VI–4. High, Thin Brick Walls That Can Beat the Energy Crunch

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ABSTRACT

High, thin economical brick walls have always been a challenge to produce, but now energy conservation restrictions are getting more and more stringent for masonry walls. The federal government, state governments, building departments, building codes, school boards and church boards are requiring lower and lower "U" factors and yet demanding more economical walls. These restrictions are causing masonry walls as we know them today to be eliminated from use even though the architects still want to use them. This paper covers the solution to one such problem.

High, thin, economical brick walls have always been a challenge to produce, but now the challenge is even greater, because energy conservation restrictions are becoming more and more stringent for masonry walls.

The federal government, state governments, building departments, building codes, school and church building boards are arbitrarily requiring lower and lower "U" factors (energy loss characteristics) and yet demanding more economical walls. These restrictions are causing time honored masonry walls, as we know them today, to be eliminated from use even though the architects still want to use them, and even though there has been no justification presented that these low "U" values are warranted, either in terms of the amount of actual heat loss through the wall or the cost effectiveness of the additional expense of construction and additional materials needed versus the small amount of energy saved.

However, until these actual heat losses and cost effectivenesses are established, the construction industry must find new wall designs and new construction techniques to meet these severe, though unnecessary restrictions.

Fortunately, modern building codes allow for the use of new innovative construction techniques in their administrative chapters such as Section 106, "Alternate Materials and Methods of Construction" of the 1976 Uniform Building Code. This section of the code was used to solve a problem created by these energy requirements.

The Problem: How to build a high, thin masonry wall designed to withstand normal wind loads and a seismic zone III earthquake load and yet have an average "U" factor, (thermal heat transmission) of .07 and in addition have an eccentric loading due to a load-bearing roof application. An additional requirement was that the architect and his owner wanted exposed clay brick on both surfaces of the wall for wearability, appearance, no maintenance and permanence. A design of such a wall was accomplished by designing a combination of several known and used walls. This 29½ foot high, 14 inch thick load bearing, reinforced brick heavily insulated wall was designed, engineered and constructed on a new gymnasium (West High School) for the Salt Lake City School District by Montmorency, Hayes & Talbot architects and Morris Page consulting engineer. This wall system is not specifically described in the Uniform Building Code but neither is it specifically prohibited, therefore, a detailed engineering analysis had to be presented for the design approval. The greatest consideration of a wall in seismic design is shear. The seismic forces must be resisted in the plane of the wall as well as perpendicular to the plane of the wall and must function as an integrated unit.

The "U" value of .07 is extremely low and can be achieved only by a cavity wall construction with 3 to 4 inches of foam insulation, but the cavity wall does not function well in a seismic application. A solid reinforced masonry wall functions well in a seismic design but is very poor according to the ASHRAE perscriptive "R" values for a solid masonry wall. Therefore a combination of the two was attempted.

A cavity wall with intra-wythe piers or pilasters was designed with a 3 inch cavity, filled with foam insulation with the intra-wythe reinforced pilasters spaced at 4 feet on center or 8 foot on center. A precise design was completed, taking into account the eccentric loading of the roof bearing, the high thin nature of the wall, the shear loading in the plane of the wall and the bending moment normal to the wall induced by the pressure and suction of the wind and the cyclic mode of application of earthquake forces. The integrally reinforced brick wall proved satisfactory in all instances, including the economic considerations, and was approved for use in the construction of the gymnasium. The building was built and is now in service. Since then several other structures have been designed and built using this high-thin hollow-wall technique.

THERMAL REQUIREMENTS:

The "U" value or Thermal Transmission value, was calculated using the ASHRAE technique of the parallel path method. That is, the flow of heat thru paths perpendicular to the wall. Each path is through a different material or combination of materials, i.e. one path through the solid grouted portion and one path through the insulated portion. Each path will have a different "U" value. Then the total area is divided into the percentage of areas apportioned to each particular path. With the intra-wythe pilasters spaced 4 foot on center, and the bond beams used to connect the wythes together, the area of solid concrete grout and brick is 10.5% and the heavily insulated areas account for 89.5% of the wall area. The "U" factor of the insulated area (.0457) is much lower than the "U" factor of the grouted areas (.385) and thus brings the overall average "U" value down to .07 which was arbitrarily required by the school district. A mass factor to account for the mass effect due to the heat flow resistance of the heavy masonry walls was also applied in a meager attempt to simulate the actual, real world conditions of heat flow.

