enough….”

In fact, she was correct in her views since aluminum not only does not rust*, it does not need painting, it is not vulnerable to insect attack and in addition, it has excellent high thermal** and electrical conductivities.

That unexpected *layman’s* assessment of a material that I became so familiar with has been in my mind ever since, and now, those same memories have taken me back to the beginning of this story. At the start of the 1960’s, the Aluminum Company of America (ALCOA) decided to look for more and wider markets for their products. In spite of some well established fears against aluminum as a construction material and the extended belief that an aluminum house would be dangerous to live in because of the latent and real possibility of *electrification* by lightning or by short-circuiting***, the high management decided nevertheless, to make an incursion into the booming housing market at the time.

This is the end of the author’s narrative in first person, from this point over the story will continue as it should be, in the third person.

In the spring of 1964 after the author had completed his engineer-in-training period, he was hired by ALCOA as part of a research team that included an architect, another engineer, three draftsmen, two office clerks, a shop foreman and two helpers. The budget was well suited and the assignment was to conceive a systemic design for a prototype house with a tropical flavor and components commensurate with the human scale (that meant, no cranes or hoisting equipment to be used), which could be mass produced by using aluminum as the predominant material, with a competitive selling price and affordable to the low-medium class families of this country.

Although written from the perspective and vision of an engineer, this course has been assembled not only for design engineers, but also and very particularly, directed to design architects. In most instances, engineers concentrate in their area of expertise and give little consideration to the other trades other than their own. In this case however, the author has made an effort to "wear the shoes of an architect" and kept his focus and consideration on all the different trades that came together in the design and conception of a dwelling, so it worked as a complete and self sustaining housing unit. Hopefully, he achieved his goal as intended.

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*When we say "it does not rust", by rust we are referring to the familiar reddish/brown dusty coating formed on iron and steel surfaces mainly consisting of dust, grime and ferric hydroxide. However, under the constant exposure to air and humidity aluminum does oxide in a different way, a whitish dense but thin oxide film develops which, unlike rust, tends to shield the underlying metal from further attack and deterioration.

Although the durability of aluminum alloys have already being amply demonstrated by many years of successful service in engineering and architectural applications, in some cases it is recommended the application of chemical or anodic finishes as a preventive protection against the detrimental effects of severe exposure.

**This *thermal conductivity* has a negative connotation; aluminum is so effective in transmitting thermal differentials that as our team advanced in the development of the proposed house models, we realized that the problem of the *thermal bridge* could not be ignored any longer. Consequently, the wall aluminum studs as used by our team and shown ahead in sections 4.0 and 5.0 had to be reconsidered. The problem was solved by splitting the studs and adding a non-conductive insulator to block thermal conductivity. Although the design was tested and perfected, it never made it to the production stage.

***According to the research models and the resulting gained experience by the National Electric Code (NEC) as sponsored by the National Fire Protection Association (NFPA), it has been concluded that such danger can be greatly reduced by using effective *ground bonding.* For further information, please refer to Section 5.0 and the details thereupon.

2.0 THE SEARCH FOR A SYSTEM

Since we were up to the challenge, we began by “learning the ropes” on modular design and so eagerly started to study the work and legacy of the architectural masters whom had left very clear tracks to be followed. In Europe there were already advanced systems in the Soviet Union, Sweden, France and Spain. In the Americas there was some work being done in Venezuela, Cuba and Argentina. We read and perused every piece of material that came our way.

We knew that any and every foreseeable path ahead of us had to be regimented by the already established rules of modularity, therefore, our first step was to adopt a logical and comprehensive *module,* whether it was bi-dimensional or tri-dimensional, that was going to be decided by the quality and reach of our own ideas. Almost everyone in the rest of the world was using the *meter* as the constant modular unit, except for a few cases where 1.20 m was being used instead.

One meter happens to be equivalent to 3.28 ft or 3’- 3” plus a residual of 3/8 of an inch. That dimension was too fractional and to a great extent meaningless in our standard methods and sense of dimension. On the other hand, the yard equaling three feet would have been good and familiar to each one of us, however, it was not wide enough to deal with our standard window and door measurements, it was indeed too small and for the same reason it would not work for passageways and hallways. We knew the selection of the module was an important step for us to take because once set up there was not going to be a way back out of it. Consequently and after a fair number of trials and debates, we agreed on adopting a bi-dimensional module of 40 inches, which would give us four extra inches passed the 36 in. door and window standard sizes, as well as a net 36 in. for hallways. As a next preconceived step, we presented our recommendations to the higher management for approval.

Peculiarly, the module of one foot could have worked well both horizontally and vertically, however that would be about the end of its benefits because the foot was not in tune with the *human scale* when it came to factory produced modular panels.

Once the module of 40 inches was accepted and established as our standard, the next move was to produce house designs that were not only in agreement with the modular principles, but also that were routinely accepted and liked by the local market where the product was going to be offered for sale.

Before proceeding with the sequence of events that we have just started, we will make a short pause to introduce a principle which is paramount in the inner workings of the aluminum industry: *the extrusion process*. Its full understanding by both the engaged design engineer and the architect is imperative to facilitate the implementation of a workable system where all components and joints are fully in harmony with each other.

3.0 THE PRINCIPLES OF EXTRUDED ALUMINUM

Aluminum first started as a mimicking of the steel industry where sections were produced by the use of rolling and machining. However, with the advent of the extrusions countless applications opened up and widened the aluminum applications in the fields of architectural en engineering design. Lightweight window frame extrusions were the first to inundate the market. After that many other applications followed suit, such as sills, door jambs and thresholds, screen frames, bus framings, airplane frames, patio sliding doors, stair railings, bridge railings, structural sections, latches and hinges, the list was endless.

Aluminum is a material that can be extruded in the form of a rod, solid bars, tubing, open structural shapes such as angles, channels, wide flanges, etc., and its uses are only limited by the applicability of the die and the power capability of the press.

Extrusions can be designed to facilitate joint and connections with other members by adding or taking off thickness where it is needed and making possible the conception of structural members of maximum efficiency within the available spaces and clearances.

In essence, extruded aluminum shapes are produced by slowly forcing* cast cylindrical billets which have been previously pre-heated to temperatures ranging from 600° to 800°F until reaching their flowing state, under high hydraulic pressure through a steel die cut opening with the desired cross section. Billet diameters may range from 4 to 12” in diameter and the pressure required to squeeze the hot aluminum through the die opening may reach pressures of up to 5,500 tons.

It should be obvious to the reader the correlation between the die’s *circumscribing circle (*the smallest circle that fully encloses the shape to be extruded), and the compressive capacity of the press. Consequently, the larger the die, the higher is the compression force needed and therefore the larger the extruding press.

If we take above reasoning and reverse it, we will conclude that the compression capacity of the press will limit the diameter of the die and therefore the size of the extrusion, which for practical purposes have been limited to 12” circles. However, when one thinks that the limits have already been reached and there are no more options left, somebody comes up with an extreme measure that surpasses all known limits. In the mid-sixties this author witnessed an idea that topped them all off. There was a need for a particular extruded flat piece with a width of 15½ inches long that was beyond the established possible limits at the time. However, due to the extreme ingenuity of an extruder, the problem was solved as shown in Figure 3.1 where we depict how a 6 in. extrusion with a 296 degree sweep was originally produced and as it looked after it was flattened while still hot and immediately after extrusion, so adopting the characteristics of the designed final product. Please also observe, and this is important to die designers and machinists, that the steel in the die still had left a 64 degree arc to “hang” from and stand the extremely high pressure developed by the press.

Figure 3.2 is a schematic isometric drawing of the main parts and components of an extrusion plant in the sequential order they are customarily arranged. In the past, the extrusion plant as illustrated would have included a station from where the operator could have coordinated and controlled all steps and phases of the operation. However, now with the dominance of the electronic devices, a computer sitting somewhere in the production control room would handle all aspects of the operation, from loading the billets into the furnace to the cutting of the fresh extruded sections, as well as even the most redundant steps in between.

Figure 3.3 is a schematic illustration of the inner parts of the extrusion press, such as the die itself, the die holder, back-up block and retainer. Those parts are integral elements of the process as the hydraulically operated ram pushes the hot aluminum through the die opening to produce the desired section.

The advantages of extrusions are many, however, there are three of those advantages that are far superior to the others and they are:

#1- The sections can be uniquely designed and customized to meet a particular use or condition.

#2- A complex composite assembly of several standard rolled sections bolted or welded together can be replaced by a single extrusion which may end up being simpler, cheaper and stronger. Figure 3.4 (a) and (b) depict the conventional method in which several rolled shapes, as commonly used in the steel industry, where several structural shapes get combined by getting welded together for a particular purpose. On the other hand, Figure 3.4 (c) and (d) show the equivalent extruded shapes and all of their advantages thereof.

#3- Specifically “tailored” extrusions can lead to simpler joints with less fasteners and quicker installation.

In addition to those advantages, for an adequate die design and a successful extrusion there are some “rules of thumb” that need to be followed:

a. The first rule is related to the *extrusion ratio* which should be not less than 16 or greater than 45. Being such ratio the relationship between the cross-sectional area of the cast extrusion ingot to the cross-sectional area of the die opening.

b. Hollow shapes should be limited to dies with a maximum circumscribing circle of 6 inches.

c. Correct proportion of thicknesses must be carefully observed, thin wings adjacent to heavy solid cores are an invitation to warping. For a better quality control, the length of a thin protruding leg (or wing) should not exceed 10 times its thickness. For more details see Table B in the Appendix Section.

d. Convex angles at the intersection of two thin legs (as in the case of an angular shape) should be protected with a generous fillet radius to maintain straightness and alignment.

e. In complex sections, the extrusion design should stride in maintaining uniform wall thickness.

