LOW-COST REINFORCED-CONCRETE HOUSING EMPLOYING PREFABRICATED PLYWOOD PANELS

by

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Bachelor of Science in Civil Engineering

from the

Massachusetts Institute of Technology
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May 20, 1949

Professor J.S. Newell
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Sir:

Attached is my thesis on "Low-Cost Reinforced-Concrete Housing Employing Prefabricated Plywood Panels" which represents a partial fulfillment of the requirements for a Bachelor of Science degree in Civil Engineering.

The paper represents my own efforts and required considerably more than the allotted time to complete. I feel that this project is worth while and one to which further study should be given.

Very truly yours,

Signature redacted

Robert W. Roberts

ACKNOWLEDGMENT

The author wishes to acknowledge his gratitude to Professor A.G.H. Dietz for his advice and guidance in this project and his generous and able instruction during the past three years; to Professor M.J. Holley for his assistance in obtaining information on light-weight concretes; to the many manufacturers' representatives for their gracious help in selecting the best materials and for furnishing unit prices; and above all others, to his wife, Eileen, for her constant moral support, and without whose assistance this paper would have been completely devoid of all punctuation.

A SUMMARY FOR BUSY READERS

The use of prefabricated plywood panels and reinforced concrete results in a decided reduction in construction time, as compared to the relatively slow assembly of brick or frame structures. It is estimated that this reinforced concrete house would require about five days to construct, using the methods outlined in this paper, and no more than the average number of workmen required for dwelling-house construction. The method employed is simple, and with the exception of the suggested use of the Gunite process, requires no unusual equipment or skilled workmen.

The estimated cost of construction for this two-bedroom house, with garage, is considerably lower than the present-day listed price of the same type house of conventional construction. The use of radiant heating eliminates the usual excavation cost. The poured concrete shell eliminates the necessity and cost of interior plastering, woodwork, and other interior trim. The labor cost is considerably lower in this project due to the saving in construction time. Possible improvements and means of further reducing the time and costs are suggested.

The advantages of this type construction are many: considerable reduction in construction time; low cost; simple technique; fire resistance; wide adaptability of design; comfort; low maintenance and compactness of the radiant heating provided; and low upkeep - among other factors. The design selected provides efficient and compact layout with larger than average-size rooms, adequate storage space, the possibility of future enlargement, and can be adapted to any type furnishings, geographic location, or neighborhood. In addition to housing, the technique described can be modified for the construction of any one-story building, such as garages, light-aircraft hangars, motor courts, roadside stands, service stations, multiple-family dwellings, housing projects, and various one-story mercantile buildings.

TABLE OF CONTENTS

	Page
List of Illustrations	6
INTRODUCTION	7
Purpose and Scope	7
Procedure	7
Standards - Building Codes, Etc.	8
References	8
DESIGN	9
Architectural	9
Structural	13
Foundation and Floor	13
Drainage	13
Insulation	13
Heating	13
Walls	16
Insulation	16
Windows	16
Lighting and Plumbing	20
Roof	20
Insulation	20
Drainage	20
Roofing	21
Lighting	21
CONSTRUCTION	27
Materials and Equipment	27
Cinders	27
Building Paper	27
Cement	28
Sand	28
Aggregate	28
Concrete	28
Design of Concrete Mix	29
Gunite	31
Form Lumber	31
Form Plywood	31
Vermiculite Concrete	32
Calking Compound	33
Floor Covering	33
Windows	33

Doors	Page 34
Hardware	34
Reinforcing Steel	35
Roof Drain	35
Roofing	35
Heating Pipes	36
Boiler	36
Lighting Equipment	37
Plumbing	37
Concrete Anchors	37
Methods	38
Forms	51
Quantities Survey	52
COST	56
General	56
Materials and Equipment	57
Forms	59
Labor	60
Summary	63
COMPARATIVE COSTS	64
SUMMARY	65
Conclusions	65
Recommendations	66
Bibliography and References	67
Appendix	i-xviii

LIST OF ILLUSTRATIONS

Figure 1.	Floor Plan	Page 10
2.	Front and Rear Elevations	11
3.	Sub-Fill	14
4.	Typical Floor Sections	15
5.	Plumbing and Heating Facilities	17
6.	Wiring Diagram	18
7.	Typical Exterior Wall Section	19
8.	Steel Casement Window Details	22
9.	Typical Roof Section	23
10.	Roof Steel Arrangement	24
11.	Roof Drainage Layout	25
12.	Typical Heating Panel Layout	26
13.	Typical Floor Form Section	40
14.	Arrangement of Concrete Anchor	41
15.	Typical Placement of Concrete Anchor	42
16.	Connection - Wall and Floor Form	44
17.	Typical Exterior Form Corner	45
18.	Typical Interior Form Corner	46
19.	Typical Window Form	47
20.	Typical Door Form	48
21.	Typical Roof Form	50

INTRODUCTION

Purpose and Scope: The purpose of this investigation is to consider the possibilities of developing a method of construction for low-cost reinforced-concrete housing. This method will employ the use of prefabricated plywood panels of standard size and design. It is planned to so construct these standard form panels so that they may serve both as wall and roof form panels. It is further planned that the panels and the methods of construction which will be developed can be adapted to the construction of other low-cost buildings, among which are motor courts, service stations, hangers for light aircraft, garages, and single-story mercantile buildings.

Procedure: It is believed that this method of construction can best be developed and presented if a single structure is chosen and a complete design and construction procedure developed for that building. In view of the present demand for low-cost housing, a single-family dwelling has been chosen, but it must be remembered that the methods are equally adaptable to the other structures mentioned above.

The remaining sections of the paper will be broken down into the following: design, construction, cost, comparative cost, and summary.

The design section will include all computations and other considerations necessary to develop a structure which is low in cost, easy to maintain, adaptable to any type of furnishings or locale, pleasing in architecture, and simple to construct.

The intention of the construction section is to explain the methods and materials which will be used. It is the purpose of this paper to develop cheap and simple methods, but not at the sacrifice of comfort or lasting qualities.

A complete analysis of the costs of labor, materials, and methods employed will be made. One complete section will be devoted to the analysis of costs for the basic plan utilizing present-day methods of construction.

The summary section will include a discussion of the merits and demerits of the system developed. In short, it will attempt to justify this system of construction by pointing out its all-around diversity which will enable it to be adapted to almost all types of one-story construction.

The appendix will include all discussions, references, and computations which would make the paper unnecessarily long or involved.

Standards: It is realized that small changes will be necessary in the basic designs suggested to adapt them to the local building codes. Since it is impossible to anticipate all the differences, certain standard and widely-accepted codes will be used as the basis of construction. Wherever it is felt that local codes will not be in agreement with those standards, the reference to the standard code is given so that the necessary adjustments can be made. The codes used as standard are

Building Code Recommended by The National Board of Fire Underwriters, 1943 Edition

National Electric Code

Building Code Requirements for Reinforced Concrete of the American Concrete Institute

References: A complete list of all references consulted will be included, together with a list of the specific pages consulted.

DESIGN

Architectural: Since the object of this investigation is to explore the possibilities of low-cost housing, it was necessary to choose a floor plan which would adapt itself to the methods intended without increasing the cost. However, the quality of the structure is not intended to be overlooked for the sake of cost. It was with these thoughts in mind that the floor plan shown in Figure 1 was developed. Front and rear elevations are shown in Figure 2.

This floor plan affords simplicity of design without loss of attractiveness. It is readily adaptable to any kind of furnishings from traditional to ultra modern; the rooms are conveniently placed and adequate storage space is afforded. The large, roomy living room and the dining room are excellent for everyday living and for entertainment purposes. The bedrooms are larger than are usually found in homes of this price bracket; and the long, narrow kitchen allows for conveniently-arranged cabinets and work space. The bedrooms are placed in a separate wing, thus affording sleeping space away from the activity center of the house. The bookcase, forming the entryway, provides some privacy for the living room and minimizes the draft from the front door, especially during the winter months. The rear door in the living room is a direct entrance to the rear porch and yard, especially convenient for outdoor social functions. With the exception of the small bathroom window, there are no openings in the sidewalls, thus assuring reasonable privacy from neighbors and at the same time reducing the construction outlay by eliminating unnecessary window forming. The use of only two sizes of casement windows also reduces the cost. For further saving, the traditional basement has been eliminated and radiant heating facilities are centralized in one small closet located in the center of the house. This central location avoids the use of long lengths of heating coils, embedded

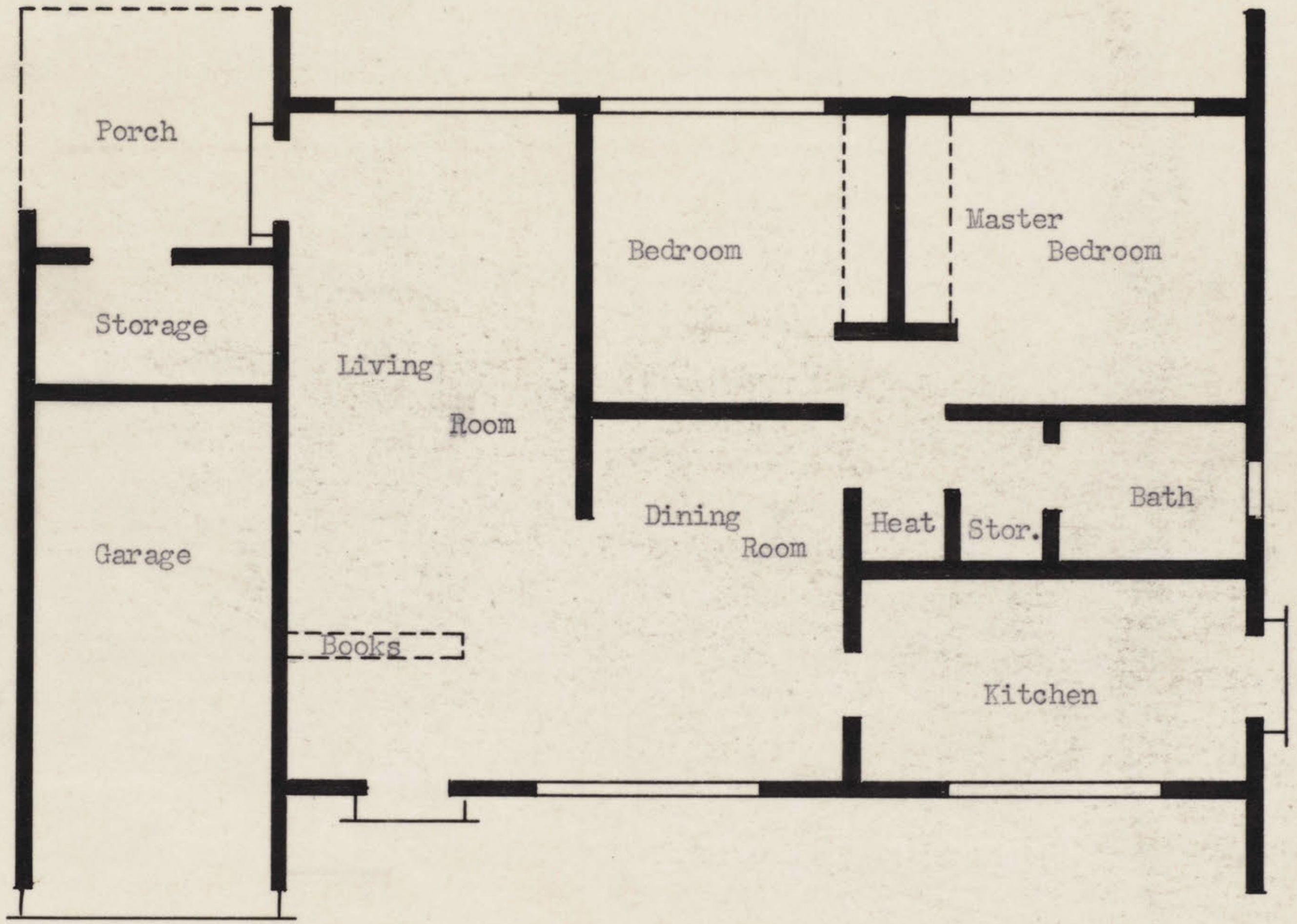


Figure 1. Floor Plan

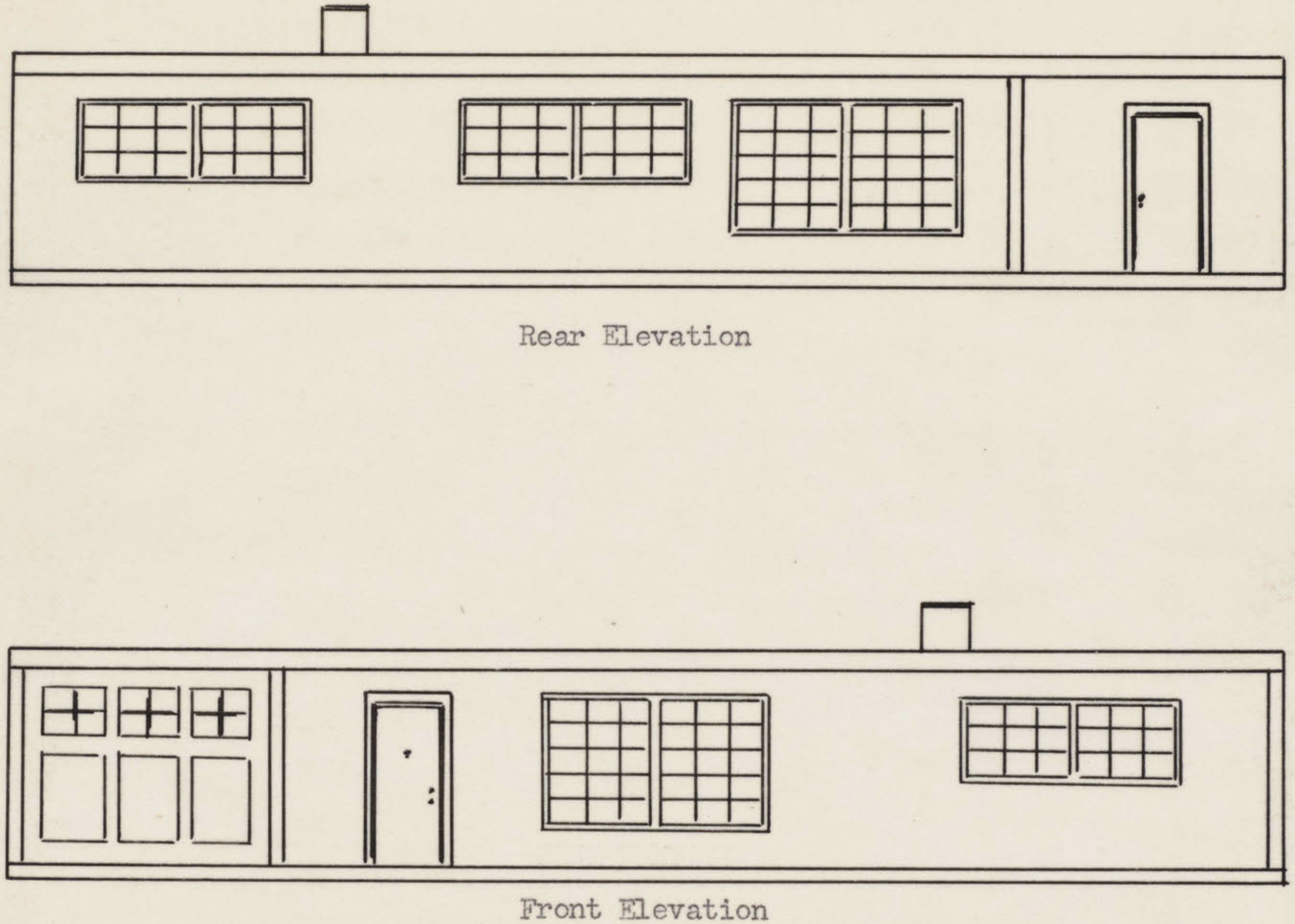


Figure 2.