The need for this insulation creates a novel twist to the construction of this "hi-R–low-U" masonry wall. The board-type foam insulation, when placed into the wall at the appropriate spacing and exact length, forms the cavity to be filled with grout to form the intra-wythe pilaster. By forming the grout space in this manner, the extra cost and effort normally needed to form masonry dams or wood forms to confine the grout on either side of the grout space prior to grouting is eliminated. Thus the cost of the insulation is reduced by the savings in the forming of the pilaster grout space.

STRUCTURAL CONCEPT:

The structural concept of this wall assembly is that of 2 individual wythes or 2 single thickness walls standing 3 inches apart and tied together with "webs", i.e. the pilasters, so that they perform like a series of "H" columns with 2-#6 reinforcement bars connected together by two horizontally reinforced wythes. Additionally, the assembly is rigidly contained at its extremities by structural connecting members at the ends and at the top and bottom of each section of wall or, if you will, a structural picture frame. These "webs" that rigidly attach and support the flanges (which allow them to act as one unit) are reinforced grouted pilasters in the vertical direction and full width-of-wall reinforced brick bond beams in the horizontal direction. The individual brick wythes connecting the pilasters usually span horizontally between these supporting pilasters.

The size and horizontal spacing of the vertical, intra-wythe pilasters are dependent on: 1, the bending moment on the wall due to the lateral loads and eccentric vertical loads; 2, the cross-sectional area of the pilasters; 3, the amount of steel in each pilaster. If the pilasters are made larger or if they contain more reinforcing they can be spaced further apart; but then, the span of the flange wythes between pilasters get larger and may need additional reinforcing. (This must be investigated.) Also, if the pilasters are more than 4 feet apart and the wall is built in a seismic area, additional vertical steel will have to be added to comply with the arbitrary "minimum steel- 4′ on center" requirements. This minimum steel requirement on this particular building made the 4 foot spacing the logical solution. In other areas of the country not requiring "minimum" steel, 6 foot, 8 foot, or greater spacing may be more appropriate.

The engineer, Morris Page, P.E. of Salt Lake City had several options to choose from when he decided on the overall thickness of the wall required. The typical solution is to use the required height to thickness ratio equal to 25. This results in a 14″ wall ($29.5' \times 12 \div 25 = 14$). This 14″ wall assemblage of 2 wythes of 6 inch thick Atlas hollow brick with 3 inches of rigid board-type insulation in between, supplied the "U" factor required. Had the overall coefficient of thermal transmission ("U") been less severe, the engineer could have reduced the thickness and hence the cost, by using one of several alternate methods of determining the required thickness. These methods include:

1. The use of the interaction formula in Section 2418 (g) of the UBC and the exception provided in Section 2417 (c) i.e. the h/t restriction are waived when substantiating data is submitted.
2. Create fixed-end conditions at the top or the bottom of the wall or both. Thus reducing the effective height (h′) to 80% or 60% of the clear height (h) respectively.
3. The use of the requirements of the U.B.C. Research Report #2727 which allows the employment of the more reasonable h/t of 36 instead of the arbitrary 25, but requires special foundation designs to be used. This system is fully investigated and illustrated in a structural design booklet titled "Tall-Thin Brick Walls" by John Tawresey, P.E. of KPFF Consulting Engineers of Seattle, Washington.

The engineer, Mr. Page, also had several "structural" options to choose from when he decided upon the shape of the pilasters in the wall. He could have used a single wythe filler wall with pilasters protruding out each side of the wall as in Figure 1 or the connecting filler wall could be replaced by two thinner walls spread apart to line up with the outside surface of the pilaster as in Figure 2, in order to accommodate the necessary insulation. This latter wall gave him the required "U" value as well as the required strength. While the first wall gave him the strength but not the required "U" value.

