HOLLOW FACE BRICK FOR WIND AND SEISMIC RESISTANCE

Optimum Reinforced Masonry Construction

By

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ABSTRACT

There have been many hollow reinforcable units manufactured in the past, each contributing to experience in using reinforcing and grout, especially for seismic and wind resistance, for in-situ construction as well as for prefabrication.

The newest units developed for Higgins Brick Company (1981) to incorporate maximum benefit, utility, and economy for optimum design are described and amplified, that is, the 5" nominal thickness (4.5") (114), a minimum to save building space and weight while adequate for most building requirements; thick face shells for high capacity; large grout spaces for ease and assurance of grouting; high strength for stress compatability with grout for maximum combined net area masonry (f'm) strength; modular 4" (102) face dimensions.

Tables are prepared for easy design for specific installations, use of high stresses, and of extensions of height limits.

Fire endurance ratings with various plaster applications are listed for functional selection of walls as required for Types of Construction.

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Optimum Reinforced Masonry Construction

HISTORICAL

The period of consecutive development of reinforced masonry to the present design use began with the impetus of the Long Beach, California, earthquake of March 10, 1933. All the masonry school buildings of the area, and many other buildings were demolished. Consequently new seismic considerations and reinforced masonry requirements were immediately introduced into the local codes which have since been continuously improved and developed. The first provisions were about six pages, which grew to the present forty pages or more in recent codes.

The first intensive development for reinforced brickwork was the early two wythe brick construction, with grout between the two in order to bond the brick to the reinforcing in the grouted space. The procedure consisted of laying up one wythe about eighteen inches (.46m) then laying a course of the opposite wythe, grouting the space between, laying another course and grouting, and another course and grouting, and placing the reinforcing in the grouted space. Part of the reason for pouring the grout was to minimize the possibility for human error.

Much later that method was revised to the high lift grouted method. This consisted of building the two wythes full height, with wire ties between to serve as "form ties," with the reinforcing in place. Then the grout was poured about four feet ( ) high, and consolidated, then reconsolidated, another lift was poured and the operation continued to complete the wall.

A parallel later development to the two wythe construction was the grouted hollow unit construction in concrete block. Clay block followed similarly considerably later. The hollow units were laid about four feet (1.2m) high, then grouted, another four feet (1.2m) was then laid, and grouted. A later development was the "high lift" grout method in which the units were laid full height and then the grout poured and consolidated in consecutive lifts of about four (1.2m) to six (1.8m) feet.

The initial concrete block was generally six inches (.15m) or eight inches (.2m) thick in the early construction. Clay block developed similarly, that is, six inch (.15m) and eight inch (.2m) hollow units. However, since the clay units were formed with straight sided cores or cells an early development was also the use of four inch nominal hollow clay units. These were actually three and a half inches (89mm) thick. In order to provide a two inch (50mm) grout space the face shells were only three quarters of an inch (19mm) thick, or less. This introduced the difficulty of laying the horizontal mortar bed joints on the narrow face shell. Also these narrow bed joints could not accept joint reinforcing with adequate cover and there was not as good bond. Although these units were used extensively in Denver, Utah and the Northwest the shortcomings were noted.

HIGGINS BRICK COMPANY

In the late 70's the Higgins Brick Company initiated updating many of its methods and products and searched for the optimum design of unit for most effective use of reinforced brick masonry. After their research, described briefly in the following discussion, they started the manufacture of the Higgins Hollow Five, as the best single unit with the widest, most effective application.

The goal was to use the smallest or thinnest wall that would be feasible for the maximum numbers of conventional walls, with consideration of the arbitrary code limits currently in practice governing wall heights and loads. By making the unit thinner than the conventional eight inch (.2m) bearing walls considerable labor cost and expensive floor space was saved. (at $75 to $100 per square foot of floor area).

The general result of the studies to achieve that goal was, in outline, about as follows. Incidentally the Dutch manufacturers had arrived some time before, at a similar thickness as being optimum. The investigations converged from two directions, that is, from the economy and practicality of field installation, as well as from design suitability.

