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Publication of conference paper texts include --(1) history and development of masonry cavity walls, (2) recent research related to determination of thermal and moisture resistance, (3) wall design and detailing, (4) design for crack prevention, (5) mortar specification characteristics, (6) performance experience with low-rise buildings, (7) performance experience with high-rise buildings, (8) techniques for construction economy, and (9) thermal economics and ultimate costs. Also included are abstracts of each paper, the text of an open forum discussion, and a list of previously published conference proceedings. (MH)

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INSULATED MASONRY CAVITY WALLS

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publication 793

INSULATED MASONRY CAVITY WALLS

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Abstracts of Conference Papers

HISTORY OF MASONRY CAVITY WALLS
Harry C. Plummer, Structural Clay Products Institute

This paper traces the development and use of masonry cavity walls from approximately 1930 to the present date, including the early testing processes used to establish the structural properties of such construction. Acceptance by code officials is discussed and some of the pioneer work in this country is mentioned.

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REVIEW OF RECENT RESEARCH
C. B. Monk, Jr., Structural Clay Products Research Foundation

The major constructional features of a standard cavity wall are defined, and the author then reports recent research to ascertain the thermal, water and water vapor resistance of a cavity wall filled with insulation. The influence of the introduction of a cavity between two wythes of face brick is discussed in terms of the cost in dollars per sq. ft.; the U factor in terms of Btu per sq. ft. per $^{\circ}F$; the percentage of increase in cost; and the percentage of heat loss reduction. A summary of thermal tests is presented in tabular form and analyzed, as is a summary of vapor transmission tests. Test results are said to establish that the cavity fill insulation, to be economically significant, should increase the thermal resistance over 50% at a cost not to exceed 10 to 20¢ per sq. ft. installed.

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DESIGN OF INSULATED MASONRY CAVITY WALLS
Werner Gottschalk, Severud-Elstad-Krueger Associates

Convincing performance of cavity walls requires compliance with building codes, which means complete or substantial concurrence of cavity wall sections with code requirements for solid masonry walls (unbraced spans, cross-sectional area, etc.). Excellence of workmanship and adequate details of support, lateral bracing, strut action at openings, disruption of homogeneity of wall by flashings are also mentioned as primary considerations in the design of such construction. Detailed discussion of cavity walls divides them into bearing walls, panel walls and curtain or enclosure walls. Emphasis is also laid on the importance of ties in the cavity wall assembly and types of ties, tie materials and coatings are analyzed. The author also points out why results of laboratory type tests are no more than an indication of what may be expected in field performance.

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DESIGN FOR CRACK PREVENTION
J. Neils Thompson and Franklin B. Johnson, The University of Texas

Foundation movements, thermal load distribution, structural configurations, static and dynamic loads and mechanical properties of the materials must be considered in the design of cavity walls to resist cracking. Each of these factors is discussed, along with examples of construction where cracking has occurred. Design recommendations are made that should aid in the prevention of cracking.

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MORTAR FOR CAVITY WALLS
Cyrus C. Fishburn, National Bureau of Standards

The flexural strength of masonry walls depends on the bond between masonry units and the mortar. The ASA Standard A41-1953 recommends the use of ASTM C270 Type M or Type S mortar in cavity walls subjected to wind load in excess of 20 psf. Portland cement or portland blast-furnace cement blended in sufficient quantity with either lime or a masonry cement is a suitable material for such mortars. Mortars with a water retention higher than that specified in C270 are also desired; such mortars will not readily segregate at the wet consistencies conducive to high bond strength. The 28-day compressive strengths of the Type S mortars giving the high bond strengths are shown to have exceeded 2,000 psi, even when mixed to flows over 140%. The cementing materials in these bond-test mortars were tested as masonry cements in accordance with ASTM C91 and yielded mortars having compressive strengths in excess of 3,000 psi.

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PERFORMANCE EXPERIENCE WITH LOW-RISE BUILDINGS
Harry B. Zackrison, Sr., U. S. Army Office of Chief of Engineers

This paper covers the experience of the Corps of Engineers with cavity walls used in low-rise buildings constructed for the Army and the Air Force. The type of cavity wall construction employed on specific buildings is described and illustrated, as well as the conditions and specifications set down by the Government which such buildings must meet. Replies made by the field officials of the Corps to a set of questions about their experiences with this type of wall are then reported. These relate to weep holes, leakage, flashing, control joints, shrinkage or cracking, waterproofing, heat losses, etc.

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PERFORMANCE EXPERIENCE WITH HIGH-RISE BUILDINGS
C. B. Litchfield, LaPierre, Litchfield & Partners, Architects

This paper relates the experience of the author's architectural firm as a pioneer in the design of cavity walls since 1920, and the actual performance of such walls in a number of buildings of high-rise construction. Emphasis is on an unfilled cavity where the insulation values are derived from the materials of the two wythes and the cavity space, with drain openings only at the bottom of the cavity.

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CONSTRUCTION AND INITIAL COST
Harold W. Peterson, Harold W. Peterson & Sons, Inc.

The importance of good workmanship is pointed out, with particular emphasis on the need to keep the cavity clean. Several techniques for accomplishing this are discussed. The necessity for a good system of ties is also stressed and the various types of ties are discussed in detail. Methods of constructing effective weep holes are presented. Initial costs are analyzed in terms of average figures drawn up by the Mason Contractors Assn. of America and include costs per square foot for labor, materials, cleaning, overhead and profit.

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THERMAL ECONOMICS AND ULTIMATE COSTS
C. T. Grimm, Zonolite Company

A study of the effects of insulation in masonry cavity walls on the present and ultimate costs of the walls is reported. Computations made are based on data presented in the Structural Clay Products Institute report, "Ultimate Cost of Building Walls." The author details 15 cost items which must be studied to determine the relative economics of wall types, and presents graphs and tables showing the relationship between first cost and ultimate cost for glass and metal walls as compared to masonry cavity walls.

History of Masonry Cavity Walls

By Harry C. Plummer,* Director, Engineering & Technology Dept.
Structural Clay Products Institute

Since insulated cavity walls may be considered a modern development of the cavity walls that have been used in Great Britain for many years, and early in this century were considered conventional construction for exterior load-bearing walls, perhaps a brief review of the development of cavity walls in this country is in order.

Demolition projects have disclosed that cavity walls were built in the United States 60 or more years ago. However, there appears to have been little use made of cavity walls in this country during the first 30 years of this century, and the earliest reference we find to them in technical literature published in the United States is a mimeographed publication of the Brick Manufacturers Association of America, since merged with Structural Clay Products Institute, entitled "Engineering Notes on Brick Masonry," Bulletin No. 2. This publication describes the cavity wall, to which it refers as "the barrier wall," as a 9-1/2" hollow wall laid in common bond without headers, and consisting of two wythes spaced 2" apart and bonded together at every fifth course with metal ties on 12" centers. The metal ties were 1/4" round rods bent in the form of Z's; the total length of the rods before bending being approximately 12", thus providing 3" legs on the Z tie. This bulletin also reproduces data and construction details published by the Clay Products Technical Bureau of Great Britain.

The following year, the Federal Housing Administration issued General Ruling No. 68, dated August 17, 1937, accepting cavity walls as described in the brick manufacturers' bulletin "for exterior enclosing walls of dwellings otherwise eligible for mortgage insurance."

Since that time, interest in and use of cavity walls in this country has constantly increased and, as a result of this, extensive tests have been conducted to determine the properties of cavity walls built of masonry materials available in this country. Many of these tests were conducted at the National Bureau of Standards as part of its building materials and structures testing program and, in 1939, the Bureau published three BMS Reports on structural properties of various types of cavity walls. Subsequently, the Bureau published reports on strength and resistance to corrosion of ties for cavity walls, and on the fire resistance of cavity walls.

*PLUMMER, HARRY C., Secretary, Structural Clay Products Research Foundation; B.A., Ohio State University and B.S. in Civil Engineering, Case Institute of Technology; Member American Ceramic Society (Fellow), American Society of Civil Engineers, American Society for Testing Materials, American Standards Association, Building Research Institute and Secretary-Treasurer of Construction Specifications Institute; associated with SCPI since 1937.

Under date of May 20, 1953, the Bureau published BMS Report 136, Properties of Cavity Walls, which summarizes the data included in previous reports and includes hitherto unpublished data on heat transmission. Structural properties, reported in BMS-136 are compressive strength, transverse strength, resistance to concentrated and impact loads and racking strength. The report also includes data on water permeability, heat transfer and fire resistance.

With the increasing use of air conditioning in both residential and commercial buildings, the need for increasing the resistance of cavity walls to heat flow became apparent, and the Structural Clay Products Research Foundation, in cooperation with Owens-Corning Fiberglas Corporation, developed a pouring type of fiberglas insulation which tests indicated would perform satisfactorily within the cavity. This construction was described in the May 1951 issue of Technical Notes of the Structural Clay Products Institute.

Subsequently, research on cavity walls has been continued, some of the results of which will be reported at this meeting.

In January 1944, the American Standards Council approved American Standard Building Code Requirements for Masonry which cover cavity wall construction. At this time, neither the National Code of the National Board of Fire Underwriters nor the Uniform Code of the International Conference of Building Officials, the principal codes available, covered cavity wall construction, and few local codes permitted its use except under special permits.

As ot today, both the National Code and the Uniform Code provide for cavity wall construction, as well as the Basic Code of the Building Officials Conference of America, and the Southern Code of the Southern Building Code Congress. Many municipal codes also permit cavity wall construction, as indicated by a survey conducted by the Structural Clay Products Institute during the spring of 1957.

Questionnaires were addressed to the building officials of 239 cities in the United States having a population of 50,000 or more, and 124 replies were received, a 52% response. One question asked was: "Does your building code permit the construction of masonry 10" cavity walls, (a) as load-bearing in residential and nonresidential, and (b) as nonload-bearing in spandrel, panel or curtain walls?"

Of the replies received, 84% permit load-bearing cavity walls in residential construction; 68-1/2% permit these walls in nonresidential construction: and 86-1/2% permit nonload-bearing cavity walls for spandrel or curtain walls. This widespread acceptance of cavity wall construction in building codes during a period of 20 years is some indication of the interest of designers in this type of construction.

The early use of cavity walls in this country was limited primarily to exterior load-bearing walls, one and two stories high, and this appears to be true in England also, since Fitzmaurice of the Building Research Station of England makes no mention of cavity walls in skeleton frame construction in his book, "Principles of Modern Building," published in 1939. However, in this country, designers of high-rise buildings soon recognized the advantages of cavity walls and early in the 1940's began to use them for the design of curtain and panel walls.

Pioneers in this field include the architectural firm of Alfred Hopkins and Associates (now LaPierre, Litchfield & Associates), the structural engineering firm of Severud-Elstad-Krueger Associates, and U. S. Corps of Engineers, all represented on this program.

Problems still arise in the design of cavity walls to provide for differential movements between the walls and other elements of the structure. However, much has been learned from experience during the past 20 years, and the pooling of this experience through conferences such as this should go far toward solving these problems.

Review of Recent Research

By C. B. Monk, Jr., * Manager of Architectural & Engineering Research,
Structural Clay Products Research Foundation

Introduction

Cavity wall construction is theoretically superior to its equivalent solid wall construction in both thermal and water permeability resistance. The deliberate separation of the two wythes of the equivalent solid construction is to interrupt water penetration through the wall, and the air space so formed substantially reduces the heat flow. The effect of cavity construction on vapor transmission is not so obvious; the over-all vapor permeance remains unchanged but the location of the dew point is altered by the increased thermal resistance from the air space. While structural resistance is beyond the major interest of this paper, for the sake of general completeness it is to be noted that unless special care is taken to load a cavity concentrically, most of a bearing load may be delivered into one wythe due to general detailing practice. This is of no serious consequence since the full bearing capacity of most masonry walls is seldom utilized. However, the transverse resistance of a cavity wall is expected to be weaker than its equivalent solid counterpart, as the metal wall ties commonly employed in tying the two wythes together cannot develop flexural shear resistance between the two wythes, but merely act as compression struts or tension ties to distribute lateral loads equally to each wythe.

While theory suggests that an equivalent solid wall should be twice as strong as a cavity wall, "the ratio of unsupported height to nominal thickness or the ratio of unsupported length to nominal thickness (one or the other but not necessarily both) shall not exceed 20 for solid masonry and 18 for cavity walls for which the thickness shall be the sum of the nominal thicknesses of the inner and outer wythes."(1) Thus, the ratio of solid wall lateral strength to cavity wall lateral strength is 10:9 as allowed by standard codes. This discrepancy with the theoretical relative strength value may be due in part to the lack of insufficient bond existing between wythes of solid walls despite the presence of a collar joint. It has been demonstrated by test(2) that the lack of a completely filled collar joint may cause a solid 8" wall to approach the strength of two 4" walls acting separately as in cavity construction. Code requirements are largely based on historical performance of masonry walls

(1)Raised numbers in parentheses refer to List of References at end of paper.

*MONK, C. B., Jr., B. S. in Architectural Engineering, Pennsylvania State University, M. S. in Structural Engineering, University of Illinois; Member of American Society of Civil Engineers, Building Research Institute, National Society of Professional Engineers; formerly associated with Armour Research Foundation and with the theoretical and applied mechanics department, University of Illinois.

Definition of an Insulated Cavity Wall

It is well for the purposes of this paper to describe the major constructional features of a standard cavity wall. By standard code requirements the minimum wythe thickness is 4" with the cavity being not less than 2" nor more than 3" wide. Hence, the minimum thickness of cavity construction is a nominal 10" which is typical of the majority of those built in practice. As stated before, lateral support (either horizontal or vertical) shall be provided every 18 times the sum of the thickness of the wythes. A height limitation of not to exceed 25' above the support of such walls is usually imposed. The facing and backing of all cavity walls shall be bonded with corrosion-resistant metal ties, one for every 4-1/2 sq. ft. of wall area, staggered in alternate courses, with the maximum vertical distance between ties not to exceed 18", and the maximum horizontal distance not to exceed 36". Ties are to be 3/16" diameter steel rods or metal ties of equivalent stiffness; such ties may be rectangular shape (particularly with hollow masonry units) or Z-shaped to provide hooks not less than 2" long. Around openings ties shall be not more than 3' apart within 12" of the opening. It is to be noted that masonry ties are not permitted in this definition of a cavity wall. To insure proper water drainage of the cavity, the base should be flashed and provided with weep holes about every third head joint.

As defined above, a cavity wall filled with insulation has been investigated for its thermal, water and water vapor resistance and the results reported in this paper. One special design advantage of the insulated cavity wall is to permit exposed masonry interiors with high thermal resistance at an economic level. This is evident if we compare the cost[3] and U factor[4] of a double wythe of face brick first as a solid 8" wall, second as a 10" cavity with a still air space, and third as an insulated cavity wall.

TABLE I

Influence of the Introduction of a Cavity Between Two Wythes of Face Brick

Wall Type (Exposed Brick Both Faces)	Cost $/SF	U Btu/SF °F	% Cost Increase	% Heat Loss Reduction
8" solid (uninsulated)	2.80	0.61	0	0
10" cavity	3.10	0.38	10.7	37.5
10" insulated cavity	3.25	0.13	16.1	78.7

The 10% additional expense of building a cavity wall (due primarily to the cost of wall ties plus the additional labor of laying each wythe to a line) is more than offset due to increased thermal efficiency from the air space. For about a further 5% increase of cost a cavity wall can be filled with loose fill insulation to reduce the heat loss by nearly 80% over the uninsulated solid wall. Thus, the performance of the cavity fill is critical to the success of the insulated cavity wall. The following criteria are listed as being important to an adequate cavity fill insulation. It should:

1) Permit the cavity to function in its traditional way as a moisture barrier against chance penetration of wind-driven moisture through the exterior wythe. Essentially, the insulation must permit such moisture to drain without transmission to the interior wythe.

2) Not have its thermal efficiency impaired from probable quantities of moisture due to wind-driven rain or vapor condensation within the cavity.

3) Enable the over-all thermal coefficient to be less than U=.15. This requires an insulation of k=.5 or less.

4) Be capable of supporting its own weight in cavity heights up to 25'.

5) Preferably be inorganic or have comparable rot, termite and fire resistance properties.

6) Be pourable into the cavity in lifts of not less than 4' for practical field installation.

Aspects of the above criteria were investigated in detail by the Structural Clay Products Research Foundation through water permeability, heat flow, and vapor transmission tests in sponsored work done at Armour Research Foundation and Pennsylvania State University and work at its own laboratory in Geneva, Ill. As indicated in the list of references, some of the recent work was sponsored and performed jointly with the Vermiculite Institute. Two kinds of cavity fill insulation have been proved successful by this work: Pouring type glass fiber insulation and water repellent vermiculite loose fill insulation.

Water Permeability Tests

Based on prior test[5, 6] of water permeability of masonry walls by the National Bureau of Standards, suitable testing equipment was developed.

For the glass fiber tests (Fig. 1) a test specimen 16" wide and 96" high having a full 10" depth with cavity was employed. To the face of the apparatus was clamped an aluminum chamber with viewing ports inside of which a sheet of water was maintained flowing over the wall face under a pressure of 2" of water (about 10 psf or the force of a 60 mph wind). Based on the flow rate used in the National Bureau of Standards test (40 gal. per hour over an exposed wall area approximately 3' x 4'), it has been computed that the equivalent rainfall rate was nearly 5-1/2" per hour assuming that a 60 mph wind would impinge the rain droplets horizontally at the same rate as rain accumulation on a horizontal surface. The inside of the interior wythe was coated with a whitewash containing a blue dye that readily detected the presence of moisture. As established by the Bureau of Standards the water permeability resistance of masonry walls have been rated[6] Excellent, Good, Fair, Poor or Very Poor, depending on the amount of dampness and the time at which it first appeared, plus the amount of water leakage, if any. Using these criteria the exterior wythe was made deliberately to leak as a "Very Poor" (rate of leakage equal to or greater than 5 liters per hour) wall to test the effectiveness of the cavity wall fill for a moisture barrier. Typical results of the effectiveness of the dye as a detector of moisture are shown in Fig. 2 which shows the progression of dampness for a cavity filled with a non-water repellent insulation fill.[7, 8]

The glass fiber fill gave a performance that would be rated as "Excellent" according to the Bureau of Standards rating. This rating requires that no water be visible on back of the wall at the end of one day, not more than 25% of the wall area damp at the end of five days, and no leakage through the wall in five days. This particular test was extended to a sixth day as a small area of dampness (less than 25%) did appear at the end of the second day that proceeded to dry immediately, showing no further progress, the wall being totally dry at the end of the sixth day. The base of the cavity was so arranged that leakage draining primarily from the cavity face of the exterior wythe could be collected separately from that at the back of the cavity. Of the total leakage collected from the cavity

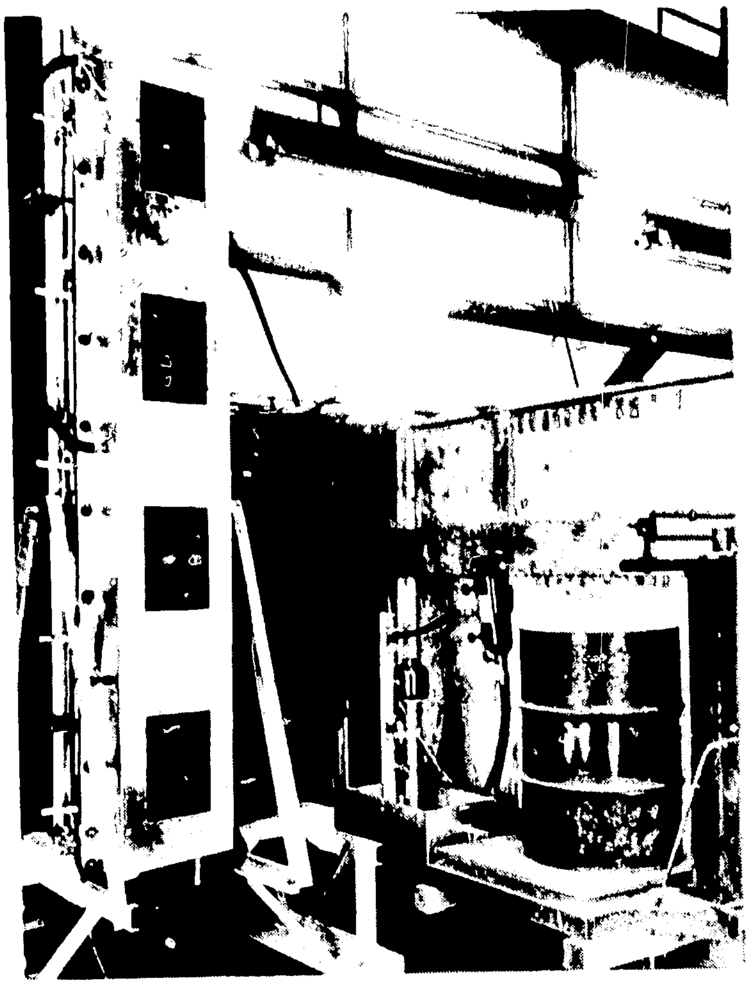
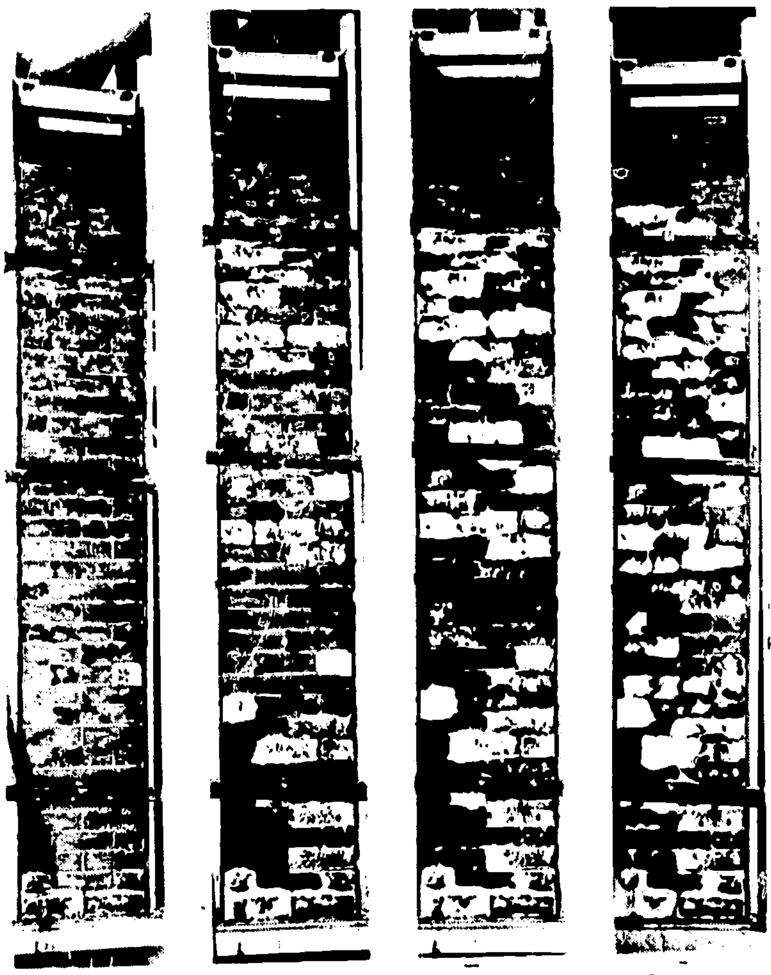


Fig. 1 - Water permeability apparatus used during the glass fiber test.



After 24 hrs. After 48 hrs. After 72 hrs. After 120 hrs.

Fig. 2 - Patterns of moisture penetration on back of cavity wall as detected by a whitewash coating containing a blue dye.

due to the arbitrary "Very Poor" exterior wythe, 99% was collected at the front and 1% at the back, suggesting that most of the leakage drained directly down the inside face of the exterior wythe. At the end of the test the glass fiber was removed and found dry to the touch, but did contain 14% moisture by weight. The dry density in place was about 4 lbs/ft^3. No consolidation or slump was observed in any tests with glass fiber. To insure that a pressure gradient was maintained across the exterior wythe, manometer readings were taken at quarter point positions along the height of the cavity. Such measurements indicated no pressure equalization by air flow through the weep holes (as the exterior pressure was varied from 14" to 2" the cavity pressure changed from 0.2" to 0.075").

In the water repellent vermiculite test a modified test procedure used a 4' x 8' specimen with a simple polyethylene pressure chamber (Fig. 3). In this case the interior wythe was omitted; plate glass sheets were placed in lieu of an interior wythe to create a cavity, subsequently filled with water repellent vermiculite (Fig. 4). (This technique had been used in the first glass fiber tests and found satisfactory). Test conditions of a continuous sheet of water over a deliberately created "Poor" (rate of leakage equal to less than 5 liters per hour but greater than 1 liter per hour) exterior wythe maintained under a 2" water pressure was again used as in the glass fiber test. A blue dye was placed in the water to aid in the detection of the water permeation, if any, through the vermiculite.(9)

The vermiculite test was continued for a total of six days. Under the simulated weather conditions there was no visible permeation of the water across the cavity space through

Fig. 3 - Modified water permeability apparatus using a polyethylene chamber during the tests of water repellent vermiculite.

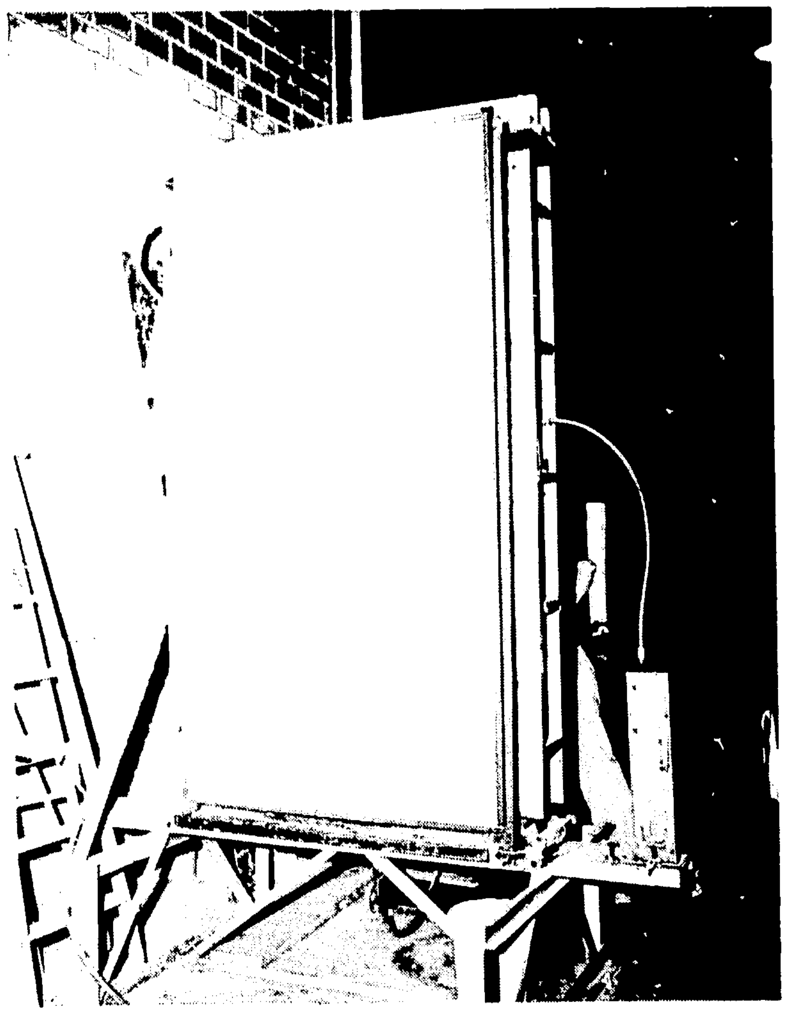


Fig. 4 - Cavity space created by plate glass sheets as part of modified apparatus.

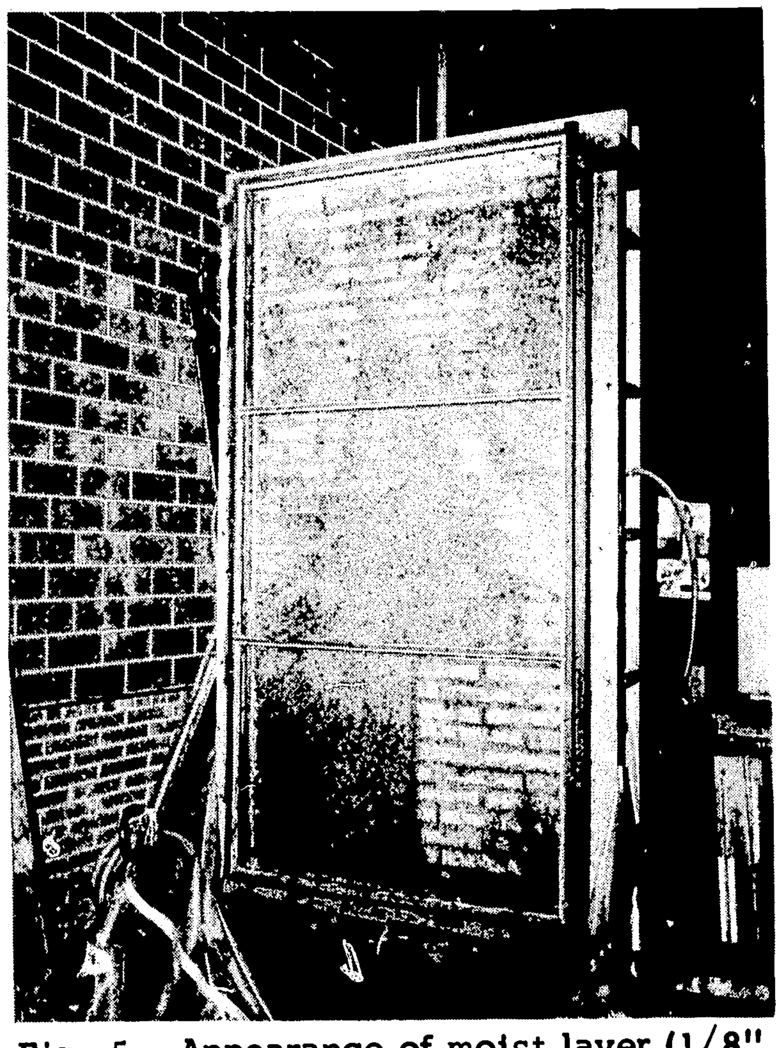


Fig. 5 - Appearance of moist layer (1/8" to 1/4" thick) of vermiculite clinging to cavity face of exterior wythe after water permeability test.