When applying above rules the extrusion designer should keep in mind the different aluminum alloys available, since every alloy has it best particular use; for instance, the minimum thickness for an extruded section with a circumscribing circle of 8 in. is 3/32 in. for a 63S alloy, but 1/8 in. for a 14S alloy.

THE DIE DESIGN

Die design is an important part of the extrusion technology, it requires knowledge of machining, accurate tooling, total awareness of the characteristics of the material, as well as the rules of thumb already indicated above.

When a die is designed, it represents the threshold of a section shape that did not exist before, therefore, in order for that shape to be fully helpful to the design engineer or architect, the die designer should complete his task by providing fairly accurate figures related to the characteristics of the new section as it would be needed in the structural design. Those characteristics are as a minimum: the net sectional area, position of the neutral axis, the moment of inertia and the section modulus**.

Although this is not a course in structural mechanics, we have included the following short term definitions for the purpose of completeness. More information on this matter can be found as part of the Appendix Section at the end of this course. In the same manner, for further information we recommend as a “must read” the full collection of the ALCOA Aluminum Handbooks.

NET SECTIONAL AREA

The area of the new section or shape is important and generally part of the calculations in the finding of the rest of the values as listed below. If the section has a known geometrical figure, which rarely does, it can be figured based on the rules of common geometry. Any other shape should be figured out by breaking it down into known geometric shapes.

POSITION OF THE NEUTRAL AXIS

The position of the neutral axis is important in the study of flexural stresses. In regular conditions flexural stresses become zero at the neutral axis and also reverse their polarity from tension to compression or vice versa. Also, at the neutral axis is where horizontal shear stresses reach their maximum intensity within the effective section. In order to determine the position of the neutral axis one may start by selecting a reference axis (usually passing by the bottom of the section). Break the given area into rectangular sections. The moment of each section is found about the reference axis. Add them all together and then divide by the total area, the resultant value will be the distance the neutral axis is from the reference axis at the bottom. You may see a worked out example included as part of the Appendix.

THE MOMENT OF INERTIA

The moment of inertia (I) is a measure of the stiffness of a beam. It is one of the values needed when rigidity is sought as part of the solution of a beam or a long column. The moment of inertia is also needed to figure the value of the *polar* moment of inertia. See example worked out at the Appendix at the end of this course.

THE SECTION MODULUS

The section modulus (Z) is a measure of the strength of a beam in bending and is found by dividing the moment of inertia by the distance from the neutral axis to the outermost fiber of the section. Since such distance is measurable two ways, there are two distances of which the largest is considered since is the one which will produce the lower value of section modulus.

As it is easily realized, all the four above characteristics are interrelated, once a mistake is made in one of them, it all becomes a progressively erroneous set of calculations. Therefore caution is highly recommended, and since we are all prone to making mistakes, always have your calculations reviewed and checked by another engineer.

What we have covered in this section is about the minimum knowledge related to the extrusion methodology that an architect or design engineer should have in order to get involved in the modular design of aluminum houses and structures.

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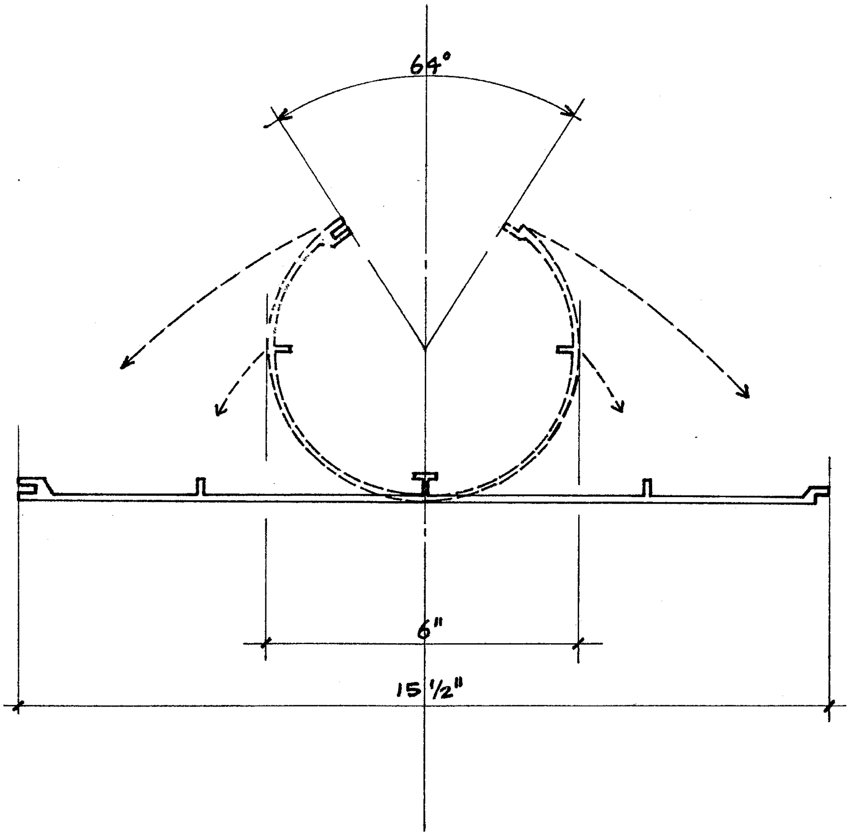
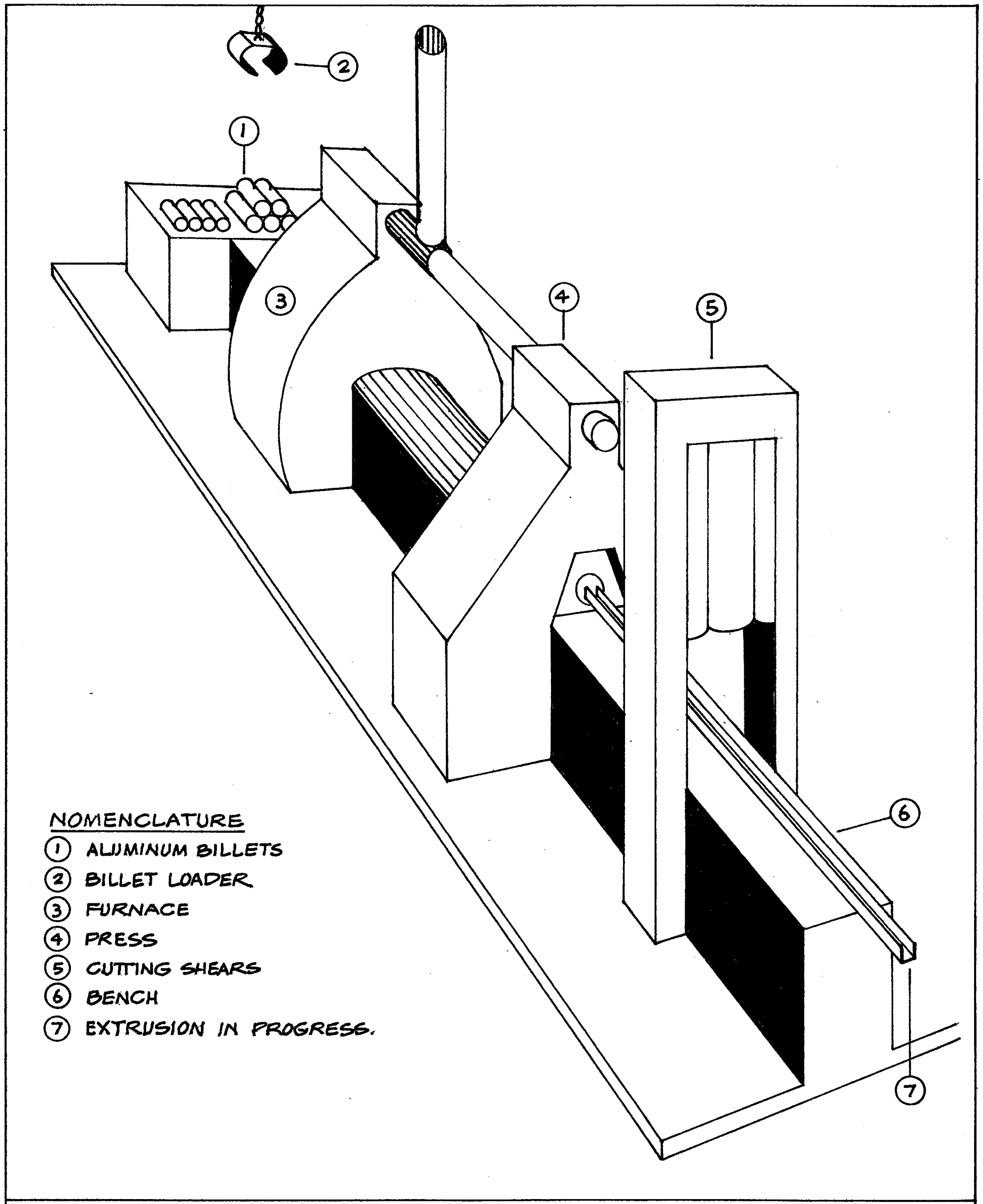
*One may think of it as the common analogy of the tooth paste being forced out of its container through the neck and hole at the end of the tube. One may see how every crevice and imperfection in the hole gets reproduced in the flowing paste. Naturally, in this analogy the “toothpaste” would be the hot billet and the “tube” as squeezed by your fingers, would be analogous to the gigantic press exerting the necessary pressure to start and keep the flow of the semi-molten aluminum in progress.