in the concrete floor, thereby utilizing to a greater extent the heat available. The use of light-weight vermiculite concrete panels affords excellent insulation for the building by its complete two-inch shell. These precast panels eliminate the time ordinarily required for setting of the concrete. Concentration of plumbing facilities on the wall between the bathroom and the kitchen also avoids unnecessary installation expense.

In short, the best of materials are intended to be used in this construction, but they are to be assembled in a unique manner to provide a good low-cost house. Quality is not to be sacrificed for economy.

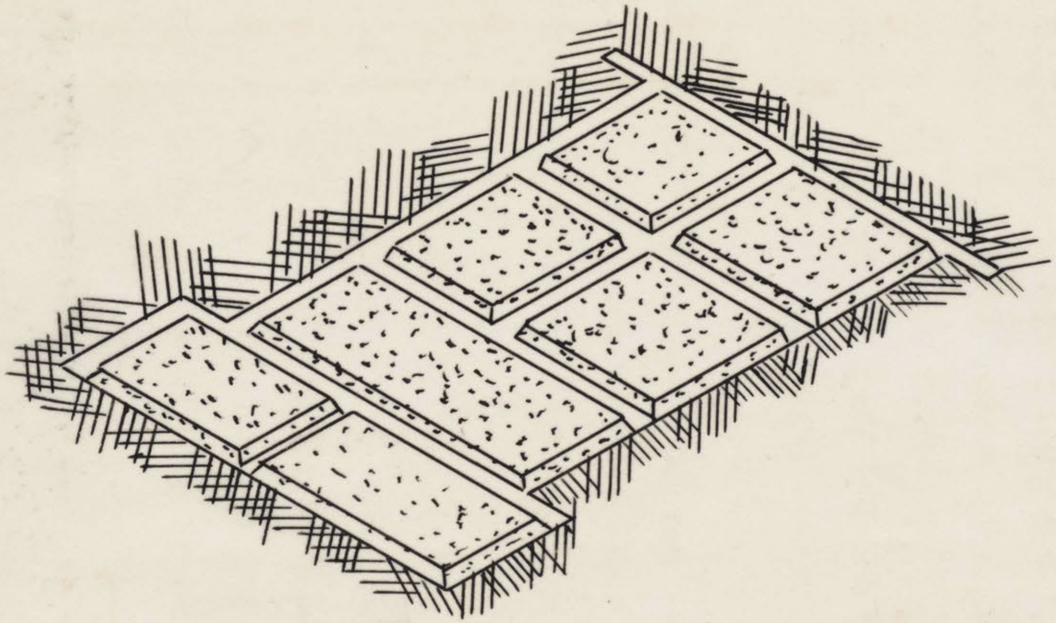
Structural:

Foundation and Floor: The house floor will be a six-inch reinforced concrete slab (mat type reinforcing steel will be used) resting on the ground. The sections beneath the interior and exterior walls will be made at least one to one and one-half feet thick and will be cast at the same time as the floor, thus providing a well-integrated combination of reinforced slab and concrete floor beams. Since this is a residential building and thus subject to light loads, a formal floor slab design procedure is not necessary - the six-inch slab will be more than adequate.

Drainage will be afforded by a foot to a foot and a half of cinders beneath the floor slab. It is of course essential that these cinders be well tamped in place to avoid structural failure. Providing trenches in the cinder base will provide the necessary forms for the concrete floor beams. The use of a heavy building paper over the cinder base will eliminate seepage of underground water through the concrete floor.

Insulation for the floor will be provided by a two-inch panel of precast vermiculite concrete between two two-inch layers of reinforced concrete. The radiant heating pipes will be placed one quarter of one inch from the surface in the upper two-inch concrete panel and will thus be insulated from the ground by the layer of vermiculite concrete. The discussion of the design and fabrication of the vermiculite panels is included in the materials section of the paper on page 33.

Heating of the house is provided by a radiant floor panel section and the complete design procedure followed is based on a procedure established by F.W. Hutchinson for the Revere Copper and Brass Company Incorporated. This work is considered outstanding in this field and has



Scale: 1/16" = 1'0"

Figure 3. Sub-Fill

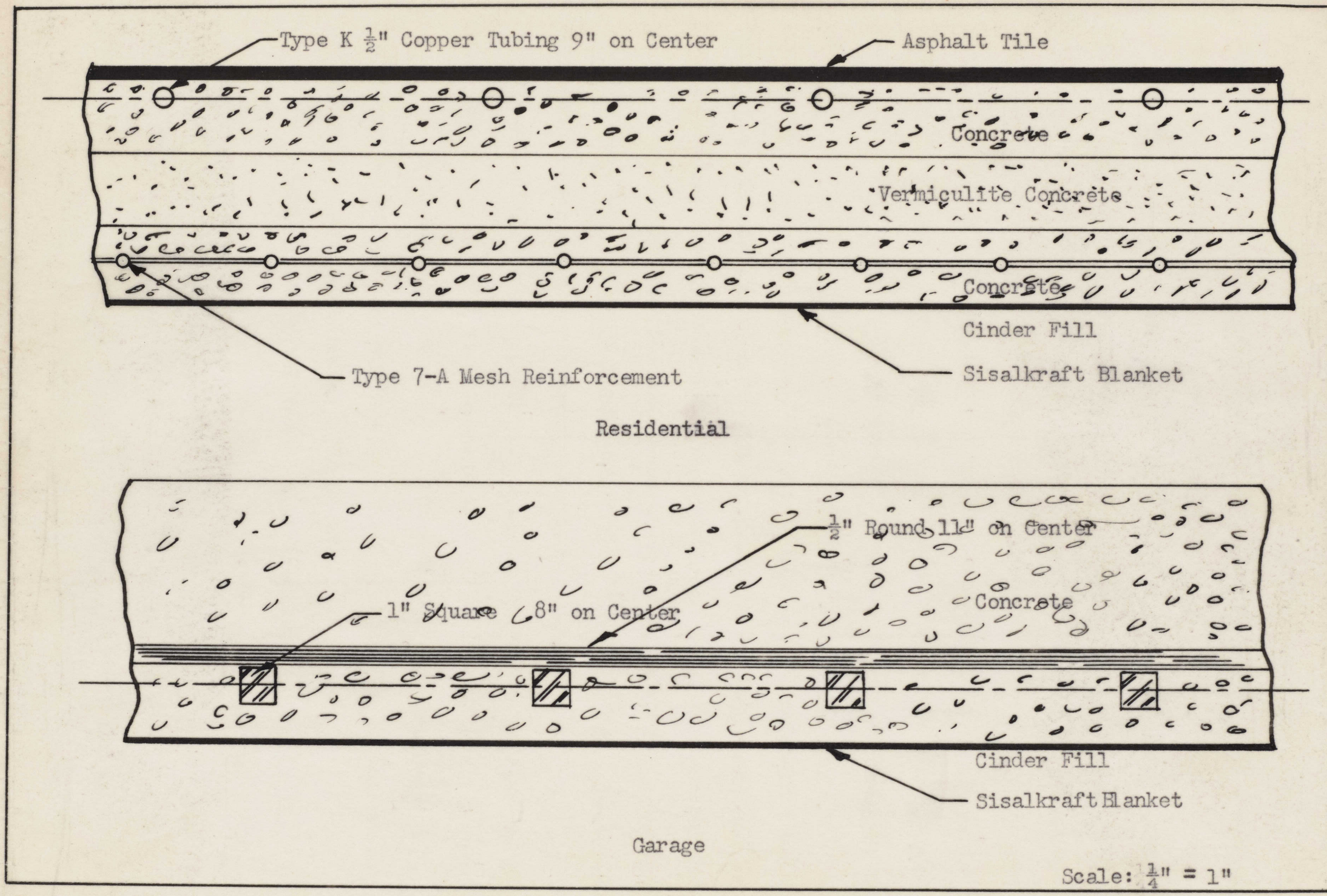


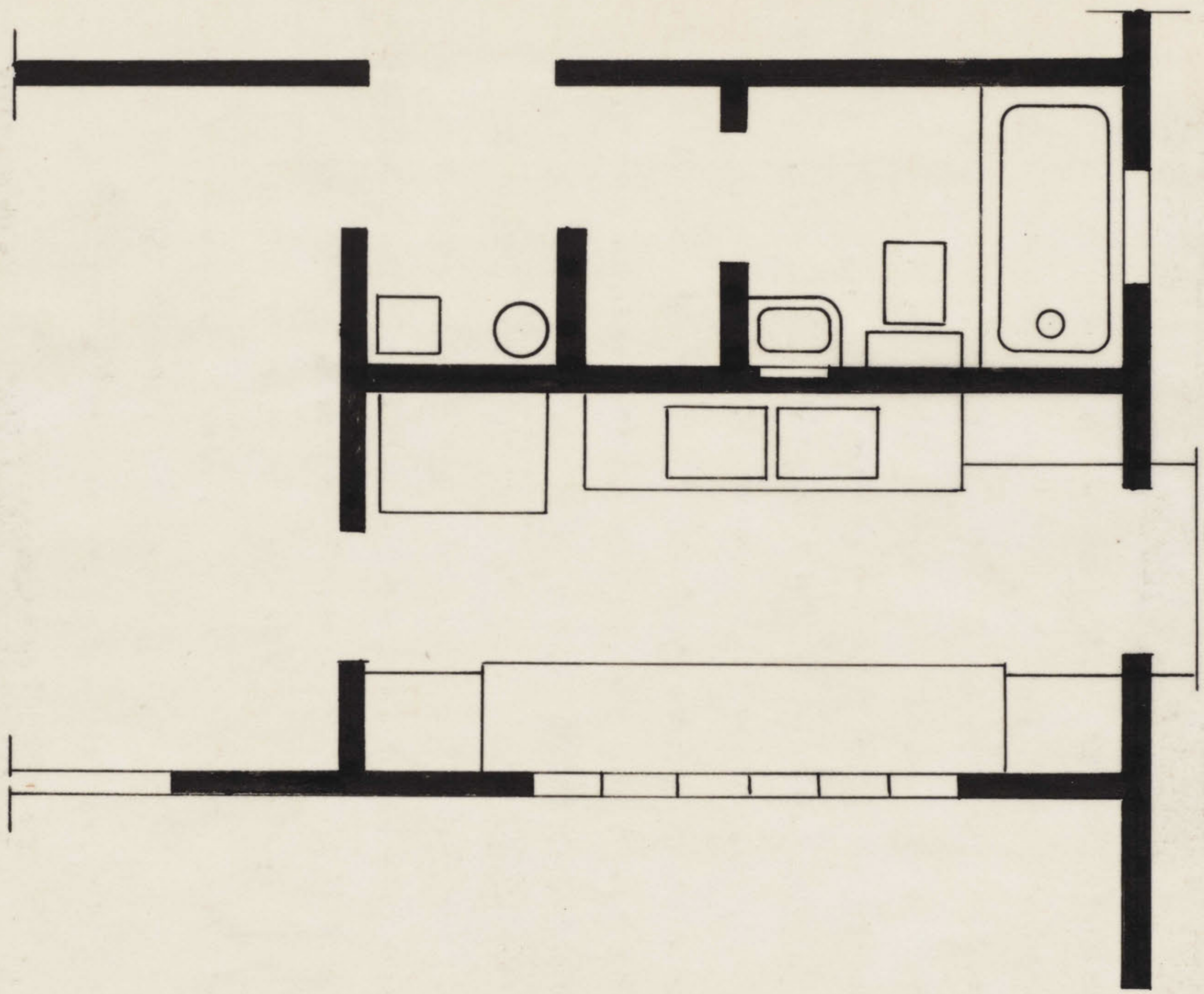
Figure 4. Typical Floor Sections

full approval of the American Society of Heating and Ventilating Engineers. A complete design is given in the Appendix, pages i to xvi. Figure 12, on page 26, shows a typical pipe layout.