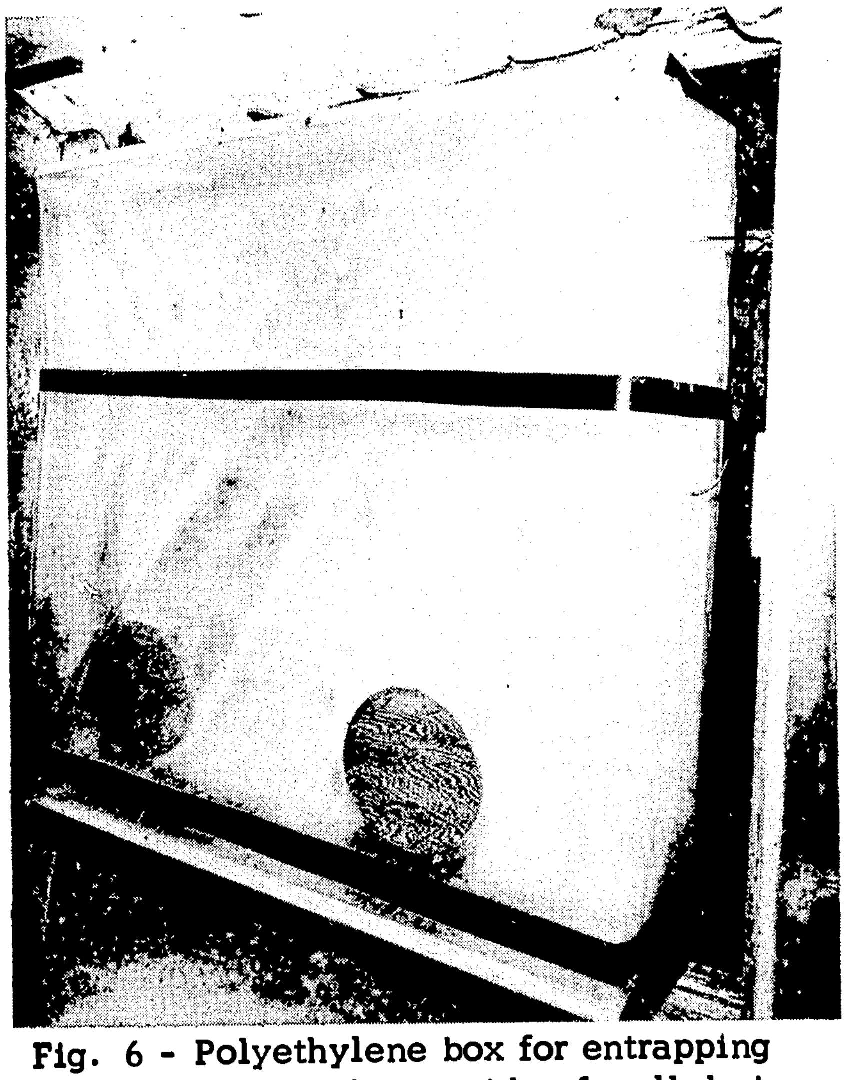


Fig. 6 - Polyethylene box for entrapping vapor placed on the outside of wall during vapor transmission test.

the vermiculite during the entire period of the test. Upon removal at the end of the test most of the vermiculite appeared dry to the touch, except for a layer 1/8" to 1/4" adjacent to the brick wall. This layer of material appeared to be 100% saturated and could only be removed from the wall surface by deliberate scraping (Fig. 5). The average moisture content of the fill was 32.7% by weight. Original dry density in place was 6.85 lbs/ft^3.

Heat Flow Tests

Heat flow tests on both the glass fiber and the vermiculite insulated cavity walls were conducted at Pennsylvania State University using the typical guarded hot box technique. For both experiments the exterior wythe was 4" face brick and the interior wythe a typical 4" horizontal cell (5-1/3 x 12 face size) back-up tile to which a sand gypsum plaster was applied. The in-place density of the cavity fill was as follows:

Pouring type glass fiber	3.70 lbs/ft^3
Water repellent vermiculite	6.45 lbs/ft^3

In both cases, tests were run on the construction with and without the insulation.[10, 11]

Since, in the water permeability tests, a water content of 32.7% by weight was picked up by the vermiculite, it was thought of interest to determine the influence of this amount of moisture on the heat transfer. Accordingly, an additional test was performed on the vermiculite wall with the cavity fill containing this percentage of moisture. At the end of the test it was noted that the moisture migrated to the colder brick side of the cavity, accumulating as frost to a depth of 5/8". The results of these tests are tabulated in Table II.

A study of this summary reveals some significant observations:

1) The k factor for the face brick and C factor for the tile may be compared with the following data taken from the ASHRAE Guide:

k factor for face brick	9.0
C factor for 4" hollow clay tile	0.90

2) For the walls tested introduction of dry insulation will reduce heat losses from 68% to 58%.

3) A moisture content of 32.7% in the cavity fill increased the heat flow through the vermiculite wall only 13.3%.

Vapor Transmission Tests

As one traditional purpose of a masonry cavity wall is to permit the drainage of any water penetration through the exterior wythe, the prospect of water within an unfilled cavity space due to vapor condensation does not present the same hazard as such condensation does in frame construction where swelling, rotting or blistering of painted surfaces may occur. However, in the absence of any specific information, the early development of the insulated cavity wall included a vapor barrier to be applied to the wall on the warm side of the insulation. Accordingly, the cavity face of the interior wythe was covered

TABLE II

Summary of Thermal Tests

Type of Insulation	Pouring Type Glass Fiber		Water Repellent Vermiculite		
Cavity	Uninsulated	Insulated Dry	Uninsulated	Insulated Dry	Insulated Wet*
HEAT FLOW Btu/sq. ft., hr.	19.7	7.36	16.85	8.21	9.36
TEMPERATURES, °F					
Warm Air	75.2	74.6	74.7	76.5	74.2
Warm Surface	62.1	70.0	65.1	71.6	68.8
Tile-Cavity Interface	45.8	64.5	46.1	62.5	57.9
Brick-Cavity Interface	30.0	17.4	31.4	22.0	20.7
Cold Surface	20.7	14.4	22.9	17.3	15.8
Cold Air	9.0	10.3	13.7	11.8	10.9
THERMAL COEFFICIENTS Btu/sq. ft., Hr., °F					
Warm Surface Film	1.50	1.60	1.76	1.67	1.73
Plaster and Tile Conductance	1.21	1.34	0.89	0.90	0.86
Cavity or Insulation Conductance (2-1/4")	1.25	0.156	1.15	0.202	0.252
Brick Conductance	2.12	2.45	1.98	1.75	1.91
Cold Surface Film	1.68	1.79	1.83	1.49	1.91
Transmittance U as Tested, Air to Air	0.298	0.114	0.276	0.127	0.148
k factor for insulation	---	0.351	---	0.455	0.567
k factor for face brick	8.48	9.80	7.92	7.00	7.64
C factor for 4" back-up tile	1.40	1.57	0.990	1.00	0.950
CORRECTED U FOR	0.348	0.112	0.360	0.126	0.146
Interior surface coefficient 1.65					
Exterior surface coefficient 6.00 (15 mph wind)					
Cavity 2-1/2" wide					

* 32.7% moisture by weight.

with one brush coat of water emulsion asphalt paint capable of serving as a vapor barrier of at least 1 perm resistance. To reduce cost and simplify construction the omission of the vapor barrier was recently entertained on the grounds that vapor condensation may not produce any effect worse than obtained by rain penetration for which provision is made. Some insight on this approach was obtained by a vapor transmission test performed on a cavity wall insulated with water repellent vermiculite, using again the guarded hot box apparatus at Pennsylvania State University.[12,13]

The test specimen (67" x 67") was constructed of high density, low permeability face brick (cold water absorption of about 2%) in the exterior wythe and low density, high permeability horizontal cell back-up tile (somewhat underfired with cold water absorption in excess of 12%) in the interior wythe. Such a selection of materials, it was felt, would represent the extremes as to vapor transmission resistance arranged in a manner most conducive to entrap moisture from vapor condensation. The specimen was built in a frame that permitted the exterior brick wythe to be swung like a door in order that the cavity might be examined at the end of a test run. The edges of the test specimen were sealed with polyethylene to stop any migration of vapor across the boundaries. The wall contained standard wall tie and weep hole construction except the wall ties were cut at the cavity face of the tile wythe to permit opening the cavity.

The guarded hot box apparatus proved a successful means of providing at full scale a vapor transmission test. Constant 50% relative humidity was maintained on the warm side by means of a small fan, actuated by a humidistat, circulating air over a water surface. The loss of water from this surface was periodically determined by weighing. Such losses, once steady state conditions were obtained, indicated the absolute amount of vapor passing into the wall from the warm side. Dew point measurements were made by withdrawing air samples from the cavity space and the cold side. The cold face of the panel was enclosed in a polyethylene box to entrap any moisture migrating all the way through the panel (Fig. 6). Heat transfer observations during the test are tabulated in Table III.

On the 18th day the cavity was opened for inspection (Fig. 7). At this time it was noted that there was no accumulation of dry frost in the polyethylene bag on the brick face. This fact was not surprising when it was observed that frost had accumulated on the brick side of the cavity after the bulk of the insulation dropped to the floor. This thin layer of frost mixed with insulation can be observed in Fig. 8. Most of the frost was in the upper 1/3 of the panel having a maximum thickness of 3/8"; the frost decreased in thickness from top to bottom of the wall where it stopped 10" above the bottom of the panel. The accumulation of the frost at the brick-insulation interface agrees with the experimental observation that dew point measurement of the air withdrawn from the cavity was about 25-26°F, whereas the warm face of the brick measured between 24-25°F. Thus, condensation conditions prevailed just inside the cavity from the brick wythe.

The major observation of the heat transfer data is the relative constant air to air conductance of the wall during the 18 days of steady state conditions, indicating no change in the thermal characteristics of the wall due to the frost observed at the end of the test.

From the data obtained it was possible to determine the vapor permeance of the tile wythe as 3.0 perms for the 4" thickness. After this test, the construction permitted testing the brick wythe separately to determine its vapor permeance as 2.09 perms. These values differ substantially from those reported by H. J. Barre and published in the ASHRAE

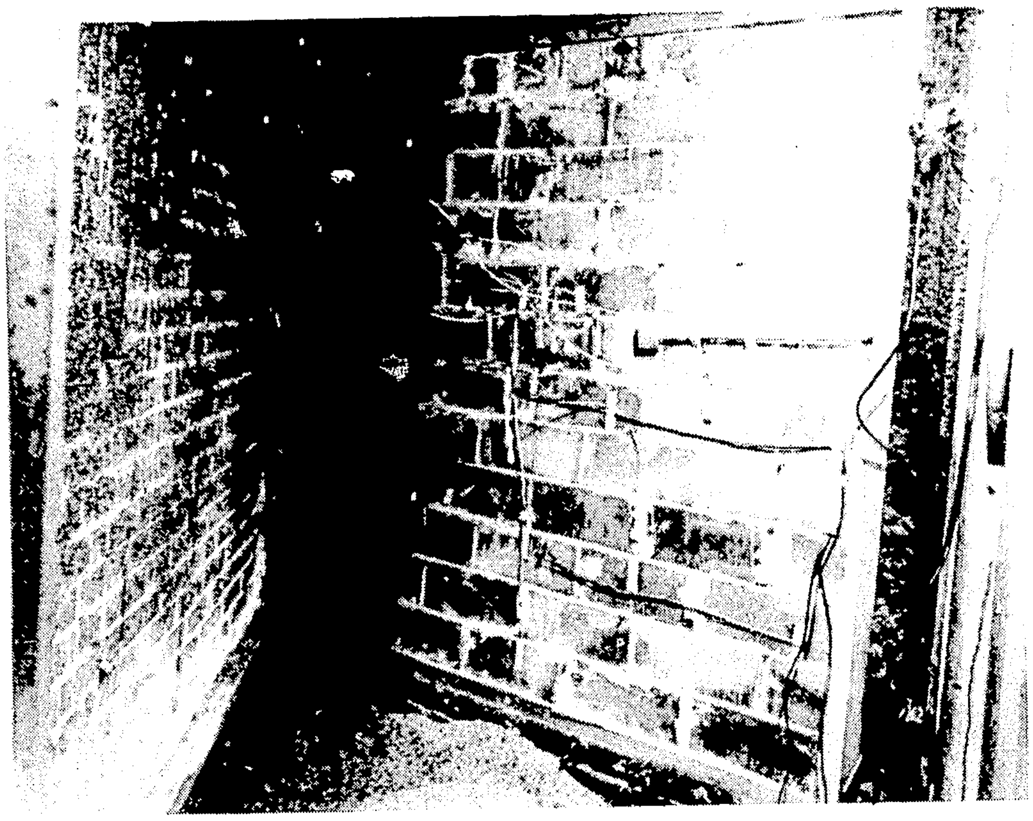


Fig. 7 - Opened cavity on 18th day of vapor transmission test.

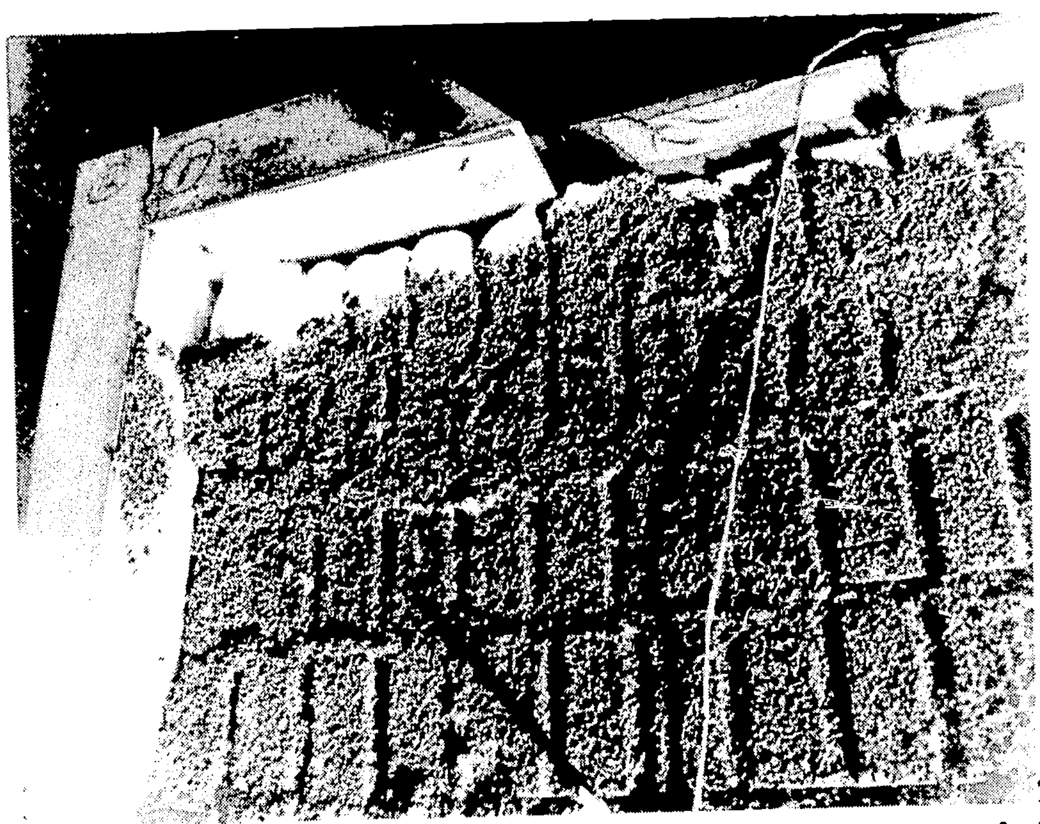


Fig. 8 - Frost accumulation on cavity face of exterior brick wythe.

Guide.[(14)*] The test specimen used by Barre was small, 111 sq. in. against the guarded hot box area of 2304 sq. in. Since, as in the case of water permeability, the vapor transmission resistance is probably a function of the bond at the mortar-clay unit interface, more representative conditions of commercial practice as to ratio of mortar joint length to brick face area and as to workmanship are obtained in the larger test specimen.

*Brick wall - with mortar - 4 in. 0.8 perms
Tile wall - with mortar - 4 in. 0.12 perms

TABLE III

Summary of Vapor Transmission Test

Heat Flow Data

Days	1	2	3	4	7	8	14	15	16	17	Average
Heat Flow Rate Btu/sq. ft., hr.	6.40	6.82	7.24	7.24	7.42	6.85	6.85	6.90	6.96	6.93	
TEMPERATURES, °F											
Warm Air	74.9	75.0	75.1	75.3	75.1	75.4	75.1	75.1	75.3	75.2	75.2
Warm Surface	71.8	71.2	71.1	71.8	71.0	71.7	71.2	71.4	71.4	71.3	71.4
Tile-Cavity Interface	63.8	63.0	62.7	63.4	62.3	63.3	62.7	63.1	63.0	63.1	63.0
Brick-Cavity Interface	25.0	24.8	24.6	24.5	24.3	24.6	24.6	24.6	24.6	24.6	24.6
Cold Surface	20.7	20.6	20.0	20.0	19.5	20.6	20.6	20.4	20.4	20.6	20.0
Cold Air	16.6	16.6	16.5	16.5	16.4	16.7	16.7	16.8	16.7	16.8	16.6
THERMAL COEFFICIENTS Btu/sq. ft., hr., °F											
Warm Surface Film	2.07	1.42	1.81	2.07	1.81	1.85	1.76	1.87	1.79	1.87	1.83
Tile Conductance	0.80	0.83	0.86	0.86	0.85	0.82	0.81	0.83	0.83	0.83	0.83
Insulation Conductance	0.165	0.179	0.190	0.186	0.195	0.177	0.180	0.179	0.182	0.180	0.181
Brick Conductance	1.49	1.62	1.57	1.61	1.55	1.71	1.71	1.64	1.66	1.73	1.63
Cold Surface Film	0.85	0.91	1.07	1.07	1.14	0.93	0.94	0.92	0.97	0.95	0.98
Surface to Surface Conductance	0.125	0.135	0.142	0.140	0.144	0.134	0.135	0.138	0.137	0.136	0.136
Air to Air Conductance	0.104	0.110	0.117	0.117	0.119	0.110	0.111	0.112	0.112	0.112	0.112

DEW POINT OF AIR IN CAVITY

Days	1	2	3	4	6	7	9	10	14	15	16	Average
Dew Point, °F	19	22	23	27	22	24	26	24	27	25	25	24.0

Discussion of Test Results

As the three tests (water, thermal and vapor) are interrelated it is well that their results be discussed together.

Both insulations showed, under the water permeability test, a satisfactory performance in allowing the cavity to drain without serious transport of moisture to the inner wythe. While the vermiculite fill picked up 32.7% moisture, it showed no signs of causing moisture penetration to the cavity side of the interior wythe, much less through the interior wythe itself. The test conditions of an equivalent rainfall rate of 5-1/2" per hour subject to a pressure of a 60 mph wind sustained for 6 days, is most severe. Annual rainfall in excess of 100" is rarely encountered in the world's climate. More severe winds up to 150 mph with gustiness may be experienced in a hurricane, but the duration is a matter of hours. The test as originally designed at the National Bureau of Standards was not intended as a precise simulation of reality, but as an arbitrary test used to study comparative behaviors of building constructions. Performance can only have meaning as related to the Bureau's ratings.

From the above discussion it would seem that the moisture pick-up by the insulation is much higher than might be expected in practice. As noted before, most of the moisture in the vermiculite was confined to a thin, saturated layer (1/8" to 1/4" thick) adjacent to the exterior wythe. When this amount of moisture (32.7%) was uniformly introduced into the vermiculite, the thermal tests showed only a 13.3% increase in heat flow over the dry material. Visual inspection of the cavity indicated the moisture migrated to the cold side where it accumulated as a frost to a maximum depth of 5/8".

Interestingly, based on information obtained from the Corps of Engineers through their work on snow, ice and permafrost, the thermal resistances of such materials are related to their density (p) as follows:

$$k = .0032p^2$$

If the density of frost is estimated at 14.1 lbs/ft.^{3}, then k = .633. Assuming that 5/8" of the 2-1/2" cavity fill (k=.455) is filled with frost, the theoretical increase in U factor would be 5.5%. The 13.3% increase obtained in actual test is perhaps due in part to the loss of some still air space between vermiculite particles being filled by the frost.

The results of the heat flow tests verify that, based on published information in the ASHRAE Guide, (4) it is possible to construct insulated clay masonry cavity walls depending on the choice of clay units, type of insulation, and interior finish (i.e. exposed or plastered) having U factors ranging from .10 to .14. Comparable uninsulated cavity walls will have U factors ranging from .24 to .38. Thus, the reduction in heat loss will vary from 56% to 67%, or an average of 60%.

Worth noting from the test results is the fact that the insulated wall surface temperatures are higher than those for the uninsulated core. Theoretically, if the coefficient of surface film transmission is identical in both cases (1.65 for still air), then the air to surface temperature drops should be proportional to the U factor. Thus, the uninsulated wall is expected to have a temperature drop 2-1/2 times greater than the insulated wall. When it is considered that radiant exchange of heat between two surfaces is proportional to the differences of the fourth power of the absolute surface temperature (Stefan-Boltzmann Law $q_r = C[T_1^4 - T_2^4]$), the influence of wall surface temperature on comfort is apparent. If skin temperature is assumed at 90°F and if 4°F and 10°F temperature drops below an interior ambient of 75°F is considered for the insulated and uninsulated walls respectively, then the occupant will experience a noticeable increase in heat loss from his body to the colder surface (theoretically over 30%). Comfort is thus not entirely a function of air temperature, movement and moisture content. Radiation to surrounding surfaces is equally important.

Under steady state heat flow, the contribution of the mass of the wall to thermal resistance is relatively low. For the two experimental walls considered, the clay masonry contributed about 16% of the total thermal resistance. However, under dynamic heat gain such as occurs during the cooling season when the rise in exterior surface temperature varies with the solar radiation, the influence of the mass becomes more apparent. Complete analysis of dynamic heat flow is very complex. However, the ASHRAE Guide recognizes a method, "Equivalent Temperature Differential," (ETD) based on the steady state U such as obtained in these tests. The ETD multiplied by U gives the rate of maximum heat gain.

For a dull red brick surface on a western exposure the average wall surface temperature at 40° Latitude (August 1) is likely to be about 93.0°F. The maximum surface temperature (141°F) will be reached about 4:00 P.M. (Sol-air temperatures and wall surface temperatures are assumed here equal for sake of the simplicity of argument).[14,15,16,17] If the interior temperature is held at 80°F, the average temperature difference is 13°F, whereas the maximum is 61°F (13°F + 48°F). Obviously it is important to dampen the 48°F dynamic part of this temperature difference. With 4" of face brick on the exterior and interior wythes this dynamic component is reduced to 8°F. This dampening of the surface temperature rise is due to the mass and the specific heat of the clay. Theoretically, a wall composed of pure insulation (k=.4), but having the same exterior surface characteristics of the brick and total U factor as the insulated cavity wall, would transmit the full dynamic temperature effect almost instantly, whereas the heavier wall would dampen the peak and delay its gain to the interior for 10 hrs. This difference is intuitively appreciated when it is observed that, while the specific heat of types of inorganic insulation used here is nearly the same as the clay masonry (.22 Btu/pound °F), the densities are in the ratio of 1:25 (5 lbs/ft^3 to 125 lbs/ft^3). From the above, the ETD of the standard cavity wall is expected to be 21°F (13° + 8°) whereas, for the pure insulation wall, it is 61°F (13° + 48°). Thus, the mass effect reduces the maximum rate of heat gain by about two-thirds.

The most significant observation of the vapor transmission test is the relatively unchanged state of the thermal conductance during the period of the test despite the accumulation of the frost to a depth average 3/16". As pointed out earlier, frost itself has a k factor approaching that of the insulation. The test conditions (75°F and 50% RH inside and 19°F and 89% RH outside when adjusted for standard wind of 15 mph) represents an overall vapor pressure difference of 1/3" of mercury per sq. ft. of wall sustained for a period of 18 days. The thermal gradient was such that condensation took place just inside of the exterior wythe. Had the external temperature reached 10°F and 80% RH (typical mean average daily temperature of Ottawa, Montreal, Quebec, Calgary and Prince George for January) the vapor pressure difference would have increased only 10%, since the change in saturated vapor pressure at low temperatures is proportionately smaller than at higher temperatures.

As a previous heat transfer test on the vermiculite fill had been performed with 32.7% moisture content, it might be of interest to note what equivalent vapor condensation conditions would produce a similar result. Assuming a vapor pressure gradient of 1" of mercury (3 times that of the test) and knowing that the interior wythe may have a permeance of 3 perms, steady state conditions would have to prevail 45 days before condensation conditions within the cavity would accumulate 32.7% moisture. Theoretically, such vapor pressure and condensing conditions would be produced by an interior temperature of 80°F at 100% RH and an exterior temperature of -15°F at 90% RH. Not only are such conditions unlikely in themselves, but steady state values are never realized in nature. While rates of accumulation of frost over a period of time must be based on average values, actual diurnal variation in temperature and humidity significantly affect the problem. Wall surface temperatures due to direct or diffused sky radiation may rise much above ambient, permitting periodic thawing within the cavity.

Summary

The foregoing test results and discussion suggest that the following statements are justified:

1) The traditional water resistance of masonry cavity wall construction is not endangered by the introduction of a suitable water repellent cavity fill insulation.

2) To be economically significant, the cavity fill insulation should increase the thermal resistance of a conventional cavity wall over 50% (i.e., k=.50 or better) at a cost not to exceed 10 to 20¢ per sq. ft. installed.

3) In the absence of a vapor barrier, the thermal efficiency of the insulation is not significantly changed if the vapor pressure gradient is less than 1" of mercury, providing the wythes have a vapor resistance of 3 perms or less (as determined by the standard guarded hot box apparatus) and providing the duration of such conditions does not last much beyond 30 days. The following conditions could be maximum of possible vapor pressure gradients:

Season	Interior Condition		Exterior Condition		Vapor Pressure Gradient
	Temp.	Humidity	Temp.	Humidity	
Winter	75°F	60%	-15°F	80%	1/2" mercury
Summer	75°F	40%	95°F	90%	2/3" mercury

Based on information in the ASHRAE Guide(4) interior relative humidity in the winter seldom exceeds 60% for residences. For conditioned space during the summer, comfort seldom requires the relative humidity lower than 40%. Thus, probable pressure gradients of less than 1" of mercury are likely to prevail for normal circumstances. When the vapor permeabilities exceed 3 perms, the vapor pressure gradient 1" of mercury, or the duration of conditions more than 30 days (e.g. cold storage walls) analysis may require a vapor barrier.

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Design of Insulated Masonry Cavity Walls

By Werner Gottschalk, * Consulting Engineer Associate
Severud-Elstad-Krueger-Associates

Within the large, and still venerable, family of types of construction which make the field of building so colorful, cavity walls have established themselves quite solidly. Just as so many elements of construction do, exterior walls call for solution of a number of problems. It has occurred to me that my contribution to the topic at hand might be most apropos, if I gave an account of how the practicing structural engineer approaches cavity walls.

Our clients, the architects, are the people who are constantly called upon to provide their clients with buildings for some substantial amount less than everybody knows the job should cost. It is first cost in combination with maintenance budgets which spotlight the fearful matter of economy. Cavity wall construction comes in for unending scrutiny because it suggests help in the search for economy in the following items:

1) Passage of water and, more importantly perhaps, formation of condensation at the inner face of the exterior wall is eliminated, so that plaster may be applied directly to the masonry without furring. In fact, the inner wythe may become the finished product, and plastering be completely eliminated. This, then, is insulation against moisture.

2) The air cushion between the two wythes of masonry acts as an insulator against temperature transmission. This means a favorable U factor that will save on heating and cooling.

3) In our present age of the "Alternate Bid," cavity wall construction seems to offer good flexibility in the writing of specifications of alternate exterior and interior finishes. This would apply primarily to nonbearing panel walls rather than to bearing wall construction.

Now, before the structural engineer can apply his own judgment in the evaluation of a particular project, compliance with the applicable building code is generally to be investigated. It would be too far afield to discuss here at length the lack of clarity or even the complete overlooking of cavity wall construction in some building codes. The matter is certainly not approached uniformly. The New York City Building Code, for example, discusses "Hollow Walls" as bearing walls only, and as brick masonry at that. Permissible compressive stresses over the total cross section are reduced by 50% compared to solid

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*GOTTSCHALK, WERNER, Graduate Engineer, Institute of Technology, Berlin, Germany; Member of American Concrete Institute and New York Assn. of Consulting Engineers; formerly design engineer, Cherokee Ordnance Works.

walls. This reduction in allowable stresses would penalize walls with thicker inner wythes, a rather standard type of cavity wall. However, in actuality, compression stresses in bearing walls do not generally become a problem. For masonry laid in cement-lime mortar, the New York Code permits 250 psi in bearing, which would be 125 psi for "hollow walls". The ASA is more specific about cavity walls, allowing 140 psi for walls laid in high strength mortars. Such unit stresses are only reached in multi-story structures, or by long span slabs for garages or similar uses where other restrictions are bound to preclude high compressive stresses.

Code requirements for minimum thickness of bearing walls and for resistance to lateral forces in panel walls invariably govern the cross-section of cavity walls. Here again, the New York Code refers back to stipulated thicknesses for solid bearing walls, and to the requirement that 30 psf wind be resisted by panel walls "without undue deflection." This introduces maximum permissible spacing of bracing members, horizontal or vertical, as a function of the thickness of a bearing or enclosure wall. Nonbearing panel wall sections are not so positively defined.

When our firm, over 10 years ago, proposed 4" + 2" + 4" cavity panel walls for a New York City Housing Development 14 stories high, no precedent satisfactory to the client was available, and computations could obviously not be convincing. We arranged for a simulated windload test of such severe nature that approval was assured to follow a successful test. You may find the data interesting, particularly since the test was in reality a field test. We selected a 4'2" wide pier between two windows, 5'1" and 3'1" wide respectively, in one of the buildings, where exterior masonry had not as yet been installed in the floor above. Nor had plaster been applied on the inside face of the wall. The test load was to be applied from the inside. This, then, could well be considered a very severe condition. A load-spreading frame in steel, with eight contact points in two rows, applied roughly 2 ft. from top and bottom supports of the 7'3" vertical clear span of the masonry pier was brought to bear against the wall by means of a hydraulic jack assembly. Pressure was registered in calibrations of 200 lbs., six Ames dials set up in two lines to contact with the test wall registered deflections to 1/1000". The jacking pressure, equivalent to a 30 psf windload on pier plus pertinent window areas, was computed to be 1650 lbs. for moment, 1790 lbs. for shear at supports. The wall pier was, of course, largely free at the jambs of the windows, restrained at the top by the mortar grout between top of brick or back-up block and underside of steel angle or concrete spandrel beam, at the bottom by the top of concrete frame on which it was built.