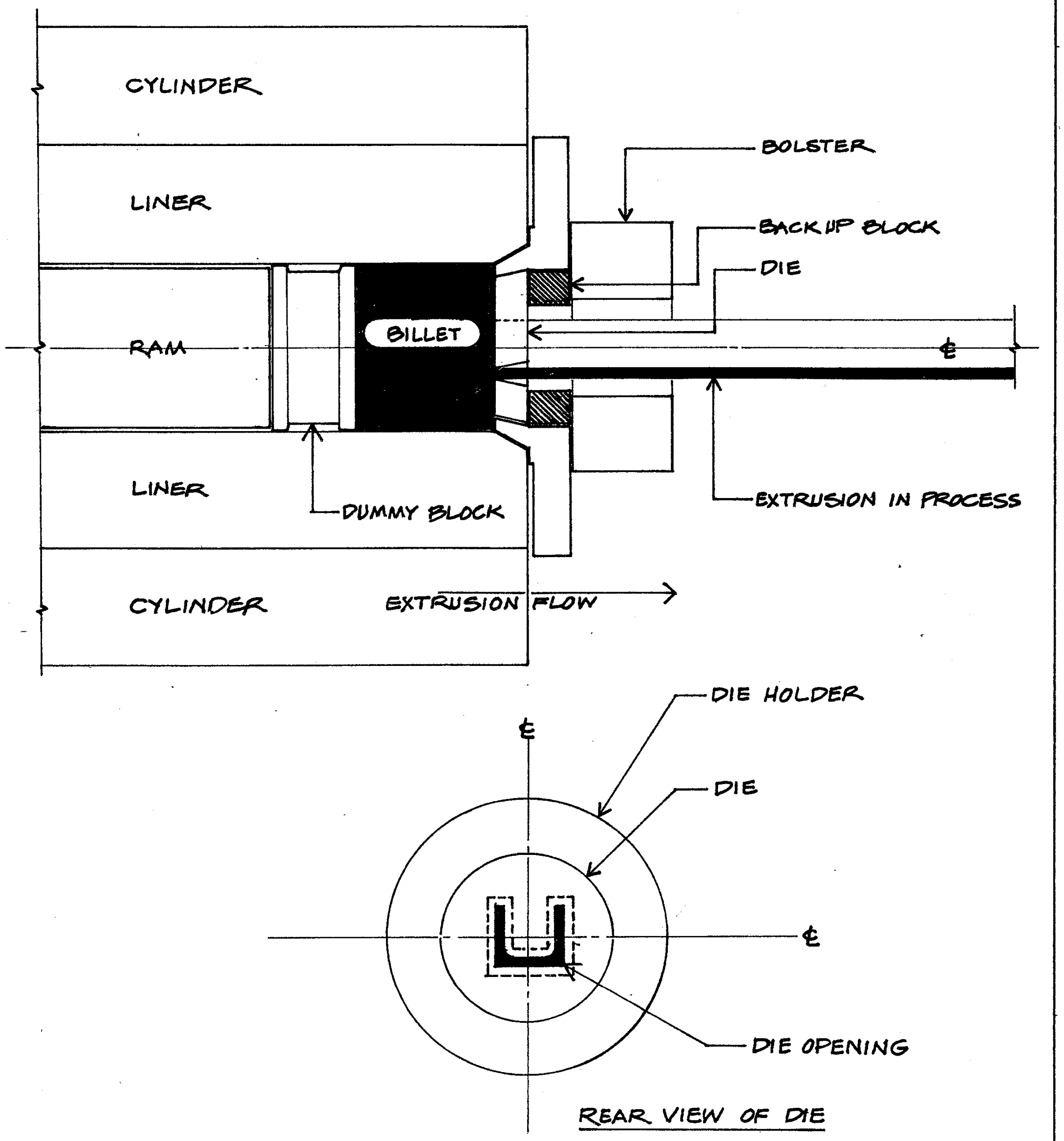
**Not to mention the *radius of gyration* and the *polar moment of inertia.*



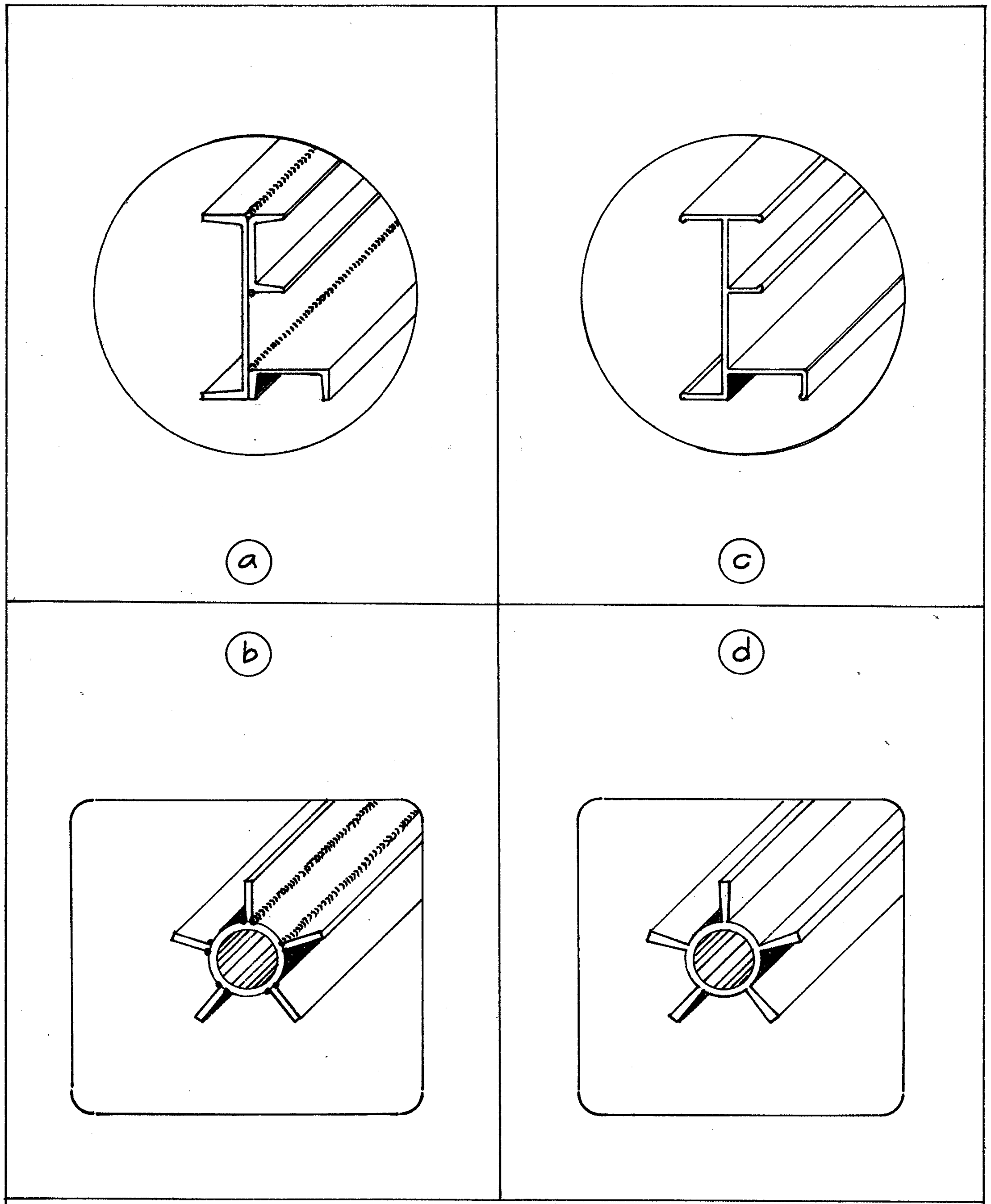
POSSIBILITIES BEYOND EXTRUSION LIMITATIONS
FIGURE 3.1



EXTRUSION PLANT SCHEME
FIGURE 3.2



INNER COMPONENTS OF THE EXTRUSION PRESS
FIGURE 3.3



CONVENTIONAL ASSEMBLIES VS EXTRUDED SHAPES
FIGURE 3.4

4.0 THE TRIAL & ERROR PROCESS

After reviewing the general principles of the aluminum extrusion technology, we can go back to the trail on the modular house. As indicated before, after establishing the pivotal concept of modularity, it was time to create the prototype house(s) which were going to mark the beginning and set the path for the production process.

After the dimensional module was determined and approved, it was then time to create the modular panels. Six typical panels were developed, the regular exterior wall panel, the interior wall panel, the window panel, the exterior door panel, the interior door panel and the roof panel in addition to the plumbing wall.

As already indicated it was the era of the 1960's, the housing market was competitive but filled with opportunities and abundance of resources. Our directive was to create a product to compete in the niche of the low medium class, therefore, to meet that goal we needed to maintain our prices at or below $39, 900, consequently and in the same manner, that price would have a reflection on the house's square footage and the amenities offered. We needed to put together a series of no-frill house plans with a construction area below 900 square feet, yet large enough to provide shelter for a family of four.