STRUCTURAL SOLUTION:

Excerpts from the author's preliminary design feasibility study for the West High School Gymnasium are included here to illustrate some procedures of the design technique. This feasibility study was also used and expanded by two senior civil engineering students (Bill Hughes and Mehradad Shahibi) at the University of Utah Civil Engineering School as the basis for a senior design project.

Professor Dave VanStreen was the student's sponsoring professor and aided materially in the review, expansion and evaluation of their project.

The conclusion of this university design project was that the system is valid and is a reasonable approach to an engineering problem; that the analysis presented here is correct and accurate; and that this design system successfully resolved a difficult problem.

This research paper reiterated that a double-wythe wall is not new, but this new combination of several established wall types, even though it is not described in any of the commonly used building codes, may well be the best answer to the severe energy requirements that threaten to prevent the use of most of the known masonry wall assemblages.

In the process of preparing his student research project, Mr. Bill Hughes collaborated with several local, practicing professional engineers. It is interesting to note that every practicing engineer shown the design agreed in principal with the concept, but each had a somewhat different approach to the analysis of this hybrid wall, but the method of construction used by Morris Page, P.E., the structural engineer in the actual building is almost identical to the design described here.

FULL SCALE DESTRUCTION TESTING:

Everyone involved with this project or consulted on it, including myself concluded that it would be extremely valuable and interesting to do a structural performance test

project on full scale walls. The major deterrent to this test, however, is the enormous scale of the project. The original design was based on 5 safety factors for working stress design and very conservative height reduction formulas, thus making the loading requirements on the test walls extremely large to cause actual destruction.

COST CONSIDERATION:

An important consideration in building any wall, regardless of the material, is the cost. Even though a better insulated wall will cut down on energy loss, it will probably never pay for the increase in cost due to the insulation. A cost estimate prepared by Western States Masonry, Masonry Contractor, on the gym concluded that a double wythe wall of 6-inch Atlas brick with 3″ of styrofoam SM board in between costs $10.81 per square foot, while a similar wall of 8-inch thru-wall, insulated Atlas brick costs $5.91 per square foot—a difference of $4.90 per square foot. A gym with dimensions of 240 feet by 110 feet by 25 feet high would have an added cost of $85,750.00 using the 6-inch brick and styrofoam SM board.

An energy flow measurement study of the Woods Cross LDS Church near Salt Lake City by Dr. Jay McGrew's research staff measured heat flow through two masonry walls. One wall was lightly insulated ("U" = .194), the other was heavily insulated ("U" = .07). The actual difference of heat flow in energy cost was two cents a year. The added insulation cost two dollars to install and at two cents a square foot per year saving that means it will take 100 years to regain the cost of the insulation in energy saved. That is *not* a reasonable pay-back period. Consideration should be given to the cost-to-benefit ratio.

CONCLUSION:

A frustrating and multi-faceted problem was presented and a novel and economical solution was developed and now, a new wall system is available for further use by the construction industry.

This hollow wall with structural "intra-wythe" pilasters supplied the structural solution, the thermal solution and the economical solution to the architects' needs.

A further refinement was added by making the two parallel wythes (flanges) out of hollow, load-bearing clay brick units called "Atlas" brick as specified by ASTM C-652 to reduce the overall wall weight thereby reducing the seismic forces generated and at the same time increasing the resistance to heat flow and thereby lowering the thermal transmission factor ("U" factor).

Even though this concept has been used on several large scale projects and is scheduled to be used on many others, it would still be of interest to have a full scale testing program to ascertain just how many extra safety factors it really has; five, six, ten or more?

The calculations at the end of this paper are from the preliminary feasibility study prepared by the author for use by the project engineer. The project engineer continued the design much further and in much greater detail, as did also the two civil engineering students mentioned above, in their senior design project. In the student project they checked the vertical load-bearing capacity and bending resistance by using the column reduction formulas and the interaction formulas:

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} = 1.33$$

It is recommended that a thorough rational analysis be completed when using this system of construction.