Walls: The exterior walls of the building are six inches thick, and like the floor slab, are made up of two two-inch reinforced layers separated by one two-inch layer of prefabricated vermiculite concrete. The portions of the exterior walls which protrude beyond the front and rear walls add to the appearance of the building, but are not insulated. They are reinforced, thus giving the effect of four corner columns supporting the roof slab. This arrangement avoids cantilever overhangs of the roof slab. To simplify the design and to make the form panels usable for other purposes, the interior walls are also made six inches thick, but with the exception of the walls on the heating room, are not insulated. The heating room walls are insulated to make this room fireproof. It is felt that fireproofing is needed because of the concentration of house and hot water heating facilities in this room. Insulation will also prevent excessive heating of the surrounding rooms in the summer months when it is necessary to operate the hot-water heating system. See Figure 7 for a typical section.

Insulation of the walls is afforded by a two-inch layer of prefabricated vermiculite concrete. See page 33 for the discussion of the composition and fabrication of these panels.

Windows in this residence are of the metal casement type, except for the bathroom window which is a double-hung wood sash. Since the bathroom is on the grade floor, it is felt that greater privacy can be assured through the use of this type sash. Two sizes of standard metal casements of the same width are employed, thus minimizing variation in forms. The living and dining room windows are five feet six



Scale: $\frac{1}{4}$" = 1'0"

Figure 5. Plumbing and Heating Facilities

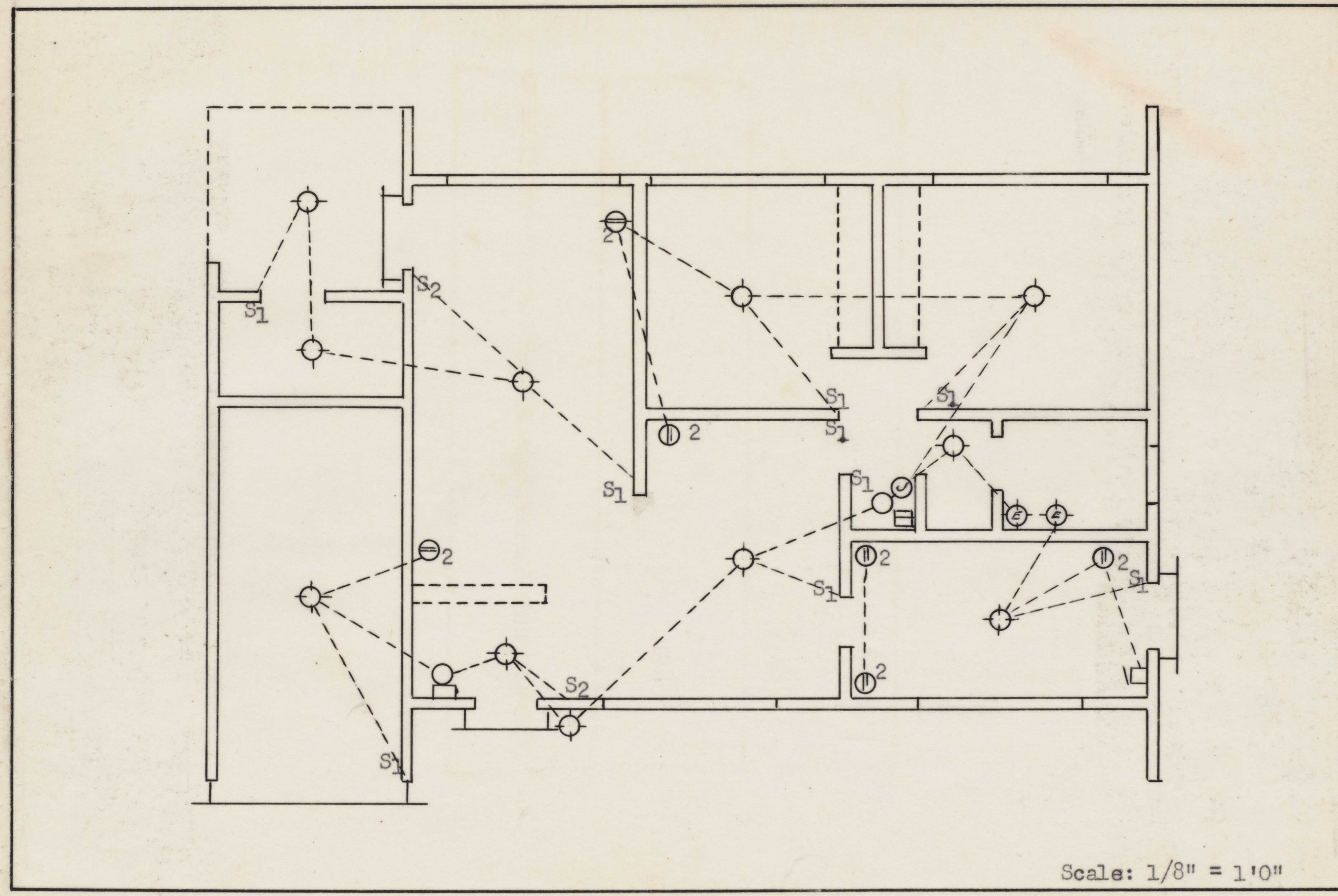


Figure 6. Wiring Diagram

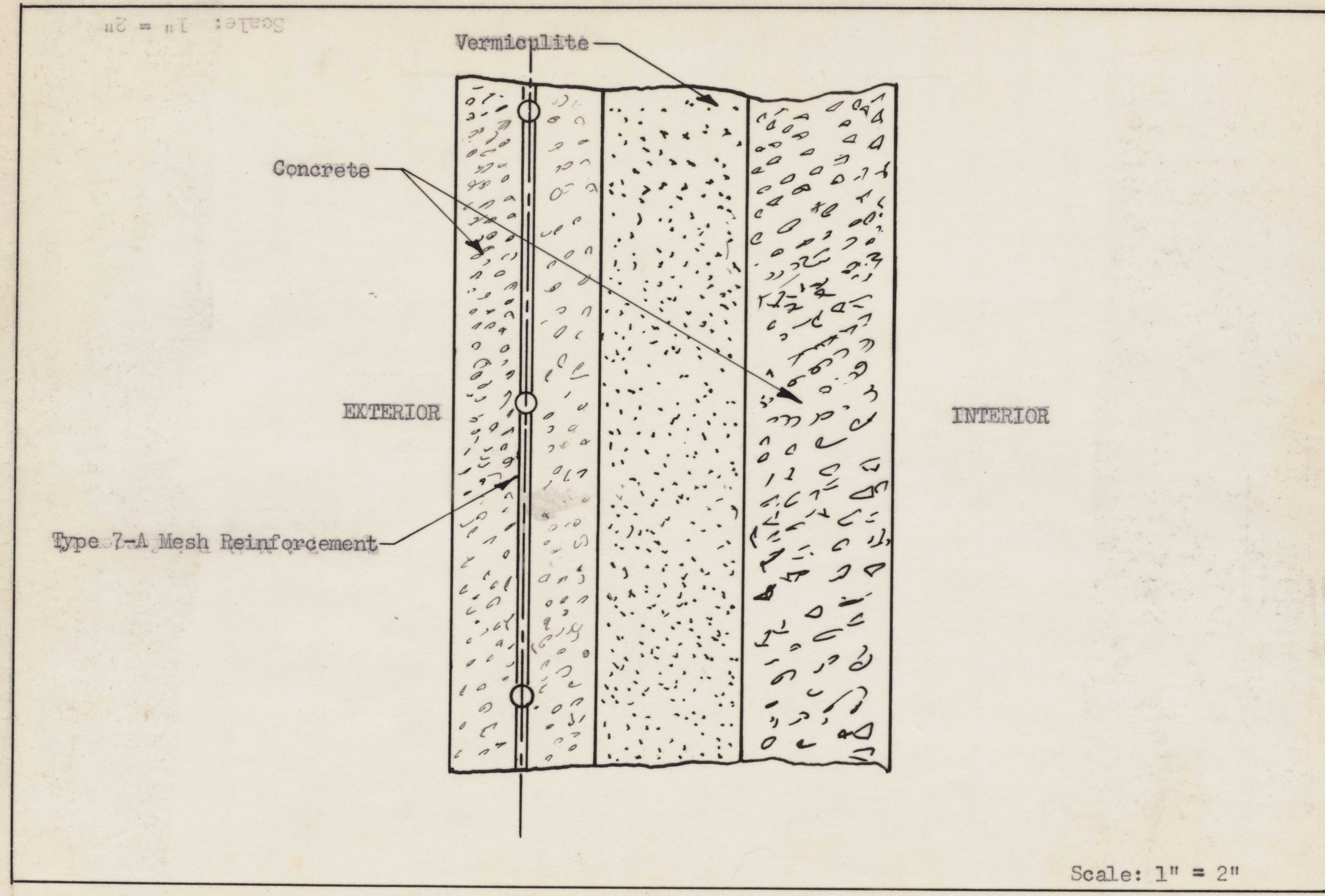


Figure 7. Typical Exterior Wall Section

inches high, while those in the bedrooms and the kitchen are three feet six inches in height. Thus adequate light and ventilation are provided, and the use of the smaller height in the kitchen and bedrooms affords greater privacy. The standard windows have been adapted to a unique installation technique, the details of which are best shown by an illustration, Figure 8. Necessary installation instructions are given in the construction section of this paper.

Lighting conduits are embedded in the concrete walls and ceilings, and all of the necessary fuse boxes and switches are placed in the heating room. Thus all of the house service equipment is centered in the heating room, and all control of heat, light, and plumbing is from this room. Figure 6 shows the placing of all outlets and wall lights. For a discussion of the electrical equipment used, see page 37. of the materials portion of the construction section of this paper.

Roof: The roof slab is a six and one-half inch reinforced concrete slab with a two-inch layer of prefabricated vermiculite concrete insulation, and covered with a tar and gravel surface. It extends four feet beyond the front and rear walls, thus affording protection for the windows in a driving rainstorm and from the hot sun rays during the summer months of the year. The design procedure of the roof slab is given in the Appendix, pages xvi to xviii.

Insulation of the roof is obtained by the vermiculite layer mentioned above and also to some extent by the tar and gravel surface. The cross section of the roof slab is shown in Figure 9, page 23; and the steel placement diagram in Figure 10, page 24.

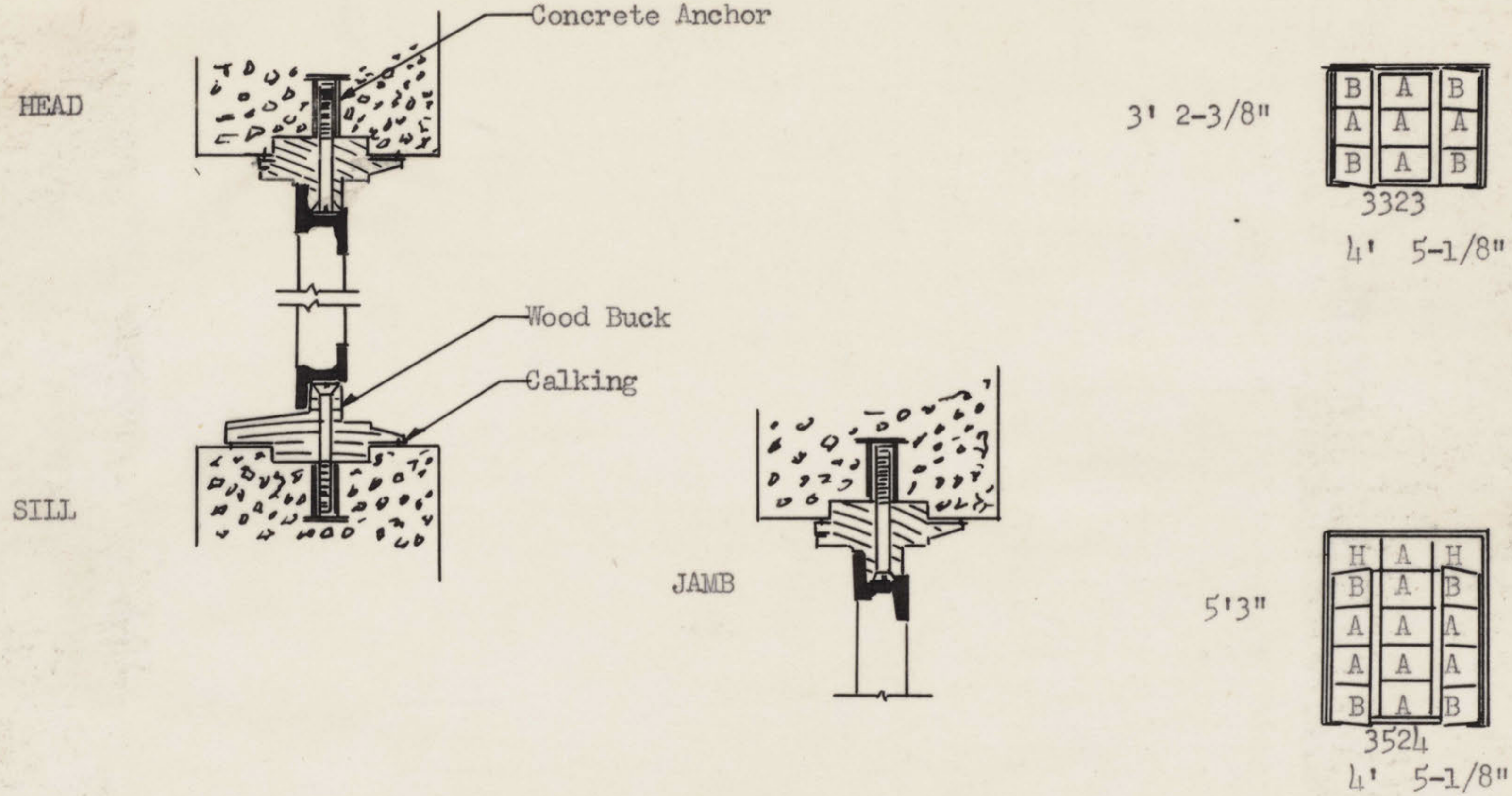
Drainage of the roof is afforded by sloping all sections of the roof toward the drain pipe which goes through the heating room and into the sewer. Thus the roof drainage facilities are connected to existing plumbing and are concentrated in the same section of the building. The recommended slope is one inch in ten feet. See Figure 11 for an explanation of the roof drainage system.