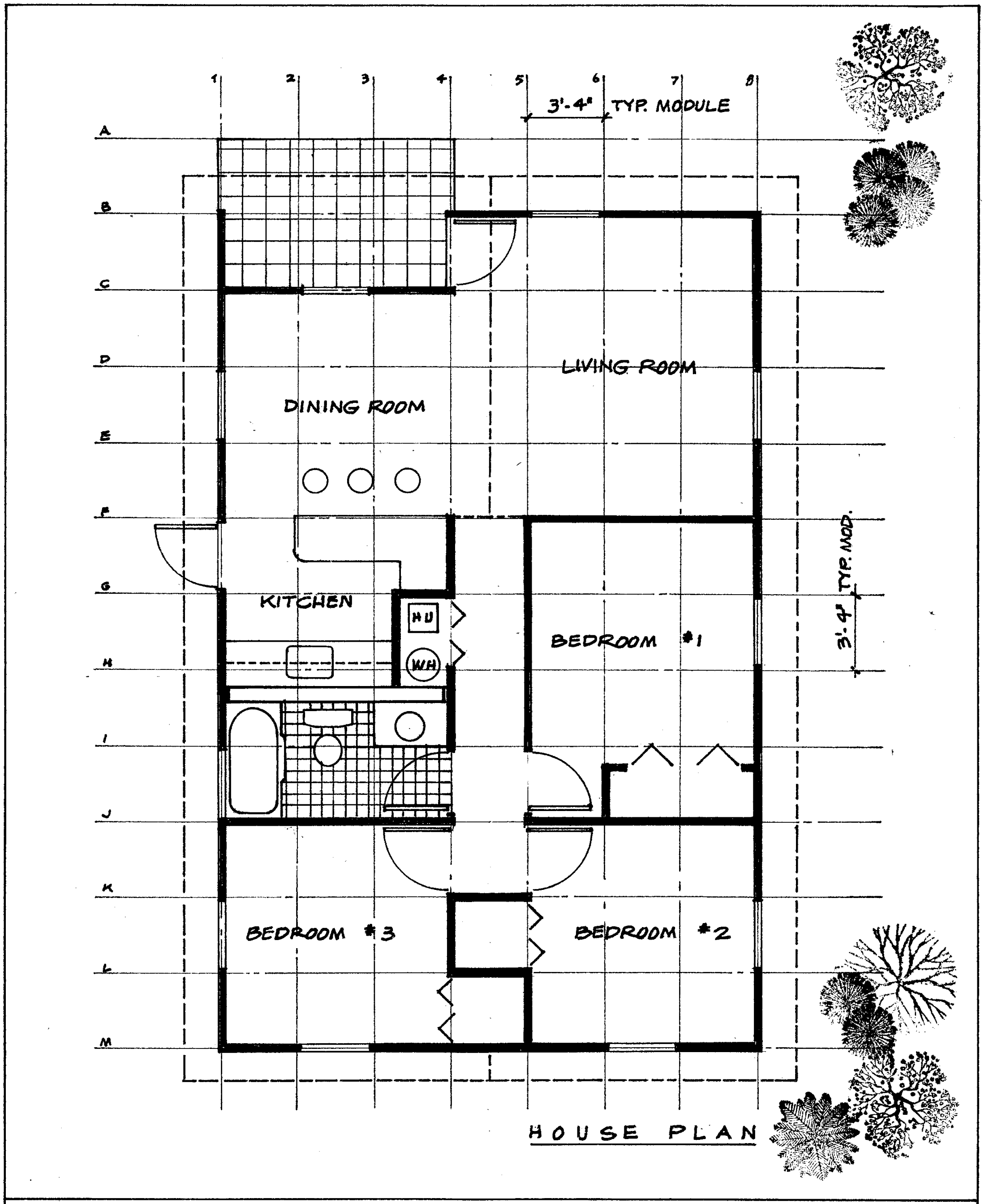
After a close team work and numerous trial-and-error efforts, we (in this case the "we" refers to the above described ALCOA's team) came up with several preliminary house lay-outs for our high management to approve. Out of the plurality of solutions sent for their consideration they selected three *pilot plans,* one of which has been herein reproduced as illustration for this course.

Figure 4.1 depicts the largest house of the three selected, it was called Model 900 since its floor area was close to 900 square feet. A three bedroom and one bathroom dwelling; enough to shelter a family of four, consisting of the two parents and two children. Most decidedly a compact design with no garage; considering that in practice garages were rarely used to keep the family car. They were used as a carpentry shop, a storage room or both. It was presumed that if the family ever decided to protect their car from the elements they could have bought an aluminum porte-cochere for a few hundred dollars, as well as a re-locatable storage building if a storage room was ever wanted or needed.

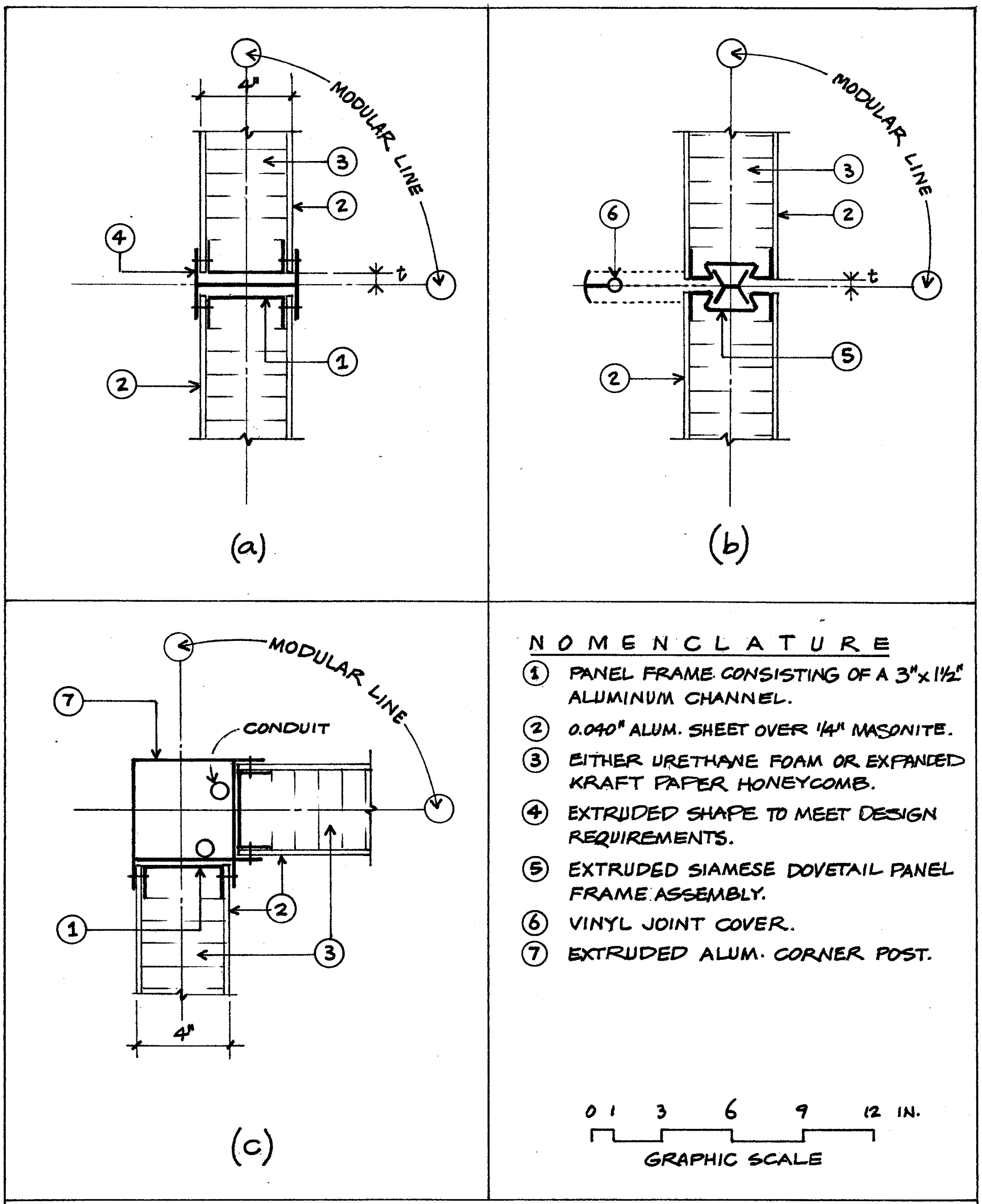
The typical wall conditions have been depicted in Figure 4.2 as two wall panels joined together at the modular line. Figure 4.2 (a) describes the case of two contiguous wall panels fastened to an extruded aluminum post that allowed a certain tolerance "t" to match the common inaccuracies of concrete work where most commonly these houses were expected to have been erected on.

Figure 4.2 (b) is an alternate wall detail solved without fasteners by using a sliding double-dovetail extruded friction bar that was inserted as the wall erection progressed. This system saved considerable time, however, allowed a much smaller tolerance and only was selected when the concrete contractor was bound by a strict quality control.

Figure 4.2 (c) depicts a wall corner where a hollow corner post was used to connect the two adjoining wall panels. Notice that such post presented the opportunity to allow the placing of conduits and/or electric wiring inside.



HOUSE MODEL 900
FIGURE 4.1



NOMENCLATURE

① PANEL FRAME CONSISTING OF A 3"x 1½" ALUMINUM CHANNEL.

② 0.040" ALUM. SHEET OVER ¼" MASONITE.

③ EITHER URETHANE FOAM OR EXPANDED KRAFT PAPER HONEYCOMB.

④ EXTRUDED SHAPE TO MEET DESIGN REQUIREMENTS.

⑤ EXTRUDED SIAMESE DOVETAIL PANEL FRAME ASSEMBLY.

⑥ VINYL JOINT COVER.

⑦ EXTRUDED ALUM. CORNER POST.

GENERAL WALL JOINT DETAILS
FIGURE 4.2

5.0 THE FIRST GROUP OF MODEL HOUSES

In the previous Section 4.0 we have already seen one of the prototype house plans as they were used in the production process for the experimental aluminum homes initiated by ALCOA in its effort to join the highly competitive housing market.

We will highlight the most important features of the aluminum houses and the very particular characteristics that made them different from the other houses that flooded the market at the time.

THE FOUNDATION SYSTEM

The foundation details included as part of Figure 5.1 herein were generic in nature and those omitted dimensions and features were related to design conditions which could not have been anticipated and therefore were left to the design engineer or architect to figure out based on the information they had at hand.

Figure 5.1 (a) shows a regular monolithic foundation for those sites above the minimum flooding standards. Notice how the wall base channel was cast with the foundation and pre-welded to an aluminum anchor bar rather than an anchor bolt for a more even and stable mode of attachment (see "warning" in the appendix section). After the concrete work was complete, the wall panels were then set in the base channel and fastened laterally.