CONTRIBUTORS:

Appreciation for assistance is gratefully extended for their help and assistance in taking an idea and making it into a viable reality. The contributors are:

Morris Page, Professional Engineer
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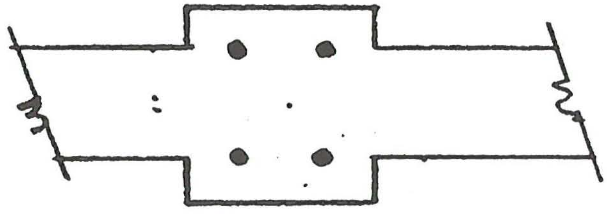


Figure 1.

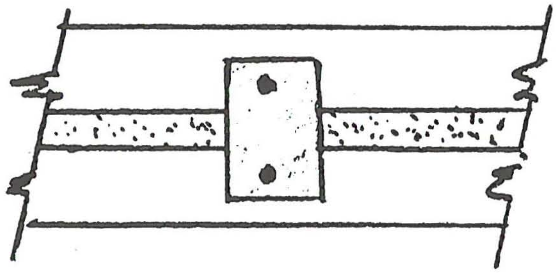
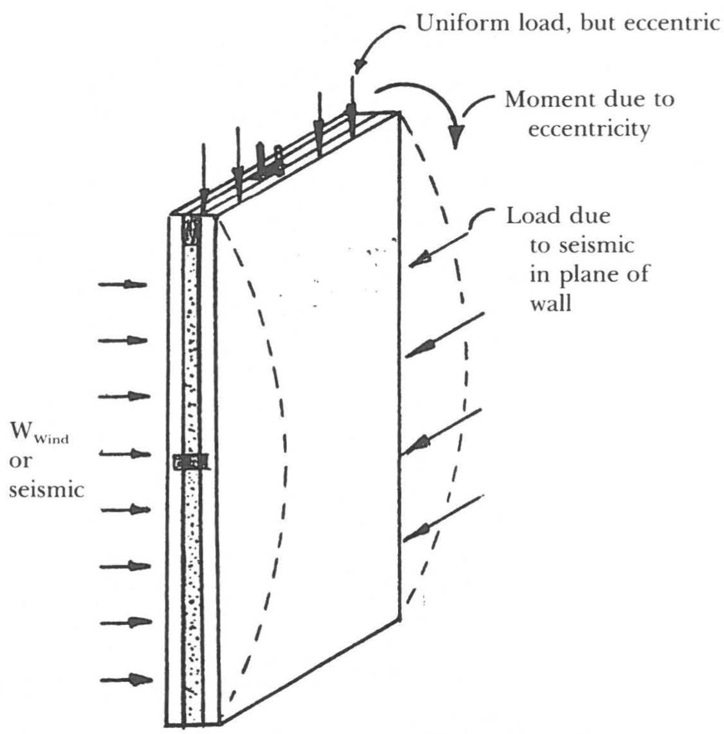
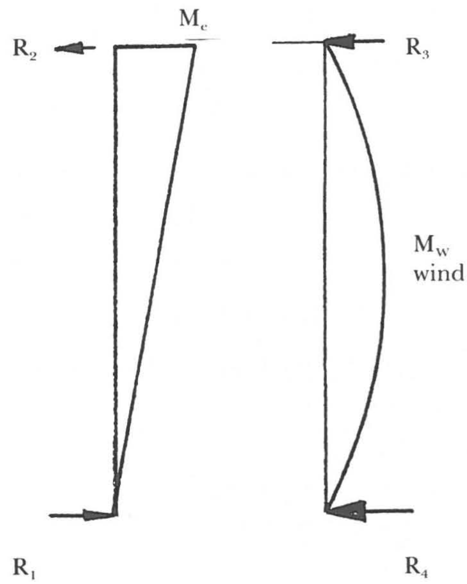


Figure 2.