Roofing for the house is afforded by a tar and gravel coating over the reinforced concrete roof slab. A standard type drain is employed and is described in the materials section of this paper.

Lighting of the building employs the embedding of some of the conduit in the roof slab, especially the conduits leading to the ceiling lighting fixtures. Details are shown in Figure 6 on page 18, and the symbols used are based on the American Society of Architects, Specification C-10 - 1924.* An explanation of these symbols is as follows:

	Ceiling outlet		Junction box
	Wall outlet with extension		Meter
	Double convenience outlet		Bell
S_1	Single pole switch		Buzzer
S_2	Double pole switch		

*Charles George Ramsey and Harold Reeve Sleeper, Architectural Graphic Standards (New York, 1946), p. 310.



Glass Sizes

A	16"	x 12"
B	16"	x 11-5/16"
H	$17\frac{1}{4}$"	x 12"

Figure 8. Steel Casement Window Details

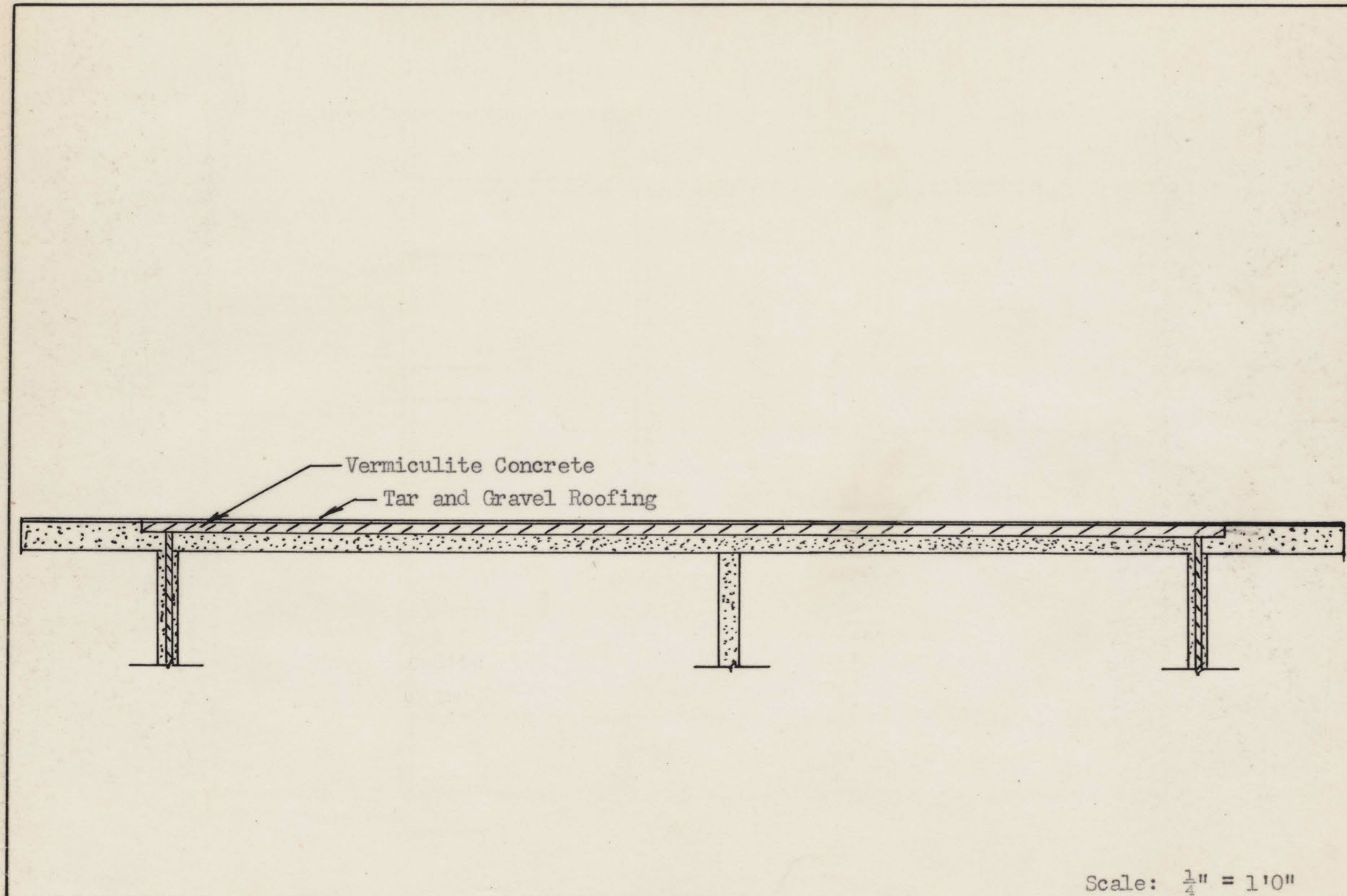


Figure 9. Typical Roof Section

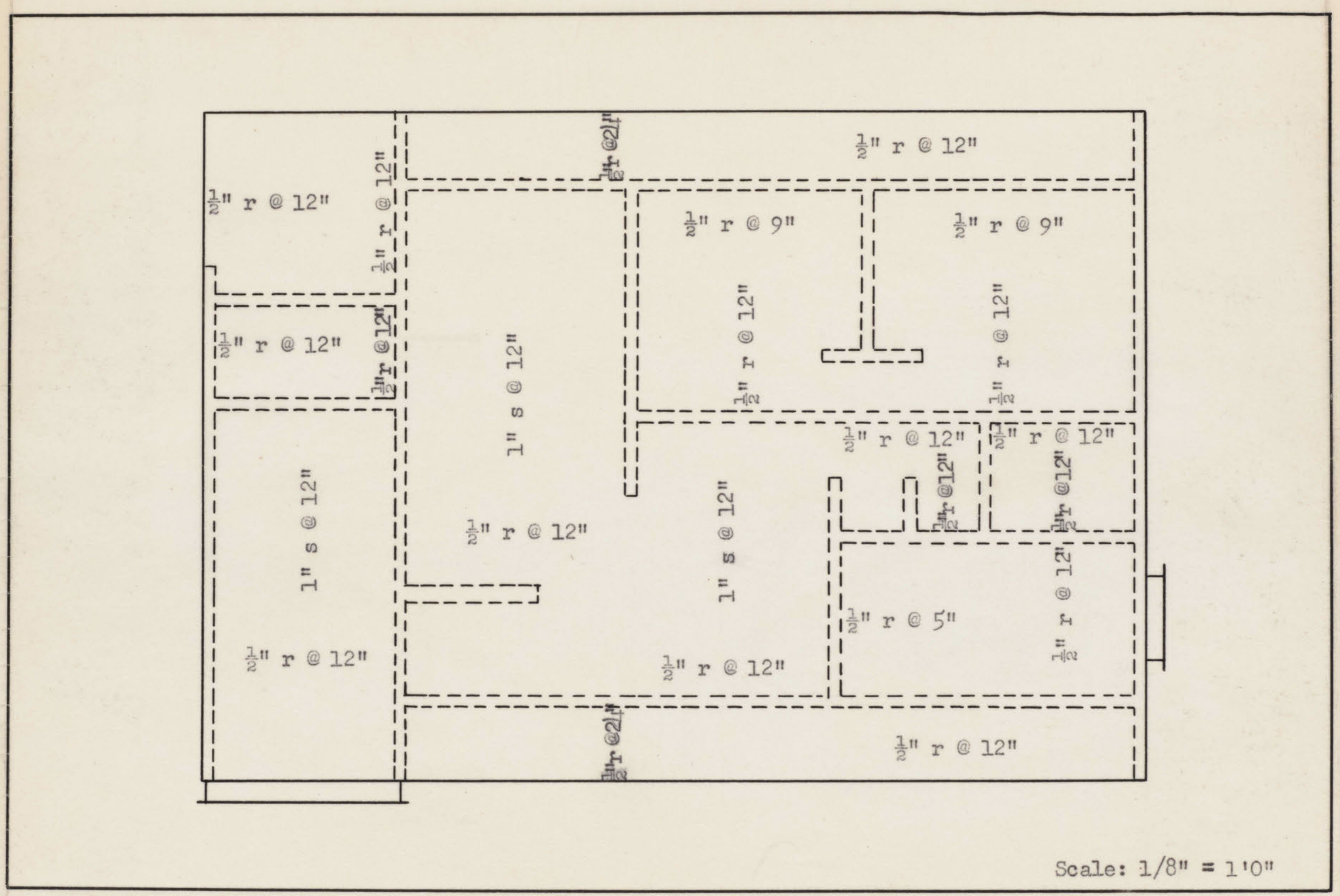


Figure 10. Roof Steel Arrangement

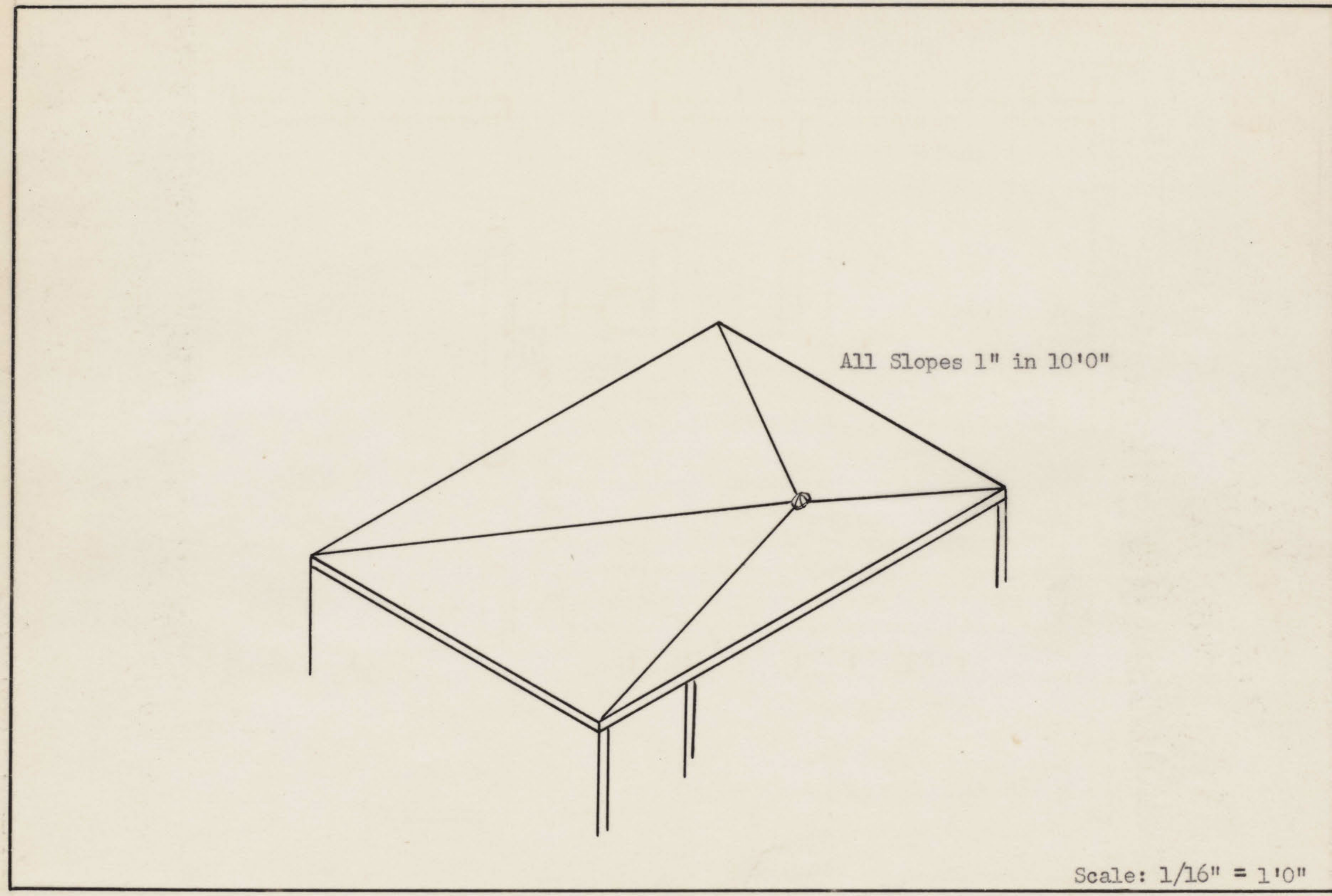


Figure 11. Roof Drainage Layout

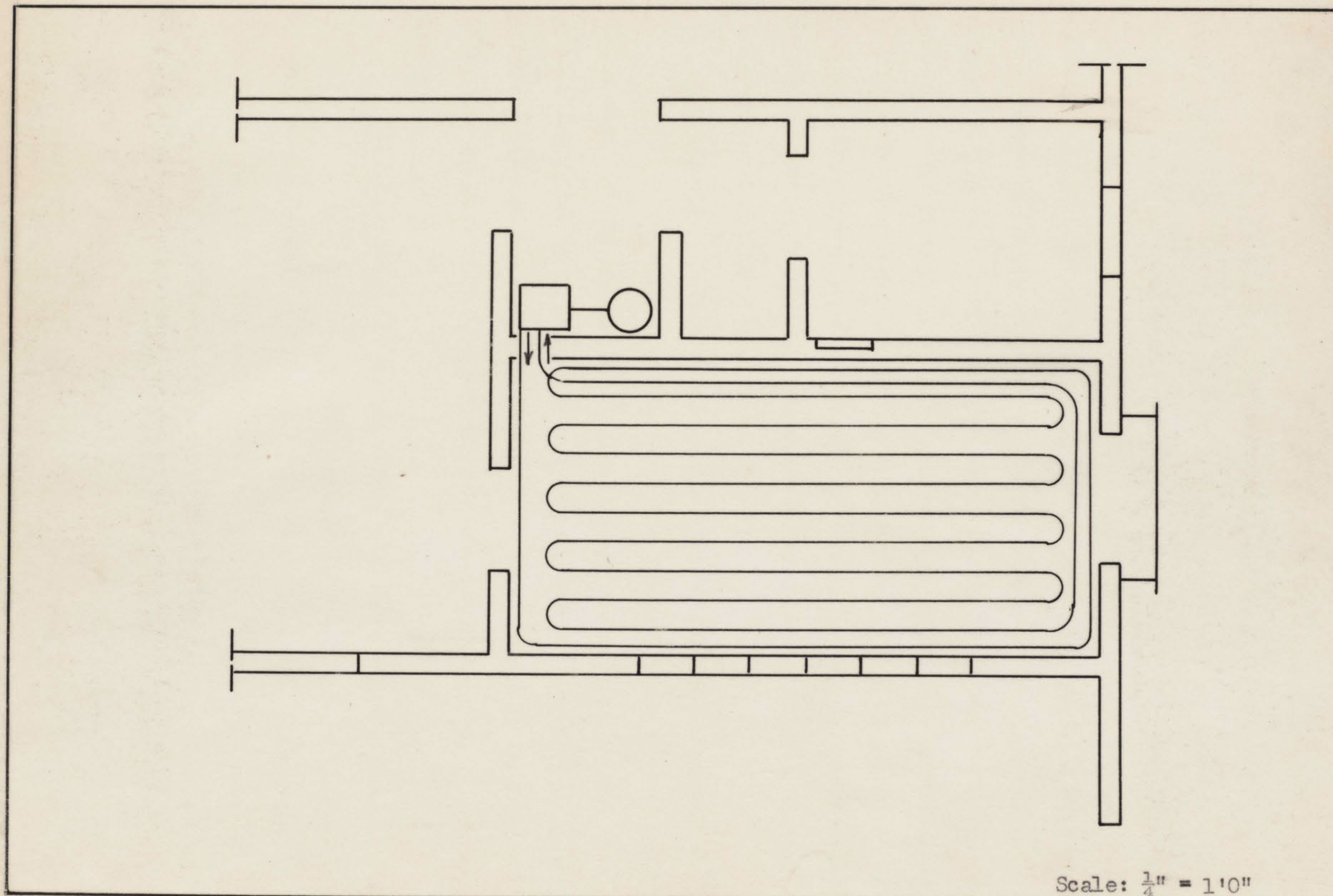


Figure 12. Typical Heating Panel Layout

CONSTRUCTION

Materials: It is the purpose of this section to present a brief description of each of the materials used in this construction. The descriptions will be in the nature of specifications, but in most instances will not be as involved or as precise as required for specifications. In all instances, where a specific item has been selected, the manufacturer's name and a brief description of the merits of the item will be given. Where it is possible to do so, the reference to the advertising literature will be given, thereby providing a ready reference for future readers of this paper. If this investigation should prove to be successful, it would be a simple matter to look further into each of the selected items and thus have at hand the necessary information to develop the required specifications. In general, the following list of materials is in the order of their use on the job.

Cinders: This material is employed for the fill beneath the concrete floor slab and almost any available cinders may be used. It is recommended that any large clinkers be broken into smaller particles, and the the entire fill be well tamped to provide a stable foundation material to prevent undue settlements in the future. If cinders are not available, a gravel foundation may be used. See page 14, Figure 3.

Building Paper: Very probably, the best available material for this purpose is Sisalkraft, a product of the Sisalkraft Company of Chicago. This paper is tough, reinforced, waterproof, windproof, and dustproof. It should prove to be an ideal paper to use over the cinder fill, acting as a barrier to water seepage through the floor slab and as an insulation material to prevent excess cold under the floors. See Figure 4 for position of Sisalkraft. The paper is tough enough to withstand considerable foot traffic by workmen during the pouring of the slab and will also prevent undue loss of concrete in the loose subfill. For a more complete description of the material, refer to page one of section 9b of Sweet's Catalog.* Sisalkraft is available in "blankets" in widths up to twenty-six and one-half feet. Use of this size would eliminate overlapping in most instances in this particular construction. Where overlaps are required, it is suggested that they be made at least nine inches and that the joints be coated with an asphalt mastic.

Cement: It is recommended that any Portland Cement meeting the specifications for Type 1 Portland Cement as given in the A.S.T.M. Specifications C150-42, may be employed. For a more complete discussion of this material, the reader is referred to the Concrete Manual.**

Sand: In the selection of sand for the job, considerable thought should be given to the gradation of the particles. Experience has shown that either very fine or very coarse particles are undesirable, and that a sand having a smooth grading curve will produce more satisfactory concrete. Of course, the availability of the sand types will control the selection, but that type which most nearly approaches the ideal conditions and specifications set forth in pages 65 to 73 of the Concrete Manual should be selected.

Aggregate: As in the selection of sand, care should be exercised to obtain a well-graded aggregate since density rather than high compressive strength is the fundamental requirement for all of the mixes used on this job. It is highly recommended that the size of the aggregate particles be limited to one-half inch to make it possible to obtain a smooth finish on all walls and floors. This is especially desirable in view of the fact that the walls are not provided with any interior finish other than the poured concrete. For

*Sweet's Catalog File - Engineering, "Sweet's Catalog Service," Division of F.W. Dodge Corporation (New York, 1949), Section 9b, p. 1.

**Concrete Manual, U.S. Department of the Interior, Bureau of Reclamation (Denver, U.S. Government Printing Office, 1947), pp. 50-54.

further information on the selection of aggregates, refer to Chapter 1, Section 16, of the Concrete Manual.*

Concrete: It is believed that considerable cost and time can be saved if all parts of the structure are made with the same mix. The mix chosen, based on the procedure set forth by the American Concrete Institute, is of the ratio 1:2½:4.** A complete calculation for this mix is given below, with specific page references:

**Design of Concrete Mix

Water cement ratio	0.53	(Table 1, p. 653)
Compressive strength @ 28 days	4000#/sq. in.	(Table 2, p. 654)
Maximum slump	6"	(Table 3, p. 655)
Minimum slump	3"	(Table 3, p. 655)
Maximum size of aggregate	½"	(Table 4, p. 655)

Materials:

Cement	Type 1, Average characteristics	
	Specific gravity = 3.15 (assumed)	
Sand	River sand, damp.	Medium fineness and grading.
	Specific gravity = 2.65 (saturated, surface - dry)	
	Free moisture content = 5% by weight	
Aggregate	Crushed stone	(saturated, surface - dry)
	Well graded, angular	
	Specific gravity = 2.55 (saturated, surface - dry)	

(From Table 5, p. 656) It is estimated that the percentage of sand for the trial mix should be 41, by absolute volume of the total aggregate, and that 310 pounds (about 37 gallons) of water will be required per cubic yard of concrete. Actually the water content is subject to change, as indicated by the amount of water required for a 3" slump. This is determined on the job by trial mixes and slump tests.

*Ibid., Chapter 1, Section 16.

**"Recommended Practice for the Design of Concrete Mixes," Journal of the American Concrete Institute, XVI (June, 1945), pp. 651-671.

*Cement Content = $= \frac{\text{Net Water Content}}{\text{Water-Cement Ratio}}$

$= \frac{310}{0.53} =$ 585 pounds per cubic yard

$= \frac{5.85}{94} =$ 6.22 sacks per cubic yard