The behavior of the cavity wall pier was remarkable. Deflections were very uniform at all dial positions, for total as well as for increment values. The deflection increments at 2000 lb. jack pressure, by the way, were larger than at higher loads, indicating the interesting if not surprising fact that at some point above that stage of loading and deflection, the top and bottom supports of the wall developed a wedge action, thus bracing and stiffening the masonry assembly. Pressure was increased in steps of 500 lbs. each; it was continued beyond the point where "undue deflection" became obvious. For this wall, 7'3" high, the standard allowable deflection of 1/360 of the span, i.e. 0.241", was not reached until 5,500 lbs. were applied through the jack. At that load, a horizontal crack began to show in a brick joint in the outer wythe, but the load by then represented 100 psf wind. At 7,500 lbs. pressure, deflection readings were still reasonably interrelated, the maximum reading about 1/2". Upon raising the jack pressure to 8000 lbs. the pressure balance was lost, the load frame was pushed out of position and the test was discontinued. The 7,500 lbs. load had represented 136.5 psf of wind. The top of the pier was then demolished to examine the mortar grouting, the wall anchors, etc.

Interestingly enough, grouting to the underside of the spandrels was only mediocre (as one might expect under field conditions); of the drip Z-anchors exposed, two were slightly bent but still fully bonded in the mortar beds. Well, 4" + 2" + 4" cavity walls have since been used in housing jobs up to 20 stories high in New York many times over, always with emphasis on workmanship spelled out in specification and detail.

It must be kept in mind that a cavity wall assembly is a product of limited homogeneity at best--"at best" meaning high grade field labor performance more than high quality of the component parts. I have conducted another windload test on a cavity wall panel where the inner wythe was built up of a material definitely low in strength. The assembly was very well put together, and the test was successful. On the other hand, I was called into a situation where a cavity wall installation covering a number of extensive structures was undertaken by a team of architect, builder and mason contractor to all of whom cavity walls were a novelty. The saddest part of that picture was that the finished product showed excellent workmanship in the exterior face of the walls. The trouble was wrong relation of bed joints between inner and outer wythe, deficient ties, insufficient lateral bracing. A number of adjustments had to be made to the details. That job, however, proved to me more than any other experience the inherent quality of cavity wall construction which had in this instance taken such a degree of misunderstanding, of mistreatment.

Realization by codes of the elusive quality of masonry work is expressed in the generally valid requirement holding allowable unit stresses in masonry to 10%, even to 8%, of ultimate compressive stresses developed in laboratory tests.

While special conditions and individual solutions are likely to occur from project to project, certain construction features are basic with cavity wall construction. These will be analyzed throughout this symposium and I would like to discuss my firm's approach.

We have employed cavity bearing walls extensively, practically always in such manner that the inner wythe constitutes the load-bearing element, while the outer wythe becomes the weather-protective sheath and also adds to the cross-sectional spread of the wall, increasing the permissible unbraced length or height as individual code requirements may permit. Only in 1- or 2-story structures with medium floor spans will both wythes be called upon for support of the framework. The outer wythe is generally brick laid in running bond, or concrete block, rarely stone. The inner wythe, 6", 8", or 10", even 12" thick, may be of brick, concrete block or precast concrete panels. Since such wall-bearing type of structure is rarely more than 4 or 5 stories high, we have always favored a continuous 2" air space from top of foundation wall to cornice. In this manner, the limited movement of air within the cavity, from weepholes at bottom to a smaller number of "breather" openings under the cornice, just as small as the weepholes, is very effective in preventing the accumulation of condensate moisture. Condensation, to our observation, is the much more frequent culprit when moisture appears on the inside, rather than rain driving through the masonry. Also, the following provision then becomes economically and technically defensible: every third brick or so, in the bottom course, is placed dry and wedged into proper position so that it can be removed when the entire wall is finished. Mortar droppings at the base of the cavity can thus be quite easily removed, and weepholes are provided when the respective bricks are finally placed in mortar. These are then certain to be operative. To be sure, the method just described is not standard. It should not be necessary when a wall is laid up by experienced hands, even if 4 or 5 stories high, particularly not if the cavity extends several brick courses below the ground floor level (which is a very frequent condition) and if the weepholes are well constructed. Elimination of the cavity at the spandrel beams of every floor has been found undesirable in our experience because a solid wall section, in the absence of furring, invites condensation on the room face of the wall. Results have been particularly dismaying in kitchen, toilet and shower rooms, in other words, in areas where a high level of air saturation inside is bound to occur. The U factor, on the other hand, does not seem to be noticeably affected by a cavity ascending vertically throughout the wall compared to a cavity of single story height. National Bureau of Standards tests appear to bear this out.

Flashing, then, is confined to the areas over openings. Simpler, more uniform details can be used and, again, any accumulation of moisture will be at the bottom of the cavity where it is directed to weep holes. Furthermore, the wall is not weakened in its entirety by extended planes of flashings, it maintains better its capacity to overcome temperature stresses. You have all had parapet trouble, I suspect, and you realize the danger of through flashing in connection with it. The influence of movement in roof parapets on the outer wythe of a cavity wall below the parapet level is inescapable. Just visualize that a massive masonry section, exposed to the full temperature differential of the climate, is monolithic, so to speak, with a thin leaf apron of brick masonry which is further weakened by window openings. Trouble is always most apparent at the corners of buildings. We advocate strongly that expansion joints through parapet walls be near corners, so arranged as to line up with a jamb of the top window nearest the corner and that the joint shall extend through the face of the cavity wall down to the window head. Depending on the length and configuration of a wall, additional expansion joints through the parapet are, of course, required. Some of the ill behavior of parapets can be overcome by extending the cavity to the parapet coping.

In the case of bearing walls, wall thicknesses will generally not be a problem, except that in codes the question of just what constitutes thickness of a cavity wall is often not answered. The American Standard Building Code Requirements for Masonry (U. S. Dept. of Commerce publication) plainly state, however, "In computing the ratio for cavity walls, the value for thickness shall be the sum of the nominal thicknesses of the inner and outer wythes." The ratio referred to is that of unbraced height or length to thickness, which varies also. New York maintains the ratio of 20 which is pretty standard for solid masonry walls; the ASA code says 18; some codes require a ratio of 14. The differences are substantial, yet I would not have much conviction in my voice if I cried out for conformity, because I know that the product has a tendency to lack conformity. Tests, preferably field tests, and in quantity, are necessary to give this aspect of cavity wall performance a solid footing. Only then can we expect codes to become more uniform. Compressive stresses are rarely, if ever, extreme. I have had occasion, in a few church towers of square or nearly square plan section, to rely on vertical bracing provided by the corners and have taken a pure cavity of 10" + 2" + 4" up 50' or so, with highly satisfactory results. It may be pertinent to say at this point, that we think in terms of cavity wall details on the basis of trouble-free behavior of foundations. Uneven settlement is the bane of any wall built up of small units. Expanding clays, for example, call for a whole set of different rules.

The category of enclosure or curtain walls is akin to bearing walls. The matter of distance between bracing elements and corresponding wall thickness is of importance to design, to be sure. So are details at openings, where an increase in the lateral stability of the wall by masonry struts or by rod reinforcement or both, may have to be considered. Securing an enclosure wall to the structural frame at given lines of contact may also require more than the normal extent of anchorage.

Non-bearing cavity walls, i. e. panel walls within tiers of a framed structure, will vary in thickness and detail with the size of the framing bays, with story height and with the fenestration. In the absence of windows, or when openings are quite small, the cavity wall may act as a two-way slab supported on four sides. Effective reinforcement is generally easier to achieve horizontally than vertically. The horizontal dimension between supports is also more likely to be the greater one. Rods or welded wire type of reinforcement placed in a given number of joints will add substantially to the strength of the wall. At top and bottom supports, solid mortar beds and grouting are the natural seats. Vertical supports into columns are most effective when dovetail anchor slots are provided on three faces of the column so that the inner wythe will be anchored in addition to being mortar wedged between columns. The outer wythe should receive a line of standard cavity anchors vertically arranged close to the ends of the inner wythe, in addition to a line of dovetail anchors securing it directly to the columns across the cavity.

In the case of continuous (strip) windows, the wall becomes a cantilever spandrel and may be in trouble without exact scrutiny. The inner wythe must be reinforced so that it will withstand lateral forces (wind or suction) and it must act as anchorage for the outer wythe which is supported on continuous angle lintels at the head of each strip of windows. Up to a certain span between columns, the inner wythe may be figured as a horizontally acting plate, reinforced in the masonry bed joints and keyed to the sides of columns. If the column spacing is too wide for this arrangement, vertical dowels extending from floor slabs up into the inner wythe must take the cantilever moment. It is obvious that 6" or 8" thickness of the inner wythe is indicated for such cantilever spandrel walls.

Nonbearing cavity panel walls, more than bearing walls, are likely to be quite extensive, covering facades sometimes hundreds of feet in length and many stories in height. The inner wythe is firmly braced between columns, individual panels are confined in size, and they act together with the frame of the building. The outer wythe is a continuous sheath in front of the framework, rather flexibly supported and anchored to it. Most importantly, the range of temperatures which the outer wythe will assume through the seasons is vastly greater than that of the inner wythe which is closely tempered by heating and cooling devices of the building. These factors point to the necessity of cutting the outer wythe by as many expansion joints as the architectural pattern will allow. Certainly, uninterrupted bond of 100' to 125' horizontally should be considered a maximum; all re-entrant corners should be so developed that bond is interrupted.

A fine detail has been adopted by the New York Housing Authority; namely, a continuous vertical joint in the outer wythe within a few feet of the corners of the building, top to bottom. The topmost portion of a building must be considered as particularly susceptible to developing "weak sections" and again, the parapet exerts its influence. Regarding the latter, I think it becomes more and more recognized that the best way to attack problems of the parapet wall is to eliminate it.

Throughout the foregoing discussion, ties between the two wythes of the cavity wall have been the unsung heroes who make the assembly work. They must be strong enough to resist deflection of one wythe in relation to the other, they must be so formed that their bond to the mortar bed of either wythe promises optimum efficiency, and they must be of such shape within the width of the cavity that mortar drippings do not come to rest on them, forming bridges for the transfer of moisture. Last, but not least, ties must be resistant to loss of cross-section through corrosion. Several types of quite satisfactory cavity ties are in use, generally shaped of round bar material in galvanized steel, a rust-free amalgamation, or bronze. A drip depression located in the center of the cavity, and loops or bends within both mortar beds, are very much standard. Ties to be secured into dovetail anchor slots which are located in concrete backup walls or columns, are variations of the standard ties. I am sure you have seen such ties, Z shaped, rectangular shaped, or with looped ends in the field, in catalogs, or in pictures.

Code requirements as to the frequency of ties vary somewhat: New York City requires one tie per four sq. ft. of wall; Cincinnati and the Pacific Code require one tie for every three sq. ft. of wall; the ASA Code requires one tie for every 4-1/2 sq. ft. of wall. The main concern to the designer is assurance that all of the ties remain operative, being firmly embedded in and bonded to the mortar. To achieve that, the two wythes of the cavity must be laid up at the same time and bed joints fully buttered. When hollow units are used for either or both wythes, strips of metal lath should be placed in the joints receiving ties. In any case, ties must be placed firmly and in correct position so that later disturbance of the wall assembly is ruled out. There exists extensive proof that wall ties have excellent capacity if they are in good bond with the masonry, and also that the cavity wall is a very weak member indeed, if few working ties must do the job of many.

In summing up cavity wall construction, we can perhaps agree that the issues are quite clear, but invariably qualified by factors of climate, architecture, craftsmanship and, very importantly, expense. Size of installation is really the overriding element in the problem. This is why laboratory tests performed on panels of limited extent can only give an indication of likely behavior in the field. Laboratory results must be translated by the voice of experience. What this means is simply that cavity walls are no more ready for a patent solution than any other assembly of materials in the art of building. Test data, field experience, high quality materials are all helpful and necessary. Yet, we must always stay alert to the special set of conditions which a particular job is likely to pose.

Design for Crack Prevention

By J. Neils Thompson,* Professor of Civil Engineering
And
Franklin B. Johnson, Asst. Professor of Architectural Engineering
The University of Texas

Introduction

An important factor in the design of cavity walls is that due consideration be given to those design aspects that may affect cracking. From the standpoint of appearance and serviceability, cracks are certainly undesirable. It is the writers' intention in this paper to present a few simple illustrations of design features that are important, to indicate the value of discontinuity in structure, to illustrate the importance of structural integrity of components, to provide for expansion and contraction, to give consideration to foundation movements, to consider the properties of materials and to describe a research program that is under way.

It is believed that from a structural standpoint it is highly desirable to balance the design to give due consideration to strength and rigidity versus flexibility and resilience. F. O. Anderegg, in an article titled, Lime-Sand Stuccos in Europe, published in Rock Products, May, 1952, makes the following comment: "In this country we somehow feel that if we can get just enough portland cement into our mixes, they are bound to be very strong and durable. European philosophy, on the other hand, seems to be to keep the mortar or unit masonry for stuccos sufficiently flexible to take up the movements of the building that are constantly taking place. Europeans feel they get less leakage through about one-inch of higher lime mortar than occurs, for instance, through the cracks that were to develop in a rigid surfacing. The author feels that an appropriate flexibility is a very desirable property to incorporate in our masonry structures."

It has been the experience of the authors in observing structures in the Southwest where foundations, in many instances, are extremely poor and where there are rather substantial movements imposed upon masonry walls, that cavity type walls perform exceedingly well in some instances, and then again they do not. There are a number of contributing factors to performance and if proper consideration is given to them, improved performance should result.

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*THOMPSON, J. NEILS, B. S. and M. S. degrees from University of Texas; Member of American Concrete Institute, American Society of Civil Engineers, National Society of Professional Engineers, Society for Experimental Stress Analysis; has been associated with U. T. for 20 years.

Exploratory research is being performed in the hope of developing an approach to an extensive study on the extent of flexibility that could be permitted in a masonry wall. Also, due consideration is to be given to the balancing of the various design aspects in walls.

Causes

Cracking in masonry walls is usually caused by one or a combination of several factors which introduce strain into the wall. These factors include foundation movement, thermal strain, expansion and curling of concrete slabs in wall-bearing structures and movement of concrete or steel frame in framed structures. The cracks that result from these strains show up in a multitude of ways.

Damage from differential movement of foundation may result in diagonal, vertical or horizontal cracks, depending on the location and degree of movement. Damage from thermal strain is often found in the form of a vertical crack near the center of a long wall, and horizontal cracks near the roofline of parapet walls. Expansion and curling of concrete slabs bearing on masonry walls usually result in horizontal cracks at corners of the structure and in the vicinity of the slab. Movement of framed structures usually causes cracks at the point where restraint is offered. A column that has masonry tied to it is quite likely to be a point of trouble.

Cracks in masonry can be prevented or minimized with attention given to some of the details of design and construction. Cracking from foundation movements is less in the large structures, since in these adequate design and soils investigations have been provided.

The suggestions made herein are not original with the authors and many designers utilize these procedures; however, there are many designers who ignore these factors. Also there are frequently other design considerations that must take priority over cracking considerations.

Joints

Thermal strains may be relieved by incorporating expansion joints into the design of structures. Walls have been constructed in lengths of up to 400' in length without expansion joints and have suffered no ill effects from extreme temperature changes. The Structural Clay Products Institute recommends maximum lengths of wall to be not over 300' for heated structures in moderate climates, with lesser lengths for the more extreme climates, unheated structures and walls with openings. Figure 1 shows a crack that has occurred near the center of a 300' brick wall. Near one end of the same wall the horizontal displacement on the foundation has amounted to about 1-1/4". (See Fig. 2) The shape and location of columns and partitions in a structure will also govern the location and spacing of expansion joints.

In framed structures the expansion joint should be a through joint, that is, the joint should go completely through the structure, including floor and roof slabs, partitions, ceilings and walls. Figure 3 shows typical expansion joints in cavity walls. The details can vary as to method of concealment and weatherproofing, as long as a complete separation is provided. Parapet walls which are subject to cracking from thermal strain should use the same quality of back-up tile as used in the face brick. This will insure a uniform coefficient of expansion. This uniformity cannot be achieved when back-up material of lesser quality is used. Horizontal reinforcing rods of 1/4" at 16" o.c. and vertical rods of 1/2" at 24" o.c. placed in the parapet wall will confine and minimize cracking.

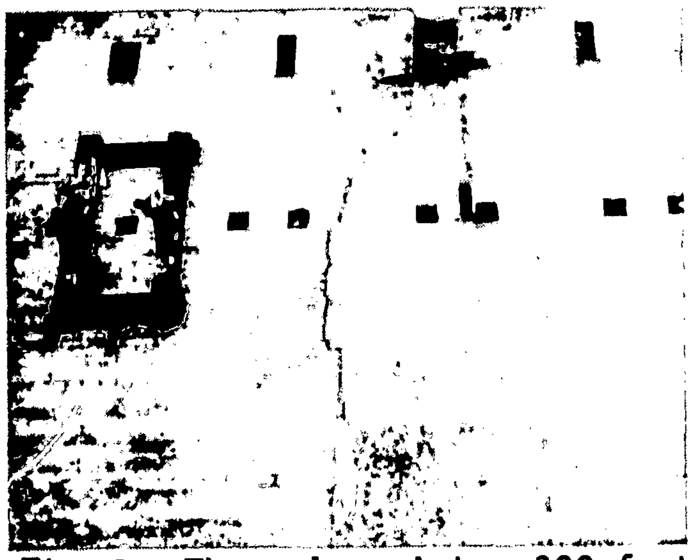


Fig. 1 - Thermal crack in a 300-foot wall

Fig. 2 - Expansion at one end of a 300-foot wall

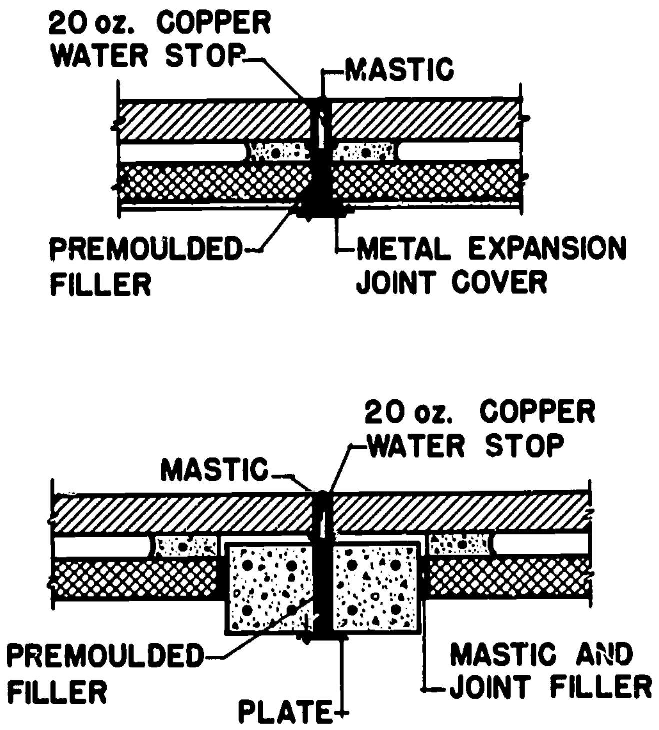


Fig. 3 - Typical expansion joints

Discontinuity of Structure

This expression is intended to emphasize the aspect of providing as much freedom as possible between components of the structure and yet maintain integrity in the structure as a whole. The aim is to have as much flexibility as possible between the wall and the foundation, between the wall and the structural frame, between the wall and roof trusses or slabs, and yet to have ties that maintain the integrity of the structure as a whole. It is believed that flexibility is of value in that it permits the structure to "roll with the punches."

Cracking in masonry walls in framed structures can be reduced by freeing the frame from any direct contact with the masonry. Figure 4 illustrates a column in a cavity wall. The masonry does not touch the concrete column and is secured from lateral movement only by metal ties. These ties are flexible to the extent that some relative movement may occur between the column and the masonry.

Figure 5 illustrates beams in a framed structure with the wall adequately anchored, but with sufficient flexibility to prevent strains in the frame from being transferred into the masonry.

Roof and Floor Ties

Thermal strains or other movements are often blamed for cracking in walls when the actual cause is expansion or curling in concrete slabs bearing on walls. The curling of a concrete slab has been known to pick up the brick bonded to it. This behavior is frequently overlooked by the designer in preparing the details of the structure. Figure 6a illustrates some typical details that relieve this condition. In this design the bond is broken between the concrete and the wall by building paper. This will permit the slab to have some freedom in respect to the wall. The slab is also thickened into a beam to stiffen the slab and help minimize curling.

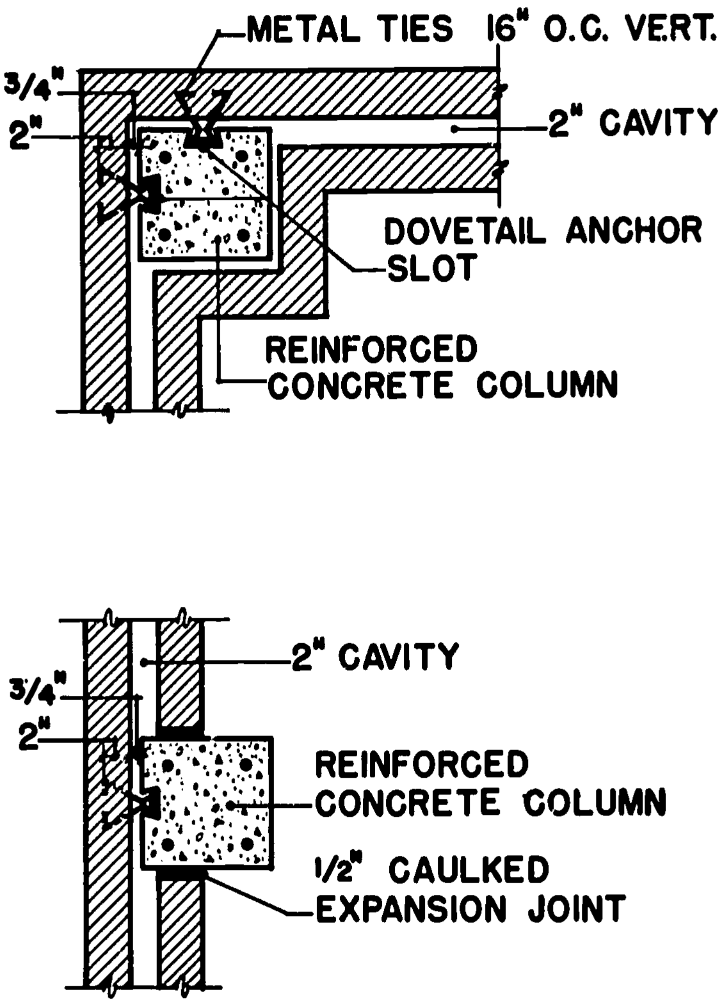


Figure 4

Figure 6b illustrates a structural system using steel joists bearing on a masonry wall. Steel has a coefficient of expansion approximately twice that of masonry and, if the temperature difference in the materials is large and the steel is firmly anchored to the masonry, then cracking of the masonry will probably occur. The practice has been to anchor the joists or steel in the masonry. This in effect rigidly ties the steel to the masonry. This design can be improved by greasing the bearing surfaces and by providing slotted holes in the seats of the steel members. These bolts should be only hand-tightened, or friction will prevent movement from occurring.

Foundation Separation

Figure 7 illustrates typical foundations. In both cases bond is broken between the cavity wall and concrete beam by building paper. The transfer of movements in the

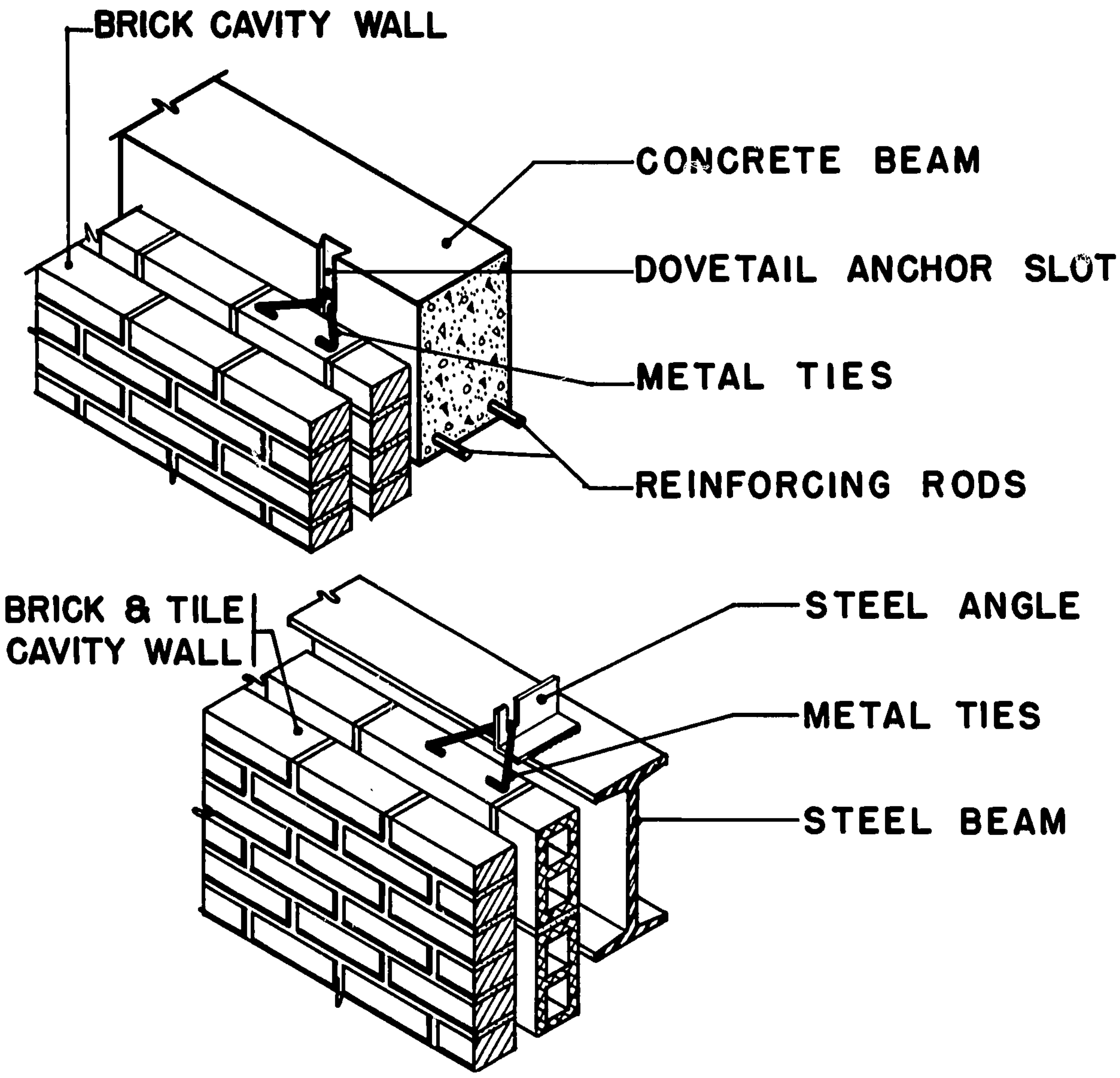


Figure 5

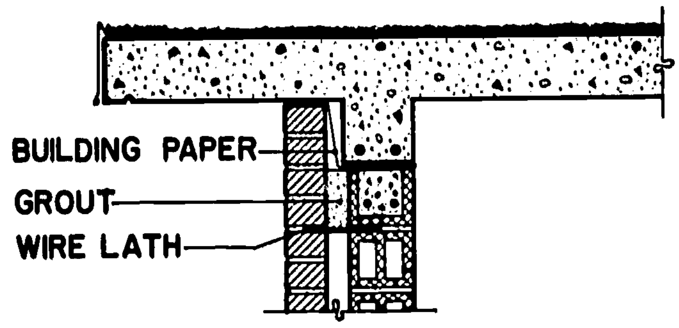


Figure 6a

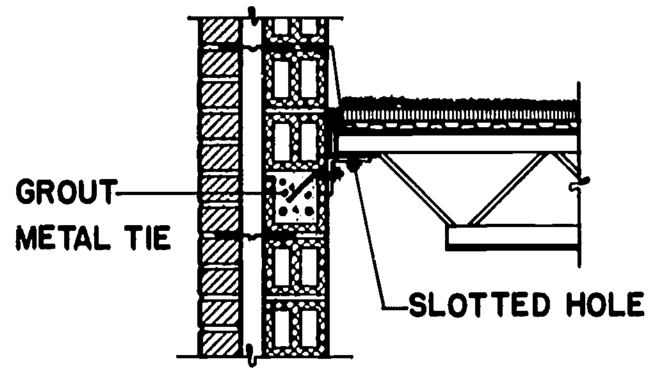
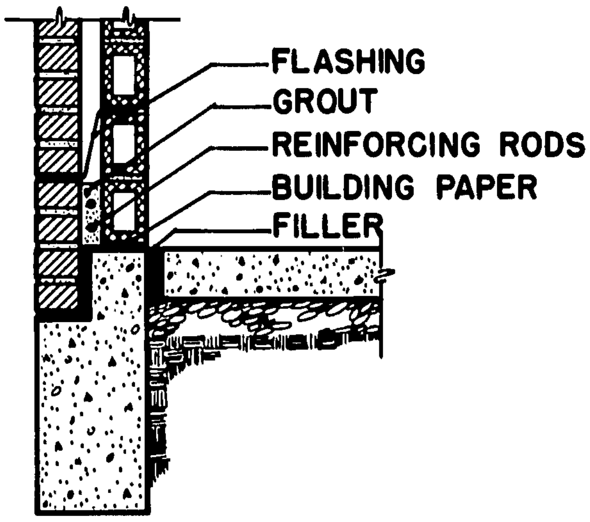


Figure 6b



foundation to the wall is minimized. A bond beam or tie beam can be formed at the bottom of the wall by placing reinforcing rods and filling with grout. This will tie the inner and outer wythes of masonry together and distribute the strain over a longer length of wall. The above procedure will tend to contain any vertical cracks that may originate at the bottom of the wall. The top of bearing walls should also have a bond or tie beam constructed into the wall for the same reasons. (See Fig. 6a) Under certain climatic conditions provisions must also be made for insulation which has not been shown in these designs.

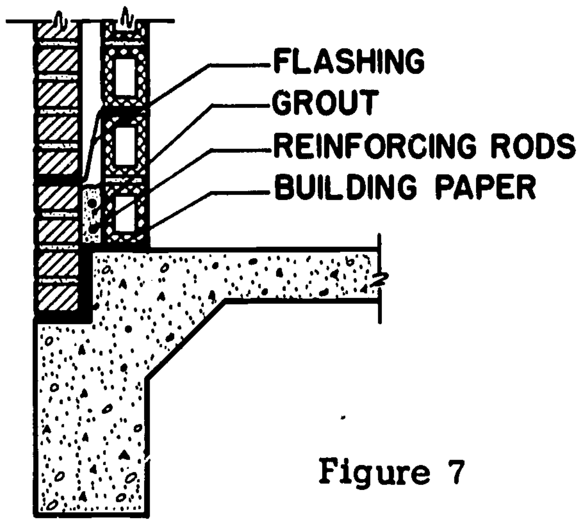


Figure 7

Foundation Movements

It is the general opinion that differential movements in foundations supporting cavity walls must be kept to a minimum or serious destruction will result. Differential movement of 1/4" in 15' has been considered sufficient to cause cracking in masonry walls. However, observations on cavity type and other masonry walls have shown that differential movements in the foundation of more than 1/2" in 15' could occur and yet the walls remain in good shape and have no cracks.