APPENDIX

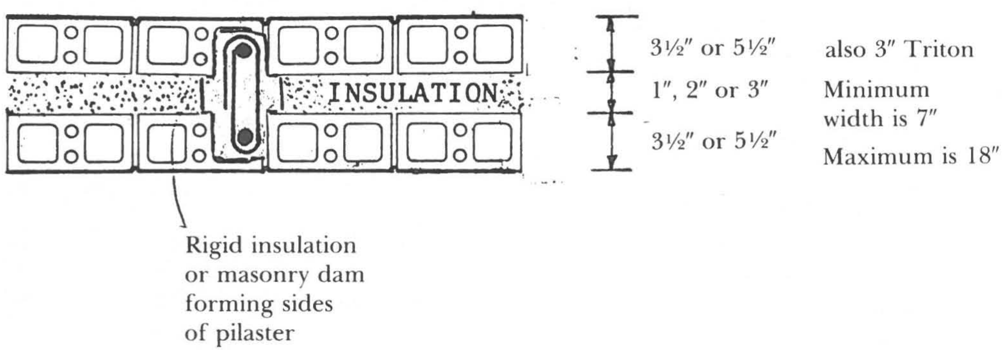
Design of masonry walls constructed of two wythes separated by insulation, but tied together by reinforced intrawythe pilasters so as to create composite action under wind and seismic loading.





Moment Diagram

b′ = 7″ at 4′-0″ o.c.



Note: Width of pilaster can vary from 3″ to any width.

W or uniform horizontal load due to wind and earthquake

$W_{Seismic} = Z\ I\ C_pS\ W_p$

$3/4 \times 1.25 \times .20 \times 1 \times 86\# = 16.13\#$

$W_{Wind} = 16\#$ positive & 13 #/□′ Negative

∴ Use 16#/□′ for both in and outward pressure

PROBLEM: To design a wall 29′-6″ clear height with a uniform roof load with a 4″ eccentricity & zone 3 seismic load.

P = roof load = 1526#/Lin.Ft. Dead load
+ 817 Snow load
2343#/L.Ft. Total

Eccentric moment = Pe = 2343#/L.Ft. × 4′ = 9372#

$$\text{Seismic Moment} = \frac{Wl^2}{8} = 16\#/\square' \times 29.5' \times 29.5' \times \frac{12}{8}$$

$= 20{,}886\#''/\text{Lin.Ft.}$

REACTIONS:

$$R_{2+3} = \frac{wl}{2} + \frac{M_1 - M_2}{l}$$

$$= \frac{16 \times 29.5}{2} + \frac{9372 - 0}{29.5 \times 12}$$

$$= 236 + 26.5 = 262.5\#$$

$$R_{1+4} = \frac{wl}{2} - \frac{M_1 - M_2}{l}$$

$$= 236 - 26.47 = 209.5\#$$

$$\text{Mom. Max.} = \frac{wl^2}{8} - \frac{M_1 + M_2}{2} + \frac{(M_1 - M_2)^2}{2\,wl^2}$$

$$= 20{,}886 - \frac{9372}{2} + \frac{9372^2}{2 \times 16 \times 29.5^2 \times 12}$$

$$= \underline{\underline{25{,}309}}''\#\ \text{Neg. Wind}$$

$$= 16462.84\#''\ \text{Positive Wind}$$

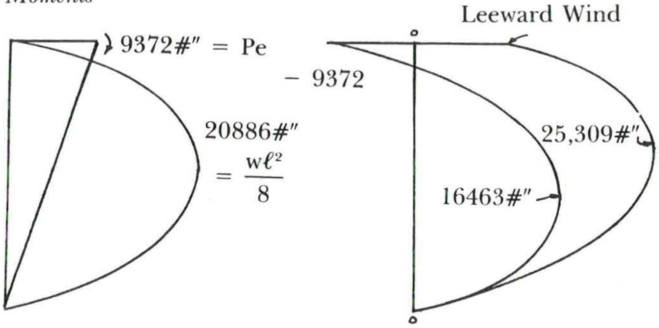
$\therefore$ Max. Moment = 25,309#"