Absolute Volume (water + cement) $= \frac{\text{Water Content}}{62.4} + \frac{\text{Cement Content}}{\text{Specific Gravity} \times 62.4} =$

$\frac{310}{62.4} + \frac{585}{3.15 \times 62.4} = 4.96 + 2.98$

= 7.94 cu. ft. per cu. yd. of concrete

Absolute Volume (total aggregate) = 27 - Absolute Volume (water + cement)**

= 27 - 7.94 = 19.06 cu. ft. per cu. yd. of concrete

Absolute Volume (sand) = percent sand x Absolute Volume (total aggregate)

= 0.41 x 19.06

= 7.80 cu. ft. per cu. yd. of concrete

Absolute Volume (aggregate) = Absolute Volume (total aggregate) - Absolute Volume (sand)

= 19.06 - 7.80 = 11.26 cu. ft. per cu. yd. of concrete

(Sand Content) = Absolute Volume x Specific Gravity x 62.4

= 7.80 x 2.65 x 62.4

= 1,290 lbs. per cu. yd. of concrete

(Aggregate Content) = 11.26 x 2.55 x 62.4

= 1,790 lbs. per cu. yd. of concrete

Trial Mix Proportions $= \frac{585}{585} : \frac{1,290}{585} : \frac{1,790}{585}$

1 : 2.2 : 3.5

This proportion is near $1:2\frac{1}{2}:4$. For purposes of further computations, it will be assumed that the final mix used, as determined by the slump test gives a $1:2\frac{1}{2}:4$ mix. This mix will be used for all parts of the structure to avoid unnecessary complication of construction.

*Ibid., p. 658.

**Air voids assumed to be negligible. When the air content is appreciable, as when air entraining agents are used, a suitable allowance should be made, considering the air as replacing an equal volume of sand.

Gunite: Gunite, as the trade name suggests, is concrete applied by a cement-gun process. This process has been recognized as producing a very dense concrete, and as a result thereof, the most waterproof concrete available by present methods. The density and moisture resistance of the product is undoubtedly due to the pressure continually applied to the green concrete as it is forced into the forms, thus resulting in the elimination insofar as possible of all voids or air pockets in the mixture. To date, the general application of the Gunite process has been in the repair of crumbling concrete structures rather than in the construction of new projects. However, it is believed that the process can be readily adapted to new work. Some modifications may be required, especially if large aggregate is used in the mix. In the cost analysis section of this paper, the time allotted to the placement of the concrete walls by this process has been purposely over-estimated. Considerable reduction in time would undoubtedly result after experience with the process in this type of construction.

Form Lumber: A good grade of structural timber is recommended for this purpose since it is believed that considerable savings will result due to the fact that the forms could then be re-used several times in the construction of similar houses. With proper car, it is not too optimistic to assume that these forms would be usable for twelve such houses at least, and that thereafter the better pieces might be re-used as small bracing members in subsequent forms.

Form Plywood: It is recommended that the SO2S-Ext. (sound 2 sides exterior) grade of form plywood be used and that the faces be mill-oiled. It is further recommended that the thickness be not less than three-quarters of an inch, and the material be built up of five layers, and that the bonding agent used be very highly water-resistant.*

Vermiculite Concrete: This concrete is a mixture of vermiculite aggregate, Portland cement, and water. The chemical composition and the physical properties of the vermiculite aggregate are given below.

**Chemical Composition: Vermiculite is an altered form of mica classified chemically as aluminum magnesium silicate.

	Montana Ore	North Carolina Ore
Si 0	41.00	33.93
Al 203	18.00	17.36
Fe 203	7.00	5.42
Mg 0	21.00	23.43
Ca 0	1.00	-----
K2 0 + Na 2o	1.00	-----
Ni 0	-----	.35
Ignition Loss	11.00	19.17
Specific Gravity	2.8	2.4
Specific Heat	2.0	2.0
Fusion Point	2462°F.	2850°F.
Color (Crude)	Olive Green	Deep Green
(Expanded)	Gold-Silver-Brown	Tan-Ecru-Gold
Cleavage	Basal	Basal

Vermiculite is an inorganic mineral and will not react with other substances, will not corrode metal, nor dissolve, nor give off odors or gases when wetted. It is a non-conductor of electricity and virtually, none hygroscopic.

Physical Properties:
Vermiculite concrete is resistant to freezing and thawing tests as it is sufficiently resilient to absorb, within its own mass, stresses and strains.

Cement Vermiculite Ratio by Volume	Strength Ultimate Lbs. per Sq. In.	Density Weight Per Cu. Ft.	Thermal Conductivity "K"	Materials for 1 Cu. Yd. Finished Vermiculite Concrete: Bags of Vermiculite	Bags of Concrete
1 - 3	650	60	1.200	8.25	11.00
1 - 4	500	48	1.020	8.25	8.25
1 - 6	245	36	.826	8.25	5.50
1 - 8	195	30	.795	8.25	4.125
1 - 10	139	26	.775	8.25	3.333
1 - 12	85	23	.722	8.25	2.25

Verm. @ $1.35/Bag	Cem. @ $1.10/Bag	Labor/Cu. Yd.	Cost/Cu. Yd.	Cu. Ft.	Bd Ft.
11.14	12.10	3.50	26.74	.99	.082
11.14	9.08	3.50	23.72	.88	.073
11.14	6.05	3.50	20.69	.78	.065
11.14	4.54	3.50	19.18	.71	.057
11.14	3.67	3.50	18.31	.68	.056
11.14	2.48	3.50	17.12	.63	.052

Vermiculite is packed in four cu. ft. bags when shipped; sold by vol., not wt.

*For further information consult "Commercial Standard CS 45-12," published by the Douglas Fir Plywood Association.

**"Vermiculite Concrete," California Stucco Products of N.E., Inc., Cambridge, Mass., pp. 3 and 4.

Vermiculite concrete is employed as the main insulation material. It is prefabricated on location in panels which are two inches thick. It is suggested that eight feet by four feet panels be cast and that these panels then be cut to size (an ordinary carpenter's saw may be used) and placed in position. The four feet by eight feet size will eliminate considerable cutting and fitting.

If a large number of these panels are required, such as for a housing project, the California Stucco Company considers it economically feasible to fabricate them for the contractor. This would result in considerable saving, but this possible cost reduction was not considered in the analysis.

Calking Compound: Any good grade of water-resistant calking compound may be employed. See installation details and Figure 8, page 22.

Floor Covering: The use of radiant floor panel heating makes it necessary to employ a heat-resistant floor covering. Either Johns-Manville Asphalt Tile* or Armstrong's Asphalt Tile** may be employed for this purpose.

Windows: Windows used in this house are of two types. The living room, dining room, kitchen, and bedroom windows are steel casements, while the bathroom window is a double-hung wood sash. The steel windows selected are manufactured by the Detroit Steel Products Company and are sold under the trade name of Fenestra. Installation details are given in the methods section of this paper, and window details in Figure 8. Any good grade wood sash may be employed for the bathroom window.