Figure 5.1 (b) depicts an alternate foundation detail for application where the floor elevation was required at a higher level due to the possibility of seasonal flooding. Notice how in both cases the base channel was set (at least ½") lower to avoid rain water seepage into the house. Figure 5.1 (c) shows the interior bearing wall condition. Here again, the base channel was set lower into the concrete to maintain the walls at the same elevation. If there was ever a need to avoid such condition, then the interior walls had to be fabricated shorter in the same amount.

THE DOOR & WINDOW MODULES

Typical examples of both modular panels as they were used are presented in Figure 5.2 where the door module shown depicts a 36 in. wide unit as the widest allowed by the system, on the other hand, if a narrower door was required, fillers had to be added on both or one end to make up for the difference. When it came to the window modular panel, the detail shows a picture window which would not be much different than the conditions generated by any regular operable window, except for the frame that needed to be accommodated accordingly.

THE PLUMBING WALL

It was a common practice amongst architects and house designers engaged in the design of competitive houses to try to avoid long runs in the plumbing soil pipes. That was in most cases achieved by grouping kitchens, bathrooms and laundry rooms in the proximity of each other to provide economic solutions.

The logic in modular prefabrication was no different, except that in the latter we went one step further by pre-assembling, whenever possible, all the plumbing pipes in one single plumbing wall. In doing so, the design team took upon themselves tasks that were traditionally the responsibility of the plumbing contractor.

Figure 5.3 illustrates one example of the many attempts made by our team to conceive in a shop drawing form, a plumbing wall that was not only comprehensible but also compact enough and still within the weight imposed by the “human scale” principle. Although the plumbing wall shown in the figure calls for a total thickness of 9 inches, after some more accurate and careful detailing and in spite of all the pipe crossings, a way was found to adjust the stud depth to 7 inches and the overall wall thickness to 8 inches, which became the standard for all plumbing walls produced thereinafter.

THE ROOF STRUCTURE

In spite of the apparent limitations of a house system such as the one illustrated in this course, some features were introduced in the roof structural concept that provided a large degree of flexibility and the possibility of dozens of alternatives which allowed a successful integration of the structural system with all the other trades that were part of the house design.

The fact that the roof could be designed as a folded plate, or rather fully supported by composite roof joists, or a combination of those two, was a great advantage to have at hand. While it was true that every idea had its own limitations and every solution its own drawbacks, our agenda was always to make available the maximum number of alternatives which could be taken advantage of by a skillful architect or designer.

As a matter of example, the concept of the cathedral ceiling supported by the folded plate design concept provided the desirable perception of spaciousness even in a small house, however, it also brought in difficulty for the other trades while also making the house more vulnerable to becoming “the weaker link in the chain” of resistance to lateral loads. The details provided in this section will take us through the entire gamut of possibilities.

Figure 5.4 (a) describes the roof under the folded plate design concept with the addition of the extruded ridge beam being able to span spaces of up to fourteen feet. In order to overcome the high stresses usually developed in that area, an adequate number of fasteners had to be provided at the connection between the ridge beam and the roof panels. The joints of the roof panels ran across the width of the house and along the grid lines marked with letters on the plan (see Figure 4.1). In order to achieve an acceptable water tightness two coats of elastomeric sealant were sprayed on the entire roof in a continuous and uninterrupted application.

On the other hand, Figure 5.4 (b) shows a typical aluminum joist with the potential to span up to forty feet, enough to cover the entire width of any of the proposed prototype homes. In order to avoid running the roof panel joints across the slope, it was decided to exchange the roof panels for full length corrugated sheets placed in two directions and spot welded together so to achieve an effective diaphragm action. The deck so conceived was carried by composite aluminum joists on every modular line. As you may notice on the figure, 2 in. diameter pass-over openings were provided through the joist web to accommodate passage for pipes and wires. In the case shown, insulation had to be filled in the attic to reach a minimum R-19 value, or more if the climatic conditions required.

THE MECHANICAL SYSTEM (HVAC)

Figure 5.5 illustrates an integrated air conditioning and ceiling fan ventilating system. Such a lay-out is predicated on the assumption that cathedral ceilings were used in the entire house and a dropped hung ceiling installed above the hallway only, so to provide room to accommodate the ductwork shown in the same figure.

The A/C handling unit was usually located in the closet next to the water heater, and from there piped to the condensing unit located outdoors.

THE ELECTRICAL GROUNDING SYSTEM

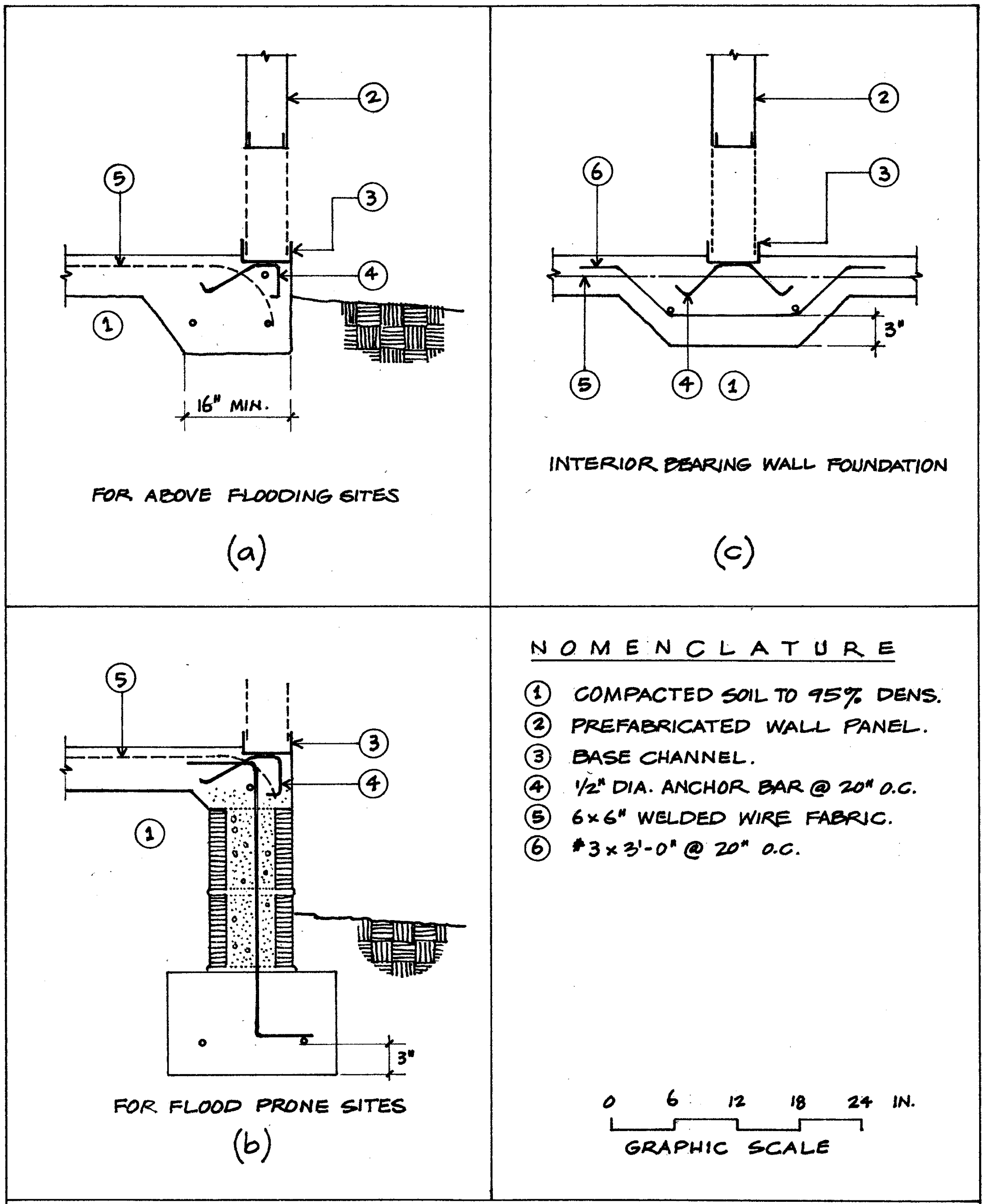
In more than one occasion aluminum houses, or metals homes in general, have been blamed for attracting the occurrence of lightning strikes. Although the statement is somewhat exaggerated, there are some grounds for such a concern. Figure 5.6 describes, along with the recommendations of the National Electric Code (NEC), a method of effective grounding which would minimize the possible damage caused by such an act of Nature, by providing a viable path into the ground.

In addition to the multiple connections shown to the grounding electrode, the system could also be clamped to the water supply line, provided it was a metal pipe (copper or galvanized iron) and had a minimum diameter of ¾ in.

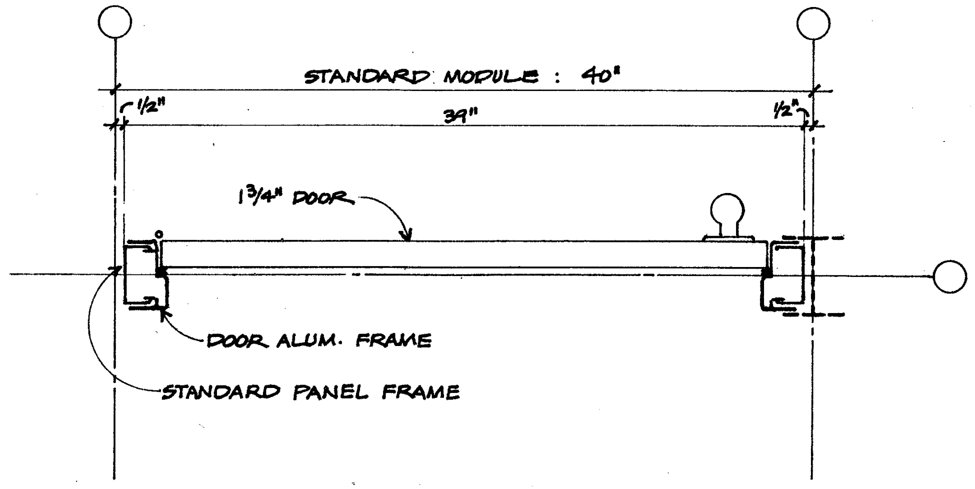
TOLERANCES

Although prefabricated aluminum panels can be manufactured with a high degree of precision, however, the concrete work (ground slabs, suspended slabs, stem walls, grade beams, etc.) or the rough carpentry work (decks and wood frames) are built with a large degree of irregularities and tolerances, therefore, the manufactured panels so installed must allow for those tolerances as a necessity for a full integration.