at 13' above base

$$\text{or } \sqrt{\frac{l^2}{4} - \frac{(M_1 + 0)}{(w)} + \frac{(M_1 - 0)^2}{(wl)}}$$

$$= \sqrt{31{,}329 - 7045 + 2.73} = \frac{155.84}{12} = 13\ \text{Ft.}$$

Moments



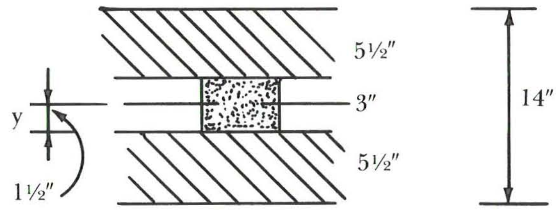
Combined Moments

If both wythes are similar material and units, design for maximum moment of 25,309#". If not, design for weakest material assumed on both sides. Check for resisting moment of section thru solid masonry and grout per inch wide. Using Salt Lake Co. Code and inspected stresses

$$\text{Mom Resisting} = 1/2\ f_m\,kjbd^2 = 1/2\ (.33 \times 5000) \times .85 \times .45 \times 1 \times 11.25^2 \times 1.33 = 53{,}655\#''/\text{inch}$$

The width of the grout (concrete) web is predicated by the end shear (diagonal tension) and the horizontal shear developed in it.

CHECK FOR HORIZONTAL SHEAR:



$$S_s = \frac{VQ}{Ib} \therefore b = \frac{S_s I}{VQ}$$

V per foot = 263#

$$S_s = \frac{V}{2I}\left(\frac{h^2}{4} - y^2\right)$$

S_s max. = 70 psi by ACI 318

$$V_{all.} = \frac{S_s \times 2I}{\left(\frac{h^2}{4} - y^2\right)}$$

$$= \frac{70 \times 2 \times 228.67}{\left(\frac{14^2}{4} - 1.5^2\right)}$$

= 685#/Inch at interface of brick and grout

$$\frac{685\#}{263} = 2.6\ \text{S.F.} \qquad \text{o.k.}$$

AT CENTER LINE

$V = 2/3\ b\,h\,S_s = 2/3 \times 14 \times 70 = 653\#/\text{Inch}$

		Thickness
V = 263# Per Ft.	4 ft. spacing needs $\frac{263 \times 4}{653}$ =	1.61"
	6 ft. spacing needs	2.42"
	8 ft. spacing needs	3.22"
	10 ft. spacing needs	4.03"
	12 ft. spacing needs	4.83"

DIAGONAL TENSION IN MASONRY

	Spacing		*Thickness*
V = vbjd = 50 × 1 × .85 × 11.5	4'	=	2.14"
= 488.75#/Inch	6'	=	3.23"
	8'	=	4.30"
	12'	=	6.46"