*"Asphalt Tile Flooring," A.I.A. File No. 23-M (Johns-Manville Sales Corporation).

**"Armstrong's Asphalt Tile," (Armstrong Cork Company, Lancaster, Pa., 1948).

Doors: Doors of two types, exterior and interior, have been employed in this house. There are three exterior doors, seven feet by three feet; and five interior doors, seven feet by two and one-half feet. In addition, a garage door eight feet by eight feet is employed.

It is recommended that Western Pine flush veneered slab doors be used for the exterior. This type is finished with a one-quarter inch face veneer and assembled with waterproof glue. The door is one and three quarters inch thick, low in cost, and durable for the purpose intended.

It is further recommended that hollow flush doors which are built up over a hollow core be employed for interior doors. These doors are one and three-quarters inch thick and finished with a one-sixteenth inch veneer surface. The hollow construction provides a door which is low in cost and light in weight. To further reduce expense, plain gumwood doors are employed.

A one-piece overhead type garage door has been employed. It is made up of three fir doors which are held together with angle irons. The door hardware (included in the total) consists of operating arms, which are secured to each jamb. Heat-treated springs attached to the operating arms equalize the weight of the door in all positions. When raised, the door protrudes about eighteen inches, forming a canopy. Five inch head room is required.

Hardware: The hardware employed in this house is made up solely of the door locks and hinges, since steel casement windows are used. Any good average type and style may be employed. The prices selected are representative of the average price range.

Reinforcing Steel: Reinforcing steel employed consists of bar and mesh types. The bars used have been restricted to two sizes, one inch square and one-half inch round. Both are of the deformed type specified as Structural Grade by the A.S.T.M. The serial designation of that organization is A15-39.

The mesh reinforcement is style number 7-A, which is manufactured by the American Steel and Wire Company. This type is designed for use with the Gunite process and consists of twelve-gauge wire longitudinals spaced at four inches, and fourteen-gauge cross wires spaced at two inches. It weighs approximately thirty-one pounds per one hundred square feet and is available in 150', 200' or 300' rolls. of 16", 20", 24", 28", 32", 36", 40", 44", 48", 52", and 56" widths. The ultimate strength is seventy thousand to eighty-five thousand pounds per square inch. The material is available either plain or galvanized.

The 300' roll of 48" width which is not galvanized is suggested as the most economical for this project.

Roof Drain: It is recommended that the Holt Roof Drain Type Number 5 be employed. This type of drain has been used successfully over a period of years in concrete structures, and is available in almost all locations.

Roofing: A Barrett Specification roof is recommended. This type will cost somewhat more than the usual built-up roofing, but it is believed that the quality justifies the extra expense. The increased cost is due to the fact that the Barrett Company must approve the roofing contractor who applies their roofing and assure the use of the proper amounts of materials. This roofing is available in several grades, with varying lengths of guarantee. The type chosen is 4-ply AA and carries a twenty-year guarantee. This roofing is especially adaptable in this case since it is designed for slight inclines.

Heating Pipes: As indicated in the heating design procedure on page xv, Type K copper tubing of half inch diameter, manufactured by the Revere Copper and Brass Incorporated, is recommended for this purpose. A complete description of the tubing may be found in the design procedure reference. See Figure 12 for a typical layout.

Boiler: A Hanson-Gates Boiler-Burner Unit is recommended for this purpose. This unit, as indicated by the name, is a combination boiler and hot water heater especially adapted for use in residential construction. It has the particular advantage of being small enough in size to be placed in the relatively small heating room without taking up unnecessary space. Pertinent data on this unit, as copied from the Company circular, is given below for the convenience of the reader since this information is not given in the usual construction material and equipment catalogs and files. See Figure 5 for placement.

Size	: 15" x 15" x 43"
Insulation	: 1½" on sides, 1900° JM Test.
Combustion Chamber	: Built-in 2000° thin-skinned Hi-Temperature Brick
Coil	: 54'1", 3 turn Extra Heavy Copper
Flow and Return	: 2" connections.
Flue Opening	: 6".
Door	: Removable with 2" pop-door for flame observation
Burner	: Standard high pressure gun-type.
Controls	: M-H unless otherwise specified.
Nozzle	: .75 w/60° spray, 200 mesh screen.
Output per Hour	: 70,000 B.T.U.
Recovery in Gals. per Hr:	100 gals. with a 100° temp. rise.
Sq. ft. of H-W Radiation:	320 sq. ft. of standing forced H-W radiation.

Hook-Up Recommendation - Home Heating

Boiler	: Hanson-Gates Boiler-Burner Unit.
Summer-Winter Domestic Hot Water	: Tankless water heater build into expansion tank; 3 gal. per minute capacity.
	: 1" circulator.
	: 1½" check valve or suction tee.
	: 1" flow control valve.

: Automatic water feeder and relief valve.
: L147A M-H control or equal.
: A pressure, altitude and temperature gauge. (Optional)
: One water temperature reducing valve.
: Use 1½" piping on flow and return of expansion tank and heater.

When the above hook-up is used, it will supply the average family with an adequate supply of hot water in winter and summer. It is a neat, compact, highly efficient heating plant for small homes. This same installation can be used on cast iron, copper convector, and panel type radiation, with a high degree of efficiency. If used on radiant heating jobs, a high velocity circulator is recommended.*

Lighting Equipment: All equipment used for this purpose should meet the standards of the National Electric Code and be approved by the Underwriters Laboratories of the National Board of Fire Underwriters. Since the wire conduit and sockets employed are of standard type and design, no specific manufacturer's name is included. See Figure 6 for layout of electric lights and outlets.

Plumbing Equipment: The usual fixtures (clay pipe, lead pipe, and vents) employed for this purpose are of standard type and design and therefore no manufacturer's name or description are included. It is suggested that the contractor use only those items which meet the Specifications of the American Society for Testing Materials. See Figure 5 for layout of plumbing pipes, vents, and fixtures.

Concrete Anchors: Any materials catalog will give the trade names for several types of anchors, any of which would be suitable for this job. A half-inch size machine bolt size is recommended. One of the best is the Star Tampin.

Methods: This section is intended to be a step-by-step description of the actual assembly process for the construction of this type house. In describing the process, use has been made of many small drawings. These drawings are presented as illustrations rather than actual working drawings, and it is believed that through their use a better picture of the suggested process is presented. The following procedure is recommended:

Lay out the building site, using any of the conventional methods, such as the 3, 4, 5 right triangle; or by means of a transit if one is available. It is suggested that batterboards be constructed for reference.

Level the site and remove the top soil to allow for placement of the cinder sub-fill.

Spread the cinder sub-fill, making sure to have at least one foot of cinders under all portions of the floor slab.

Tamp or roll the cinders into position until the necessary compaction is achieved.

Dig the required trenches in the sub-fill to allow for a concrete floor beam under each of the outside and inside walls. See Figure 3 and the discussion on page 13.

At the same time it is advisable to dig the necessary plumbing trenches and to place all the piping which is required below the floor slab. Cover the exposed sections of pipe to keep them free of concrete later on.

Insulate and install asphalt coating on the plumbing pipes to prevent their becoming corroded when embedded in the concrete slab.

Place the form piles. These are the 4" x 4" posts which are driven into the ground and onto which the balance of the forms are built. Care should be taken that these posts are long enough and capable of carrying the form load. The post length will vary with the local soil condition. See Figure 13 on page 40.

Place the Sisalkraft blanket, or other building paper, in position, making sure that all joints are lapped at least nine inches and that all joints are coated with an asphalt mastic. It should also be made sure that any sections of the paper which are torn by the workmen be repaired to give a completely waterproof covering between the subsoil and the floor slab.

Construct the slab forms as shown in the illustration in Figure 13 on page 40. It is essential, of course, that these forms be leveled to insure a level floor slab. The batterboards suggested above will prove a great help in leveling the form tops.

Place temporary screeds on the inside of the forms four inches from the top to act as guides in leveling the first layer of concrete.

Pour the first layer of concrete and level, using the bottom of the screeds described above.

Remove temporary screeds.

Place the two-inch panels of vermiculite insulation, making sure that the entire floor is covered and that all joints are sealed with vermiculite concrete.

Place the radiant heating pipes, using chairs which will bring the tops of the piping one-quarter inch from the surface of the finished floor. A typical floor heating layout is shown in Figure 12 on page 26.

Place garage slab reinforcing steel.

Place the planking with the concrete anchors bolted into place, as shown in Figure 15 on page 42. These anchors are to be utilized in bolting the interior partition forms to the floor. See Figure 14 for arrangement of the anchors.

Pour the final concrete floor layer in the remaining two inches

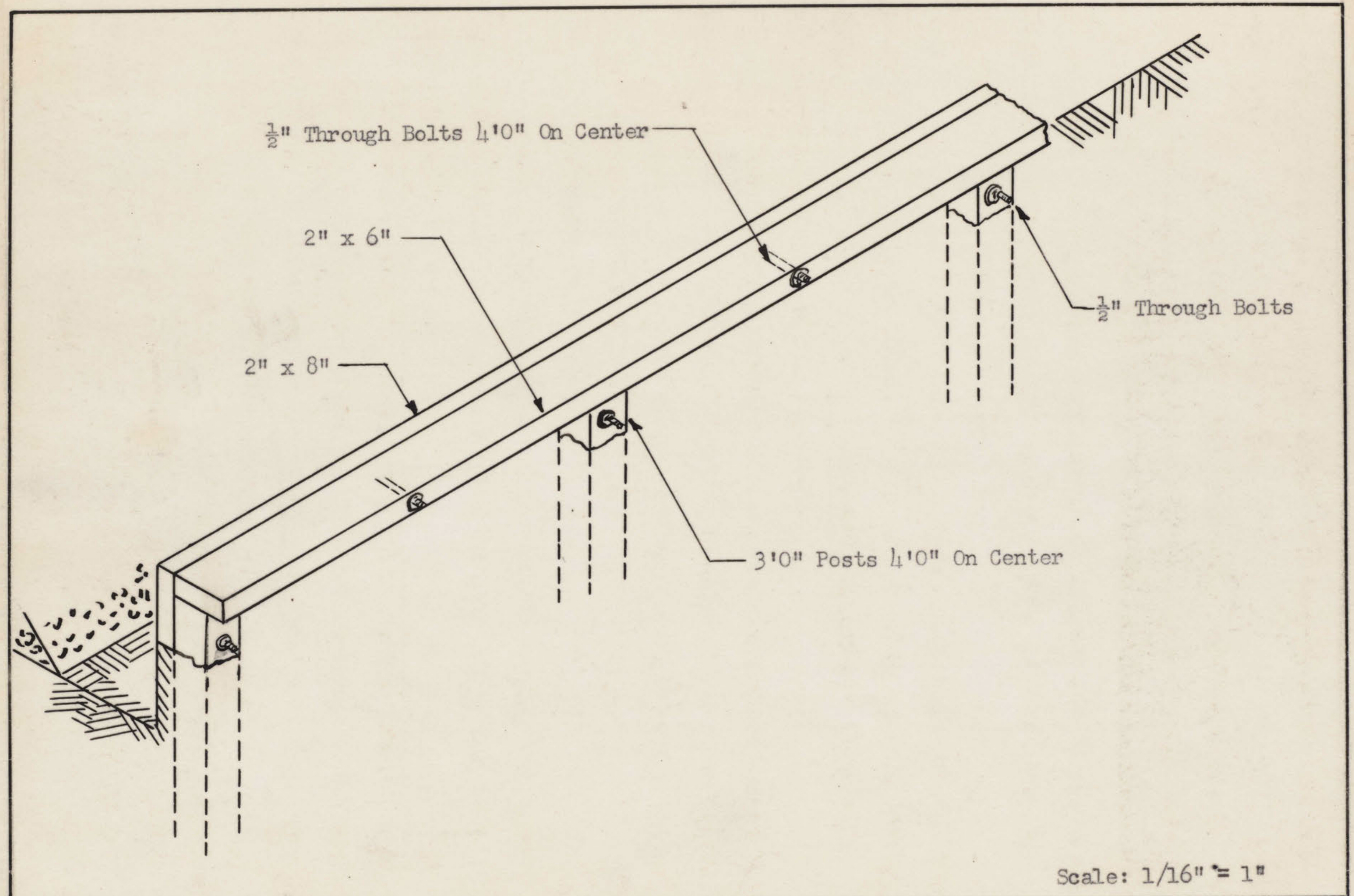
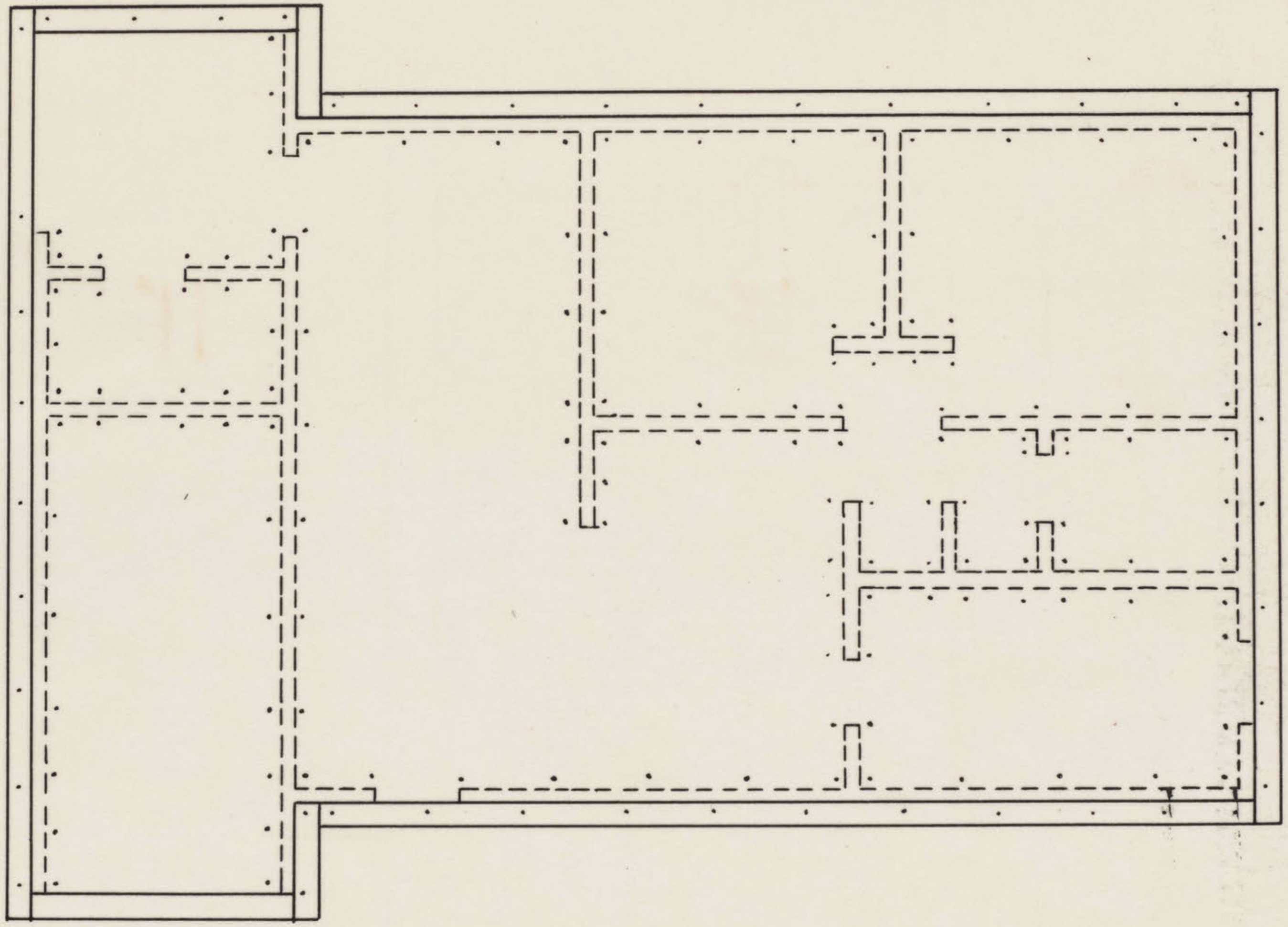