1. Hollow unit construction was decided upon because of the economy of laying as well as ease of reinforcing. One wythe is laid instead of two wythes. Thinner walls could be developed effectively.

2. The smallest feasible space for assurance of grouting reinforcing was a two inch (50mm) by three inch (75mm) cell, incidentally a requirement in the Uniform Building Code for many years. It is recognized that some grouts, made with well graded rounded aggregates, will pour easily into smaller cores or cells. However, some grouts with harsh angular poorly graded aggregates would be difficult to pour in cells that small. Practice showed that for most field conditions the two by three cell is an adequate minimum, being used under UBC for many years without serious question - a good service record and precedent.

3. The minimum face shell thickness was considered as from one inch (25mm) to one and one quarter inch (32mm). These thicknesses have also been used in ASTM and UBC for hollow units, both in clay and in concrete masonry. The one and one quarter inch (32mm) thick was selected as providing maximum capacity as well as being more effective for field laying. The bed joints are more quickly placed, either by "swiping" or by "stringing the mortar." Good support is provided as the units are shoved into place on the mortar bed.

   Also, the laying of the unit to a line was quick and effective. It could be picked up by the center cross webs like a hollow unit, or gripped overall like a solid unit, or by the face shell on the side away from from the line so it could be placed without disturbing the line and hampering other workers on the line. Therefore they arrive at $1\frac{1}{4}$" + 2" + $1\frac{1}{4}$" = $4\frac{1}{2}$" or five inch nominal.

4. Many bearing walls are from ten feet (3m) to twelve feet (3.6m) high. Many higher walls with pilasters had pilaster supports at from twelve feet (3.6m) to twenty foot (6m) spacings.

   It is recognized that customary arbitrary limits of h/t of 25 and 30 were conservative and that these could be

greater, as shown by tall slender wall tests and also in code approvals of twenty seven h/t for high strength hollow clay units. Therefore for bearing walls, t might be h x 12/27 or, for example, 11.25 (average) x 12/27 = 5" or for non-bearing walls, fixed between pilasters, t might be (.4) x 20 x 12/30 = 5" approximately. Again the decision was for 5" nominal thickness.

5. The capacity could be increased during manufacture by slightly revising the clay mix and by a slight increase of a portion of the firing time in the kiln. This could be done for very little additional cost. This considerable increase in strength would provide that the maximum compressive stress permitted by UBC could be utilized, i.e., f'm equals six thousand psi. This required a masonry unit strength of about nine thousand to ten thousand or twelve thousand psi. (69mp)

The resultant shape selected was a face dimension of modular four inch (100m) by twelve inch (300m) and a nominal five inch (125) thickness, as shown in drawing. This provided the best combination of minimum size, good economy, practical construction and adequate capacity.

ACCESSORIES

In addition to the basic standard shape there was the need for other shapes to complete the effective use. The Bond Beam is necessary for the horizontal reinforcing bars that are required. Joint reinforcing may provide a part of the horizontal steel but additional steel is required, such as perimeter bars, top bond beam bars etc. These units are generally cut from the brick being delivered to a job so that they will match the shades of color and texture exactly, to avoid the appearance of ribbands.

Since the units are nominal 5" (125) thick and 12" (300) long the head joint would be one inch (25m) off half bond if the corner units were not cut one inch (25m) shorter. The Half units provide for maintaining half bond at the end of a straight length of wall. It is, of course, slightly less than half a unit in order to provide for the mortar joint.