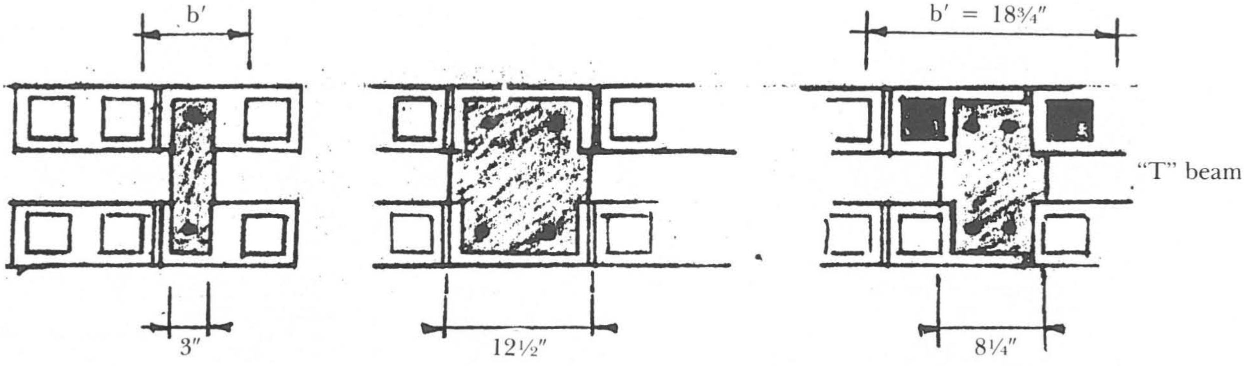
with inspected stresses

Mom. Resisting as per 1976 UBC

$$= 1/2\ (.33 \times \underset{f_m}{2700}) \times \underset{j}{.909} \times \underset{k}{.273} \times \underset{b}{1} \times \underset{d}{11.25^2} \times 1.33 = \underline{18{,}797}\#''/\text{in.}$$

using 1/3 increase for wind and seismic.

Types of intrawythe pilasters



Many sizes and configurations can be achieved by cutting out different webs. The width of the compression flange (b′) can be 6 times the width of the shell if the units are hollow *or* 6 times this width of the wythe if the units are solid or grouted solid, *plus* the width of the web. The width of the web is determined by the space formed by the insulation or the masonry (or wood) dams.

Steel required — d = 11.5″

A_s = <u>25,309 #″</u> grade 40 steel

20,000 psi × .85 × 11.5 × 1.33 = .097 □″/Ft.

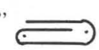
Spacing of pilasters

4′ = .39 □″	or	1 #6ϕ		
6′ = .58 □″	—	1 #7ϕ	or	2 – #5ϕ
8′ = .78 □″	—	1 #8ϕ	or	2 – #6ϕ
10′ = .97 □″	—	2 #7ϕ		
12′ = 1.16 □″	—	2 #7ϕ		

Note: When pilasters are more than 4 ft. on center, additional "minimum" steel must be placed in the cells of the hollow units. Minimum steel would be #5ϕ at 48″ o.c. for the 6″ wythes.

Width of "b" or compression flange for different spacing of pilasters

	Spacing		*Minimum thickness of "b"*
max. mom = 25,309#″/ft.	4′	—	5.39″
resisting mom. = 18,797#″/in.	6′	—	8.08″
	8′		10.77″
	10′		13.46″
	12′		16.16″

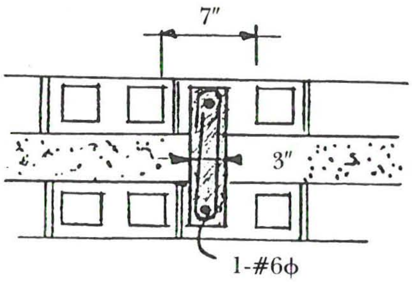
Stirrups — 1/4″ϕ "hairpins"  @ 12″ o.c. vertically in middle
or ties