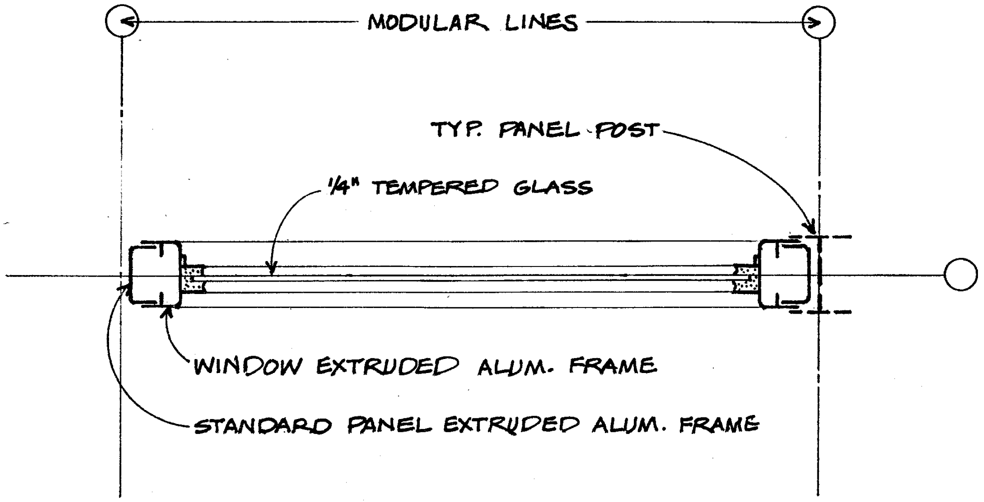
Consistent with that idea, the reader will notice that large tolerances have become part of the basic details as in Figures 4.2 and 5.2 where a ½ in. tolerance on both sides of the panel joints have been provided.