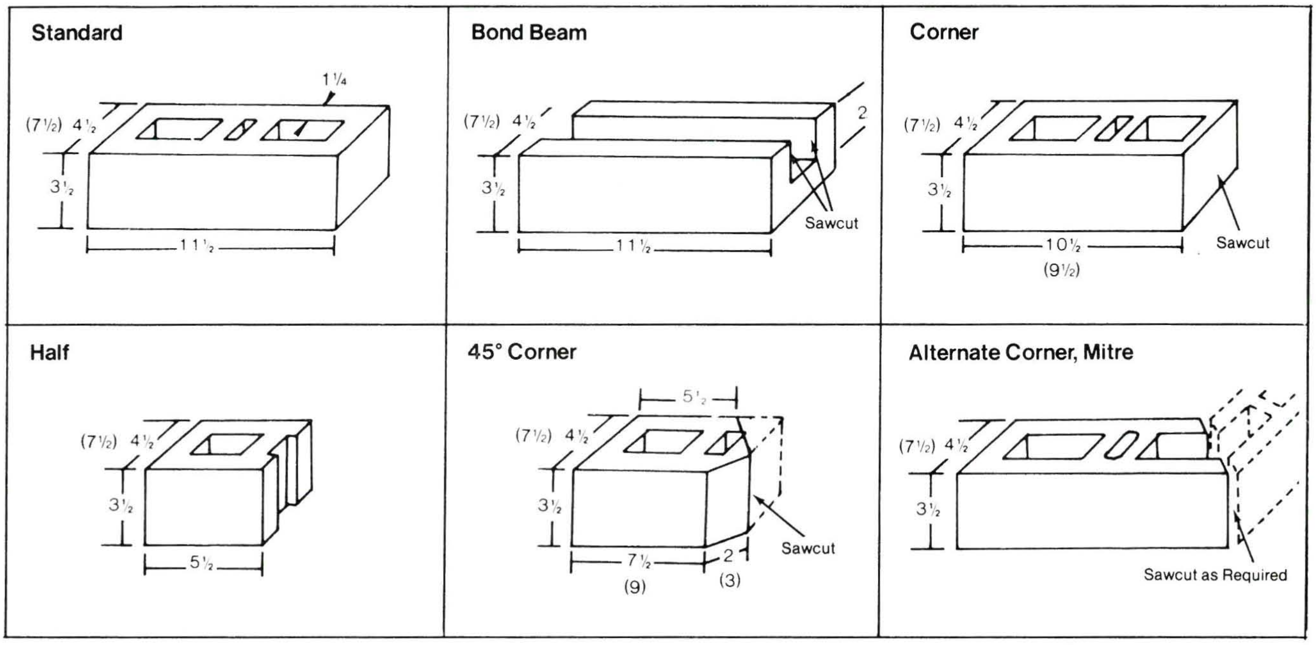
The 45^{o} corner provides for continuing the bond around a 45^{o} corner, which has been a frequent need, or desire, of architects. In order to provide for the occasional need for a corner other than 45^{o} the mitered or mitre corner is used. These may be cut to any angle required. Some of these were constructed in a prefabricated panel with the grout space or cell filled with grout to serve as a "spline." The panel was tipped over, lifted and dropped, with no indication of cracking, so it is an effective detail.

Bolt tests were made to evaluate design capacity of bolts in the high strength masonry. The shear, or lateral loads, were much higher than the current low code values. Also the tension, or pull-out, capacities were quite high. These values of pull-out are important because the UBC does not now contain values for bolt pull-out.

Also tests of bolt inserts were made to determine types to develop the high factors of safety that are required by code for prefabricated panels, a potentially large market. The inserts develop much more capacity than do simple bolt embedment.

Higgins Hollow Brick

Physical Dimensions & Properties



Dimensions shown in ( ) parenthesis are for the 8" unit.

The Standard shape has the modular face dimension of 4 x 12, for 1/2"joint.
The Bond Beam unit to provide for horizontal reinforcing bars is made by saw cutting.
The Corner unit is to provide for half bond in the field of the wall away from the corner.
The Half unit is to provide half bond from a wall end.
The 45° Corner is to provide half bond lap.
The Alternate Corner, Miter is to provide for any degree of corner angle.
It does show a continuous head joint line at the edge. Many do not regard such a line as detrimental because the light on the two wall surface planes will be visually different. However, the lap or bond structurally is provided by filling the partial cell space with grout and by providing wire ties or loops as for stack bond masonry.