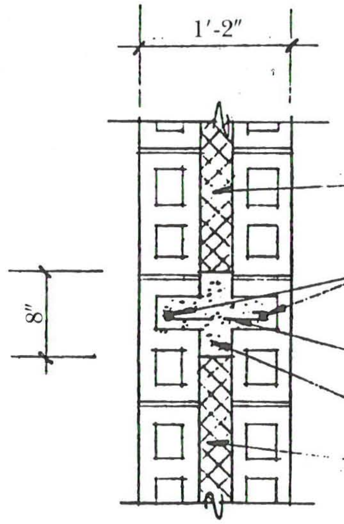
and

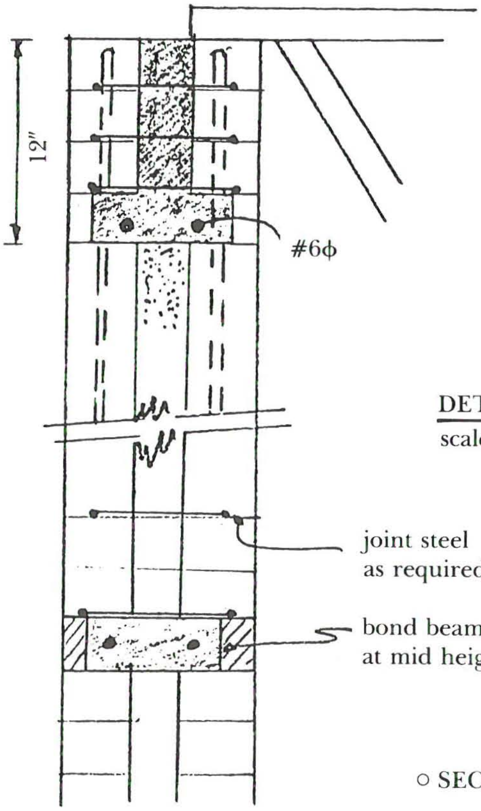
@ 8″ for 4′ top and bottom

Example for 4′-0″ spacing

○ PLAN VIEW ○







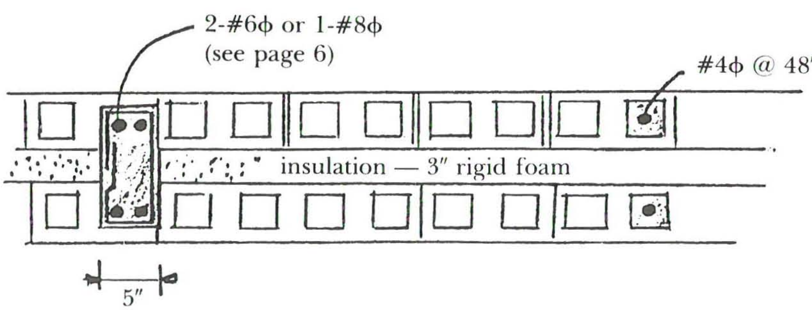
DETAIL — PLAN

scale: ¾″ = 1′-0″

K
S-4

Note: Actual detail from engineer's drawings.

○ SECTION ○



typical for 8 ft. spacing

○ PLAN VIEW ○

HEAT LOSS FACTOR — "U"

$$\text{“U”} = \frac{1}{R_t}$$

$$R_t = \frac{1}{R_o}\,\frac{1}{R_b}\,\frac{1}{R_I}\,\frac{1}{R_b}\,\frac{1}{R_{in}}$$

$$R_b = 1.15$$

$$R_o = .17$$

$$R_{in} = .68$$

$$R_{UFC} = \frac{3.0}{.20} = 15 \text{ for 3″ thick}$$

$$R_{Styrofoam} = \frac{3.0}{.185} = 16.22$$

$$R_{Polyurethane} = \frac{3.0}{.16} = 18.75$$

"U_o" total = "U_w" of wall with insulation × framing factor × mass factor

Therefore: U_o for a 14″ wall w/2 wythes of hollow 6″ Atlas plus a 3″ insulated space between.

Thru insulated part

$$R_W = .17 + 1.15 + 18.75 + 1.15 + .68 = 21.90$$

$$U_w = \frac{1}{21.90} = \underline{\underline{.0451}}$$

$$R_{W_2} = .17 + \frac{14}{8.0} + .68 = 2.6$$

$$U_{W_2} = \frac{1}{2.6} = \underline{\underline{.385}}$$

Framing factor

In every 48″ of wall there is 3″ of grout pilaster

∴ 29.5′ × 4′	= 118.0 Sq.Ft.	
Vertical core — 28.17 × .25	= 7.04	
Insulation — 28.17 × 3.75	105.64	
Top bond beam — 4 × 1.00	4.00	
Mid ht. bond beam — 4 × .33	1.32	
	118.0	Ft.

$$\text{Distribution factor} = \frac{105.64}{118.00} = \text{Insul. } 0.895$$

Solid

℄ 0.115

U_o	%	
.0457	× .895	= .0409
+ .385	× .105	= .0404
U_{wff}		.0813 adj.

Mass factor = .90

$$U_o = .0813 \times .9 = .0732 = \underline{\underline{.07}}$$