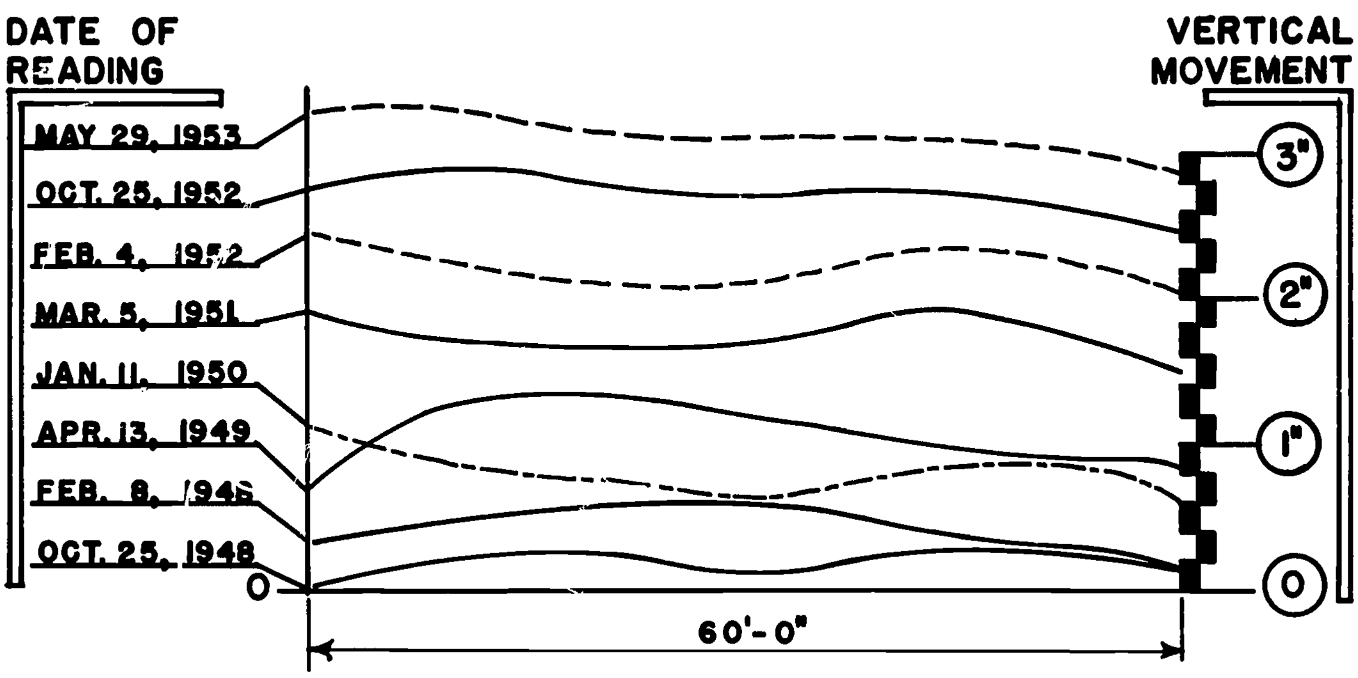


Figure 8

Figure 8 shows the elevations along a foundation on which rests a cavity type wall. This foundation is over 60' in length. It will be noted that in addition to a large over-all swelling there has been at times considerable differential movement. This wall is resting on a foundation that is firm but is relatively flexible as contrasted with a rigid type foundation of reinforced concrete grade beams on piers.

Had piers been used in this foundation there would have been relatively sharp breaks in the slopes, causing stress concentrations and high strains at points in the wall. In the flexible continuous footing, a gradual change in vertical alignment occurs and therefore the change in slope is spread over a greater distance which results in a wider distribution of strain. By spreading the strains created by these movements over a greater length of the wall, it is possible to provide sufficient elastic resilience and plastic yielding to reduce and/or prevent the rupture of the materials.

Wall Panel Research

Exploratory research pertaining to design of masonry walls is under way at the present time at The University of Texas. This study was set up, first, to obtain useful information pertaining to the behavior of masonry walls as affected by the introduction of movements, temperature, and load. Secondly, though of no less importance, the program is exploratory in nature with respect to technique.

The first phase of the program consists of a panel of two wythes of brick masonry constructed to form a single cavity wall with standard wall "Z" ties every sixth course. This panel was built in 1953 (Fig. 9). The masonry is of a good grade of burned-face brick and is bonded with a high strength cement mortar. The brick exhibits an average compressive strength of 7000 psi and the mortar has a compressive strength of 1735 psi at 28 days. The wall was built on a steel base plate (Fig. 10) with pairs of leveling screws placed at 16" o.c. to provide for controlled movement of the base.

Brass plugs were inserted in the wall to form a grid at 16" o.c. These plugs are for measuring any changes of distance that may occur between plugs. Work on this wall panel has involved the measurement of distances between the brass plugs in vertical, horizontal, and diagonal directions. Levels on the lower row of plugs have been taken to determine elevations prior to any movement of the base and also after every movement introduced into the base.

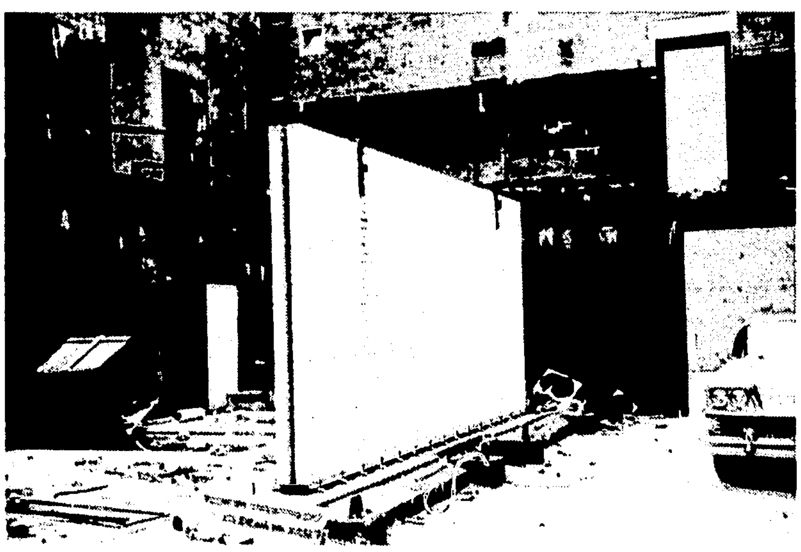


Fig. 9 - Cavity wall test panel

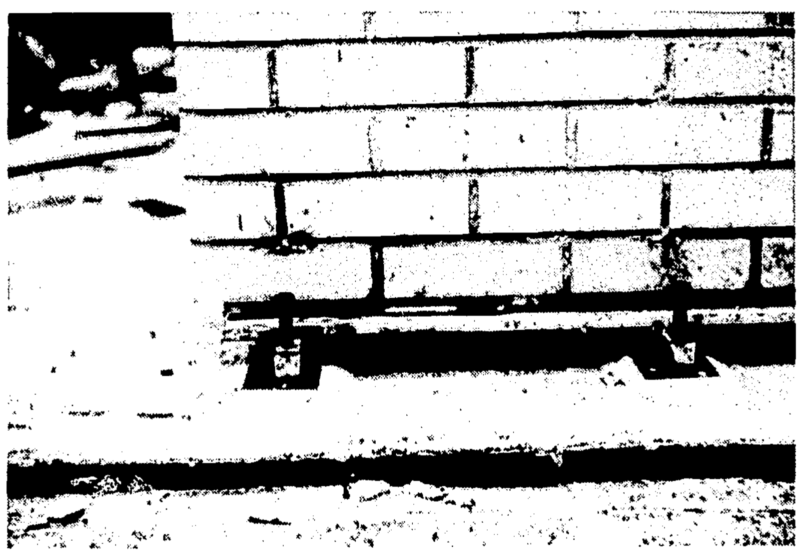


Fig. 10 - End of adjustable support plate

The movement of the base plate has consisted of a series of movements of .004" that progressively raised the center of the plate. These movements in effect give support to the center portion of the panel and cantilever the ends of the panel. Altogether, the center of the panel has undergone 63 movements for a total of 0.252" at the center. Data have been obtained that give the elevation in movements that has occurred in this wall since its construction.

It will be noted in Figure 10 that the end of the wall is off of the foundation. This wall has not been loaded, but will be in the near future. There has been very little evidence of creep of the wall; only elastic deflections are apparent. This is not surprising because of the high strength of the mortar.

The second phase of the investigation of masonry wall panels was started in 1959. Two wall panels were constructed utilizing very low strength mortar. The mortars for the walls had 28-day compressive strengths of 160 psi and 275 psi respectively (Fig. 11). These panels were also constructed in such fashion as to permit movements to introduce strains in the wall similar to those that occur in buildings as a result of differential movements of foundations.

This phase is similar in some respects to the panel built in 1953, in that a steel base plate with pairs of leveling screws (Fig. 12) at 16" o.c. was used in order to introduce into the base the desired degree of movement. Brass plugs were placed in the wall at 16" o.c., both vertically and horizontally, to form a grid so that measurements could be made of any change in distance between plugs that may occur. The panels consist of a single wythe brick masonry, 37" high and 104" long.

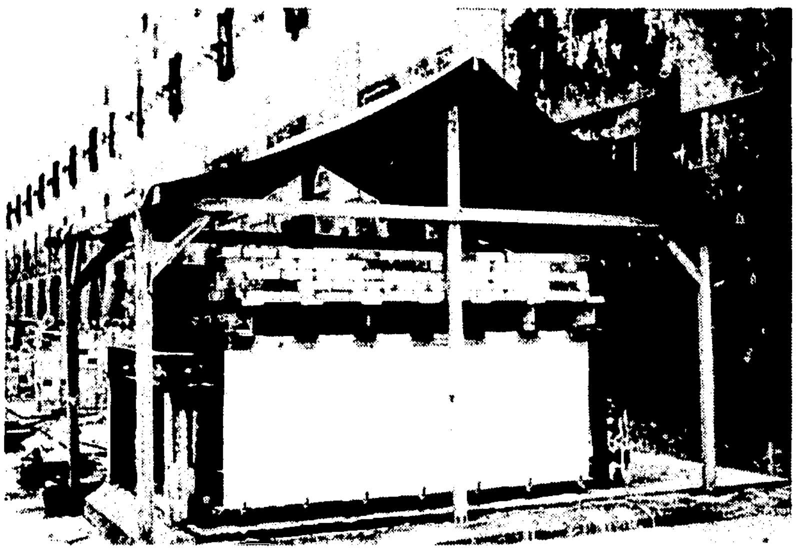


Fig. 11 - Loaded test panels

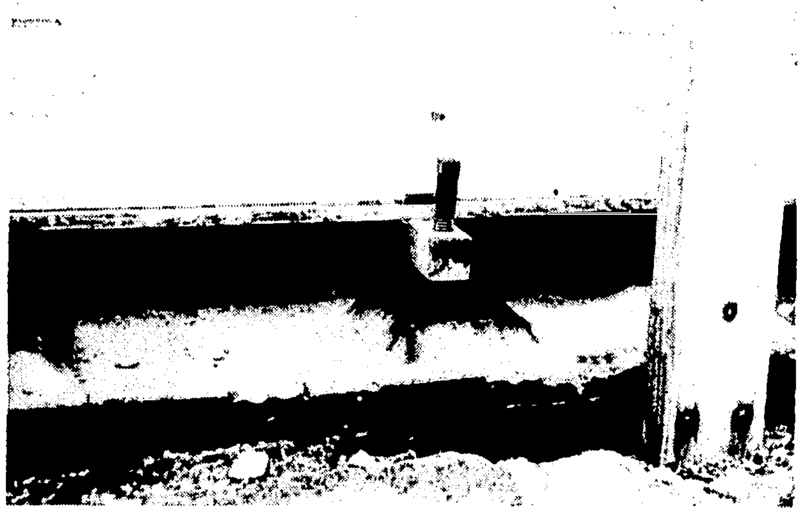


Fig. 12 - Center of adjustable support plate

The panels have been loaded and at the present time the load amounts to 300 lbs. per linear foot of wall. The base has been moved so that the center portion of the wall is free of bearing. Measurements of the distances between plugs are being recorded periodically. The levels of the lower row of plugs are also recorded. Thus a record of movements in the wall is obtained.

There are indications that with these weak mortars creep takes place for about 90 days in the walls. Then the support, along with resistance to creep of the structure, becomes sufficient to stabilize the wall. It can be noted in Figure 12 that the center of one of the walls is clear of the base. Additional movements will be imposed on these panels until cracks develop. With the grid on the walls it will be possible to determine the magnitude of rupturing strains.

An evaluation of mortar strength in relation to a masonry wall panel's ability to withstand damage or cracking with severe movement of the base is essential. The idea that mortar strength or type may have some bearing on a masonry wall's performance and on the relative amount of cracking is partially justified because of observations of old existing structures that utilized low-strength lime mortars. Many of these structures have undergone large amounts of differential movement over relatively short distances without cracking or damaging effects. Most of the present-day masonry structures utilize high strength masonry cement mortar. Most of the interior partitions of a masonry structure are not wall-bearing, and many of the exterior partitions are also not wall-bearing. In these cases a high strength mortar may not be justified, particularly from the standpoint of the load-carrying capacity required.

Summary

Every structure must meet particular requirements and must be designed accordingly. Details that are satisfactory on one structure will not necessarily be workable on another, but designs can usually be found that will minimize the possibility of damage from cracking in masonry walls. The criteria for minimizing the cracking in a structure can be summed up as follows:

1) Provide bond or tie beams at the top and bottom of walls wherever possible.
2) Break the bond between dissimilar materials with building paper or flashing (e.g., between concrete foundations and masonry walls, and concrete slabs bearing on masonry walls).
3) Provide an adequate number of vertical expansion joints to reduce thermal strain.
4) Provide freedom of restraint of structural members where the structure is framed by using flexible ties and clearing column of direct contact with the masonry wall.

Open Forum Discussion

Moderator - Harry C. Plummer, Conference Chairman

Panel Members - C. B. Monk
Werner Gottschalk
J. Niels Thompson

Charles H. Stark, Owens-Illinois Glass Co.: Why not have chimney action in cavity walls?

Mr. Monk: Chimney action can be both fruitful and unfruitful. If one is primarily interested in the insulation value of a still air space, obviously the chimney action will increase the rate of heat flow. So long as the air space is still, the efficiency of the air space is high, as far as thermal heat flow is concerned. There are certain circumstances where chimney action could be desirable, wherein one is seeking to wipe off high exterior surface wall temperatures by an air wash directly behind the exterior skin. This latter concept is widely used in hot climates.

Unsigned Question: What about bow in exterior wythes in wall with solid foam (plastics)?

Mr. Monk: Undoubtedly, the thermal gradient through the wall will give rise to differential expansion of the materials through the wall. This, in turn, will cause the bowing that is suggested by this gentlemen's question. The only answer to this situation is to provide and allow for the bowing to occur in the design. Caution should be exercised that, where one is structurally dependent upon the bonding action between the foam and the exterior skin, the deformational stresses due to this temperature gradient do not disrupt this bond. The magnitude of the bow, of course, can be reduced by decreasing the dimension of the panel so that the joint between panels in effect acts as an expansion joint to minimize this effect.

Joe Lucas, AA Wire Products Co.: You said reduction of convection currents will improve the insulating quality of a non-insulated cavity wall. Would not then a smaller cavity provide more insulation value to an uninsulated cavity wall and at the same time provide higher flexural strength to the wall because of the reduction of stress on the metal ties as a result of the smaller air space?

Mr. Monk: It is true that between 3/4" and 4" the air space dimension does not make much difference in the thermal performance of the air space, so long as air currents or chimney effect is prevented. Hence, the air space could be as low as 3/4". However, this in itself will not usually increase the structural strength of the cavity because the shear resistance of the typical wall tie is not that much greater as a result of narrowing the cavity width. The lower flexibility of the wall should theoretically increase its flexural strength. However, calculations, as well as some tests, have indicated that a typical wall tie does not possess the necessary strength to cause the two wythes to act as a through-the-wall flexural system, even if there was relatively no air space.

Mr. Lucas: What effect do high moisture areas, such as kitchens and laundries, have on cavity walls as a result of moisture traveling from the warm side to the cold side?

Mr. Monk: Precisely the same effect that any vapor pressure gradient would have through the wall, as discussed in the earlier part of the session. Condensation can occur within the cavity and the moisture will migrate to the coldest surface.

W. S. Elliott, The Vermiculite Assn., Inc.: Why all the emphasis on water repellent vermiculite? Will untreated vermiculite act any differently in the finished wall?

Mr. Monk: Experiments sponsored by our laboratories indicated that untreated vermiculite would accumulate considerable quantities of moisture, either as a result of rain penetration or vapor condensation, to a point where thermal efficiency would be largely destroyed. The main purpose of a cavity construction, unfilled, is to allow moisture to drain readily from the wall. When materials are placed in the cavity which absorb water excessively the cavity can no longer drain, and the material will not only have its thermal efficiency impaired, but will act as a vehicle by which moisture is transported across the cavity to the interior wythe.

Ray E. Camrine, Ketcham and Sharp, Architects: What is the purpose of vertical ties in cavity walls adjacent to expansion joints?

Mr. Thompson: These may not be necessary in every case, but in many instances they are desirable in order to provide the structural integrity of the system.

Mr. Camrine: What are the structural effects due to breaking bond with foundations and slabs over cavity walls?

Mr. Thompson: In many areas there are significant foundation movements which can cause severe cracking of walls when they are an integral part of the foundation. If these walls are not rigidly tied to the foundation, they tend to span the low points and thus reduce the cracking. In the case of slabs bearing on cavity walls, it has been found that if the bond is broken, the slabs can move slightly without imposing undesirable forces on the walls. Slabs bearing on walls tend to curl due to shrinkage of the concrete in the top, due to deflections from loads, and due to thermal conditions.

Harry H. Batchelor, Society of Residential Appraisers: If the inner wythe represents the load-bearing wall, would not the inner wythe have to be 8" to 12" in a multi-story apartment building?

Mr. Gottschalk: Yes. Where the 4" inner wythe becomes deficient, it is necessary to increase the inner wythe thickness to meet code requirements.

Mr. Batchelor: Well designed and constructed brick buildings have an economic life of 100 to 200 years. Will this be true of cavity walls where the metal wall ties are subject to deterioration from the air and moisture in the cavity?

Mr. Gottschalk: There are a number of noncorroding types of ties on the market, such as the bronze coated, for instance. With the use of such ties, the life expectancy of a cavity walled structure should be as great as anyone would want.

R. B. Hollister, Turner Construction Co.: Given a curtain wall with inside wythe bearing upon slab, constructed to slab or beam above; outside wythe and cavity continuous grade to parapet 8 stories up; with windows either punch type or semi-strip type, the semi-strip running between columns only; and assuming a good, normal tie between inside and outside wythe, is it necessary to introduce shelf angles between sash in the outside wythe? This shelf angle (a) costs money; (b) interrupts cavity; (c) involves weeping and staining at each level.

Mr. Gottschalk: Some codes, as you know, require supporting angles at each floor, while others allow a maximum unsupported height of 20' or 25'. Outside of highly restrictive code areas, I have taken outer wythes up four stories, self-supporting on the foundation wall. For an 8-story building I do not have an answer ready. There are too many qualifying factors to be considered, such as story height, type of spandrel construction, etc.

J. H. Stuart, Merck, Sharp and Dohme: You mentioned the dry setting of every third brick in the first course of the exterior wythe as a means of access for cleaning out mortar droppings from the cavity. Have you any other suggestions for handling such problems?

Mr. Gottschalk: No, I have not. Of course, the basic precaution should be to provide wood strips which are brought up through the cavity to catch the mortar droppings as the wall goes up.

O. E. Mathiasen, Federal Seaboard Terra Cotta Corp.: Is a requirement of good quality workmanship more important on cavity walls than on solid masonry walls?

Mr. Gottschalk: I would say yes. In either case, good quality should be a prerequisite, of course.

Mr. Mathiasen: Is it important to have good distribution of weep holes or other breathing devices?

Mr. Gottschalk: Yes, reasonably so.

J. D. Hanft, Turner Construction Co.: It appears to be your recommendation that any proposed cavity wall project should have its cavity wall design made by the engineer rather than the architect. Do you consider this to be generally followed in building design practices of today?

Mr. Gottschalk: I did not intend to suggest that cavity wall details must be "engineered" in every case. The architect may be perfectly capable of analyzing the wall design. As to this being general practice, no, I do not think that cavity wall details are analyzed as to structural requirements in all instances.

Mortars for Cavity Walls

By Cyrus C. Fishburn,* Materials Engineer
Building Technology Division, National Bureau of Standards

INTRODUCTION

The flexural strength of masonry walls is a highly important structural property and, for modern types of unreinforced masonry, is dependent directly upon the bond between the masonry units and the mortar. The resistance of a cavity wall to lateral loads does not greatly exceed the sum of the resistances of each tier or wythe taken separately and, other things being equal, the flexural strength of a cavity wall is less than that of a non-cavity wall of the same thickness. To develop adequate flexural strength, a relatively high bond strength mortar is recommended for cavity wall constructions. For resultant wind pressures in excess of 20 psf, the ASA Standard A41.1-1953 requires that the mortar in cavity walls shall meet the requirements of ASTM C270 for Type M or S mortar.

As will be discussed later, it is also suggested that the mortar have good working properties and a high water retention in addition to adequate strength.

MORTAR MATERIALS

Cementing Materials

The cementing materials in mortars for cavity walls should contain portland cement or portland blast-furnace slag cement blended with either lime or masonry cement.

1) Portland cement and portland blast-furnace slag cement should comply with the requirements listed in Section 2 of ASTM C270.

2) Lime may be either a hydrated lime or a quick lime putty. The portland cement-lime mortars depend chiefly on the water retentivity of the lime for adequate water retention of the mortar. Therefore, the plasticity of the putty made from quick lime or hydrate should be well in excess of 200 when measured in accordance with Section 7 of ASTM C110. The lime hydrates are generally preferred to the quick limes in masonry constructions and it is important that the hydrate should meet the requirements of ASTM C207 for Type S hydrate. Many dolomitic and some high-calcium hydrates now available on the market are claimed to meet the Type S requirements.

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*FISHBURN, CYRUS C., B.C.E., University of Cincinnati and M.S., University of Illinois; Member of American Concrete Institute and American Society for Testing Materials; former research associate of National Academy of Sciences--National Research Council.

3) Masonry cement should meet the specification requirements of ASTM C91 for Type II cement. The portland cement-masonry cement mortars depend chiefly upon entrained air for adequate water retention of the mortar.

Aggregates

Aggregates should meet the requirements of ASTM C144.

Other Mortar Materials

Materials other than aggregates and cementing materials should meet the respective requirements listed in Section 2 of ASTM C270.

MORTAR PROPERTIES

Water Retention

The ease with which masonry units are laid is affected by the workability of the mortar. The property requirement in mortar specifications which best reflects workability is water retention. Mortars having a high water retention are workable over a wide range of consistency, as measured by the flow table, and may be used without segregation at wetter consistencies and higher flows than is the case for mortars having a low water retention. The water retention value of a mortar does not change greatly over a consistency range at which the mortar can be used. However, the working properties and water retention values of mortars are directly affected by properties inherent in the cementing materials.

A minimum water retention of 70% is required in both the property and the proportion specification of ASTM C270. Many cementing materials are available which will yield Type S mortars having water retentions of 80 to 90%. Data obtained in a recently completed study at National Bureau of Standards indicate that mortars having water retentions of less than about 75% may segregate. Therefore, it appears desirable that mortars for cavity walls have a minimum water retention of 75%.

Bond Strength

The bond strength between mortars and masonry units is believed to be at a practical maximum when the mortar is as wet as can be conveniently handled by the mason. At such consistency the mortar readily keys to irregularities in the surfaces of the units, increasing the mechanical bond between the mortar and the units. Furthermore, the mortar will be most easily handled. Proper bed joint thickness and alignment of the units are readily obtained with a minimum of hammering of the units.

Tests were recently completed (1958) at National Bureau of Standards on the bond strength and other properties of over 40 Type II masonry cement mortars. The mortars were tempered to about as wet a consistency as could be easily handled with a trowel. The initial flow for the Type S mortars ranged from 130% to over 150%. At these consistencies, the bond strength of small masonry assemblages and the flexural strengths of masonry walls were found to be greatest for mortars having relatively high compressive strengths and low air contents; it may be noted that air content and compressive strength are not independent variables. Furthermore, a decrease in compressive strength and an increase in bond strength tend to develop with increase in the flow of a mortar above the values usually specified in ASTM and Federal Specifications. Since there is no requirement for bond strength in ASTM C270, these relationships should be kept in mind in striving to obtain the maximum bond between masonry units and mortar.

Compressive Strength

The above-mentioned tests have indicated that the compressive strength of mortar at wet consistencies affects the bond between mortars and masonry units and the flexural strength of masonry walls. The C270 property specification for Type S mortars, suggested for use in cavity walls, has a minimum compressive strength requirement of 1800 psi. In the specification tests, the mortar is of the materials and proportions intended for use in the construction and is tempered to an initial flow of 100 to 115%. The actual strength of the mortar mixed to a flow suitable for use in laying masonry units is not required to meet the specified strength requirement (1800 psi). This strength reduction is considered acceptable by some on the theory that contact with the absorptive units will tend to reduce the water content of the mortar, thereby restoring compressive strength. This theory may be in error if the units extract too little moisture from the mortar, or if the mortar loses so much moisture that normal hydration of the cement is retarded.

In the NBS bond tests previously referred to, the high bond strength, Type S mortars had compressive strengths well in excess of 2000 psi when tempered to the wet consistencies that were used. Furthermore, the air contents of such mortars were relatively low and rarely exceeded 15% by volume.

The scope of the NBS tests on Type S mortars was somewhat meager. However, the data indicate that mortars for cavity walls may easily meet a property requirement for a minimum compressive strength of about 2000 psi when tempered to initial flows of 140 to 145%, especially when the air content did not exceed 15% by volume.

The relative properties of ASTM C91 (specification for masonry cement) mortars and bond-test mortars were obtained for two portland-masonry cement blends. When the two blended cements were prepared with building sands at a flow of 150%, their average air contents and 28-day compressive strengths were 14% and 2300 psi, respectively. When the two blends were tested as C91 masonry cements in blended Ottawa sand at a flow of 110%, their average air contents and 28-day compressive strengths were 16% and 3400 psi, respectively.

Durability

The durability of masonry and its resistance to damage by freezing in the presence of moisture may be increased by the use of mortar having a relatively high compressive strength and some air entrainment. With or without entrained air, it is likely that cavity wall mortars meeting the property requirements of ASTM C270 for Type S mortars would be of satisfactory durability under most service conditions. Some air entrainment may be advisable for such mortars if they are to be exposed to extremely severe weathering conditions, such as frost action in masonry of parapet walls and in portions of walls near ground level.

Performance Experience With Low-Rise Buildings

By Harry B. Zackrison, Sr., * Chief, Engineering Division
Military Construction, U. S. Army Office of Chief of Engineers

This paper will cover only the experience of the Corps of Engineers with cavity walls for low-rise construction for the Army and the Air Force. When I was invited to deliver this paper, we had not as yet attempted to evaluate on a country-wide basis the experience of our field offices in this type of construction. The questioning of representative field offices as to their experiences in this field has shown some divergent opinions although, by and large, the reports have been most favorable.

Before giving you our field reports, I would like to outline what our policy is in this respect. To understand this policy, it is desirable also to understand the limitations imposed upon us in our designs by others, such as the Congress, the Bureau of the Budget and the Department of Defense. During the Korean War, the Congress insisted that we build minimum construction to the most austere standards possible. As a result of their instructions to the Defense Department on cost limitations, the Department issued criteria to the Services for construction of various types of buildings such as barracks, bachelor officer quarters, administrative facilities, hospitals and the like.

Typical of these instructions is the requirement that the U or over-all heat transmission factors for the major exterior elements should not be greater than those established in the criteria. For barracks and bachelor officer quarters, the requirement was that the U value for walls should not be greater than 0.27 for buildings constructed in zones where the heating design temperatures ranged from -40° F to 10° F. For areas in which the temperatures ranged from 11° F to 35° F, the U factor should not exceed 0.56 for walls. The design temperature used by the Corps of Engineers is that temperature which the Weather Bureau has determined has a probability of not being exceeded more than once in every five years.

No sand or gravel, or expanded slag, clay or shale concrete masonry unit construction, 8" or 12" thick, would meet this requirement for a U value of 0.27. A cavity wall construction consisting of 4" exterior wythe, 2" cavity, and 4" interior wythe, using lightweight aggregate concrete masonry units, would provide a 0.26 U value. We therefore adopted the policy of providing cavity wall construction on those types of structures which we are designing in Washington for repetitive use throughout the country. This cavity wall construction is being used in the areas where our design

*ZACKRISON, HARRY B., SR., B. S. in Civil Engineering, Worcester Polytechnic Institute; Member of American Concrete Institute, American Society of Mechanical Engineers; received the ASA 1956 Award for outstanding work in modular coordination.

temperatures call for 0. 27 U factor. Our major experience, therefore, has been in such types of buildings as barracks, bachelor officer quarters, post exchanges, headquarters buildings and the like, for a period of about five or six years, although we have had experience on a limited number of buildings for about 15 years.