Figure 13. Typical Floor Form Section



Anchors 4'0" On Center Except at Form Corners

Scale: 1/8" = 1'0"

Figure 14. Arrangement of Concrete Anchors

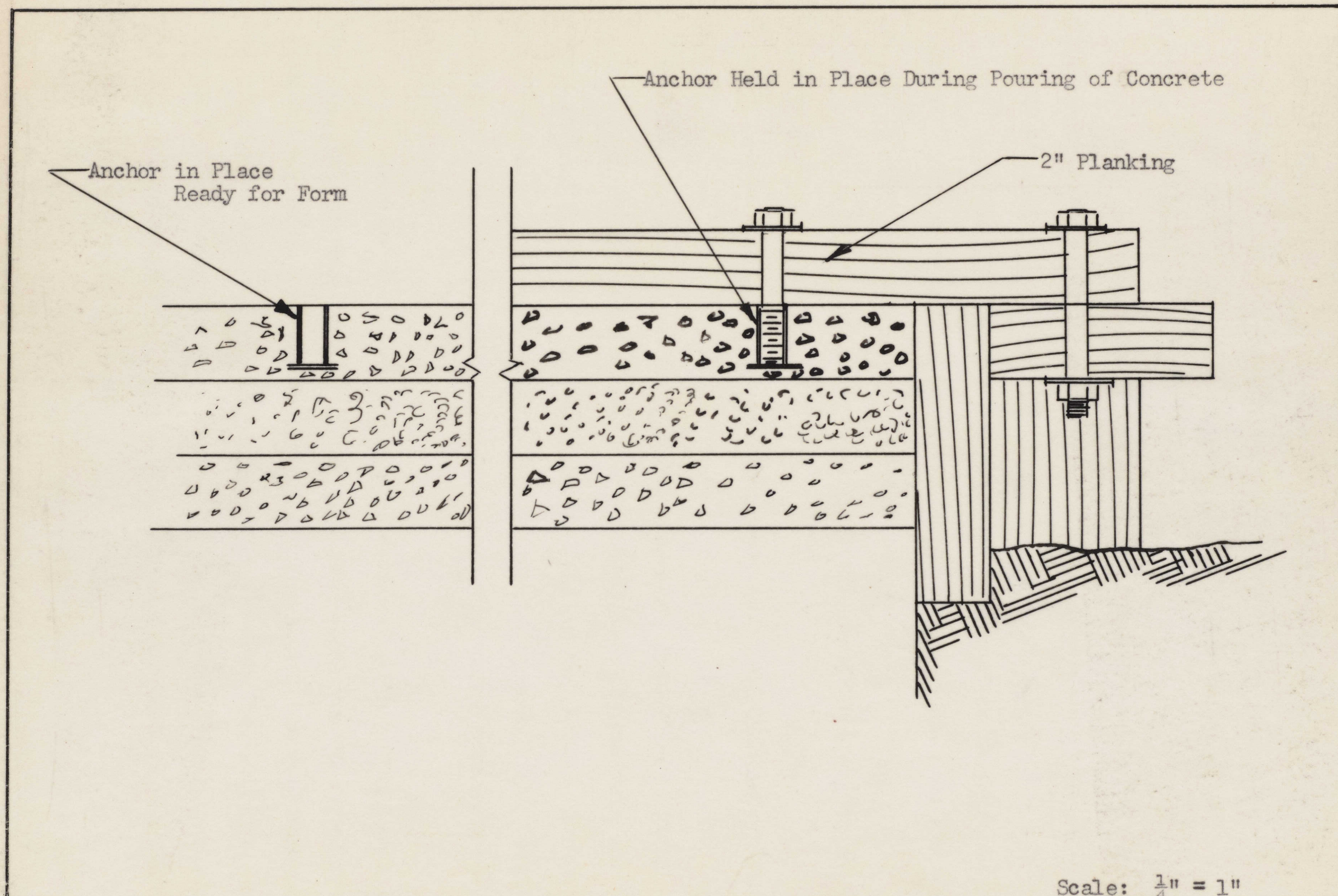


Figure 15. Typical Placement of Concrete Anchor

and level it with the tops of the floor forms. Make sure that all of the concrete anchors are securely embedded in concrete.

After the floor slab has set, remove the concrete anchor planking and bolts.

Bolt the outside wall forms into position on the top of the floor forms as shown in Figure 16 on page 44. An outside corner joint is shown in Figure 17 on page 45.

Bolt the inside wall forms and the interior partition forms in position. Figure 18 shows a typical interior corner joint. Figures 8, 19, and 20 show the necessary window and door details.

Place window and door frame forms with concrete anchors, as shown in Figures 19 and 20.

Place electrical and plumbing pipes, as shown in Figure 5 on page 17.

Brace all of the forms on the inside of the building, using cross bracing from form to form. Use 2" x 4"'s for all bracing. In this operation it is best to make sure that all corners have a triangular brace to insure the corner's being exactly ninety degrees. With this system, no exterior braces are required; each form forms a brace for the adjoining forms.

Place the roof slab forms in position as shown in Figure 21 on page 50. The overhang portion of the roof slab forms are supported by triangle bracing to the side forms, and the portion of the roof forms over the interior of the building is supported by a combination of braces and columns. After these forms are placed, it may be noted that a complete and internally-braced shell form is assembled and is ready to receive the concrete for the walls and roof.

Place the vermiculite wall insulation panels. This can best be done from over head by placing temporary planking across the top of the roof and floor forms.