Figure 1

Higgins Hollow Brick

Typical Bonding Details

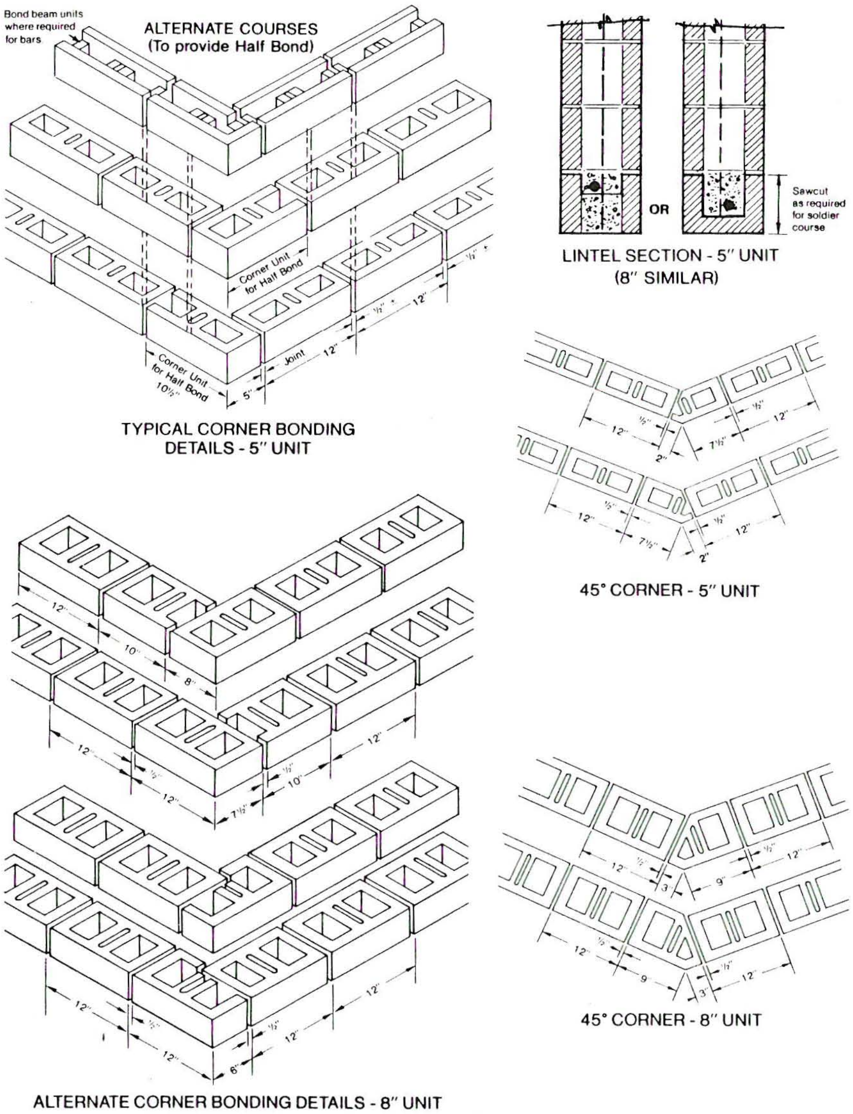


Figure 2

FIRE ENDURANCE RATING

	⅝" Plaster Installation		
Grouting	**None**	**1 Side**	**2 Sides**
5" Not Continuously Grouted	1 hour	2 hours	3 hours
5" All Cells Grouted	2 hours	3 hours	4 hours
8" Not Continuously Grouted	3 hours	4 hours	4 hours
8" All Cells Grouted	4 hours	4 hours	4 hours

Table 1

Another accessory unit is the parallel use of matching 8 inch (200m) thick units. These can be used for the few instances where the capacity of the 5 inch unit might not be adequate, or where wider bearing surface might be required. One example would be for wide support of precast concrete plank floors on each side of the wall with concrete space for dowels between the plank ends. A top course of 8 inch (200m) units could provide the width required.

Hence details and properties of the 8 inch (200m) hollow units are included with the 5 inch in Figure 1.

FIRE ENDURANCE

Another important need for a building material, and a very valuable asset of clay masonry, is fire endurance. A very common need is for a two hour fire endurance of walls. By comparison of equivalent thicknesses, and by interpolation, it was apparent that the "hollow five," when grouted, would have an endurance of about two hours and ten minutes, plus or minus ten minutes, depending on moisture content at time of test. A standard fire test was made which showed two hours and twelve minutes so the "five inch," again, is satisfactory for the frequently required two hour endurance. The test confirmed the two hour and also the interpolation, so the greater ratings achieved by adding plaster thickness could be depended upon, as shown in Table 1.