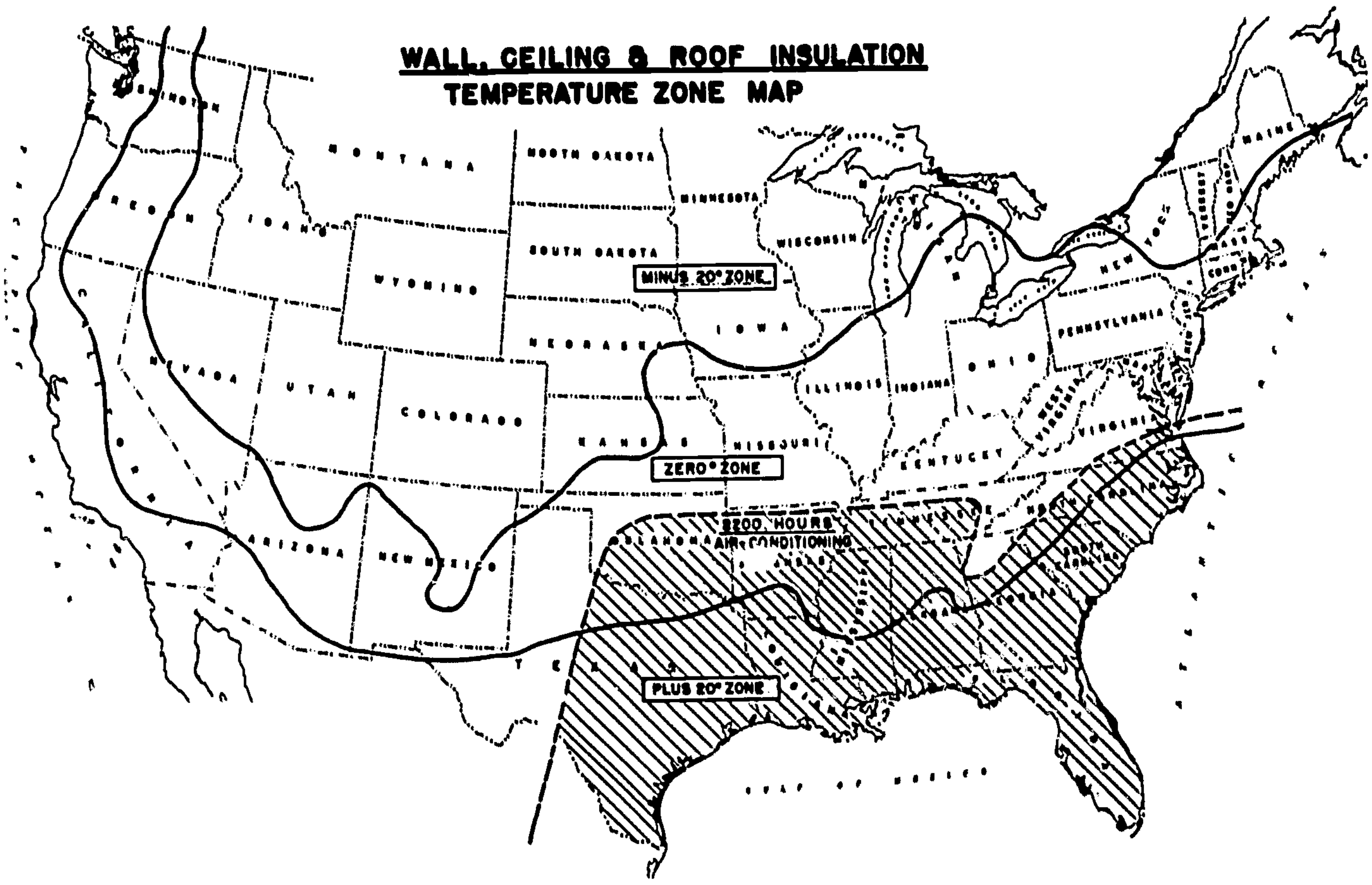


Figure 1

To provide some idea as to the geographical areas where these types of designs will be employed, Figure 1 delineates the -20° F zone and the 0° F zone, which are roughly the areas where these 0. 27 factors for walls are applicable. Figure 2 shows the first floor plan of a two-company EM barracks to illustrate the relation of the cavity wall to the concrete frames, as well as the method of construction at the door and window jambs.

Figure 3 shows an elevation of the same building using brick-faced cavity walls concealing the concrete frame. If this were a concrete masonry elevation, it would show the control joints which we require with this form of construction.

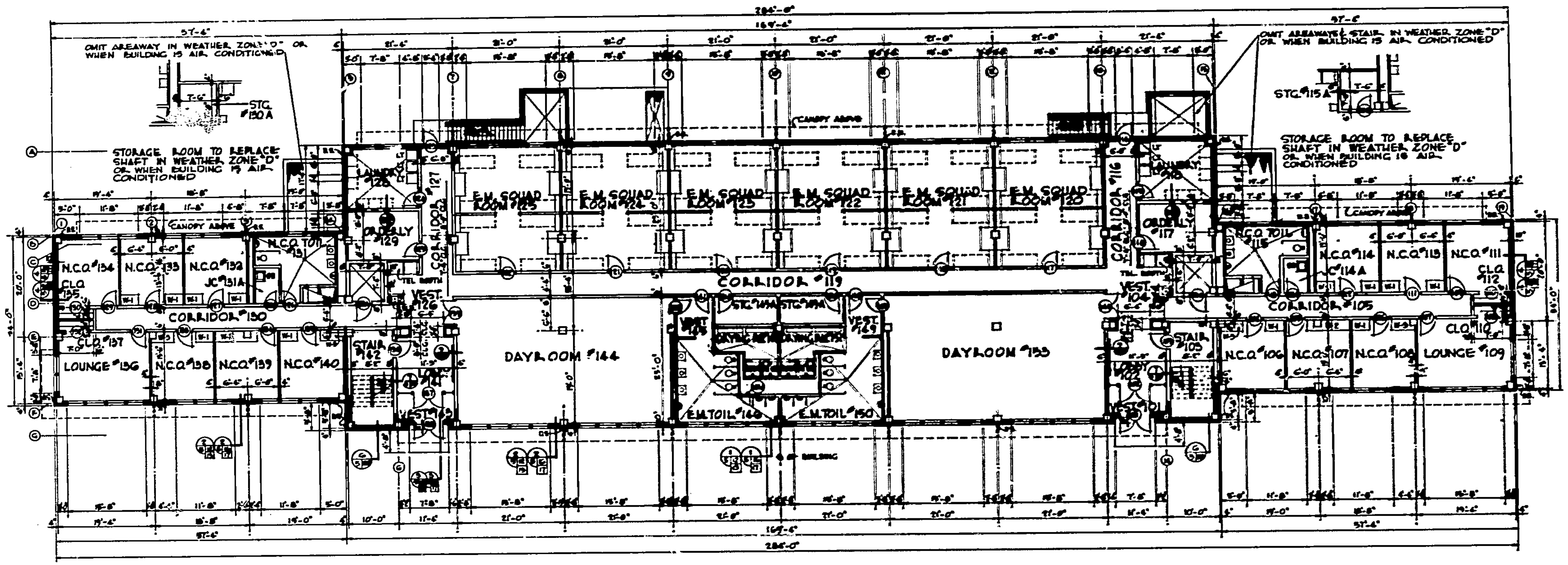


Figure 2

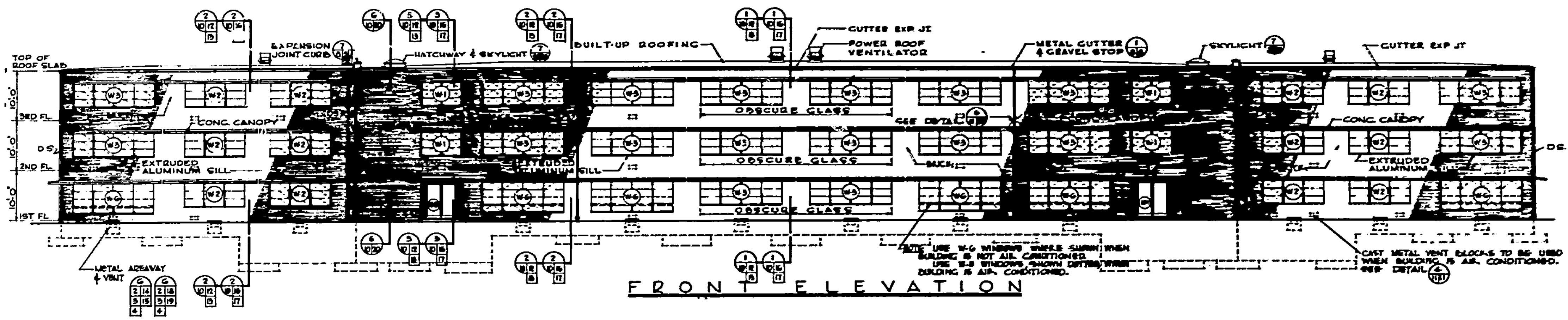
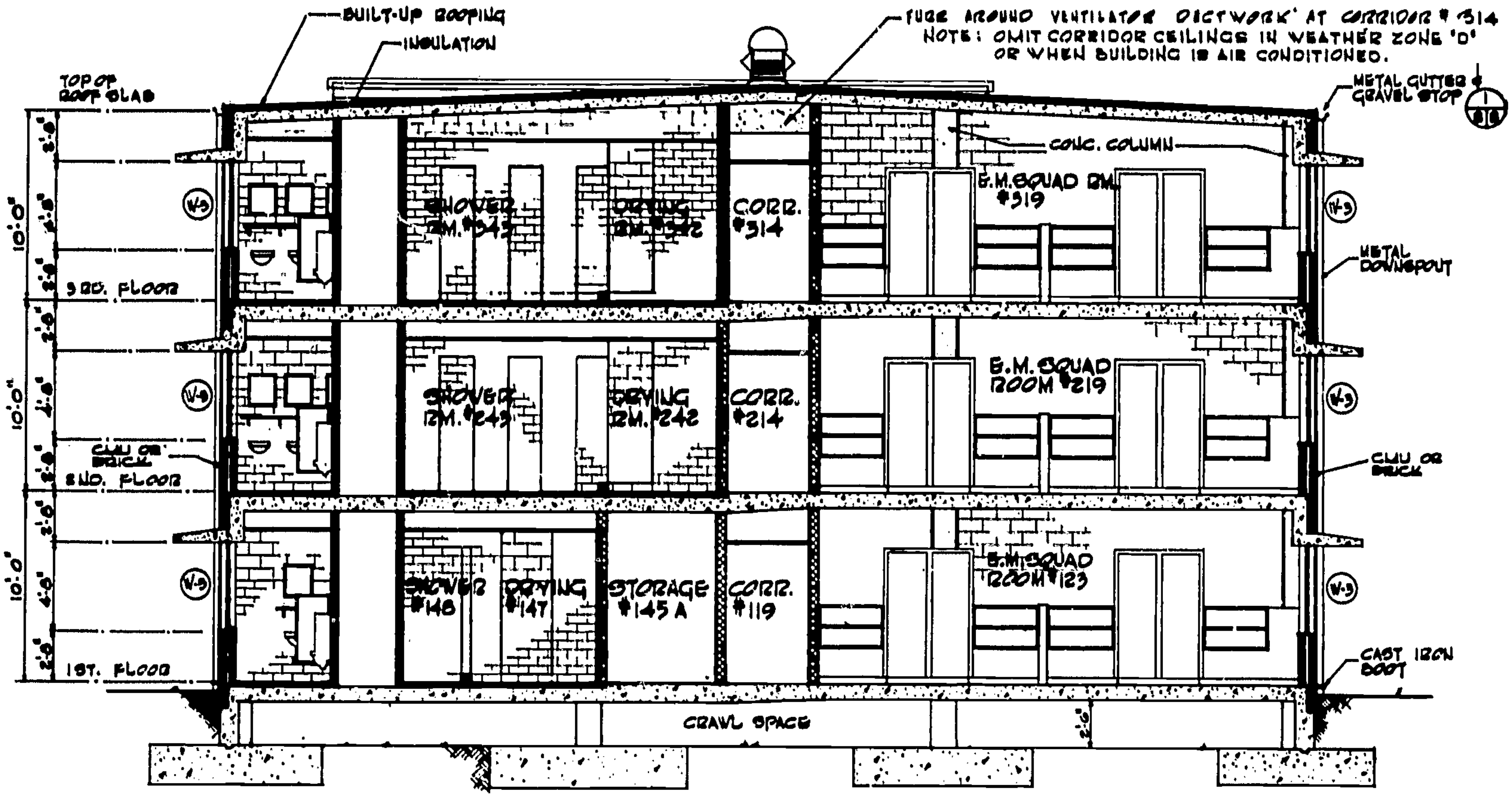


Figure 3

Figure 4 shows a cross-section of cavity wall details at spandrel and grade beams. Note the through-wall vent and flashing detail of the room fan coil unit.



SECTION
SCALE = 1/4" = 1'-0"

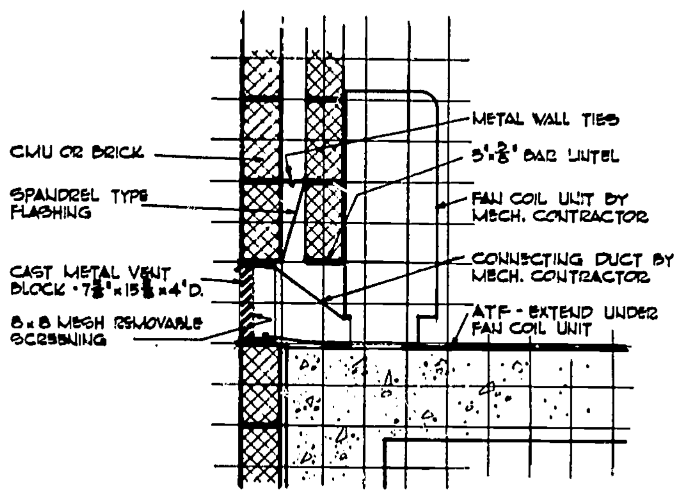


Figure 4

TYPICAL SECTION AT FAN COIL UNIT
SCALE: 1 1/2" = 1'-0"

Figure 5 has large-scale detail sections which show to better advantage the application of flashing details at spandrels, window sills, and eaves. Dove-tailed anchors are used to secure brick facing to concrete spandrel beams. Concrete beams have reglets to receive flashing. Metal ties are placed at every sixth brick joint or, if concrete masonry unit construction is used, at every second joint. Flashing is installed at floor line as well as at bottom of spandrel beams. No cavity is provided between the spandrel beams and the brick facing.

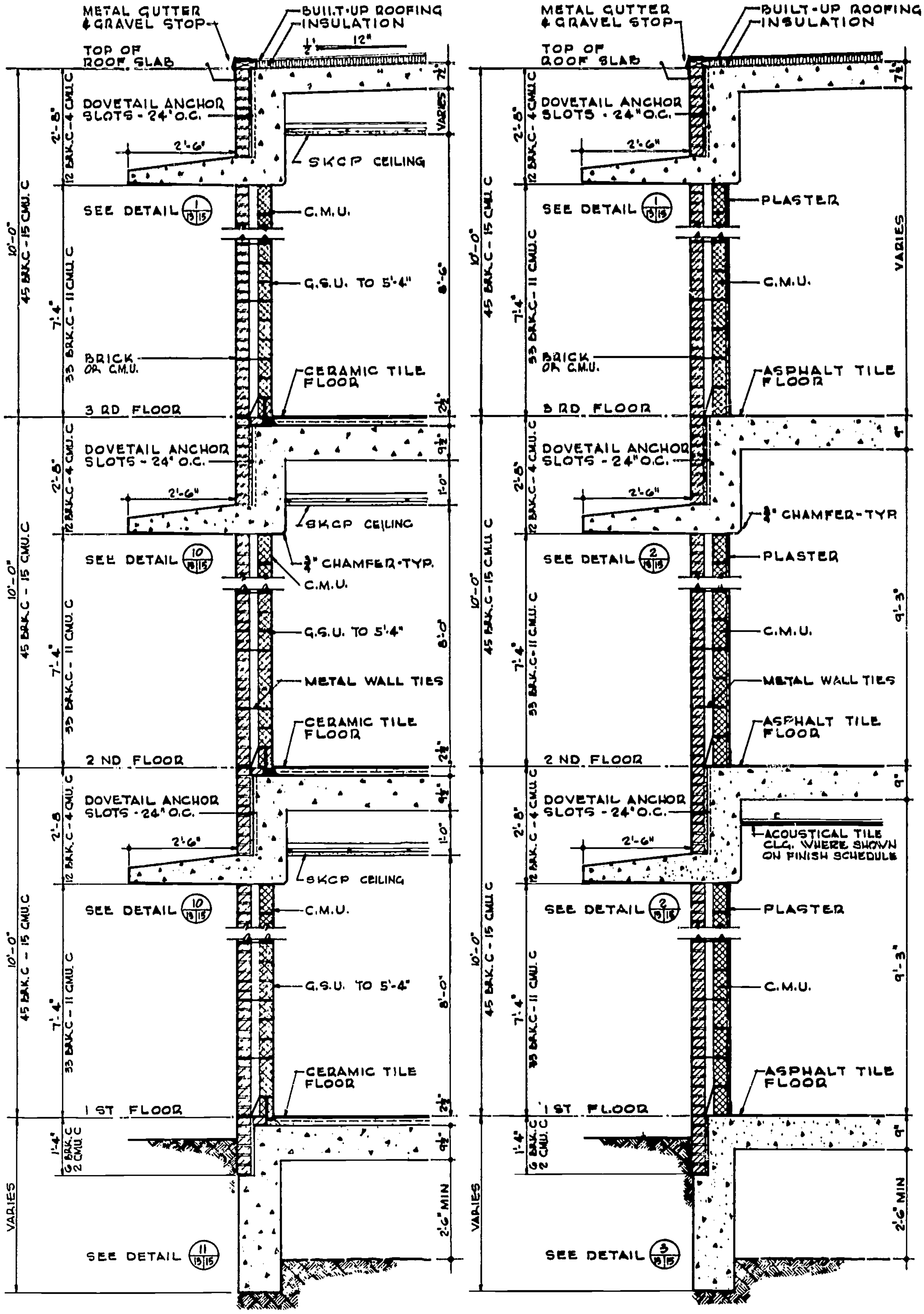


Figure 5

Figure 6 has a few details of an aluminum awning window with a system of anchorage, ties, and flashing. The cavity at window jambs is filled with a return of a 6" concrete masonry unit and at the sills with concrete for one concrete masonry unit course.

Figure 7 shows the details for the consolidated mess hall building which goes with the barracks. The floor plan shows the steel frame structure, and the relationship between frame and cavity walls. The steel columns are free-standing.

Figure 8 has a few cross-sections through the structure showing the condition at foundation walls and at the eaves. It shows the method of using the inner wythe for necessary glazed structural unit wainscots.

Figure 9 shows a few large-scale sections of cavity walls. It also has details of combination joint reinforcing and wall ties. Joint reinforcing is shown for inner and outer wythes spaced every second course of CMU with metal ties at alternate courses. When brick outer wythe is used, joint reinforcing will be used in CMU wythes only. The cavity at top of wall is filled with concrete for two CMU courses with strap anchor imbedded and welded to beams. Anchors are spaced at 2'6" o. c.

Figure 10 provides large-scale details for windows for lintels, flashing, ties, and general method of installation. The cavity at window jamb and sills is closed, with the return being made of masonry. For the outer wythe the lintels are steel angles, with precast reinforced concrete lintels sized to close the cavity and support the inner CMU wythe.

Field Office Experience

To obtain as nearly as possible a uniform interpretation of the reports from our field offices on their current experience, we developed a questionnaire, which was sent to our districts and divisions in our northern areas. It asked, "Does cavity wall construction reduce leakage problems as compared with single wythe and backup construction?" The answer from all the offices was that it does reduce and eliminate the leakage problem, even in most severe climatic conditions.

You noted in preceding illustrations that we provide weep holes throughout. Many have questioned the efficacy of these weep holes. The reply by our field offices to the question, "Do weep holes appear to be effective and operative?," was uniformly to the effect that they were, but that special care had to be taken to insure that the cavity was kept clean.

The next question evoked a variety of answers. It was: "Does cavity wall construction introduce any special leakage problems around windows, doors and other openings in walls?" Most of the answers were to the effect that windows and doors are built, and the perimeter of contact surfaces is caulked, in the same manner as for solid masonry construction. It appears that proper detailing is the answer to avoidance of leakage problems.

Our question as to whether there were any problems encountered with flashing was answered to the effect that there were no more problems than in single wythe and backup construction. In masonry construction the extension of flashings at the ends of window sills gives trouble where the masonry joints below the sills do not course

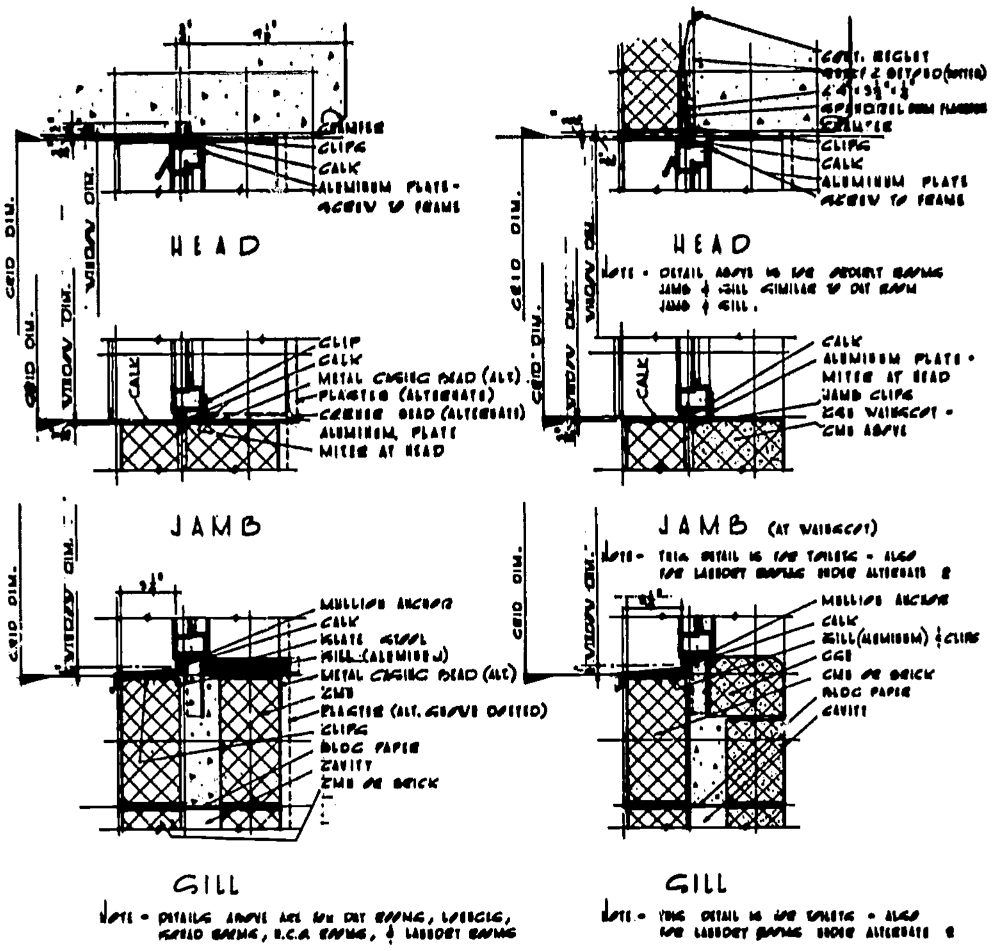
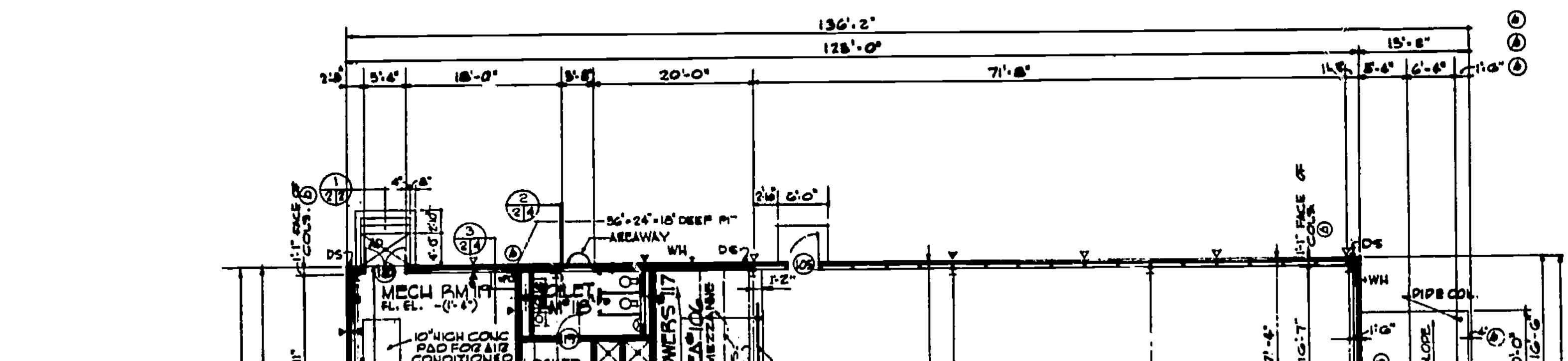


Figure 6

Figure 7



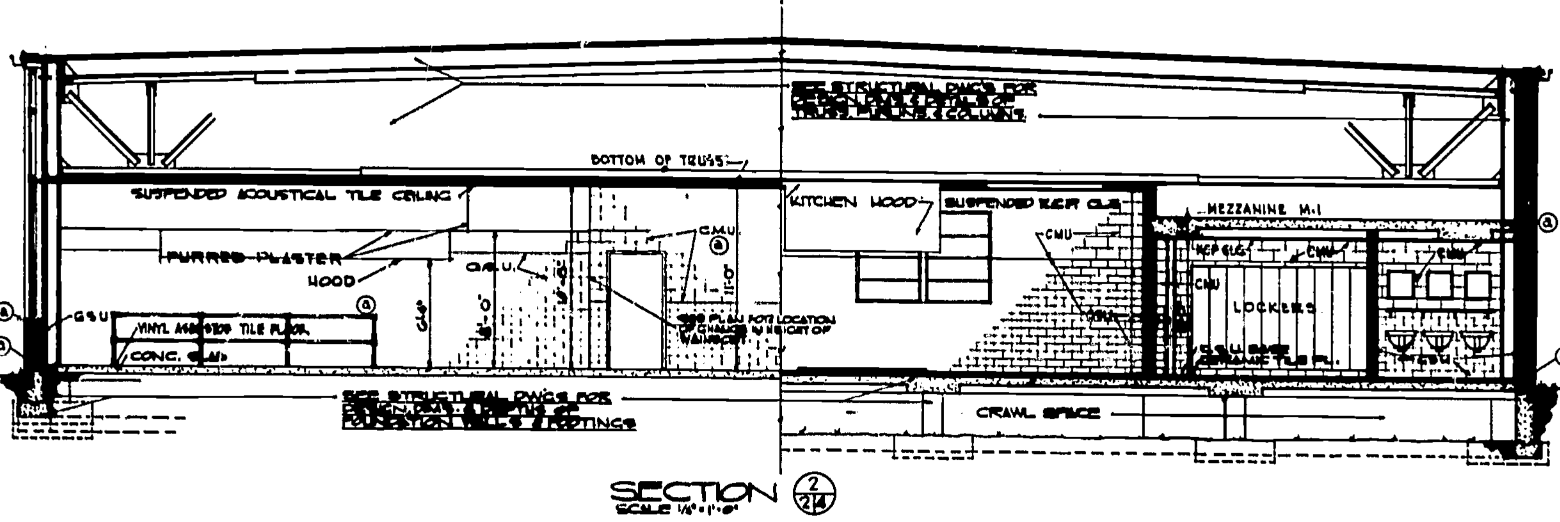


Figure 8

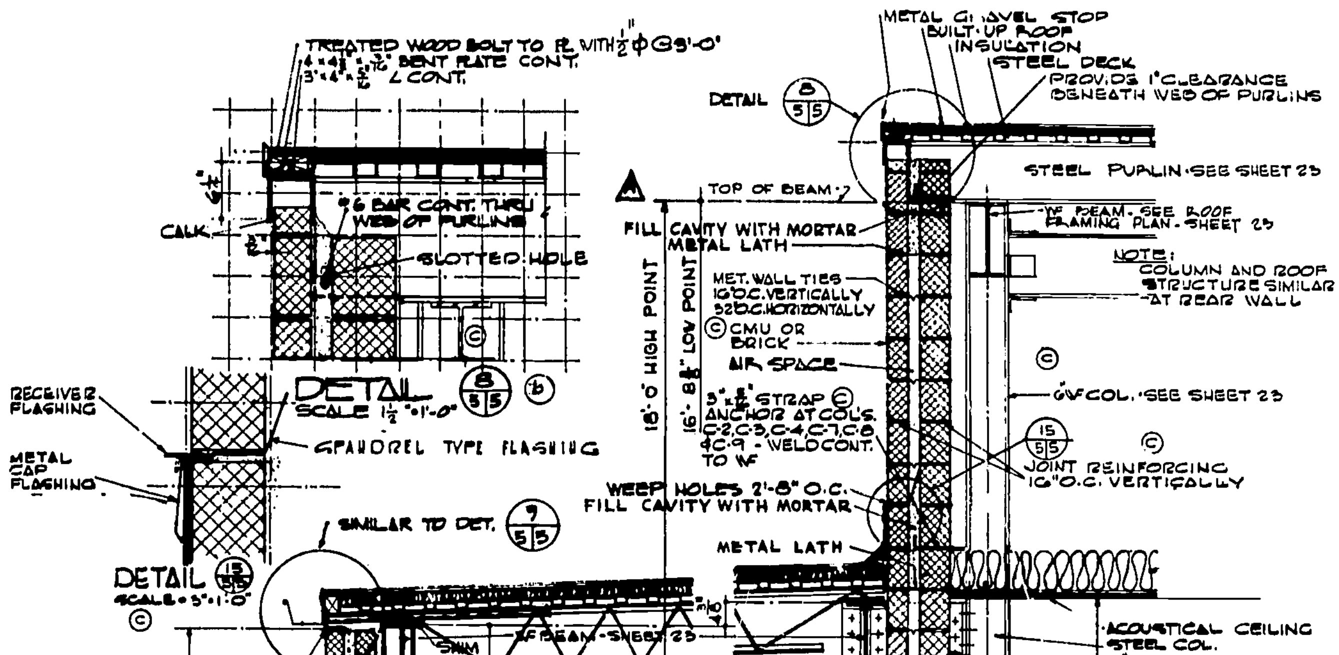


Figure 9

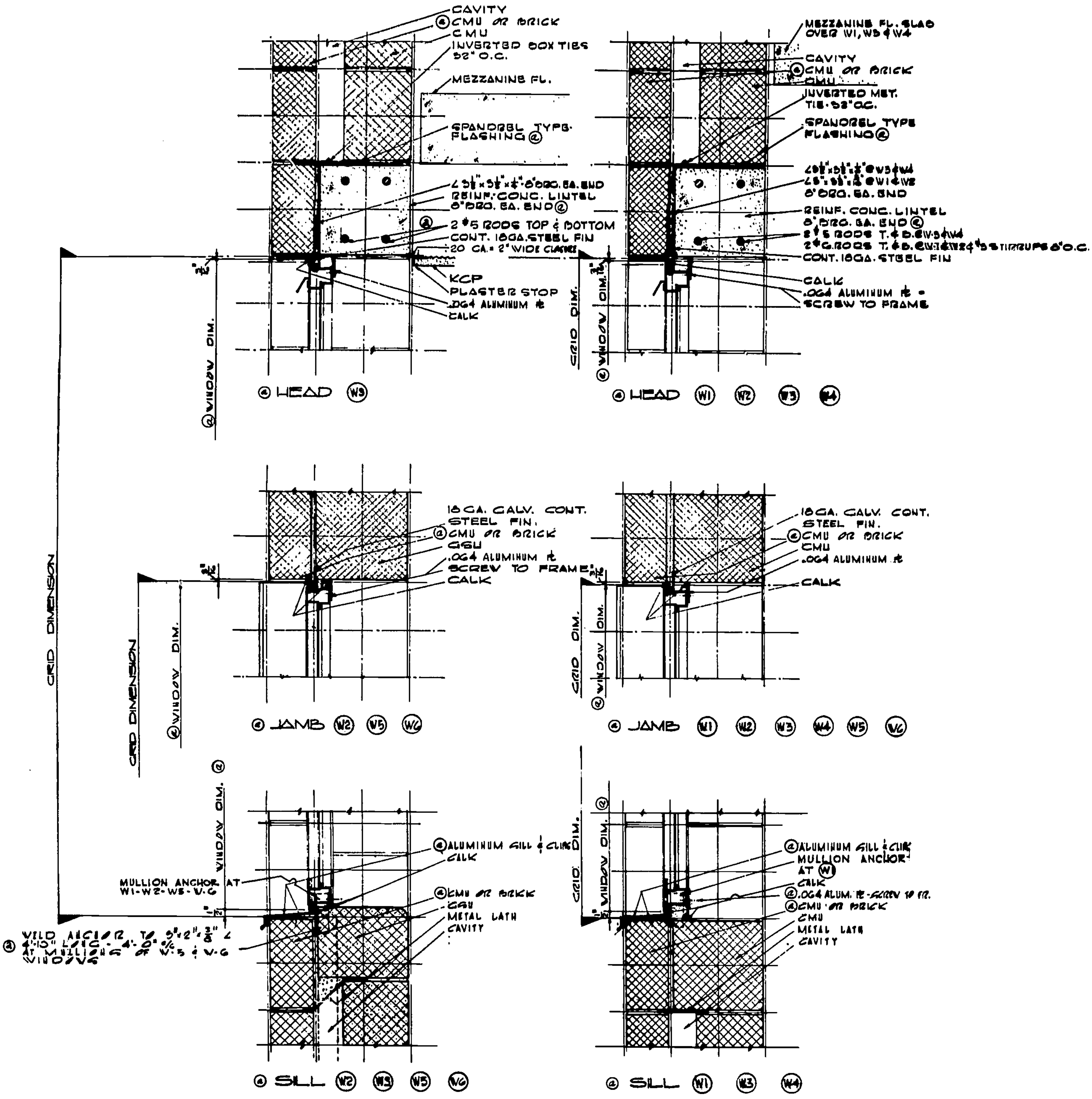


Figure 10

out with adjacent masonry work. Sill flashings also give some trouble both in cavity walls and solid masonry construction, where control joints which are called for in concrete masonry construction fall adjacent to window sills. However, this matter is being worked out satisfactorily so as to secure the flashing extension across the control joint.