FOUNDATION DETAILS
FIGURE 5.1

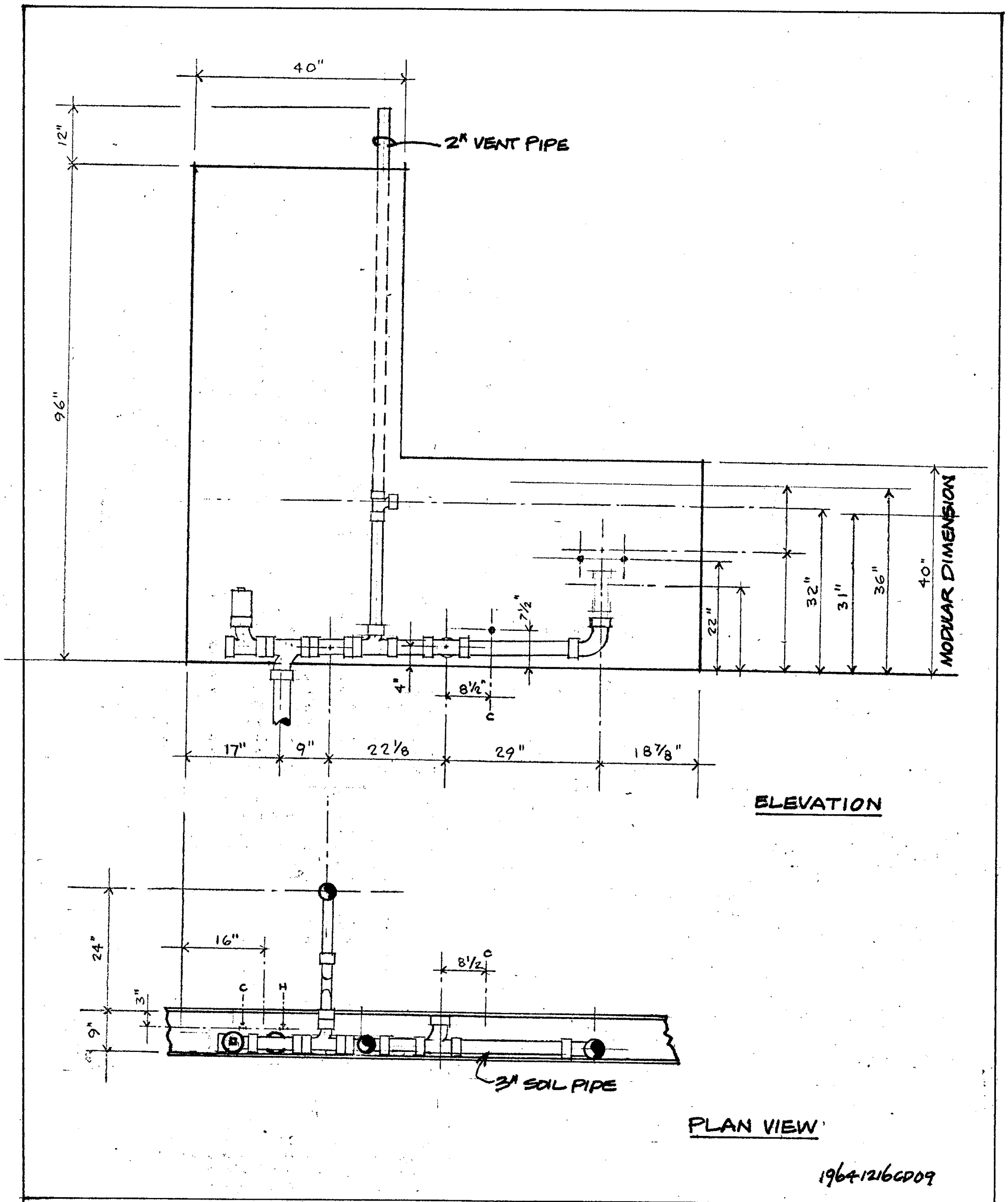


TYPICAL DOOR MODULE

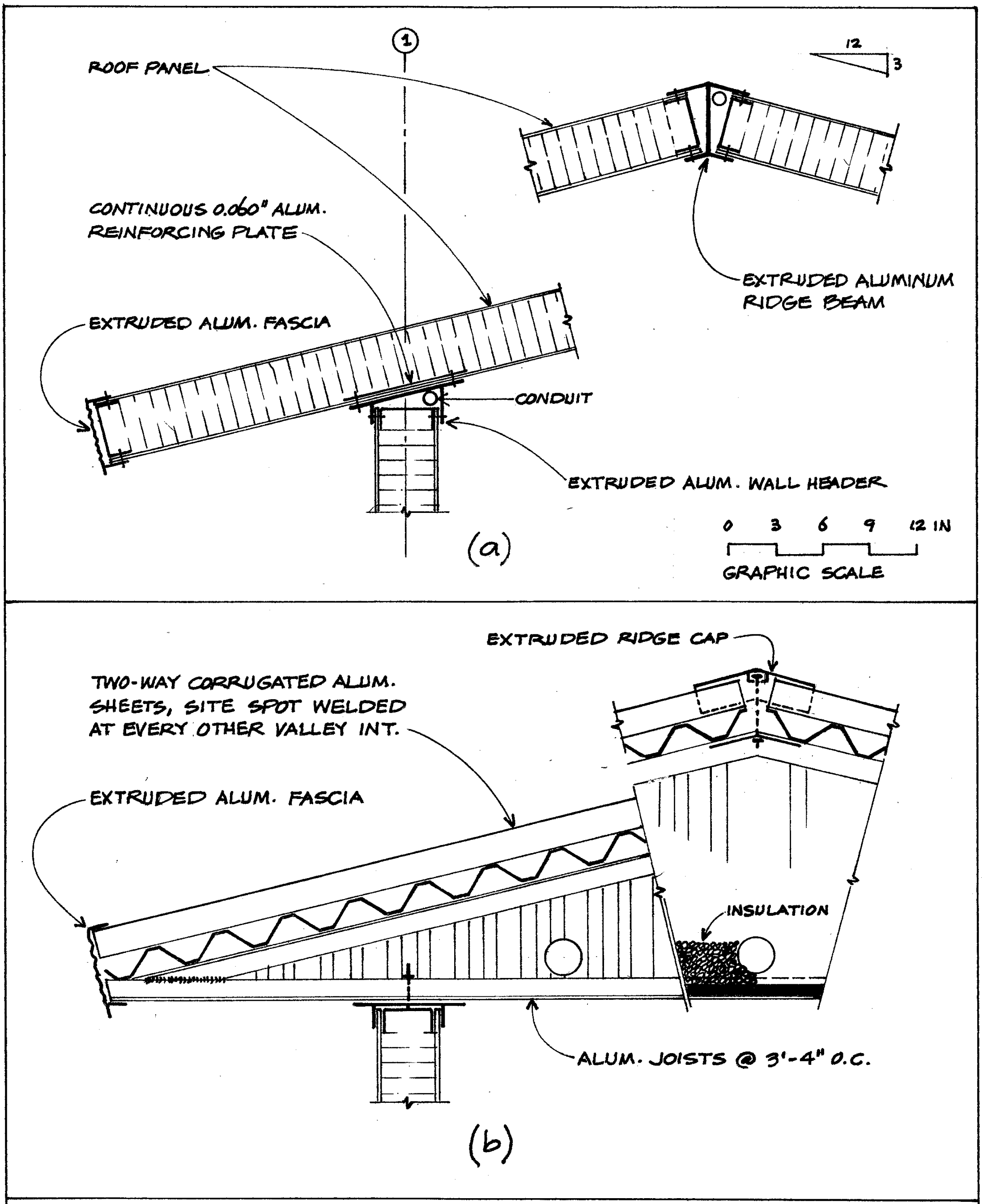


TYPICAL WINDOW MODULE

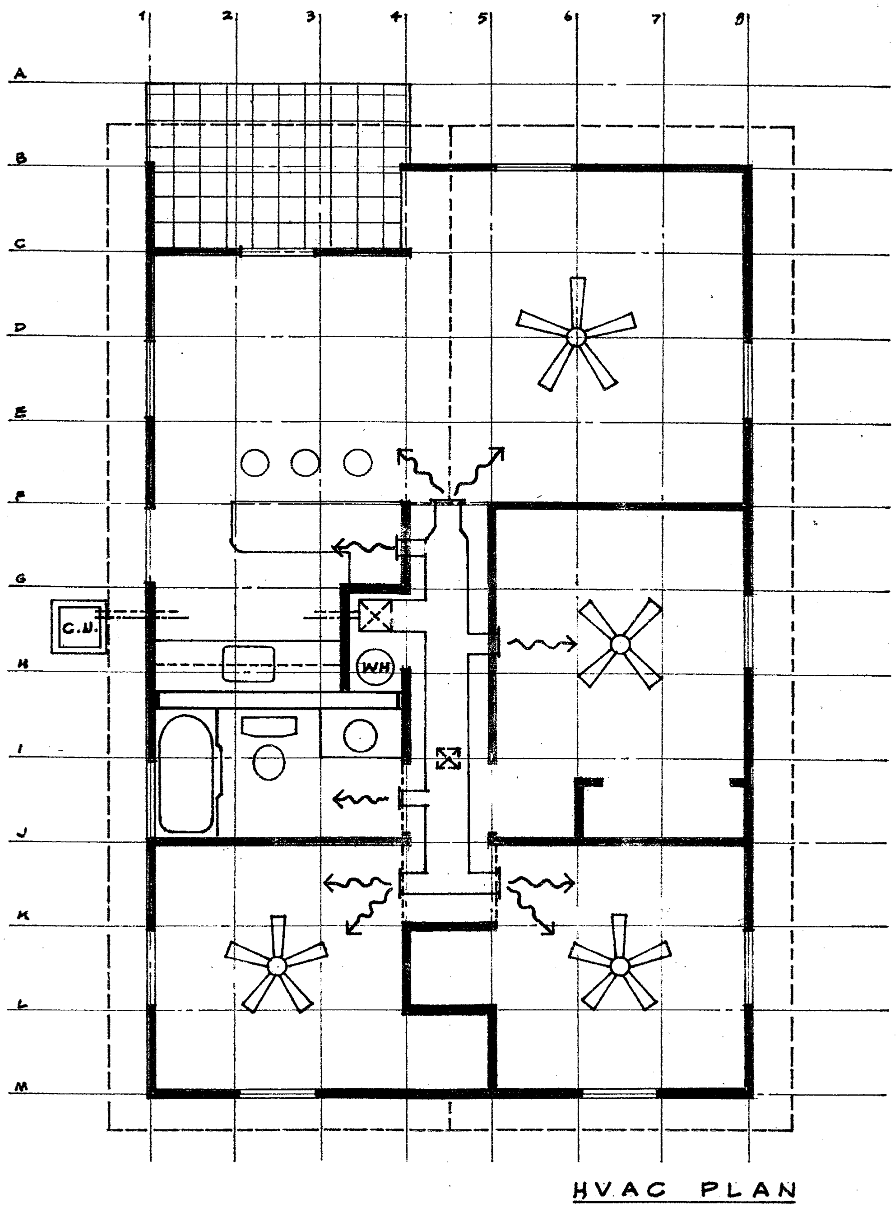
DOOR & WINDOW MODULES
FIGURE 5.2



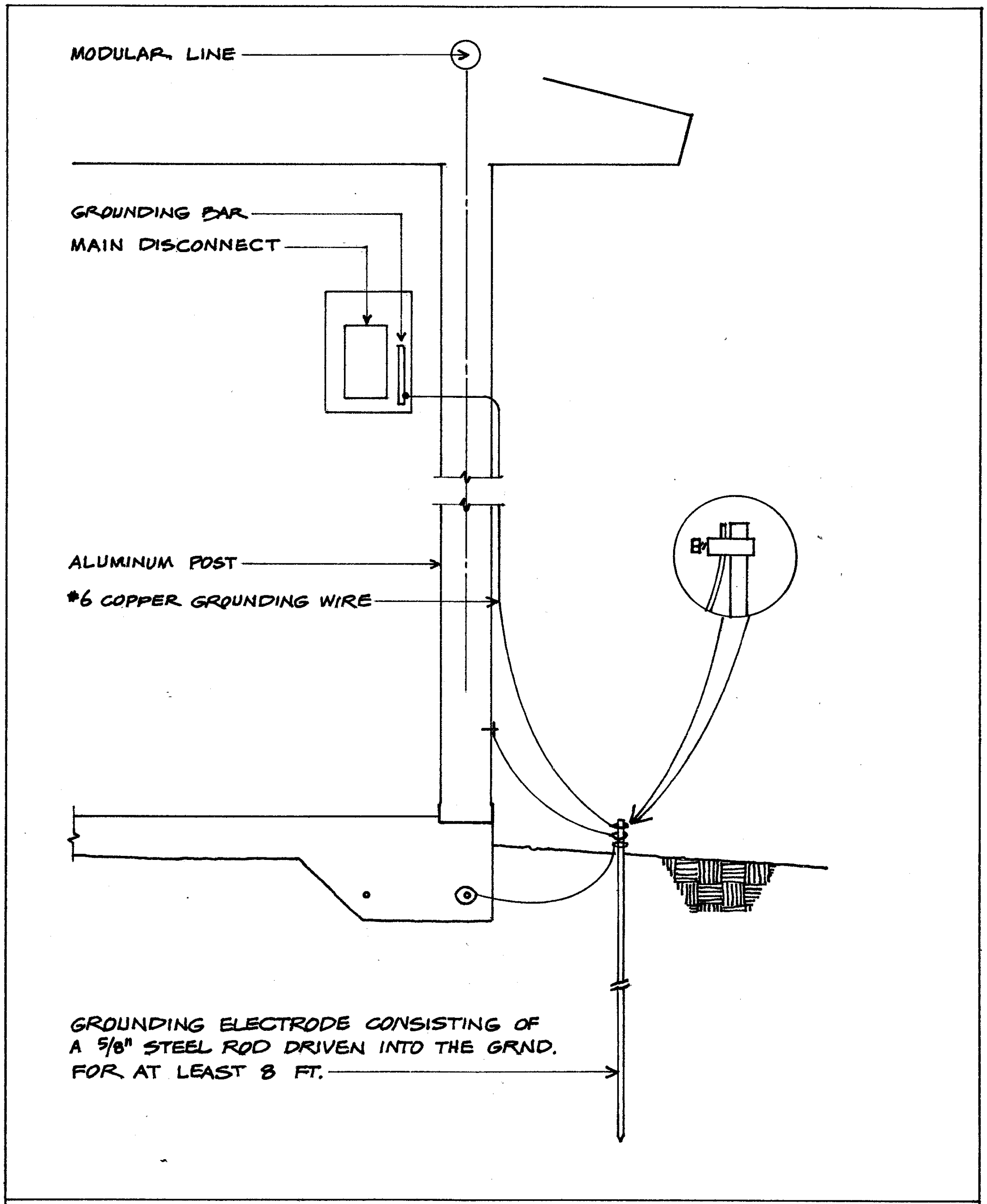
PLUMBING WALL STUDY
FIGURE 5.3



SOLUTIONS TO THE ROOF STRUCTURE
FIGURE 5.4



HOUSE MODEL 900
FIGURE 5.5



RECOMMENDED GROUNDING SYSTEM
FIGURE 5.6

6.0 PRESENT LOCATION OF THE EXPERIMENTAL HOUSES

After being fully assembled at the shop, most of the experimental houses were fully disassembled, transported, re-assembled and permanently settled in tropical locations as the final testing grounds, so as to allow measuring their long term performance.

Late in 1964, the prototype house model 900 was installed at the (inland) exhibition site in Miramar, Puerto Rico. A few years later, after completion of the exhibit term agreement it was disassembled, packed and sent to a warehouse for a period of time. There are some indications that it was later shipped to the mines in the jungles of Surinam and installed down there.

In 1965, the house model 800 was installed on a higher terrain location directly facing the brunt of the Caribbean Sea's turbulent winds at ALCOA's bauxite mining site in the town of Cabo Rojo, Dominican Republic. This house was assigned as the residence of one of the higher local employees and has remained there ever since. After nearly fifty years of service, it has survived the wrath of three major hurricanes, escaping with partial damage to doors, windows and trimmings. However, the safety of the dwellers was never seriously compromised.

At the time of writing this course in the year 2014, the location of the rest of the houses was unknown to the author.

7.0 CONCLUSION

The age of rapid growth and experimentation of the 60's and 70's came to an end as the so called "economic bubble" busted, thus marking the end of an era of remarkable and unparalleled prosperity and creativity. All that effort and progressive advancement was not lost or made in vain however, for all that methodology remains as a testimony to human ingenuity and for the use and advance of the future generations.

It all came to prove that aluminum houses, in spite of their shortcomings, are a viable solution for the low cost housing market. Aluminum is relatively abundant, attractive, lightweight, it does not rust, it is not susceptible to insect infestation, requires very low maintenance, and the panels can be produced within the human scale as demonstrated by the examples presented in this course.