CAPACITY

Design methods were studied rather carefully because the 5 inch thickness was quite close to some of the ancient arbitrary limits, requiring a closer engineering review and evaluation of design.

Also there was a concurrent development of prefabricated masonry panels, following the example of architectural precast panel construction. These elements require high factors of safety and more precise design. Also bearing capacity of the thin walls was compared.

For example:
Bearing capacity per foot of 5 inch wall (125m)
f'm = 6000 (41.4mp)
Fa = 1200 (8.3mp)
P = 38 sq. inch (24mm) x 1200 = 45,600 lbs./ft. (665.750n/m)

For comparison, bearing of an eight inch concrete block of conventional strength would be:
f'm = 1350
Fa = 270
P = 30 sq. inch(.0019m) x 270 = 8,100 lbs./ft. (119000n/m
i.e., in 4.5/7.5 = .6 of the width, the load may be 45,600/8,100 = 5.6 times as great or one foot of the five inch wall may carry more than five feet (1.5m) of eight inch concrete block.

For bending resistance such as due to wind or seismic loading,
the 5" would develop 2000 x 4/3 x 37 = 98.7 inch lbs. (11.15nm)
the 8" would develop 500 x 4/3 x 78 = 52.0 inch lbs. (5.88nm)
The five inch has 98.7/52 = 1.9, or about twice as much as bending resistance capacity.

Since these units are developed for a better engineered masonry element additional investigation was made, e.g., the effect of combined bending and direct stress, and inserts for connections.

COMBINED BENDING AND DIRECT STRESS (P-M)

The UBC provision for combined bending and direct stress is expressed by

$$\frac{f_a}{F_a} \pm \frac{f_b}{F_b} \leqslant 1$$

this may be simplified and expressed as:

$$\frac{P(\text{imposed})}{P(\text{allowable})} + \frac{M(\text{imposed})}{M(\text{allowable})} \leqslant 1$$

This would indicate a straignt line function from full vertical load and zero moment to a value of zero moment and full vertical load. However, the UBC recognizes and specifies the proper linear elastic design assumptions, which may be used. This engineering principle was used to check the actual capacities for the five inch units as shown on the following P-M charts. These curves are for the conditions of

f'm = 2500 (17mp) (inspected especially and fully)
f'm = 2500 (17mp) (not inspected fully) (i.e., x 1/2)
f'm = 6000 (41mp) (inspected)

The excerpt from the Higgins design booklet shows dramatically how the capacity can be utilized more effectively.

See P-M Charts, Figure 3

END RESTRAINT

Also heights per UBC limits were calculated. These tabular values, of course, depend upon determination of the influence of the true end restraint. There must be assurance that the calculated end restraint actually will be provided in the structure. This is explained more fully in the excerpt from "Reinforced Masonry Design" by Schneider and Dickey.

HEIGHT LIMITS OF WALLS (Per UBC Table 23-I)

WALL TYPES	Wall	h/t	Maximum h (ft.) Pinned	Pin/Fix	Fixed
Reinforced Bearing Walls	5″ 8″	27 25	11.25 18.0	14 22.4	17.3 28.0
Exterior Nonbearing Reinforced Walls	5″ 8″	30	12.5 20.0	15.63 25.0	19.23 31.0
Interior Nonbearing Reinforced Walls	5″ 8″	48	20.0 32.0	25.0 40.0	30.77 49.0
Reinforced Wall Beam, Bearing	5″ 8″	36	15 24	— —	— —
Reinforced Wall Beam, Nonbearing	5″ 8″	48	20.0 32.0	— —	— —