Our next series of questions had to do with problems of construction. The first one was: "What problems have been encountered in control joints, such as lateral stability and keying action, where 4" units are involved and a tongue-and-groove joint is not feasible?" This problem, of course, would not be as pertinent where brick exteriors are used and is caused by the need for joints to control the shrinkage in concrete masonry walls. The answer was that there definitely was a problem. One solution was to provide for the use of wire reinforcement in the joints, one end of which is greased to permit movement in the longitudinal direction in the wythe. Another solution is to specify a 3-cell masonry unit, sawing the end cells out. These end cells are then specified to receive a paper liner to provide for the joint break. The resulting space is then filled with mortar, thus providing a key in a manner similar to that provided for in 8" walls.

We next asked whether dissimilar materials such as brick and concrete masonry caused any shrinkage or cracking problems. The answer was that the field offices had not experienced any particular difficulties.

It was reported by a number of offices that all the special CMU units are not always available, such as the 10" bond beam units, and the jamb units. This would seem to be something that the industry should look into. From a construction standpoint, they reported no particular problems at wall openings, such as details for windows, except that the installation of frame anchors must be detailed to coordinate with the inner wythe. However, this is a matter of detailing and, where provided for, no trouble is being experienced.

We questioned whether through-wall flashing would have an effect on wall stability. The consensus here is that, while smooth surface flashing provides a plane of weakness, the weight of the wall is sufficient to prevent lateral movement.

Our people reported that waterproofing, other than that obtained by cavity and exterior waterproofing, was not considered to be necessary. In many locations rigid insulation has been cemented to the cavity face of the inner wythe using asphalt emulsion or hot-applied asphalt. The asphalt then serves as a vapor barrier against penetration of moisture into the inside of the building. In many instances, contractors have elected to use a low-density asphalt-felted roof insulation which provides some additional vapor barrier protection. When foamed plastic, which does not generally absorb moisture, is used, it is applied with a cold mastic. When insulation is used in this manner, a cavity of about 1" remains which provides adequately for free drainage of any moisture entering the wall from wind-driven rain.

In comparing load-bearing cavity wall construction with solid wall construction, our offices reported that where it was properly designed to conform to appropriate building code requirements, no structural weakness and very little shrinkage cracking had been experienced.

They also reported that they experienced no particular coursing problems in connection with dissimilarly proportioned or sized materials, such as GSU and CMU. Where problems did occur, they involved nonload-bearing partitions placed on top of concrete floors that keyed into the exterior walls by metal anchor ties. However, this can be taken care of by an 8" glazed structural unit base in partitions.

Our next major heading concerned heat losses and we asked how they obtained the 0.27 value for the $0^{\circ}F$ and $-20^{\circ}F$ zones when other than lightweight aggregates were used for the block backup. We found that generally our offices had been calling for either 1" rigid board insulation or foamed plastic. In a few cases they reported the use of vermiculite fill. In all cases the agencies using it have found both insulated and uninsulated cavity wall construction satisfactory from a comfort standpoint. Our experience with rigid board insulation has not generally been satisfactory. Our offices had not had sufficient experience in the use of loose fill insulation in the cavity to predict how satisfactory its use would be over the years.

Some of the general comments were to the effect that nonload-bearing exterior walls are a greater problem than load-bearing masonry walls, since there are no superimposed vertical loads to stabilize the walls. Thus, lateral stability against high winds is reduced and is dependent upon anchoring or wedging.

Another minor problem connected with the use of cavity walls is that of keeping the cavity clean. Cavity ties which are specified every other course for concrete masonry require the catch-all board to be moved each two courses. This results in the mason laying the board on the cavity ties prior to laying masonry at that particular course, so that droppings resulting from laying this course will not be caught by the board. However, a metal trough arrangement can be developed, tilted to clear the ties and retain the mortar droppings at that course.

Our preliminary investigation has disclosed a number of things which will bear closer investigation. It was reported that cavity wall construction generally costs as much and perhaps sometimes more than a solid wall construction with furring and plastering to provide the same U factor. In many cases, however, an exposed masonry wall may be considered superior from the standpoint of resistance to wear and tear, being a much harder material. As a result of this preliminary survey on which I am now reporting, we propose to make a much more thorough investigation into the types of construction which should be utilized to more effectively conserve not only heat but refrigeration required for air conditioning which is coming more to the fore each day. Refrigeration, being accomplished largely by electrical energy, which is much more expensive, is believed to warrant a study to determine the optimum amount of insulation.

J. N. Pease and Company, the architects for the barracks building illustrated previously, recently completed an economic study of the effects of providing vermiculite water repellent loose fill insulation in the cavity walls. For air conditioning, it reduced the load from 77.7 tons to 75 tons. This extra 2.2 tons might in some cases require jumping the size of the machine to 100 HP, which might be more difficult to control.

For heating, a reduction in heating plant would run around $1000 as against an estimated added cost for vermiculite water repellent loose fill insulation of $1567. The added difference in cost of some $600 could be amortized in a relatively few years by the lower operating costs.

Studies of this nature can well have a major effect on our future designs in military construction and may result in significant changes not only in wall design but in fenestration, ventilation and lighting. These are challenges which we welcome and which make our profession as architects, engineers and builders so rewarding.

Performance Experience With High-Rise Buildings

By Clarence B. Litchfield,* AIA, Partner
LaPierre, Litchfield & Partners

This paper will present our early trials and long experience with the use of the cavity wall, at first in low-rise and then in high-rise buildings, all of which continues to strengthen our conviction that this is the best, and always the safest, masonry wall to build, as far as watertightness is concerned.

The experience of our firm of architects, LaPierre, Litchfield & Partners, and our predecessor firm of Alfred Hopkins and Associates with cavity walls extends back to the late 1920's, particularly in our correctional institution work where we wanted a good economical, solid masonry interior finish.

Our first submission of the cavity wall was to the Federal Architect who was then part of the Treasury Department. The late Elwyn E. Seelye was our consulting structural engineer. The floor structures rested on an 8" inner concrete block wythe, air space, and a 4" brick exterior wythe. We were forced to change the inner wythe to a 4" concrete block furring wythe and the exterior brick was thickened to support the floor and roof slabs. This was in 1930 and this change demonstrates that Government supervising agencies were not then aware of the advantages of the cavity wall.

We continued to be impressed with the economies and watertightness of the cavity wall and continued its detailed development through the 1930's. Of course, these were in structures of 3 or 4 stories, since there was not much else being built at that time. However, this study did prepare us for our many experiences during World War II when many millions of dollars worth of economical, fireproof buildings that also looked inexpensive were wanted.

I recall one Act of Congress in 1940 that was passed for the design and construction of a Petty Officers' Training School located on the waterfront near Groton, Conn. That bill stated the structures were to be "of reinforced concrete of a temporary nature." The Admirals and Captains were scratching their heads wondering just what those descriptive words meant. I anticipated that the architect who interpreted that description to the clients' satisfaction might get the job. We proposed a reinforced concrete system of columns and floor slabs enclosed with a cavity wall having an exterior wythe of 8" concrete block, 2" air space, and 4" concrete block inner wythe. Wartime economies required the exterior wythe to support itself for the full height; the interior wythe only

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*LITCHFIELD, CLARENCE B., Bachelor of Architecture, University of Pennsylvania; Member of American Hospital Association, American Institute of Architects, The Architectural League, New York Building Congress.

extended from floor to ceiling of each floor level. It was necessary to design and construct the job in a rush. Fred Severud was our structural engineering consultant and Vermilya-Brown built it in record time. No leaks occurred anywhere, in spite of the rush, and heating costs were low.

The same experiences continued throughout the war. The results showed that the cavity wall could take a real beating from the weather and, in spite of a short and sparse labor market, was weathertight even in the most exposed ocean-side locations.

Immediately after cessation of World War I hostilities, the design of the long anticipated new buildings for the block-square Bellevue Hospital Nurses School, located on 24th Street, New York City, was begun by our office. It included a 13-story, 120' high central block. Jaros, Baum & Bolles were our consulting mechanical engineers and Fred Severud was our structural engineer. In this project many of the new ideas that had been developing during the war period found expression, including fully modular dimensioning, carefully studied coordination of standard building materials into the nearly 1,000 bedrooms, new sound-reducing partitions 2-1/8" thick, radiant panel heating, and the use of the cavity wall in a high-rise building constructed with modular brick and the newly developed retracted spandrel beam.

Ten-inch thick cavity walls, supported at each floor spandrel with 4" brick exterior wythe, 2" air space, and 4" thick block interior wythe plastered directly on the block replaced the previously used solid walls and furring up to 24" thick, which nevertheless leaked often during the storms coming from the ocean and over the East River. It was gratifying to find not a single leak in the new construction. We did not supervise this work ourselves, since this function was undertaken by the N.Y.C. Department of Public Works. We are grateful that their inspectors maintained standards of workmanship and cleanliness of the wall cavity that enabled it to perform its job of insulation and keeping out the moisture.

No coatings or waterproofing agents, either on the brick or in the mortar, were employed. Our approach to the cavity wall design is that complete exclusion of water through the outer wythe is impossible to achieve under strong wind pressure. By the time any penetrating moisture reaches the cavity, it will trickle harmlessly down the back of the outer wythe and escape through the weep holes located at each floor spandrel. We had already demonstrated to our own and our mechanical engineers' satisfaction the improved thermal insulation value of the empty cavity. We refrain from filling it with other insulating agents which, in our opinion at this time, can only serve to act as a water bridge between the exterior and interior wythes that we strive so energetically to eliminate. There are others, however, who claim to have found an ideal cavity-fill insulation.

In 1949 we were awarded a commission to design Gun Hill Houses (Fig. 1) for the New York City Housing Authority, a total of 733 dwelling units which worked out into six 14-story apartment buildings. Along with our sketch plans, we proposed cavity wall construction with reinforced concrete columns, floor and roof slabs. To the best of my knowledge this was the first proposal of the cavity wall to the New York City Housing Authority. Our structural consulting engineer, Fred Severud, and mechanical consulting engineer, Guy B. Panero, were as enthused about the wall as we were. Together, we compiled figures of estimated construction cost, heat loss, etc., as compared to the usual solid wall. Our proposal was accepted and Gun Hill Houses stand as the first cavity wall used by the Housing Authority. Still there were no leaks, and construction difficulties consisted mainly in educating mechanics to keep the air space free of mortar droppings and electric conduits. All mechanics seem to want to fill that air space, for it is an easy way to make horizontal runs.

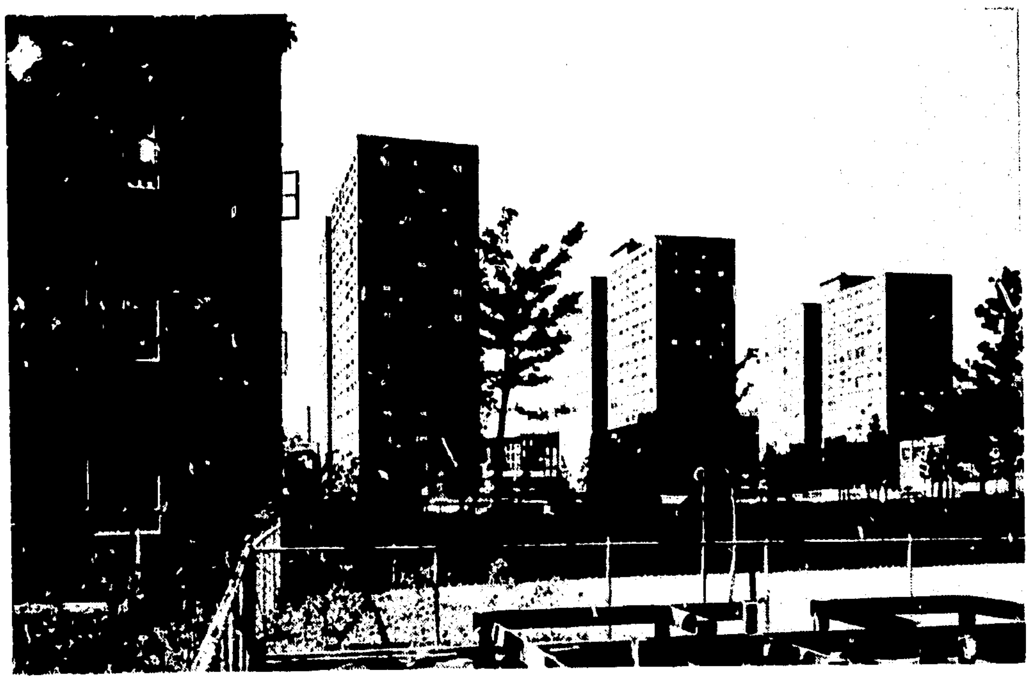


Fig. 1 - Gun Hill Houses

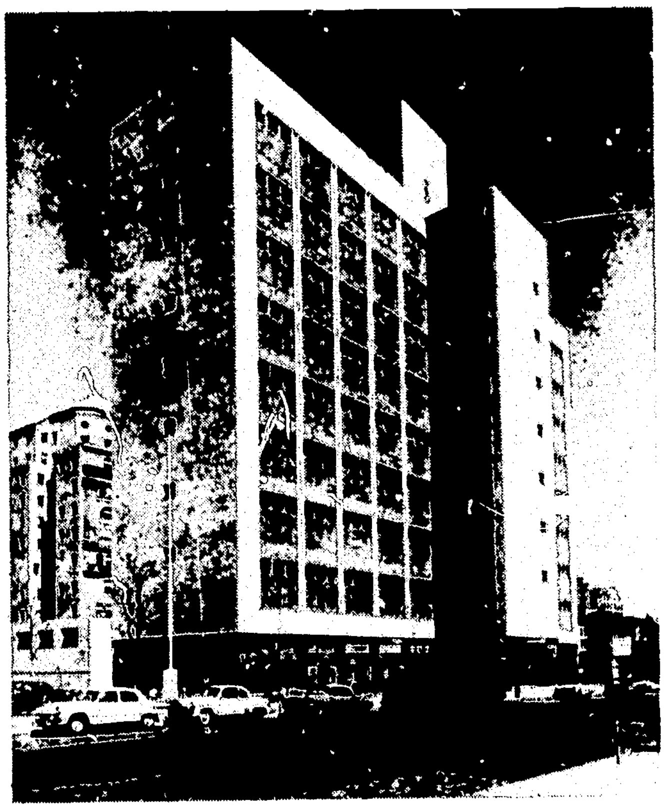


Fig. 2 - Brooklyn House of Detention

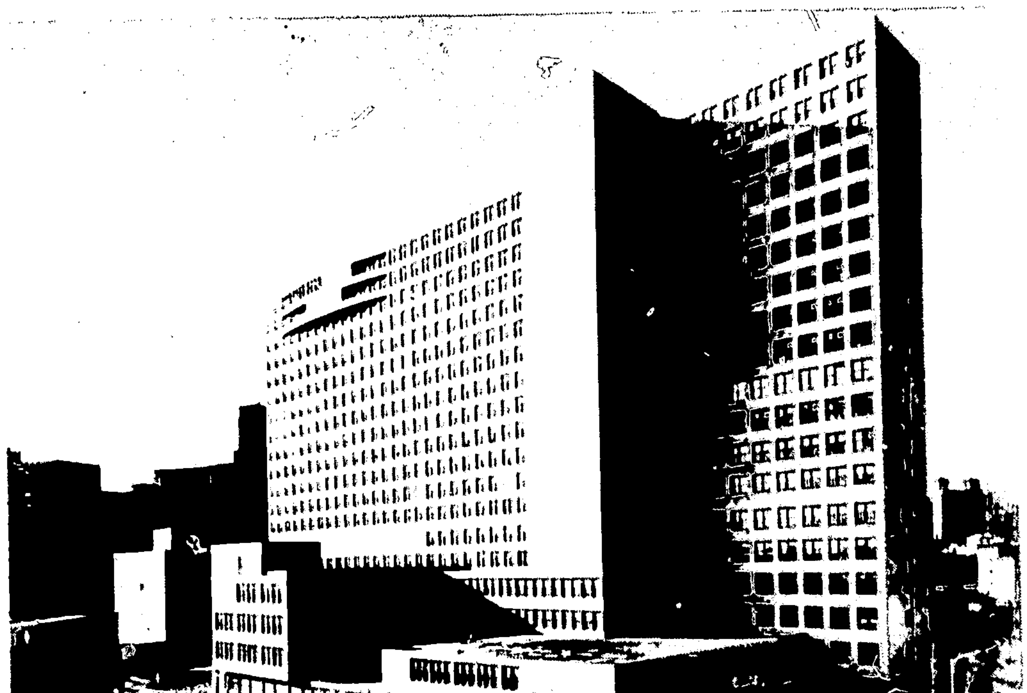


Fig. 3 - Veterans Administration Hospital

In 1950, the design of the Brooklyn House of Detention (Fig. 2) started, and again we proposed the cavity wall to the New York City Department of Public Works for the yard court walls. Commissioner Zurmuhlen approved it and during construction his department had full charge of supervision. This is a steel structure enclosed partially by a security grid with a 2" thick solid glass block curtain wall and partially by the cavity wall. The building is 10 stories tall, 190' high, with two tiers of cells between most of those floors. The performance of the cavity wall has been entirely successful again.

In 1951, the construction of the New York City Veterans Administration Hospital (Fig. 3) was begun for the New York District Corps of Engineers. Severud-Elstad-Krueger and Guy Panero were the consulting engineers. Supervision of construction was ably carried out by the New York District Corps of Engineers. This is a hospital of 20 floors in height and a bed capacity of 1252. It is the tallest cavity wall building within our experience or knowledge. It is pleasant to report no difficulty from wall leaks or condensation. Modular 12" x 4" x 4" buff brick forms the exterior wall with dark red enameled brick, also modular size, as color contrast on the transportation core tower and on certain spandrels.

No special provisions were necessary, in the opinion of the structural engineers, because of the height of the project. The wall again consists of the outer 4" brick wythe, the 2-1/4" completely unbridged and empty cavity, and a waylite block inner wythe plastered on the room side. Noncorrosive drip-type bronze anchors were used and the bottom of each cavity resting on the spandrel shelf angle was flushed clean with a hose stream before the mortar droppings had time to set up. A brick was left loose at that point every 10' or so, and mortared in later.

The George Washington Houses, also designed by our office, is a project consisting of 1,515 apartments in 14 buildings, 14 stories high. Here the lighter weight of the 10" wall (actually 8" of masonry depth) contributed to the decision to use shorter friction piles in an area where long bearing piles were usual and, of course, would have added materially to costs.

The new Medical City, 11 stories tall, which we designed for the legendary city of Baghdad in Iraq, will demonstrate the value of the cavity wall for use in a sub-tropical climate. In this case, top ventilation of the cavity to the exterior will give useful air movement within the cavity to reduce the wall temperature.

Figures 4 through 9 illustrate standard details employed by us in many of our high-rise cavity wall designs, and are reproduced from an article by my Partner, Gannett Herwig, published in Architectural Record, September, 1958.

Figure 4 shows a section through the typical retracted shelf angle which is always attached to the spandrel beam. Note the continuity of the air space and the omission of a continuous spandrel flashing characteristic of solid wall design. A band of vinyl tape closes the butted joints of the shelf angle.

In Figure 5, the corner shelf angle detail is superior to a mitered cut, as it reduces the unsupported projecting leg to 3-1/2" instead of nearly 7". Note the use of ladder or truss type corner reinforcing in the horizontal joint. Near this corner, about 3' back, is a good place to introduce the continuous vertical control joint that will eliminate corner cracking of the outer wythe.

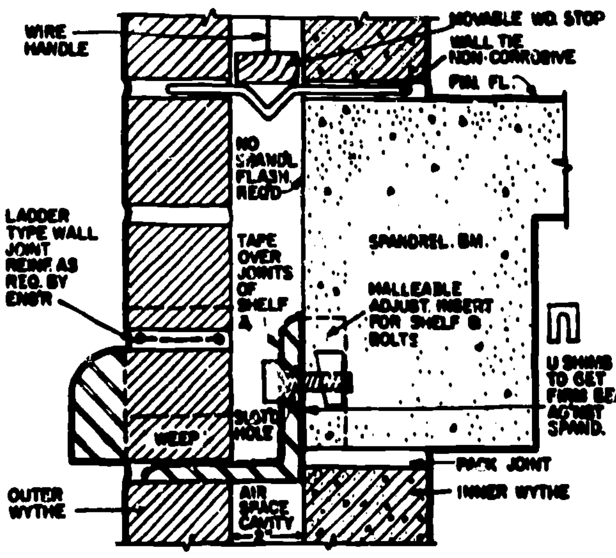


Figure 4

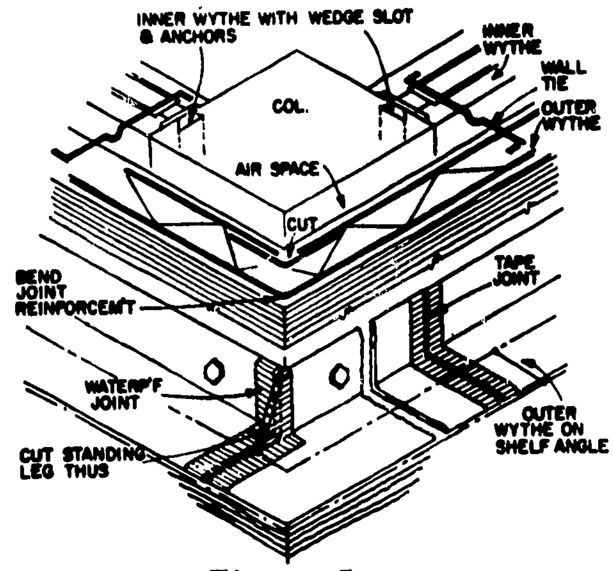


Figure 5

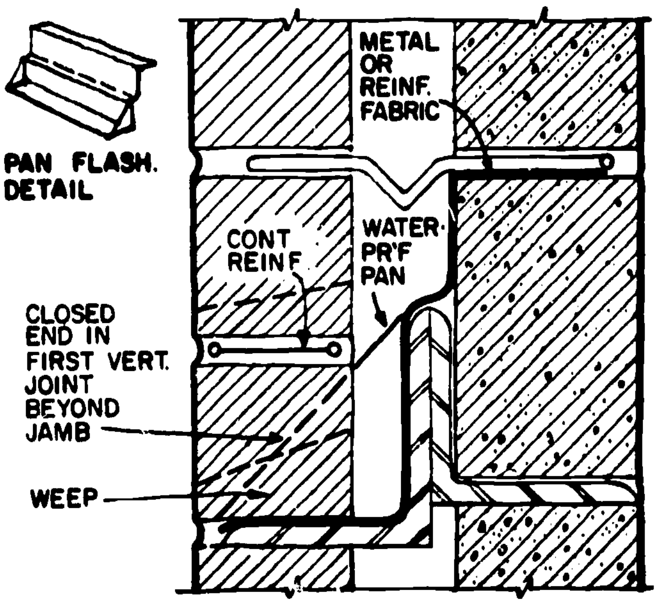


Figure 6

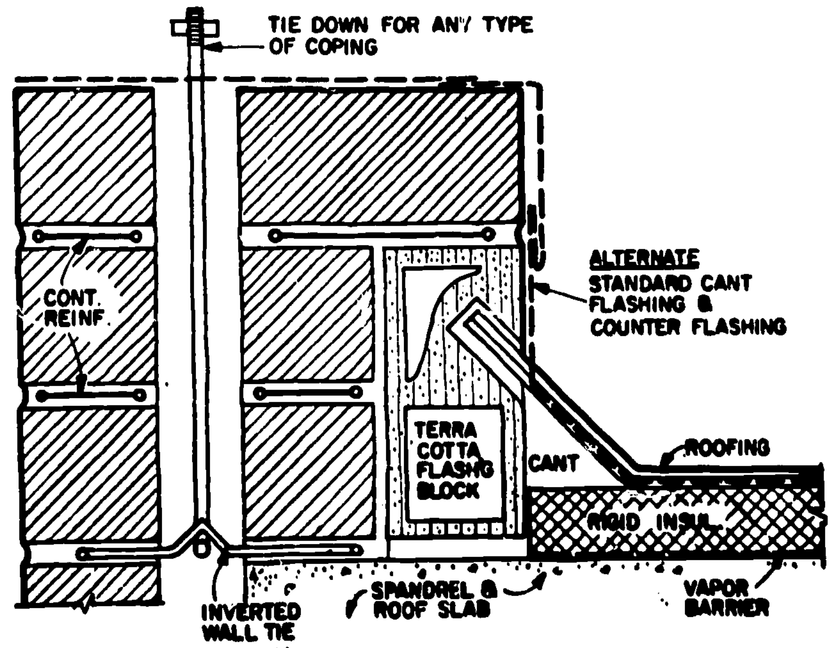


Figure 7

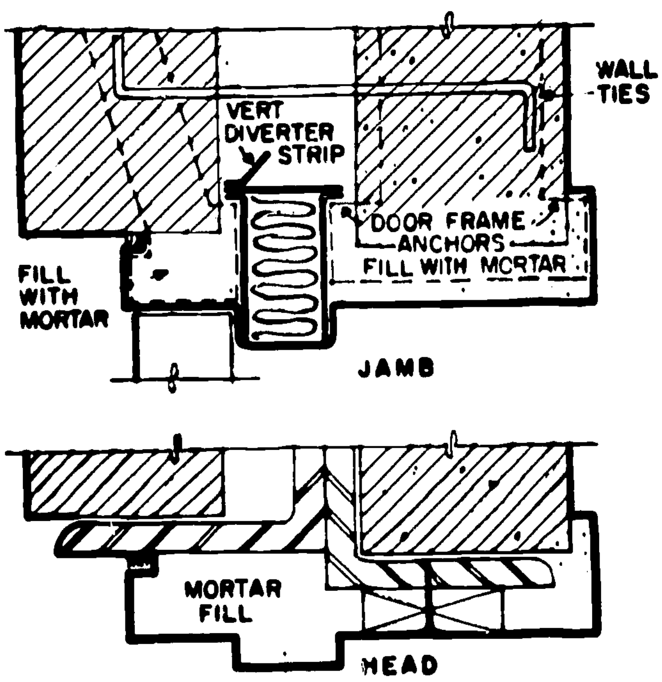
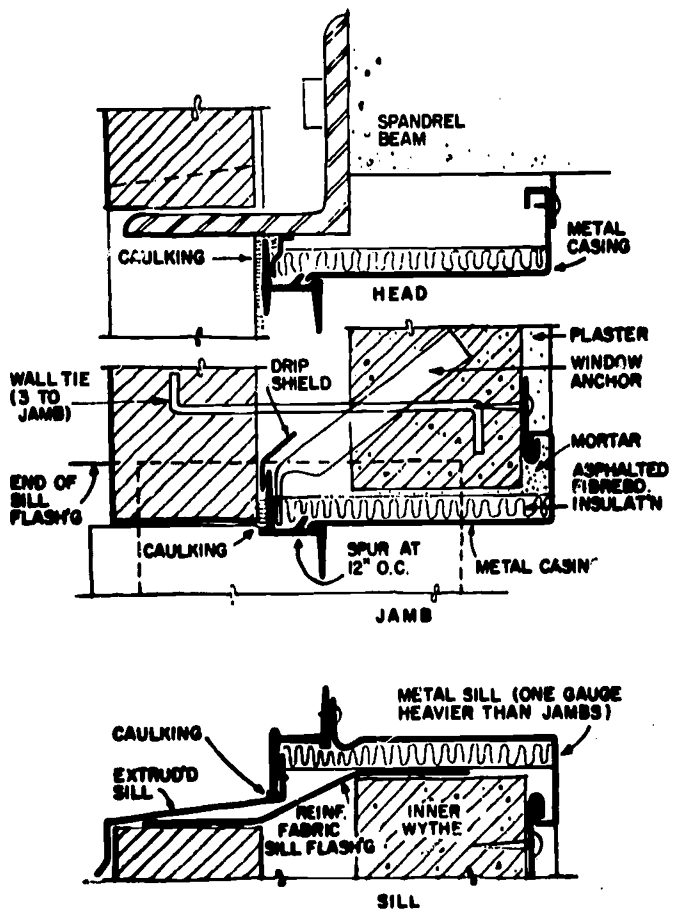


Figure 8

Figure 9



Illustrations courtesy of Architectural Record

Above openings that occur elsewhere than at the shelf angle, individual lintels supported at the jamb are necessary, and require a head flashing with closed ends as shown in Figure 6. Generally, it is made of a light, noncorrosive metal sheet folded to form the "pan" with weep holes to drain to the exterior.