When it came to hurricane winds, we made sure that every panel, every condition and the house as a whole were designed to resist winds of up to 150 mph. However, there is a second aspect of hurricanes which is often overlooked, their high winds also involve the participation of flying objects and debris which under the applied accelerations can impact and puncture walls, doors and windows and once the house's exterior envelope has been compromised, failure would not be a distant event.

In spite of the fact that we have herein described the good qualities of aluminum as a desirable construction material and how a house made of it may contribute to alleviate the present high housing costs which are preventing the low medium classes from acquiring decent living units. On the other side of the coin, we must say that the regular aluminum house (as we have also said in the past about traditional wood houses), is not the appropriate type of structure to be built in the tornado prone areas of the United States. For those areas we strongly recommend the type of construction described in our course titled "Tornado Resistant Homes" which is also available to design engineers and architects from this same source.

APPENDIX

TABLE A
Comparison of Physical & Mechanical Properties of Materials

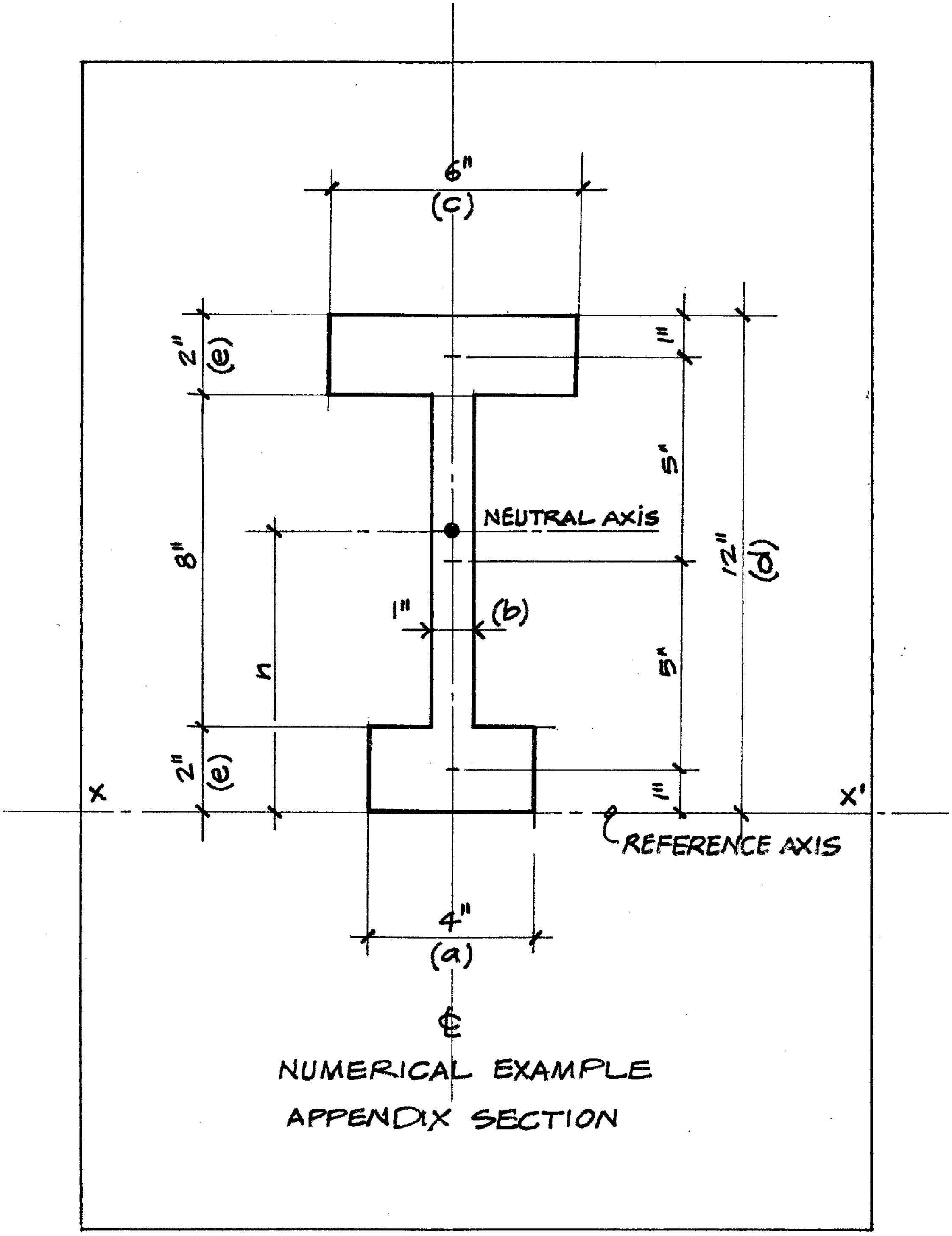
Material	Tensile Strength (psi)	Yield Strength (psi)	Shear Strength (psi)	Mod. of Elasticity (psi) x 1000	Specific Gravity	Weight (lbs/in^3)	Melting Range (Deg F)
Brass	76,000	45,000	40,000	15,000	8.46	0.306	1,690
Bronze	81,000	75,000	unknown	16,000	8.86	0.320	1,830
Copper	50,000	45,000	28,000	17,000	8.90	0.322	1,950
Cast Iron	30,000	25,000	44,000	14,000	7.10	0.257	2,200
Magnes'm	44,000	32,000	20,000	6,500	1.80	0.065	1,000
Steel	60,000	35,000	30,000	28,000	7.85	0.283	2,760
HardWood	10,000	unknown	1,500	1,600	0.67	0.024	n/a
Zinc	40,000	26,000	31,000	unknown	6.64	0.240	750
Aluminum Alloys							
3S-H18	29,000	27,000	16,000	10,000	2.73	0.099	1,200
52S-H38	41,000	36,000	24,000	10,200	2.68	0.097	1,150
24S-T4	64,000	42,000	40,000	10,600	2.77	0.100	1,060
61S-T6	45,000	40,000	30,000	10,000	2.70	0.098	1,150
52S-0	28,000	13,000	18,000	10,200	2.68	0.097	1,150

TABLE B
Minimum Thicknesses of Extrusions for Different Aluminum Alloys

Dia. Of Circ'd Circle (in)	3S, 61S (solid)	24S (solid) (in)	63S (solid) (in)	3S (hollow) (in)	61S (hollow) (in)
Under 3	0.050	0.050	0.045	0.062	0.078
4	0.050	0.063	0.050	0.078	0.094
5	0.063	0.078	0.050	0.094	0.109
6	0.063	0.094	0.050		
7	0.078	0.109	0.062		
10	0.109	0.188	0.109		
12	0.156	0.250	0.156		

The aluminum alloys listed in Tables A & B above conform to the designations used by Reynolds Aluminum, a registered trade mark of Reynolds Metals Company.

A practical example of how to proceed with the necessary steps for the determination of section characteristics as described in Section 3.0 follows below, also see enclosed figure.



THE NET SECTIONAL AREA

By breaking down the total section in three rectangular areas we get:

$$\Sigma A = (6 \text{ x } 2) + (1 \text{ x } 8) + (4 \text{ x } 2) = 12 + 8 + 8 = 28 \text{ in}^2$$

as the total sectional area.

POSITION OF THE NEUTRAL AXIS

To determine the position of the neutral axis we use this formula:

$$n = \Sigma M/\Sigma A$$

Where,

$$\Sigma M = (12 \text{ x } 11) + (8 \text{ x } 6) + (8 \text{ x } 1) = 132 + 48 + 8 = 188 \text{ in}^3$$

Thus,

$$n = 188/28 = 6.714 \text{ in}$$

THE MOMENT OF INERTIA

For the determination of the total moment of inertia, we maintain the three rectangular areas shown above while keeping in mind that the moment of inertia of each one of them is:

$$I = 1/12\ (b\ .\ d^3)$$

By taking every moment of inertia and adding the area of the section multiplied by its distance to the neutral axis squared and adding them altogether, the result is the moment of inertia of the whole.

Following the indicated procedure, we will now determine the moment of inertia about the reference axis X-X':

$I_x = [(6 \text{ x } 2^3)/12 + (6 \text{ x } 2 \text{ x } 4.29^2)] + [(1 \text{ x } 8^3)/12) + (1 \text{ x } 8 \text{ x } 0.71^2)] + [(4 \text{ x } 2^3)/12 + (2 \text{ x } 4 \text{ x } 5.71^2)] = 535.05$ in (to the 4th exponential).

THE SECTION MODULUS

To determine the section modulus we need to use the following formula:

$$Z = I/c$$

Where "I" is the moment of inertia and "c" is the distance from the neutral axis to the outermost fiber of the section.

Therefore,

$$Z_x = I_x/c = 535.05/6.71 = 79.74 \text{ in}^3$$

Please notice that in the preceding text of this course, the noun *module* has been used not only as a constant and standard unit of measurement but also as a descriptive concept of a self-contained component or sub-assembly.

WARNING!
Pertaining to Section 5.0 and Figure 5.1:

A fact finding program conducted by the ALCOA Research Laboratories regarding the behavior of aluminum components embedded in concrete demonstrated the fact that the presence of chlorides in such material accelerated the galvanic corrosion in those aluminum parts, especially when in the presence of other metals such as steel.

The incidence of chlorides was found to be substantially more accentuated in those areas of the United States of America subject to harsh winters, seemingly because of the common use of salt spreading to increase resistance to freezing, as well as in the coastal regions of the country.

According to the issued report as prepared by Frank L. McGeary on behalf of ALCOA Research Laboratories, has indicated as result of their tests that the most effective method to avoid galvanic corrosion is by pre-applying generous coatings of either epoxic or phenolic based compounds formulated for such specific purpose.