Table 2

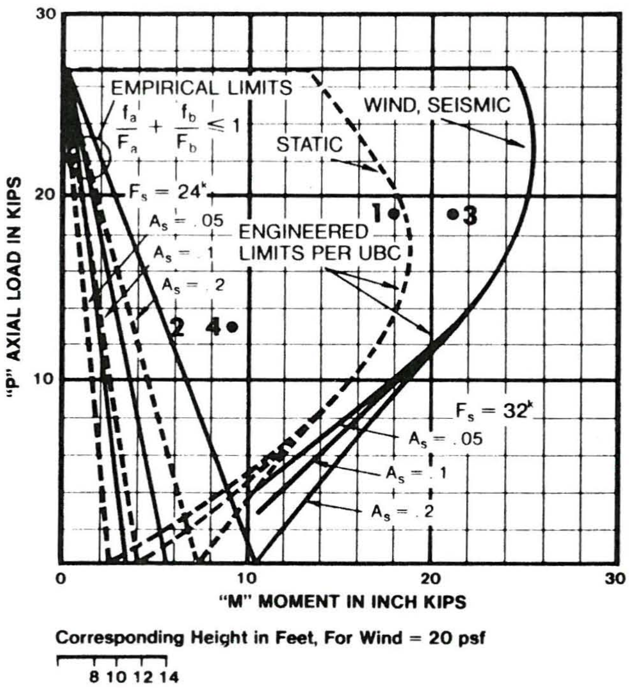
Interaction, Bending & Direct Stress - 5″ Walls

The curves are based on allowable stresses for static loads and also for the condition of ⅓ increase for bending allowables for wind or seismic. They also include the effect of reinforcing, for areas of .05, .1, and .2 square inches per foot. These represent percentages of .0009, .0019, and .0037 for comparison with UBC minimum percentages of .0007 and .002. These steel areas might be provided by #4 @ 48″, #6 @ 48″, and #6 @ 24″ respectively.

The straight lines from M @ P = 0 and P @ M = 0 are the representation of the UBC interaction equation of $\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1$ while the wider curves indicate the increased capacity based on UBC and strength of material design assumptions.

f'_m = 2500; INSPECTED; n = 12

F_a = 500; F_b = 833 (x $\frac{4}{3}$ = 1111); F_s = 24ᵏ (x $\frac{4}{3}$ = 32ᵏ)



EXAMPLES:

Given:

5″ Hollow Brick wall, grouted, h = 10′, wind = 20 psf, M_W = 3″ᵏ
f'_m = 2500 psi, Inspected masonry
F_a = 500 psi n = 12
F_b = 833 (x⁴⁄₃ = 1111)
F_s = 24,000 (x ⁴⁄₃ = 32,000), A_s = .05□″/ft., .1□″, .2□″
Vertical Live Load = 5 kpf @ e = 2.25″ (M = 11.25)
Vertical Dead Load = 7 kpf @ e = 0 (M = 0)
Floor Dead Load = 3 kpf @ e = 2.25 (M = 6.75)
18.00″

Solution:

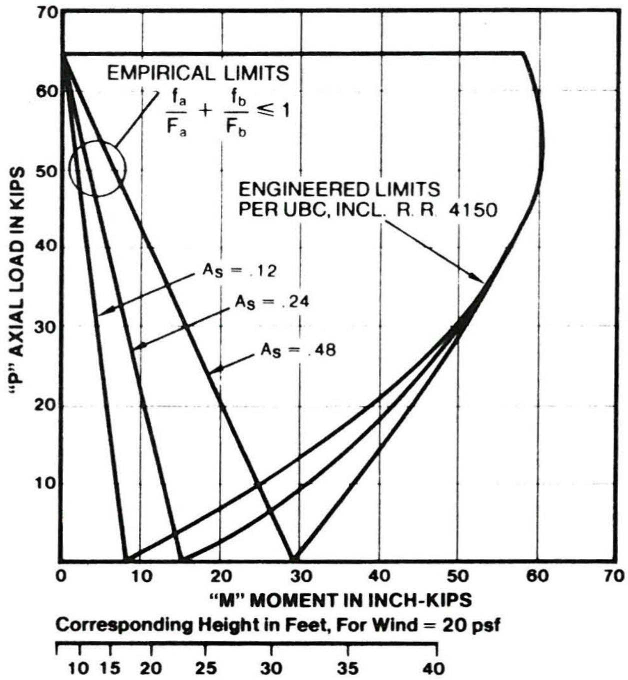
h/t = 120″/5 = 24; R = .78

For Max. imposed load, **(See 1)**	P = 15; (equivalent P = 19.2) M = 18″ᵏ This is within the capacity for static load.
For Dead Load only **(See 2)**	P = 10 (eq. P = 12.8) M = 6.75″ᵏ This is within the static load capacity.
For Max. Load plus wind **(See 3)**	P = 15 (P = 19.2) M = 21″ᵏ This is beyond the static load capacity but within the ⁴⁄₃ increased capacity permitted.
For Min. Load plus wind **(See 4)**	P = 10 (P = 12.8) M = 9.75″ᵏ This is well within the capacity curve but is far beyond the capacity indicated by $\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1$

All the loads and combinations exceed the straight line limits.

f'_m = 6000 psi; CONTINUOUS INSPECTION; n = 10

F_a = 1200 psi; F_b = 2000 x $\frac{4}{3}$ = 2667 (PER R. R. 4150); F_s = 32ᵏ



f'_m = 2500; NON-INSPECTED; n = 24

F_a = 250; F_b = 417 (x $\frac{4}{3}$ = 555); F_s = 24ᵏ (x $\frac{4}{3}$ = 32ᵏ)

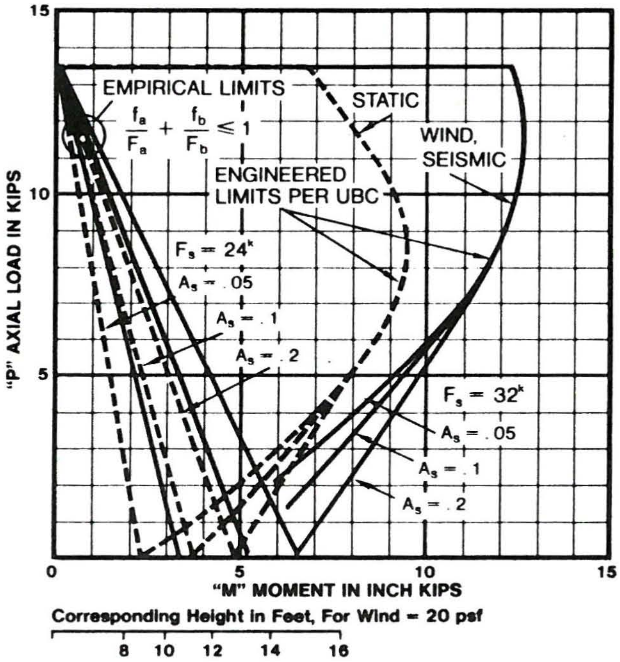


Figure 3

Higgins Hollow Brick

Tall Slender Walls

A joint ACI/SEAOSC test program recently evaluated and demonstrated the capacities of tall reinforced masonry walls to resist vertical and horizontal loads at heights greater than the empirical h/t limits of the code. (See photo.) An alternate to the UBC linear elastic method of design was developed to utilize those loads and deflection capacities in a rational and conservative manner with consideration of ultimate strength (UBC Research Recommendation No. 4189), in summary as follows.

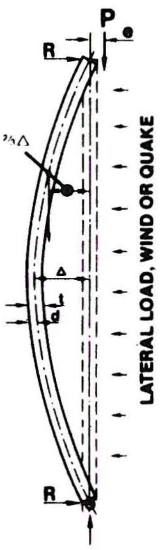
The wall load P is applied at its proper eccentricity, which deflects the wall causing a deflection Δ. That load P, plus the dead load of the wall above the mid-section, and the moment due to the eccentricity, including $P\Delta$, are resisted by the "ultimate" capacity of the wall. Steel is assumed at 40 ksi (max. p = .0060) or 60 ksi (max. p = .0040) and a masonry compression zone of .85c at .85 f'_m (ultimate compressive strength).