Figure 7 illustrates the cavity parapet. Parapets are to be avoided whenever possible; if needed, the cavity should continue up through the parapet. Maintaining a uniform structural and thermal stress on the exterior wythe prevents changes in color. Efflorescence in parapets is frequent in solid wall construction; it is eliminated by this detail.

The exterior metal door frame in cavity wall is shown in Figure 8. It is advisable to grip both wythes with the door frame. Note diverter strip to discourage water from crossing the cavity.

The metal window (Fig. 9) can be detailed in a variety of ways as long as the diverter strips protect the inner wythe from water, and the reinforced fabric flashing safeguards the sill from any drippings into the cavity. We have looked in vain for any sign of actual water drip stain from the weep holes outside of brick cavity walls. For some reason, stone concrete block walls show discolored lines of drainage in certain few cases, but we would never, in any case, recommend the omission of the weep holes. We have never placed openings at the top of the cavity in our climate, as we wish to avoid air circulation within the cavity which would reduce its insulation value.

In the early days of cavity wall design, thermal insulation values had to be computed through the various layers or elements of the wall. Comprehensive testing of the entire assembly was expensive, time consuming, and made difficult by the variety of materials that could be used in the wall. The recent research programs will enable both the architect and heating engineer to proceed with more certainty than formerly, when heating design had to assume a "safe" attitude, with the frequent consequence of unnecessary radiation.

A word on condensation--the absence of a deliberate vapor barrier on the inner face of the wall must allow water vapor to migrate to some point in the inner wythe, maybe on to the cavity and maybe on to the outer wythe, but it must be dissipated in our benign climate, for no ill effects have shown up to trouble us.

We sincerely hope that these witnesses have told their story convincingly, and that the results of our experiences in cavity wall construction versus that of the "solid" furred wall have impressed you as much as they have us.

Open Forum Discussion

Moderator - Harry C. Plummer, Conference Chairman

Panel Members - Cyrus C. Fishburn
Harry B. Zackrison, Sr.
C. B. Litchfield

M. Imber, Polytechnic Institute of Brooklyn: Did your thermal design calculations include moisture migration influences upon heat losses?

Mr. Litchfield: No, they did not. We did the best we could with the information available, when we were advocating these walls.

John C. Brandt, Corning Glass: Would a totally waterproof exterior surface on a masonry wall be a desirable goal to shoot for? If so, are there any currently available plastics, silicones, etc., which have been used and what is their performance record?

Mr. Zackrison: I know of no way to make the walls absolutely waterproof. We have attempted, particularly on concrete masonry construction, to obtain as dense an exterior surface as we could. We have experimented with all types of coatings, paints and silicones but we've not come up with any solution that's any better than a good cement water paint.

Mr. Litchfield: I have had an interesting experience in the last two years regarding silicones. Apparently the State of Connecticut Department of Public Works requires this on their public buildings. I am a New York State architect, but our firm was fortunate to be appointed architects for two correctional institutions replacing two old ones for the State of Connecticut. Apparently Connecticut has highly absorbent brick, which is different than the brick we used, for instance, on the Veterans Administration Hospital. These were very hard brick and we had no reason to use a silicone of any kind on that wall. But, in the case of the Connecticut buildings, it may be wise to put a coat of silicone on. However, I would do this after the wall had dried out, both from the inside and from the outside. On another institution, much larger, where we're using a good many concrete masonry units I'm going to try and use the silicone surface on them. I think it may be interesting to see what happens.

Mr. Plummer: That's a cavity wall, is it?

Mr. Litchfield: The purpose is not to prevent leaks into the building: it's merely to keep the water out of the highly absorbent Connecticut brick.

A. A. Hill, Dow Chemical: Has the Bureau of Standards investigated the use of latex-modified mortars for bonding masonry units?

Mr. Fishburn: If they have I don't know anything about it, but of course I don't know all of the investigations that are being made on these admixtures of latex and concrete.

C. A. Wojan, Polytechnic Institute of Brooklyn: What was the procedure used for determining the over-all heat transfer coefficient (U factor) for the cavity walls for Bellevue Hospital?

Mr. Litchfield: I tried to find that material in our files, but I couldn't find it. You're asking me to remember back about 10 years and I can't tell you. We used everything that we thought we should to prove to ourselves and to the Department of Public Works that they could get a better and more economical job with a cavity wall.

L. A. Sykes, Ohio Bell Telephone Co.: Is parging used to help control leakage in connection with cavity walls?

Mr. Zackrison: We have not practiced parging of cavity walls. We did some construction for the Veterans Administration back about 10 years ago in which they desired that we use parging on the interior surface of the exterior wythe, but this has not been our general practice with the Corps.

Mr. Litchfield: The only time we ever used parging was in back of limestone to make certain that it would not stain from the masonry behind it, but not in the cavity wall as such.

M. Hibner, Hibner Company: Does the cavity wall eliminate efflorescence completely?

Mr. Litchfield: There's a green tinge coming out on the brick that I was speaking about in Connecticut, and I think that is the thing that will convince me to put a silicone coating on it, but it's not white. I haven't seen a white efflorescence on cavity walls.

Grayson Gill, Grayson Gill Inc., Architects - Engineers: Have you had any undesirable results from the use of silicone-coated face brick?

Mr. Fishburn: I personally know of no undesirable results from the use of silicone on face brick. It has been claimed that if silicone coating is applied to a leaky brick wall, without stopping the leakage into the wall, the water that penetrates the masonry may absorb some salts and migrate to the exposed face of the wall and there evaporate, leaving the salt behind the surface of the brick. If this should occur the deposit of salt could cause some damage to the face of the brick, in my opinion. However, we have not made any tests and I know of no instance of such damage which has been related to the use of silicone.

Unidentified Comment: What you're advocating, then, is to put it on during a very dry period when the masonry is dry.

Mr. Fishburn: I advocate putting it on when you're sure there isn't any leakage into the wall, so that the water doesn't get in back of the wall surface. This would merely be an obstructive proposition from the face of a wall in which there was no leakage through openings in the joints or elsewhere.

Mr. Gill: Is there a method of plant application of silicone?

Mr. Plummer: Some brick are treated with silicone solutions at the plant. There are two methods. One is to dip the brick, which coats all faces including the bed, the other is to spray them where only the sides and ends are coated with silicone, the beds are relatively free. Do you have any opinion on the use of that type of brick, Mr. Fishburn?

Mr. Fishburn: We haven't gone into the difference in the two types of silicone application. We have treated masonry walls on the face. Such walls were highly permeable to rain penetration, in the test. The silicone treatment did not give a continuous film over the masonry or stop openings in the wall which had a low capillary potential. It permitted some leakage after the face of the wall lost its repellancy and spread out over the face of the wall. I don't know just what the effect would be in treating the whole surface of the brick. You might have an effect in laying the brick which might cause you to use a mortar with a little dryer consistency.

R. Lopez, Cornell University: You mentioned that in your opinion the cavity wall would be a contender in fields now using curtain walls. Would you include office buildings similar to those going up in New York City in this field and if so, what are your reasons for this opinion?

Mr. Litchfield: That was an expression of my feeling that the pendulum of the curtain wall has swung just about as far as it can. The nudity of the building has gone about as far as it can. We all know that architecture is a continually changing approach to design; people will get tired of looking at such baldness and nudity. It is my opinion that you and other people are getting fed up with it. The curtain wall is just another architectural expression to the exterior surface of a building.

Gray Bolich, Natl. Lumber Mfrs. Assn.: How do the costs of the cavity wall barracks compare with wood frame barracks considering first cost, maintenance and operating cost?

Mr. Zackrison: They can't be compared. You've got one that's going to explode in your face anytime and the other one is fireproof construction. You're comparing apples and oranges, and you can't do it. The masonry is more expensive; the whole fireproof structure is more expensive. There are quite definite differences in cost, because we actually have three types of construction: permanent construction as designated, semi-permanent construction which is a lesser quality built for 10-to 15-year life, and wood frame construction which we generally think of as three-to five-year life. While there's a difference of perhaps 30 to 35% in cost, it isn't just because they're wood frame buildings. It's because they represent a different type of construction, different thinking, a different standard. Everything that goes into a three-to five-year life building is designed at minimum quality, whereas in permanent construction you try to provide minimum maintenance over 20-25 years.

In 1939-40 we were building wood frame construction to what we call mobilization standards which ran from 10-, 15-to 20-year life. There are plenty of those buildings which are giving good service today, but they were built to a better quality than we are building those for three-to five-year life. Of course, the building isn't going to fall down in three to five years; this represents the period in which you can afford to keep it without having excessive maintenance. After five years it will still stand, but then it requires excessive maintenance.

Grayson Gill, Grayson Gill, Inc., Architects-Engineers: On the spandrel details shown, is wind-driven water through the weep holes ever noted? Have you had experience with wicks in weep holes to stop wind-driven water and to prevent access to cavity by vermin, which is a problem in the Gulf Coast area?

Mr. Litchfield: No, we have not noted wind-driven water through the weep holes. One of the ways of creating a weep hole is to put a piece of clothesline in the mortar joint that could be called a wick, but of course it rots out or is pulled out as soon as the scaffold is lowered. We have not had trouble with vermin. I've had people say, why don't the bees fill up this cavity? I've never seen any animal that was particularly enticed by a custodial institution, such as the cavity becomes.

Construction and Initial Cost

By Harold W. Peterson,* President
Harold W. Peterson & Sons, Inc.

In the construction of a cavity wall there are no basic changes in techniques, just modifications of practices that are commonly used in the construction of any masonry wall. Briefly then, this paper will discuss certain construction practices which we feel make for a better wall.

The fundamental principle in a cavity wall is that there shall be no tie or bridge of solid material capable of carrying water across the prescribed 2" air space. Therefore, the construction of the two separate walls is of prime importance. I might add that there is no substitute for good workmanship. There must be full head and bed joints so that there can be no moisture penetration.

In addition, under the heading of workmanship, it is necessary that the cavity be kept clean. In the building of the two walls or wythes it is a prime requisite that as much mortar as possible be kept from falling into the cavity. Over the years many methods have been developed and a considerable amount of time and discussion devoted to what is the proper method to use in keeping the cavity clean. We have found from experience that the most successful method is to take a wooden strip, 1" x 2", and place it in the cavity. This strip rests on the wall ties as the wall is built. Wire or rope is attached to the 1" x 2". Then, as the bricklayer builds the wall he can easily lift out this strip to remove any mortar which may have fallen into the cavity.

Also, the bricklayer can use several techniques that will eliminate a considerable amount of mortar falling into the cavity.

1) After spreading the mortar bed, the bricklayer will bevel the cavity edge with the flat of his trowel. When mortar is spread in this manner, very little will be squeezed out of the bed joints into the cavity when he lays the units.

2) After the bricklayer has placed the unit on the bed joint he will take his trowel and spread any mortar which may protrude into the cavity over the backs of the unit. This is very important, since it prevents the mortar from falling into the cavity and at the same time provides a smooth surface which will not impede the flow of insulation that is placed in at a later time.

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*PETERSON, HAROLD W., Past President of the Mason Contractors Association of America; engaged in masonry contracting since 1928.

Undoubtedly you will find your mason contractors using other methods. However, as I stated, this has been our most trouble-free method.

In a properly constructed cavity wall both wythes or walls of material must be adequately or properly tied together. Most specifications and recommendations used today will indicate that there must be a wall tie in every 4-1/2 sq. ft. of wall area. The most common wall tie is that referred to as the "Z" type. In the center, or in the middle of the cavity, there will appear a crimp or what is referred to as a "V drip loop," the theory being that should water find its way through the wall and to the tie, the V drip will cause it to fall before reaching the inner wythe. In addition there is the rectangular shaped tie which has been very popular when the back-up units have vertical cores.

In recent years there have been considerable advances in the masonry industry in horizontal reinforcing. Manufacturers have been very progressive in the development of new and improved systems. One manufacturer has developed a horizontal reinforcing with rectangular cavity wall ties. This type of reinforcing is to be used when the interior and exterior are constructed of different materials. Basically, it is used as a wall tie and gives added strength to the weaker wall or the wall subject to movement, therefore bringing both the exterior and interior wall or wythe more into balance. In addition, by using this type of horizontal reinforcing, the placing of the cavity tie becomes automatic and there is little concern over leaving out a wall tie. Occasionally an architect will design a building specifying materials which are modular and non-modular at the same time.

For example, you use a modular back-up unit of clay tile or block, and use a brick that is non-modular. As you have seen by the preceding examples of existing wall ties, it is somewhat of a trick to make sure that it is possible to get the wall tie in the bed joints. A device which was introduced at the MCAA Convention in Cincinnati last month solves this problem to a degree. A "V" shaped device is forced over the face of the back-up unit, upon which you have placed a modified rectangular cavity wall tie. This then allows the rectangular tie to be adjusted 8" in the vertical plane.

From a construction standpoint, the most important factors in wall ties are:

1) That they be corrosion resistant.

2) That they be properly spaced.

3) That they have the proper bedding in the bed joint. This can be easily accomplished by spreading the bed joint and then placing whatever wall tie is used into the mortar, thereby assuring full bond with the tie.

When weep holes are specified, they can be easily created by various methods, such as:

1) Inserting oil rods or pins in the head joint.

2) Placing sash cord or suitable material in the head joint.

3) Placing a copper tube in the head joint.

4) Or, by far the simplest method, that of just eliminating a head joint every two or three feet.

Weep holes in themselves are to be at the base of the cavity or at the flashing level. They provide a means of draining any moisture that has found its way into the cavity.

Flashing and its position in the wall are naturally a function of design. The type of flashing can be of sheet metal, bituminous membrane, or a combination of both. Its proper placement is naturally an important factor in the success of a cavity wall, and good workmanship is required here, too.

This special breed of cavity wall we are discussing requires that the 2" air space created be filled with insulation. One type that has been developed in recent years is water repellent vermiculite. We shall not go into all of its characteristics and resultant efficiency, however, it has been found that this material, when the cavity is properly constructed and free of obstruction, is very easy to place. All that is required is that the bag be ripped open at the proper place and the insulation flows freely into the lowest section of the wall. Where windows or other openings occur in the wall, insulation should be installed when the wall is sill high and again when the wall is complete. Each bag is packed with 4 cu. ft. of material and by the figures provided by the manufacturers it is easy to ascertain the number of bags required for a job. The one good construction feature of this type of insulation is that it can be poured, in most cases, when the wall is complete. However, it has been the practice in my firm to install the insulation every time we are scaffold high. This is an insurance that the wall be completely full when we top off.

Once more, I would like to emphasize that good workmanship insures the wall, while poor workmanship impairs the value of the cavity wall.

We have, through the Mason Contractors Association of America, tried to obtain a representative cost index of three types of cavity walls. Please bear in mind the fact that the figures contained herein are in no way to be construed as established prices for members of the MCAA. These figures are an average of those submitted and are to be used for informational and educational purposes only. To establish a basis for comparison we have set forth the following requirements:

1) The wall considered is to be one scaffold high and up to 10 feet.

2) All walls naturally would have running bond.

3) A concave joint is required.

4) Only a normal number of openings are to be considered.

5) "Z" bars placed 16" on center vertically, 24" on center horizontally.

The figures below are on a square foot basis and include labor, materials, cleaning, overhead and profit. The prices of materials that were used are:

Face Brick....................	$ 60.00 M
Common Brick..................	32.00 M
Lightweight Block (4"x8"x16")....	160.00 M

All cost figures were adjusted to these material prices.

Three walls were taken into consideration since we feel that each of them has an important place in today's construction market, and they are, perhaps, the most popular types of cavity walls used today. These will be uninsulated since the pouring type insulation is a new innovation. The walls, with their respective cost indexes, are as follows:

1) Face brick, 2" air space, and face brick, finished both sides..... $2.80 per sq. ft.

2) Face brick, 2" air space, and common brick, finished exterior side only.. $2.38 per sq. ft.

3) Face brick, 2" air space, and concrete block, finished exterior side only.. $2.15 per sq. ft.

This cost index material is for the Midwest. In the eastern section of the country the cost index of these walls would be higher by perhaps 10 to 15% depending on the specific locality and area. In the south and southwest the cost index of these walls would be 15 to 20% lower.

Now that we have the cost index for the three types of walls we must apply the cost of insulation and the placing of same into the cavity to create the insulated cavity wall. Since this type of wall is somewhat new in application, the cost index for this operation is still somewhat indeterminate. However, by our studies it would be in the area of 15¢ to 25¢ per sq. ft. with this, too, varying somewhat by the region in which the wall is going to be built. These figures, we feel, represent a fair and equitable cost index, illustrating specifically that a masonry wall, such as the insulated cavity wall, can be provided for your clients at a very reasonable cost per square foot.

Thermal Economics and Ultimate Costs

By Clayford T. Grimm,* Manager, Architectural and Engineering Dept.
Building Materials Division, Zonolite Company

The Structural Clay Products Institute has published a report, "Ultimate Cost of Building Walls," which provides a method of economical analysis for building enclosures. Our company has utilized the thermal economics aspects of that report to study the effects of insulation on the owner's pocket book. The method of analysis is fully explained in literature available from SCPI. The purpose of this paper is to summarize these studies and present the results in visual form.

It is difficult to select building materials so as to combine sound economy with the other criteria for good building, engineering and aesthetics. The problem is to select a type of wall construction which fulfills the desired functions at the least ultimate cost. Even the more experienced architects and engineers have, over the span of many years, had to rely occasionally on "guesstimates" rather than exact and authoritative information. The reason for this has not been a lack of interest in economy but rather the lack of accurate data on building costs, and inevitably the counter-claims of producers of materials and equipment. Admittedly, it is difficult and often frustrating to arrive at the truth. Yet truth is what the professional man, architect and engineer, seeks in contemporary building.

The selection of building materials to solve an architectural design problem involves aesthetics, engineering and economics. Good architecture can result only by a proper balance of these three factors. The relative aesthetic value should always be tempered by concern for true economy. The AIA Standards of Professional Practice require that an architect design for "efficient operation and economical maintenance" and that materials employed be "economical for their particular use." It is not sufficient that men or buildings be handsome and strong. They must earn their way in the world; support dependents, stockholders and families. It is a part of the business of the design professions to save their clients' money. This can only be done with reasonable certainty by analyzing the economics of alternatives.

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*GRIMM, CLAYFORD THOMAS, Bachelor's degree in architectural engineering, The Catholic University; other studies at Western Reserve University and Shrivenham University in England; Member of American Society for Testing Materials, American Society of Civil Engineers, Construction Specifications Institute, National Society of Professional Engineers; formerly assistant director of engineering and technology, Structural Clay Products Institute.

The complexity of the problem is considerable. For example, each of the following 15 cost items must be studied to determine the relative economics of wall types:

1) Price increases
2) Space occupied by the walls
3) Real estate taxes
4) Salvage value
5) Air conditioning costs
6) Income taxes
7) Insurance rates
8) Initial construction cost
9) Speed of erection
10) Heating costs
11) Depreciation
12) Cost of supporting the walls
13) Value of money
14) Maintenance expenditures
15) Illumination costs

Each cost item and its frequency must be determined and expressed in comprehensible terms. Confusion is avoided when initial and operating costs are expressed in the same terms. This may be accomplished in one of two ways. Initial cost may be amortized over a period of time and the annual amortization payment added to the annual cost of maintenance and operation. Because these annual payments fluctuate, are unequal, are off somewhere in the distant future and are a series of payments rather than a lump sum, they are vague and not so comprehensible as a demand for an immediate cash outlay. Conversely, all future costs may be converted to a "present value" and this sum added to the initial erection cost. When this is done, the owner then has an equivalent initial cost which includes in one figure the first cost of construction and the present value of all future costs.

The present worth of a future expenditure is the sum which may be obtained today in exchange for the promise to make the specified future payment or series of payments. When the value of money (that is, the interest rate) and the payment timing are known, the present value of future expenditures may be computed easily from interest tables. Figure 1 demonstrates graphically that the present value of making a $10 expenditure 10 years from now is $5.58, when the interest rate is 6 per cent. The case of the Federal Bond is similar. From the Government's point of view the present worth of making a $100 expenditure 9.73 years hence is $75, when money is valued at 3 per cent.

As the interest rate on a bond of given face value is increased, the purchase price is reduced (Fig. 2). Thus, the present worth of making a $10 expenditure 10 years from now is reduced from $5.58 at 6 per cent interest to $3.86, when the interest rate is 10 per cent.

As the maturity date is delayed, (Fig. 3) the purchase price of a bond is reduced. Thus, when the interest rate is 6 per cent, the present worth of making a $10 expenditure 10 years from now is reduced from $5.58 to $3.12 for the same expenditure 20 years hence.

As we noted earlier, future cost will fluctuate and in all probability will be higher than the current cost of a given operation. Thus, if prices increase at an annual rate of 5 per cent, the cost of what is now a $10 operation will become a $20 expenditure in 20 years (Fig. 4). The present worth of making that increased payment is $6.24, when money is valued at 6 per cent.

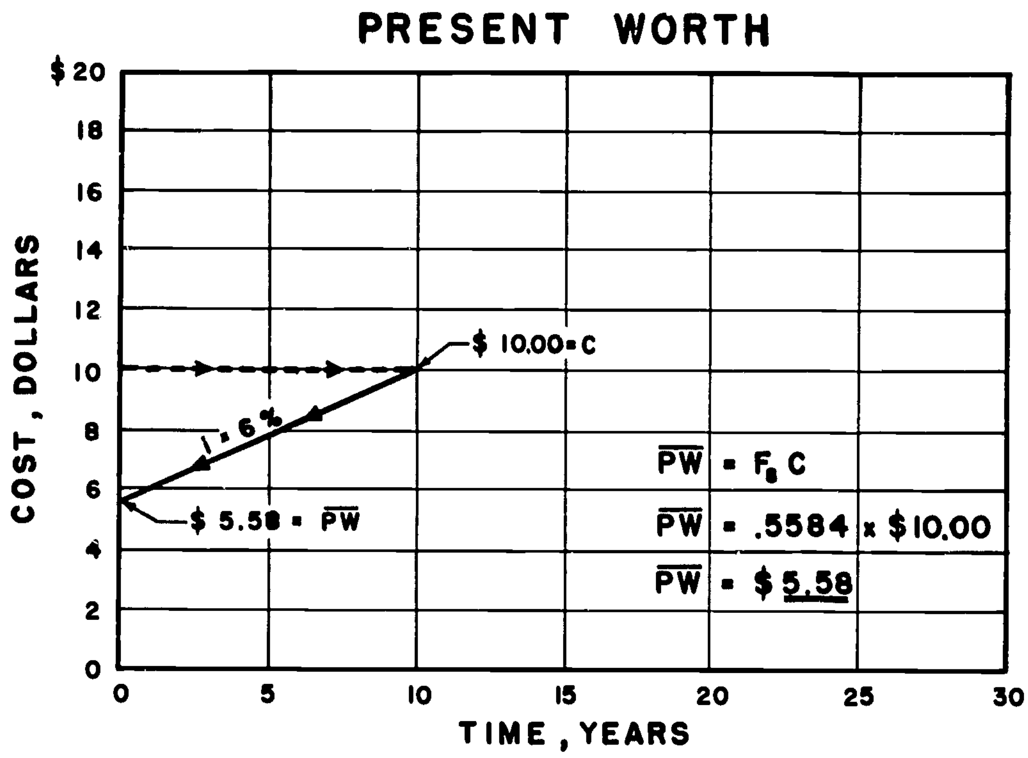
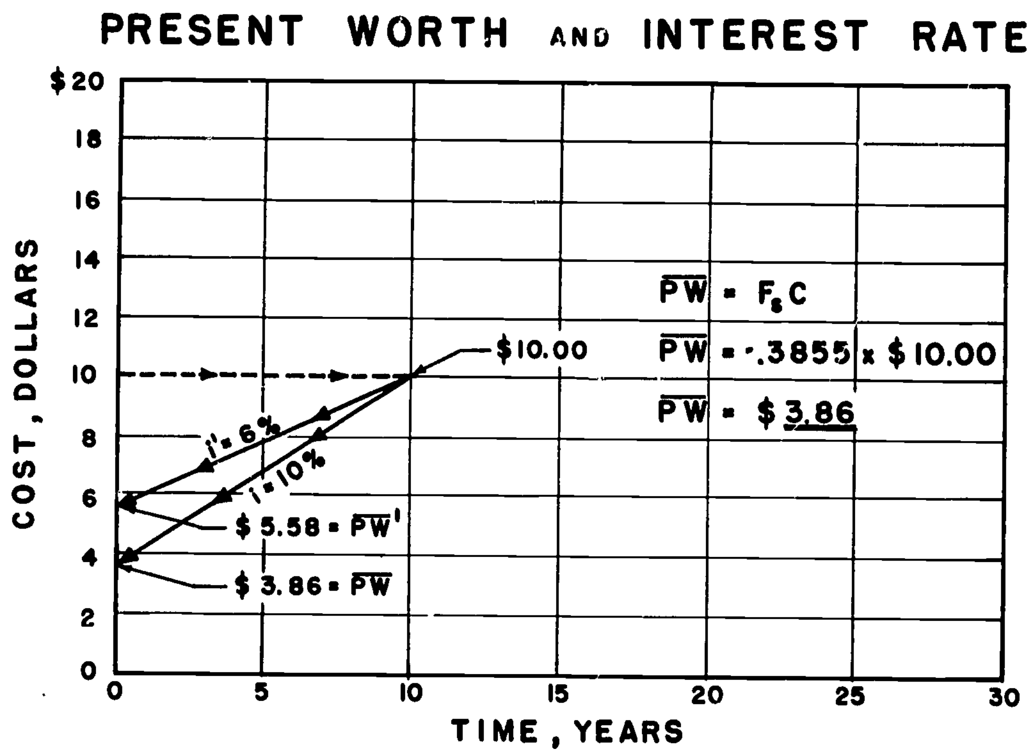


Figure 1

Figure 2



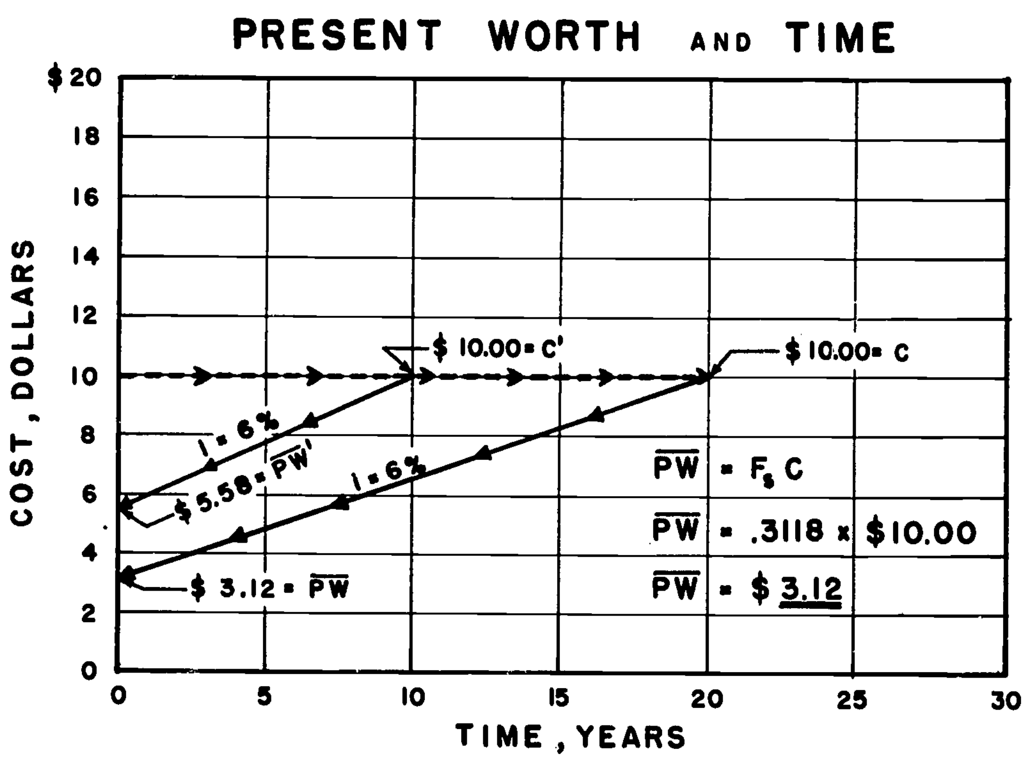


Figure 3

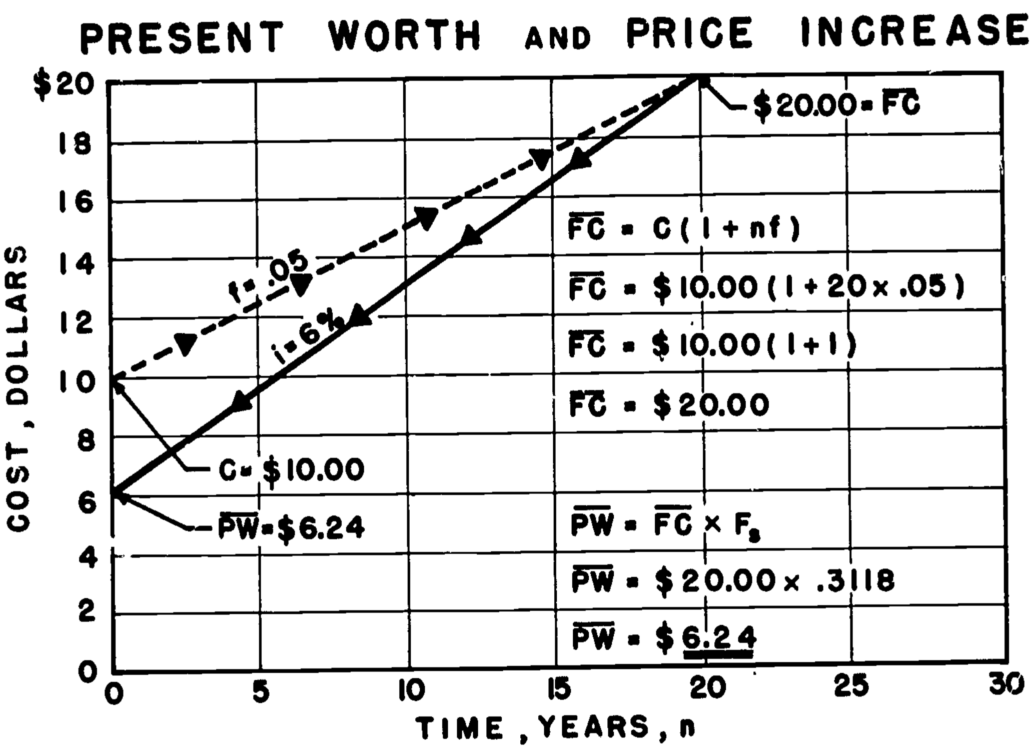


Figure 4

Of course, if you are a taxpayer, the government pays a large share of your operating cost. Thus, the cost of wall ownership to taxpayers is considerably less than for tax exempt owners. In 1959, about half of the nonfarm, nonresidential building dollar volume was spent by owners who do not pay taxes.