The deflection at mid height due to live and dead load plus wind or seismic is limited to $\Delta = 0.07\,h$. This restriction is to avoid distress such as at windows, doors or intersecting partitions. The walls could deflect much more than that with structural safety. The deflections are calculated as follows:

$$\Delta_s \begin{cases} \dfrac{5 M_s h^2}{48 E_m I_g} & (\text{for } M_s < M_{cr}) \\[2ex] \dfrac{5 M_{cr} h^2}{48 E_m I_g} + \dfrac{5 (M_s - M_{cr}) h^2}{48 E_m I_{cr}} & (\text{for } M_{cr} < M_s < M_n) \end{cases}$$

$$M_{cr} = S f_r$$

The high strength masonry provided by the Higgins Hollow Brick is shown to be very effective by this tested alternate method of design, as shown by the enclosed plot of the Hollow 5" wall (Inspected, at f'_m = 6000).



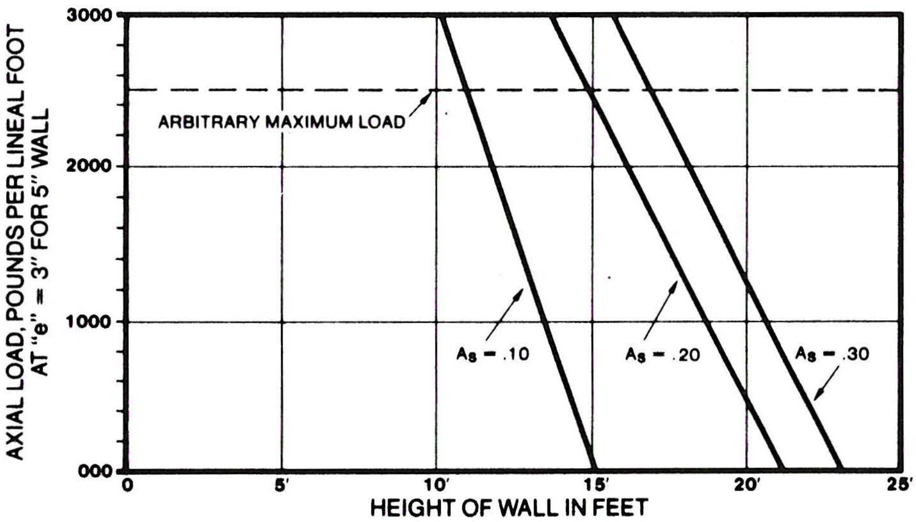


Figure 4

TALL SLENDER WALLS

The American Concrete Institute worked with the Structural Engineers Association of Southern California on a test program to determine the actual capacity of tall slender walls with eccentric vertical loading and uniformly applied wind or seismic load. As a consequence an alternate method of design was provided in the UBC to recognize this performance. It was rather amazing to see the actual startling deformations that were resisted while the walls were safely carrying the imposed loads.

The specific effect of this alternate design is shown for the five inch unit in the preceding excerpt from the Higgins brochure, Figure 4.

PROMOTION

It was recognized that any new unit or method, different from what had been used in the past, would have to be explained and promoted. An extensive educational program must be developed for professional education. Therefore, an audio-visual program was developed for the five inch unit, a lecture program for the five inch unit, and an audio-visual of the five inch prefabricated panel. Also a rather complete brochure was developed to make the use of the new unit simple and easy by use of precomputed data in the form of tables and curves. Typical folders with precomputed details for garden structures and garden walls were prepared. Also an extensive program of seminars was presented to explain the benefits and methods of use.

SUMMARY

* The Five Inch Hollow unit masonry is currently the most economical and effective reinforced masonry.
* The five inch is thin to save floor space.
* It is less weight than early thick, or two wythe, construction.
* It requires less costly arbitrary reinforcing.
* It requires less costly grout.
* It is small for excellent prefabricated panels.
* The laying is faster and more economical
* The full face shells permit splicing of economical joint reinforcing.
* The large grout cells permit easy grouting.
* The Fire Endurance is excellent for wide usage.
* The high strength provides greater capacity for bearing.
* The high strength provides for high resistance to bending.
* The high strength provides for maximum shear resistance.
* It serves well in Tall Slender Walls.
* Data is available for easy effective design.