In order to determine the ultimate cost of wall ownership, we selected three wall types (Table I) in a ten-story office building: a masonry cavity wall, metal panel wall and a double plate glass window wall. Wall thickness was considered, the weight of the wall, its fire resistance, its ability to resist the transfer of heat, and its color.

TABLE I

Wall Design Assumptions

Wall Type	A	B	C
Basic Material	Masonry Cavity Wall	Metal Panel Wall	Double Plate Glass Wall
Window Area, Per Cent	0	0	100
Wall Thickness, Inches	10	6	3*
Wall Height, Floor to Floor, Feet	12	12	12
Wall Weight, Lbs. per Sq. Ft.	65	16	7
Fire Resistance, Hours	4	1	-
U Value, Btu/Hr./Sq. Ft./°F	.12	.12	.55
Color	medium	medium	clear
Interior Artificial Illumination, Hours per Year	2000	2000	1000

* Includes Venetian Blinds

Table II shows the financial assumptions under which this study was made. Money was valued at 6 per cent. The life of the building was estimated as 50 years. Price increases are shown. This owner was in a 57 per cent income tax bracket, but data were also prepared for tax exempt owners.

Initial cost was, of course, an important consideration. Table III shows the cost of several New York office buildings built since the war. Note the range in cost from $2.60 per sq. ft. to $32 per sq. ft. for the Seagram Building.

TABLE II

Financial Assumptions

Value of Money	6% per year
Anticipated Useful Life of Building	50 years
Depreciation Rate on Building	2% per year
Anticipated Useful Life of Mechanical Equipment	20 years
Depreciation Rate on Mechanical Equipment	5% per year
Anticipated Average Annual Rate of Price Changes	
A) Income Taxes	None
B) Insurance	+.01
C) Mechanical Equipment	+.0377
D) Heating Plant Maintenance and Fuel	+.0333
E) Air Conditioning Plant Maintenance and Electricity	+.02
F) Maintenance on Walls	+.0377
G) Electricity	+.01
Total Equivalent Income Tax Rate	57% of profit
Real Estate Taxes	
A) Ratio of Assessed Value to Market Value	.75
B) Tax Rate	4%

TABLE III

Comparative Construction Costs Per Sq. Ft. of Exterior Wall of Modern New York Office Buildings. (Prices as of March, 1958)

Street Location	Spandrel Location	Window Type	Initial Wall Cost Per Sq. Ft.
380 Madison Ave.	Glazed Face Brick	Steel, Continuous	$2.60
112 West 34th St.	Aluminum Cast	Aluminum Projected	5.77
400 Park Ave.	"Hutex" Glass	Aluminum Projected	6.27
575 Lexington Ave.	Gold Anodized Aluminum		6.30
100 Park Ave.	Aluminum Cast	Aluminum Double Hung	7.62
99 Park Ave. (National Distillers)	Aluminum	Aluminum Double Hung	9.04
150 East 42nd St. (Socony-Mobil)	Stainless Steel	Stainless Steel Vertical Pivot	9.28
390 Park Ave. (Lever House)	Glass	Stainless Steel Fixed	11.66
First Ave. & 42nd St. (U. N. Secretariat)	Glass	Stainless Steel Fixed	14.27
375 Park Ave. (Seagram)	Bronze	Stainless Steel Fixed	32.00

As shown in Figure 5 a 10" masonry cavity wall, weighing 65 lbs. per sq. ft., on a 10-story windowless building would cost about $.26 per sq. ft. of wall area to support. Heavier walls are more costly to support than lightweight walls, but this cost difference has frequently been exaggerated. In low buildings where load-bearing walls may be used, wall types which require a structural frame should be charged with the entire cost of that frame.

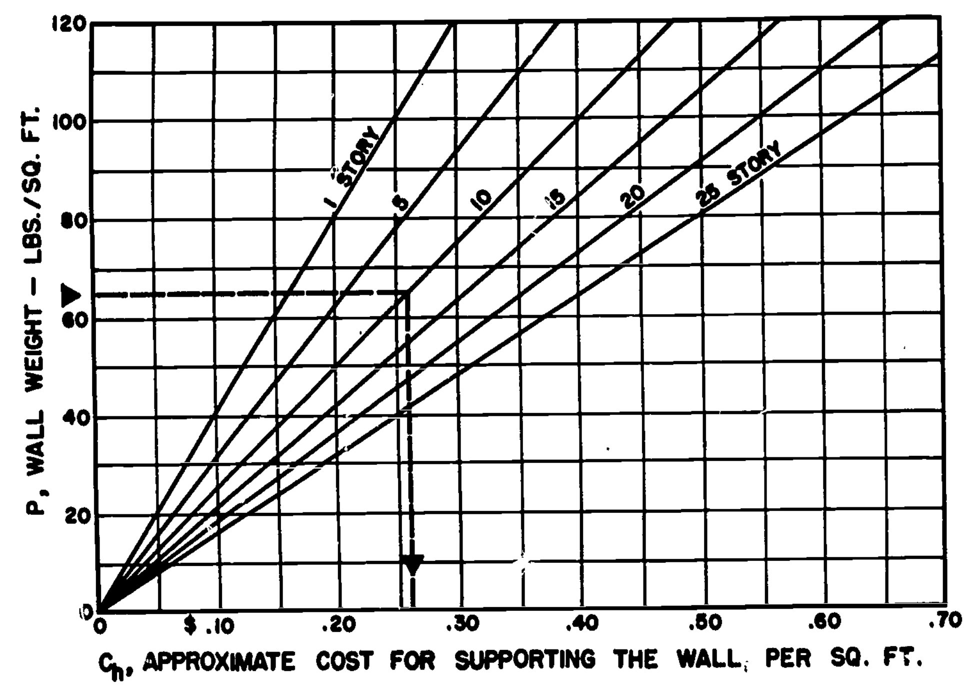


Figure 5

When space is limited and the entire building site must be used, the thickness of walls is an important economic factor because of the rentable or usable floor space which they occupy. However, when lot area is not so limited, and the walls are set back from the building restriction line, the thickness of walls is not an economic factor. In this case all of the floor area which can be economically used or rented has already been provided, and the walls are simply set outside that area.

The UN Secretariat spends $40,000 a year to wash its windows every six weeks. This fact points out the necessity of considering anticipated maintenance, when the cost is important. Maintenance costs for walls include cleaning, painting, caulking and pointing. The difference in actual maintenance expenditures between metal skin and masonry walls was negligible in the study we made, amounting to $.17 and $.15 per sq. ft. respectively. However, because the windows had to be washed every three months, the present value of that anticipated expenditure was $2.62.

For the purpose of analyzing the economics of building walls, depreciation may be considered on a straight line basis over the life of the building. In certain cases very rapid depreciation is permitted under the tax laws. Because depreciation is deductible for tax purposes, a significant portion of the initial construction cost is eventually recovered by taxpayers. Tax exempt owners, such as school boards, do not get this credit. This is a direct function of the initial cost of the wall. The higher the initial cost, the greater the depreciation credit.

Since some building materials have a salvage value, this may be considered in an economic study. Of course, it is very difficult to determine what the salvage value of the materials may be 50 years from now, but this item may be included in a meticulous study. We credited the masonry wall with $.01 per sq. ft., the glass and metal walls at $.04 and $.05 per sq. ft.

Many observers indicate that in most building types lights are fully utilized during the entire working day, regardless of the window area provided. However, because windows may sometimes permit the use of natural illumination to supplement artificial illumination, they must be credited with the savings thus achieved by reduction in power costs and in lamp replacement costs. We assumed in the glass building a 50% reduction in the annual hours of artificial illumination. The credit amounted to $1.59.

The speed with which the exterior enclosing walls are erected can, but rarely does, affect the completion date of a building. Even when walls go up faster, the building is not necesarily occupied sooner, due to concurrent work of other trades. However, we assumed that the metal and glass building would be occupied nearly three weeks sooner than the masonry building.

The cost of removing heat from air conditioned buildings is frequently a very important economic factor. Because of the greater density of masonry walls, they have the ability to absorb heat rather than to transmit it. This is called capacity insulation. Heat gain through masonry walls is about half that through wood frame or lightweight metal walls under the same design conditions.

Our company has developed a vermiculite water repellent, masonry fill insulation specifically for cavity walls, which reduces heat transfer through them by nearly 60%. The material cost is seven to nine cents per square foot of cavity wall area. As you see from Figure 6, the placement cost can be negligible. The walls are poured from the top through a cut-out tab in the bag. Where a vapor barrier is required, a water-asphalt emulsion paint may be used, bringing the total cost to about $.25 per sq. ft. of cavity wall area. As Mr. Monk points out elsewhere in these proceedings, a vapor barrier is not required under most conditions of occupancy for cavity walls insulated with water repellent vermiculite masonry fill.

Figure 6

Figure 7 shows the present worth of the ultimate air conditioning costs in several cities for heat gain rates up to 200 Btu's per hr. per sq. ft. for taxable and tax exempt owners. The chart as drawn is applicable to Atlanta, Baltimore, New York, Philadelphia and Washington. These cities may be grouped when an accuracy of plus or minus 5% is acceptable, which seems reasonable in view of the number of variables considered.

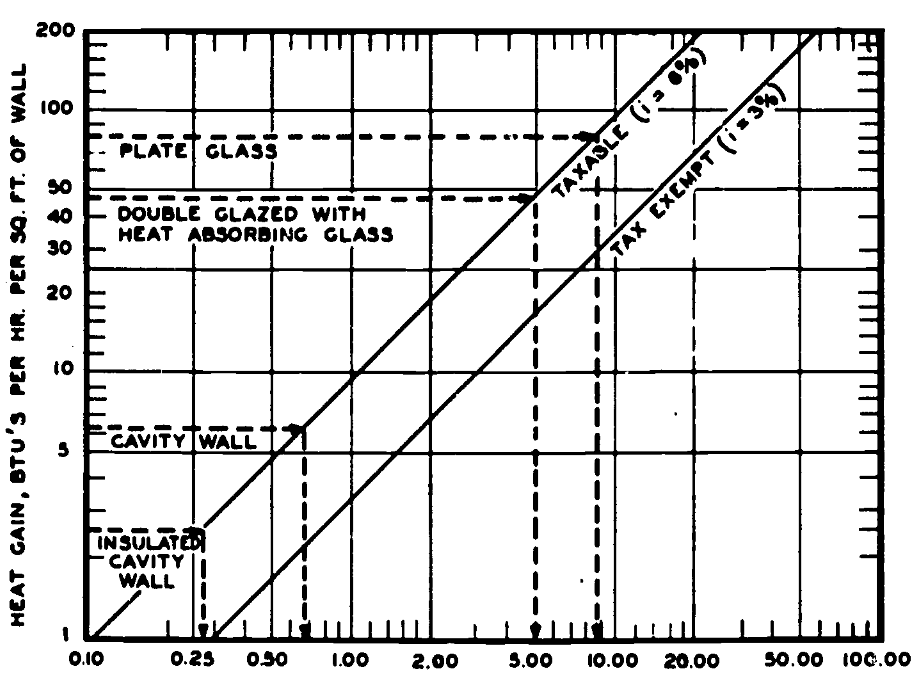


Fig. 7 - Present worth of air conditioning costs, dollars per sq. ft. of wall

The chart may also be used with the same accuracy tolerance for Chicago, Cincinnati, Cleveland, Detroit and Minneapolis by deducting 10% from the cost shown. A line is also plotted for tax exempt owners. The interest rate for tax exempt owners is reduced from 6% to 3%, and in this regard this chart differs from other calculations in this report. *

Note that the cost of heat gain through unshaded plate glass to a taxable owner is nearly $9.00 per sq. ft. as compared with a double glazed window with heat absorbing glass at about $5.00 per sq. ft.

Note particularly the reduction in the heat gain charge achieved by adding water repellent masonry fill insulation to the cavity wall. To a taxable owner the gross savings is about $.40 per sq. ft. Since the insulation costs only about $.10 per sq. ft., the net savings is $.30 per sq. ft. of wall to a taxable owner and nearly $1.00 per sq. ft. to a tax exempt owner.

By the use of this graph, one can immediately find the savings achieved by various heat gain reduction methods, such as the substitution of different wall materials, shading devices, greater reflectivity, lighter colors, and lower U values.

The quantity of heat loss through 1 sq. ft. of wall area may be computed from data presented in the ASHRAE Guide. The ultimate cost of heat lost through the wall is a direct function of U value.

The insulated cavity wall was charged with an ultimate heating cost of $.39. An uninsulated wall would have an ultimate heating cost of slightly less than $1.00. Since a water repellent masonry fill insulation for the cavity costs only about $.10 per sq. ft., a net savings of more than $.50 per sq. ft. of insulation is achieved. For a double glazed window, the present value of the ultimate heating cost would be about $2.32. These figures include the initial cost of the plant, insurance, maintenance, depreciation, real estate taxes and fuel.

Figure 8 shows the present value of the ultimate cost to tax exempt owners in 12 cities for U values up to 1.25 Btu's per hr. per sq. ft. per ^{o}F. This chart also has an accuracy tolerance of plus or minus 5 per cent. The cost to taxable owners may be determined by deducting 72 per cent from the cost shown. This assumes an interest rate of 3 per cent for tax exempt owners and 6 per cent for taxable owners.

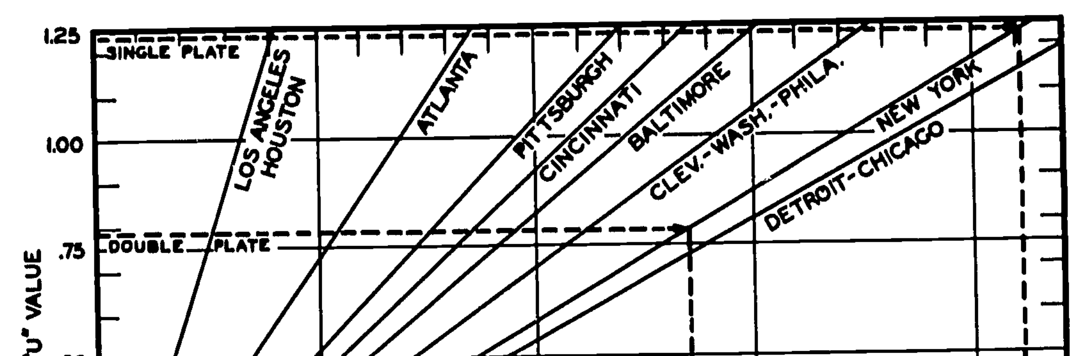


Fig. 8 - Present worth of heating costs to tax exempt owner, dollars per sq. ft.--subtract 72% for taxable owner

*For complete discussion on the derivation of Figs. 7 and 8, see SCPI Technical Notes, Vol. 10, No. 3, "Thermal Economics of Building Walls."

Taking New York as an example, the cost to a tax exempt owner for a typical single plate window is more than $21 per sq. ft. as compared with $13.50 per sq. ft. for double glazing. The addition of water repellent masonry fill insulation to the cavity wall reduces heat loss cost by more than $3 per sq. ft., from $5.25 to about $2.25 per sq. ft.

All other things being equal, fire insurance rates vary considerably with the selection of exterior wall materials. In the white area of Figure 9, insurance rates are higher on buildings having metal and glass, rather than masonry walls. They are not higher in New Jersey and Idaho. Replies to our survey were not received from insurance rating bureaus in other states.

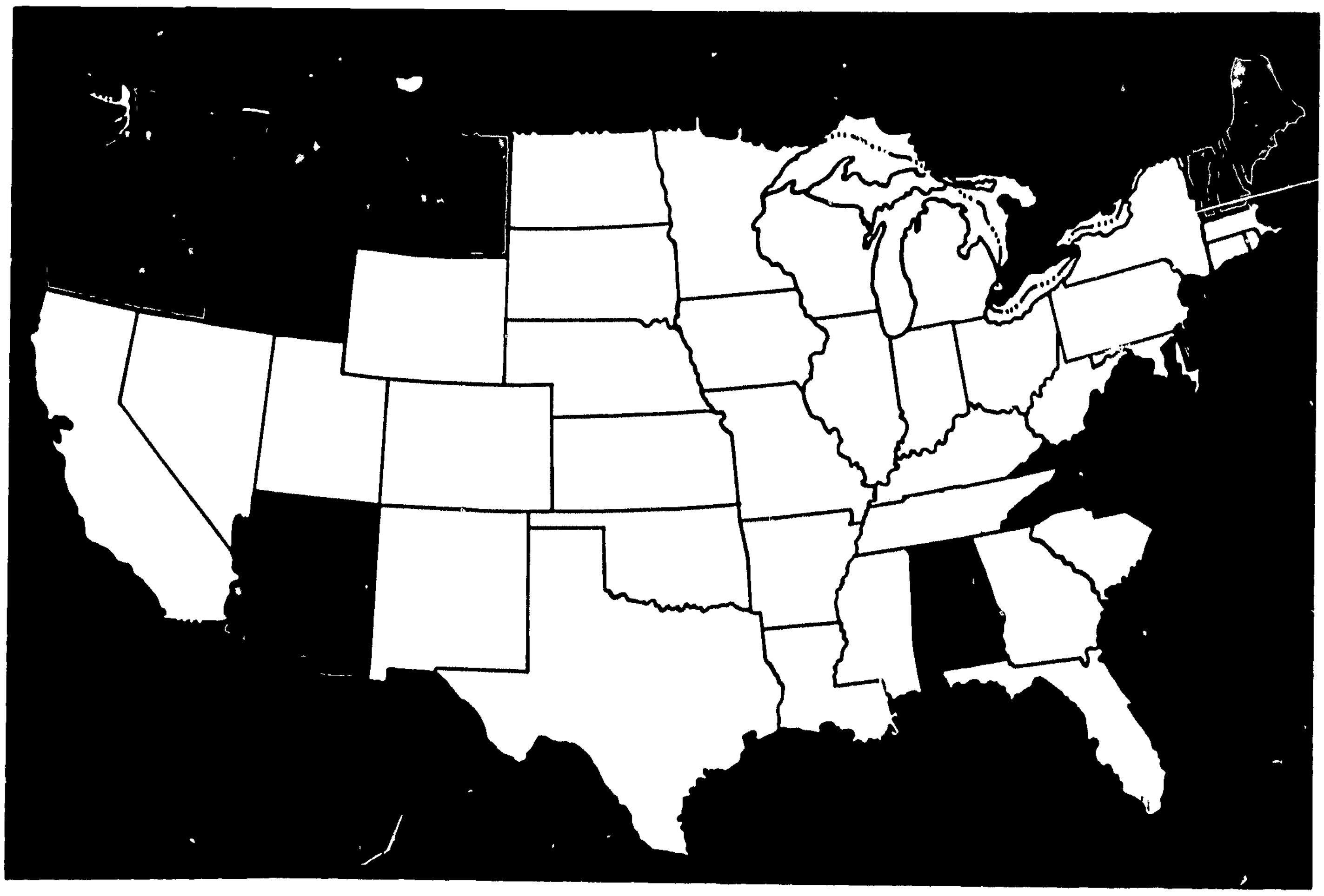


Figure 9

In the case of a hotel in Dallas, Texas, the owner discovered that the insurance premiums on his metal panel building and its contents were $5,800 per year more than if his architect had used masonry walls. This building has 63,000 sq. ft. of metal panels. The increased insurance charge per sq. ft. per year is nearly $.10. Few designers would specify an exterior wall material which had to be painted every year at a cost of $.10 per sq. ft., but the invisible cost of insurance was either ignored or considered unobjectionable.

Nearly 90 per cent of all tax revenue for local governments is derived from general property taxation. The tax rate is applied to an assessed value of the property to determine the tax due. The ratio of assessed value to market value varies greatly with the community. We conducted a survey of some 52 principal cities in the United States. Shown in Table IV are the data received from some of them. Note the wide difference in the ratio of assessed value to market value, and also in tax rate. In any event, the greater the initial cost of the wall, the greater the tax is on it.

TABLE IV

Local Tax Rates and Assessment Ratio

City	Rate per $100 Valuation	Ratio of Assessed Value to Market Value (Per Cent)
Atlanta, Ga.	$2.075	70
Boston, Mass.	8.60	100
Chicago, Ill.	3.974	100
Cleveland, Ohio	3.47	50
Dallas, Texas	3.88	39
Denver, Colo.	5.371	40
New Orleans, La.	2.9775	26.25
New York, N. Y.	4.21	100
Philadelphia, Pa.	3.46	100
Seattle, Wash.	5.80	35.6
St. Paul, Minn.	15.383	17.32
San Francisco, Calif.	7.37	50
Washington, D. C.	2.30	75

TABLE V

Ultimate Costs to Taxpaying Owner

Cost Item	Masonry Cavity Wall	Metal Panel Wall	Double Plate Glass Wall
Initial Wall Cost	$2.30	$6.00	$6.40
Support of the Wall Charge	.26	.06	.03
Charge for Floor Space Occupancy	1.25	.81	.41
TOTAL INITIAL WALL COST	3.81	6.87	6.84
Less Depreciation Credit	.69	1.23	1.23
Less Salvage Credit	.01	.05	.04
Less Illumination Credit	none	none	1.59
Less Early Occupancy Credit	none	.14	.14
TOTAL INITIAL COST LESS RECOVERED COSTS	3.11	5.45	3.84
Heat Gain Charge	.17	.34	8.00
Heat Loss Charge	.39	.39	2.32
Maintenance Charge	.15	.17	2.62
Insurance Charge	none	.12	.12
Real Estate Tax Charge	.78	1.39	1.39
PRESENT VALUE OF ULTIMATE COST	4.60	7.86	18.29
Relative Ultimate Cost	100%	171%	398%

Table V shows the ultimate cost for each of the three wall types to a tax-paying owner. The total initial cost of the masonry wall including the framing and foundation and the charge for floor space occupancy is $3.81, compared with $6.87 for the metal skin, and $6.84 for the double plate glass window. The initial cost less recovered cost is $3.11, $5.45 and $3.84 for the masonry, metal and glass walls respectively. The relative total ultimate cost is $4.60 for masonry, $7.86 for metal and $18.29 for glass. This very high cost for glass is due, as you can see, principally to the $8.00 charge for air conditioning, and the charge for heat loss and maintenance.

These costs may be applied to an office building having 72,000 sq. ft. of gross exterior wall area. That would be a 10-story office building, measuring 100' x 200' in plan, with 30 per cent window openings. Applying these figures to the office building, an additional $140,000 would be required to use a metal rather than a masonry wall. For a glass wall this increase is $590,000 over a masonry wall with 40 per cent windows.

Below is the same table for a tax exempt owner. Note the costs are considerably higher. Glass is now up to $30.02 per sq. ft., metal skin is at $9.01 and masonry walls are $5.26.

TABLE VI

Ultimate Costs to Tax Exempt Owner

Cost Item	Masonry Cavity Wall	Metal Panel Wall	Double Plate Glass Wall
Initial Wall Cost	$2.30	$6.00	$6.40
Support of the Wall Charge	.26	.06	.03
Charge for Floor Space Occupancy	1.25	.81	.41
TOTAL INITIAL WALL COST	$3.81	$6.87	$6.84
Less Depreciation Credit	none	none	none
Less Salvage Credit	.02	.13	.09
Less Illumination Credit	none	none	3.70
Less Early Occupancy Credit	-	-	-
TOTAL INITIAL COST LESS RECOVERED COSTS	$3.79	$6.74	$3.05
Heat Gain Charge	.32	.67	15.60
Heat Loss Charge	.82	.82	4.89
Maintenance Charge	.33	.39	6.09
Insurance Charge	none	.39	.39
PRESENT VALUE OF TOTAL COST	$5.26	$9.01	$30.02
Relative Ultimate Cost	100%	172%	572%

Table VII summarizes the two previous tables. Note the increased cost for tax exempt owners and also that metal and glass are considerably more expensive.

TABLE VII

Present Value of Ultimate Costs
(Per sq. ft. of Wall Area)

Wall Type	Owner Taxable	Owner Tax Exempt
Masonry Cavity Wall	$ 4.60	$ 5.26
Metal Panel Wall	7.86	9.01
Double Plate Glass Wall	18.29	30.02

For all practical purposes, when windows are combined in any proportion with opaque materials, the average total cost of the composite assembly may be computed by interpolation between the two constituent materials on a straight line basis. Although this is not a precise calculation, it offers a very reasonable solution.

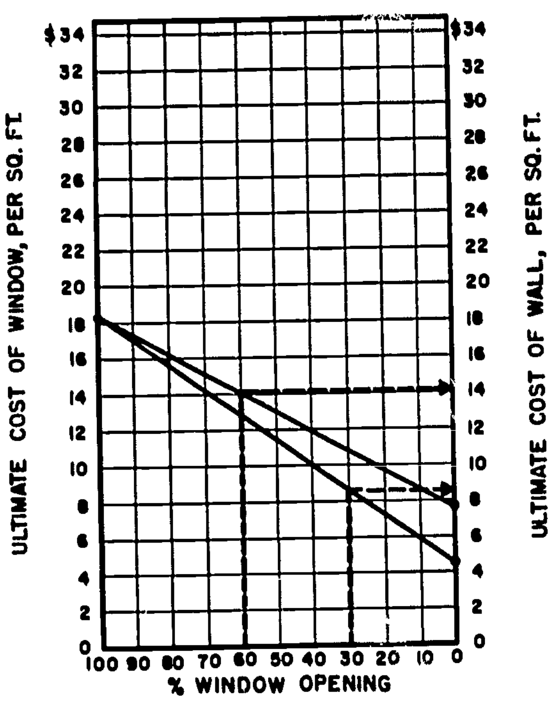


Figure 10

For example, in Figure 10, if the total ultimate cost of the window is $18.29 psf, this figure is plotted on the left ordinate. The ultimate cost of the opaque walls is plotted on the right ordinate. These points are connected and the ultimate cost of a composite wall with any per cent window opening is determined.

As stated initially, three elements are necessary for the proper performance of building walls: aesthetics, engineering and economics. Walls should be economical, but they should also contribute to the beauty and safety of man's environment.

To place too much emphasis on any one facet of the problem is to invite failure. A balanced approach will ultimately provide the best solution. To sacrifice aesthetics for economics is poor architectural practice, but the converse is also true.

Open Forum Discussion

Moderator - Harry C. Plummer, Conference Chairman

Panel Members - Harold W. Peterson
C. T. Grimm

Grayson Gill, Grayson Gill, Inc., Architects-Engineers: Is it practicable to shove the face brick of the exterior wythe of a cavity wall to insure full head joints?

Mr. Peterson: I think the most important thing is to see that the head and bed joints are filled regardless of how you do it. It can be done by shoving.

Mr. Gill: How does a 10" cavity wall, face brick exterior (tooled joint), common brick interior (cut joint), compare in cost with an 8" solid wall of the same material and finish?

Mr. Peterson: The cost is slightly higher due to the need for additional labor.

Mr. Plummer: Would you care to estimate percentage-wise how much higher?

Mr. Peterson: About 7%

Unsigned question: What type of weep hole mechanism is recommended for vermiculite filled cavity walls; i.e., empty joints, cord, grease rod, etc.?

Mr. Grimm: The granule size of the vermiculite used for this purpose is sufficiently large so that you don't have the insulation pouring out through the weep holes. This offers no particular problem.

William Lukacs, Y.M.C.A.: In lieu of wicks or screens to keep insects and water out, especially near grade level, we have used stainless steel wool, pushed in for at least 2" to 3" in depth. This is permanent, noncorroding, and lets water come out easily. What would be your opinion of that type of construction?

Mr. Peterson: There's nothing wrong with it. I think tubing is probably the easiest to use, as it is easier to cut and handle on the job.

M. Imber, Polytechnic Institute of Brooklyn: What does the capacity influence have to do with determining the heat losses as compared to the use of the U value?

Mr. Grimm: The present engineering practice does not utilize the capacity insulation feature of masonry walls in heat loss, however it is a very important part of the heat gain calculations. The reason for this is that the diurnal temperature range in the winter time is somewhat less than in the summer. There is a great deal of thermal research going on now, much of it being done by the Structural Clay Products Research Foundation, which I think will eventually lead to a consideration of capacity insulation in heat loss calculations, but it is not currently used.

Unsigned question: How can we obtain the data or procedure used in your cost analysis, so we can conduct our own evaluation of various walls?

Mr. Grimm: What is involved here is establishing estimates of anticipated future expenditures and reducing them to present value. The methodology is fully explained in a book published by the Structural Clay Products Institute and available from them, titled "The Ultimate Cost of Building Walls."

Previously Published BRI Conference Proceedings

PLASTICS IN BUILDING, 1955, 150 pages, illustrated, NAS-NRC Pub. 337, $5.00.

METAL CURTAIN WALLS, 1955, 190 pages, illustrated, NAS-NRC Pub. 378, $4.00.

FLOOR-CEILINGS AND SERVICE SYSTEMS IN MULTI-STORY BUILDINGS, 1956, 141 pages, illustrated, NAS-NRC Pub. 441, $4.00.

MODERN MASONRY, NATURAL STONE AND CLAY PRODUCTS, 1956, 163 pages, illustrated, NAS-NRC Pub. 466, $4.50.

WINDOWS AND GLASS IN THE EXTERIOR OF BUILDINGS, 1957, 176 pages, illustrated, NAS-NRC Pub. 478, $5.00.

ADHESIVES AND SEALANTS IN BUILDING, 1958, 160 pages, illustrated, NAS-NRC Pub. 577, $5.00.

INSTALLATION AND MAINTENANCE OF RESILIENT SMOOTH-SURFACE FLOORING, 1959, 146 pages, illustrated, NAS-NRC Pub. 597, $5.00.

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SEALANTS FOR CURTAIN WALLS, 1959, 82 pages, illustrated, NAS-NRC Pub. 715, $3.00.

BUILDING RESEARCH, INTERNATIONAL, 1960, 42 pages, illustrated, $1.50.

NEW METHODS OF HEATING BUILDINGS, 1960, 138 pages, illustrated, NAS-NRC Pub. 760, $5.00.

CURRENT STATUS OF MODULAR COORDINATION, 1960, 30 pages, illustrated, NAS-NRC Pub. 782, $2.50.

DESIGN POTENTIAL OF METAL CURTAIN WALLS, 1960, 96 pages, illustrated, NAS-NRC Pub. 788, $5.00.

These publications are available on order from the Printing and Publishing Office, National Academy of Sciences--National Research Council, 2101 Constitution Avenue, N. W., Washington 25, D. C.

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2) Workshop, round-table and study groups on specific subjects (Open to BRI members and invited guests)

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