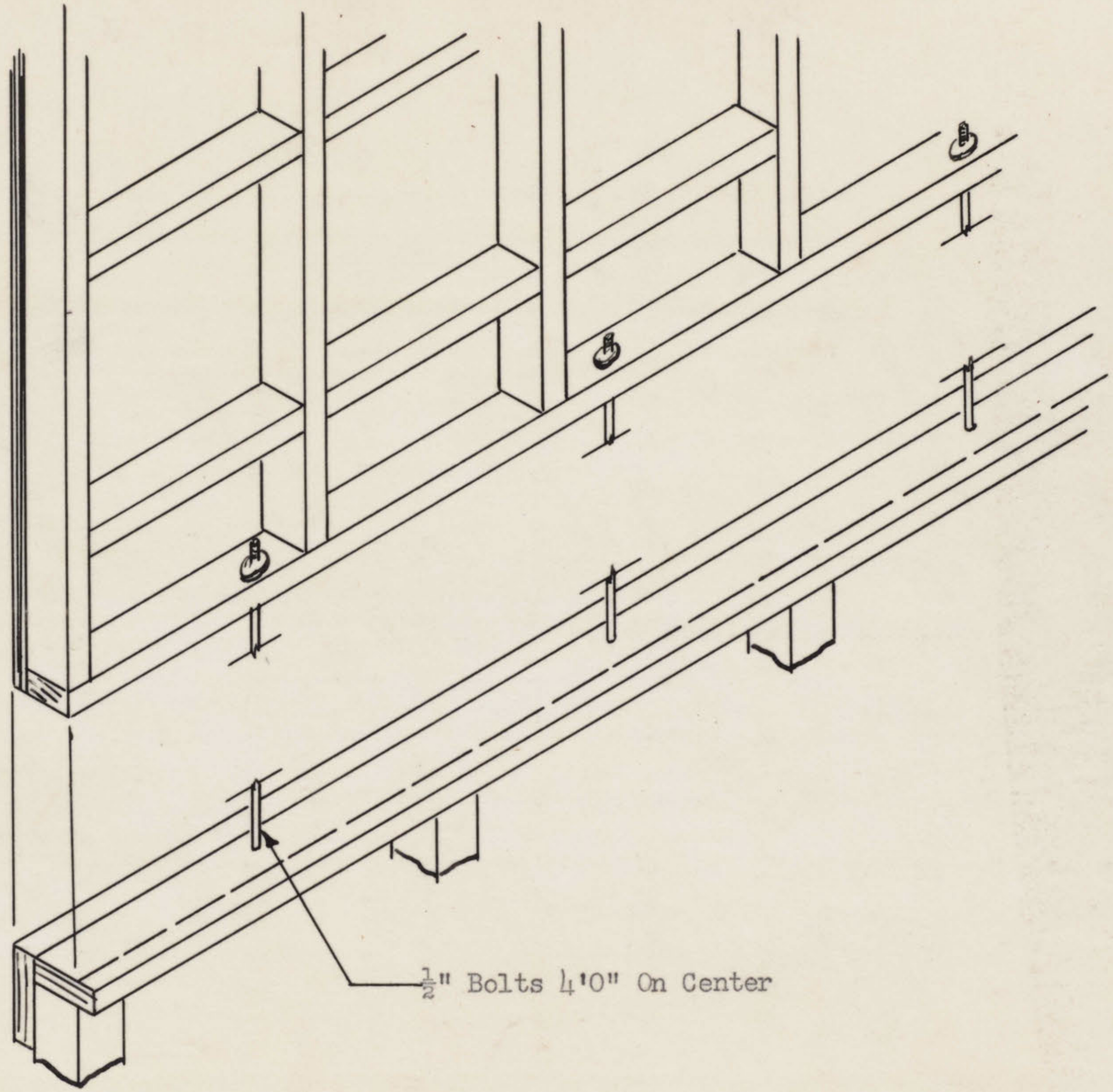


Figure 16. Connection - Wall and Floor Form

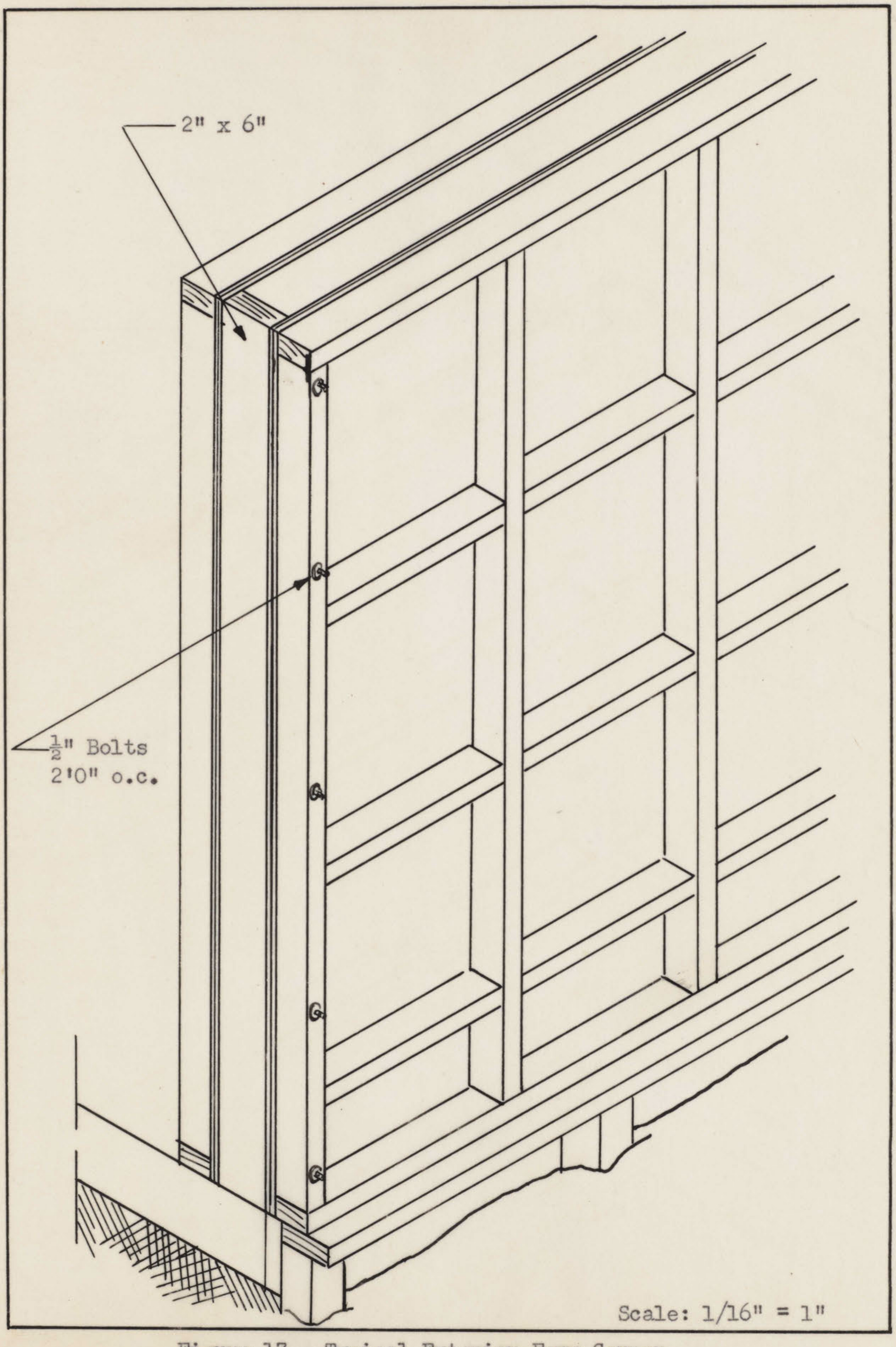


Figure 17. Typical Exterior Form Corner

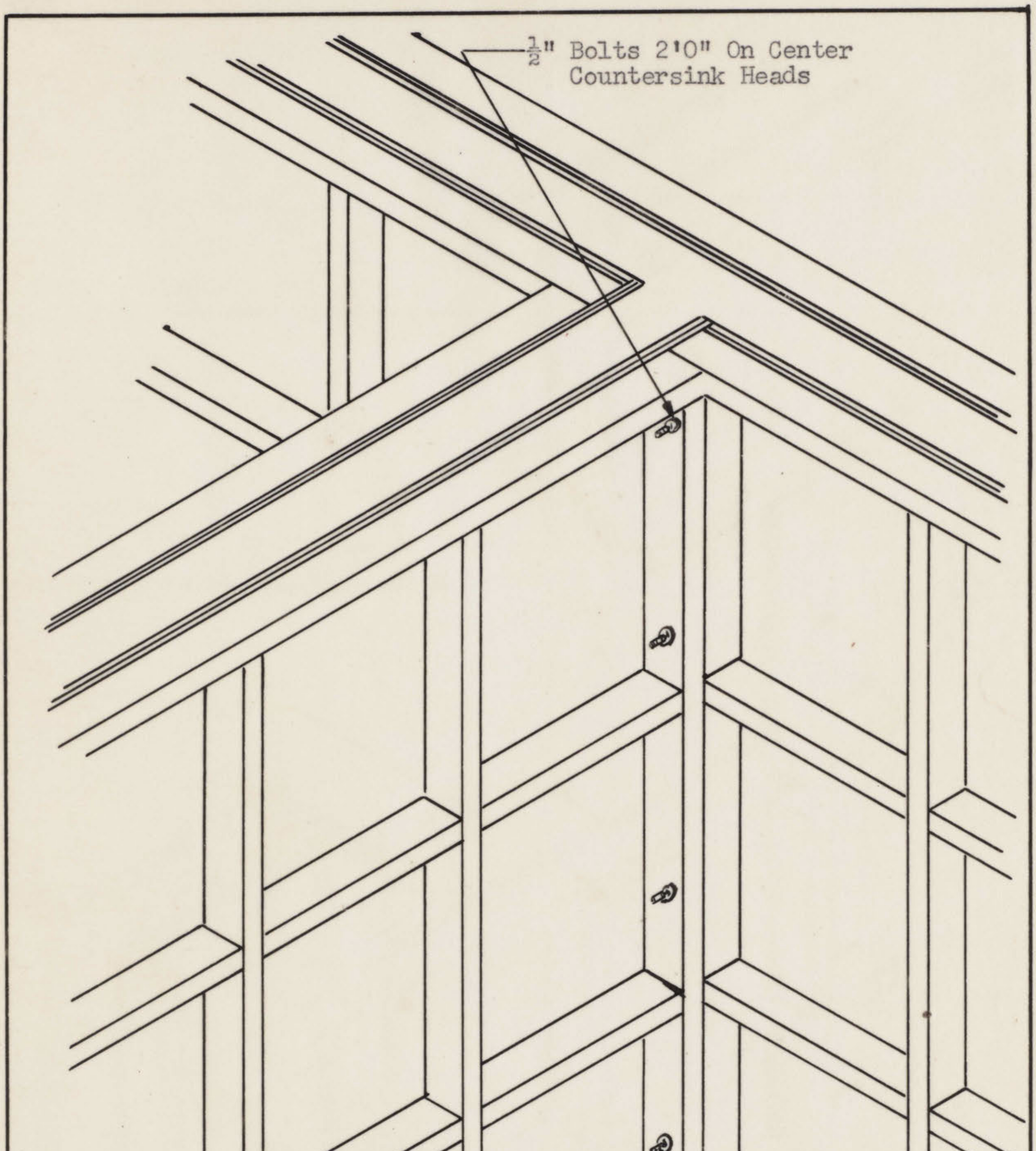


Figure 18. Typical Interior Form Corner

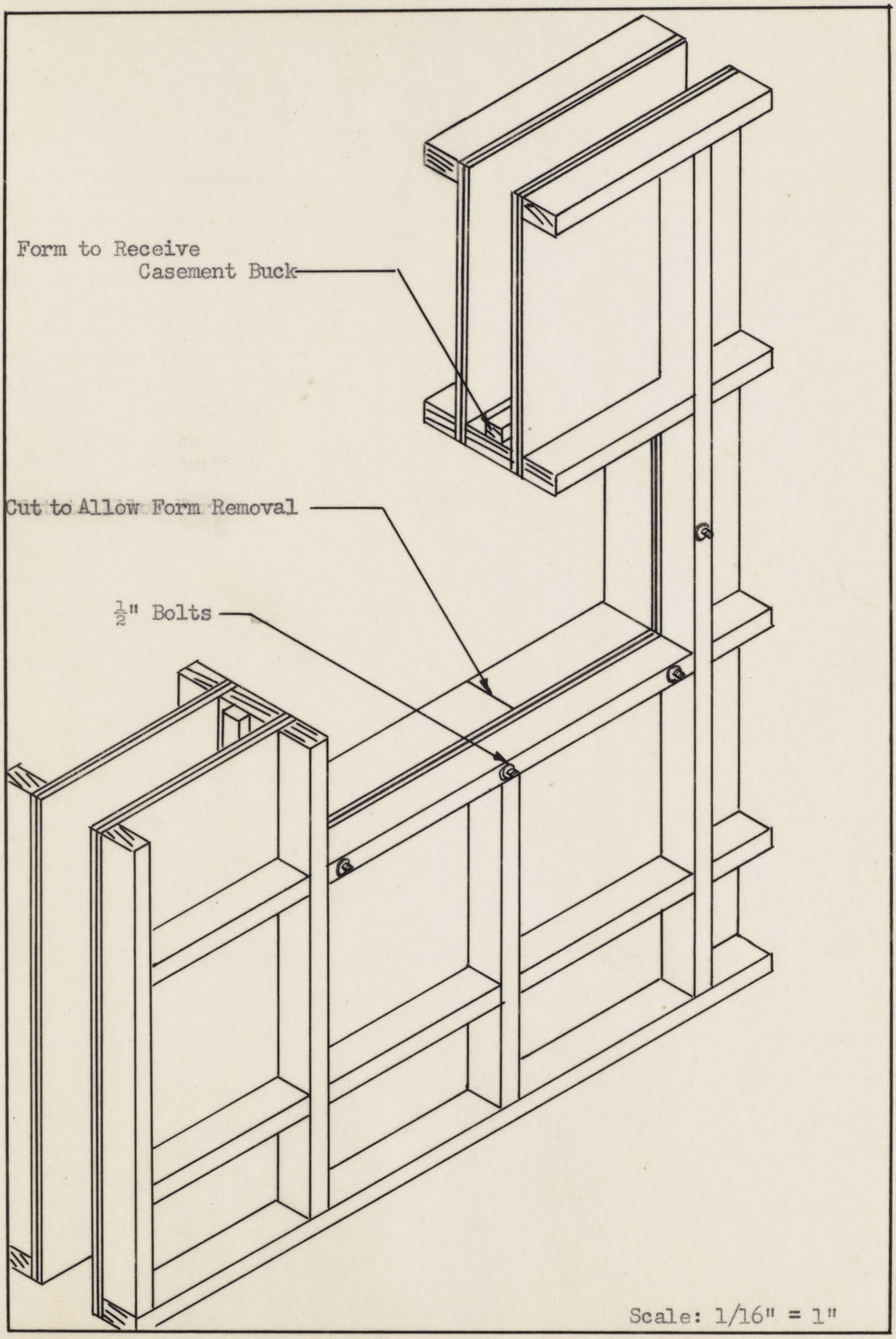


Figure 19. Typical Window Form

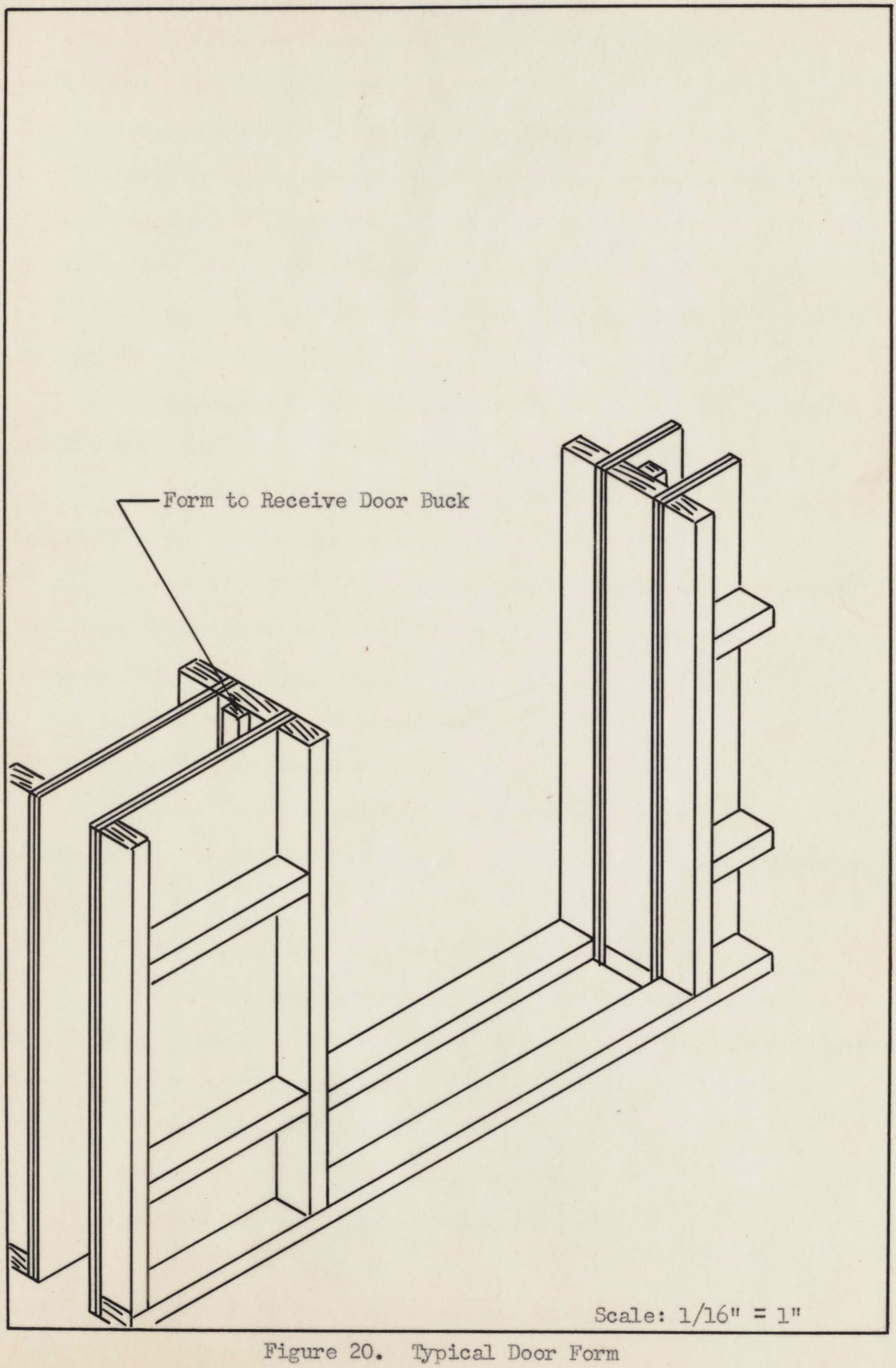


Figure 20. Typical Door Form

Place the wall mesh reinforcing. This steel may be held in position as shown in Figure 21, page 50.

Place the wall concrete, using the Gunite process. To secure a satisfactory job, the operators must make sure to force the concrete into all portions of the forms. This is especially important around the lower portions of the windows.

Place the roof slab reinforcing steel as shown in Figure 10 on page 24.

Pour the roof slab as shown in Figure 9, leaving the recess to provide space for the roof vermiculite insulation panels.

Place the roof vermiculite insulation panels; or, as an alternative, cast vermiculite concrete in the recess.

Cover the entire roof with an additional layer of concrete. This final layer is to be sloped to provide the necessary roof drains as shown in Figure 11 on page 25.

Apply the tar and gravel roof.

Remove all forms.

Install windows and doors as shown in Figures 8, 19, and 20, making use of the concrete anchors for support of the window frames and door bucks.

Calk the windows as shown in Figure 8, page 22.

Smooth all rough portions of the interior and exterior walls and ceiling by using a concrete surface grinder. Since no finish coat is to be applied, it is essential to provide a smooth and finished surface to the interior walls.

Place concrete in all floor anchors.

Install asphalt floor covering.

Paint as desired.

Remove all debris, and landscape as desired.

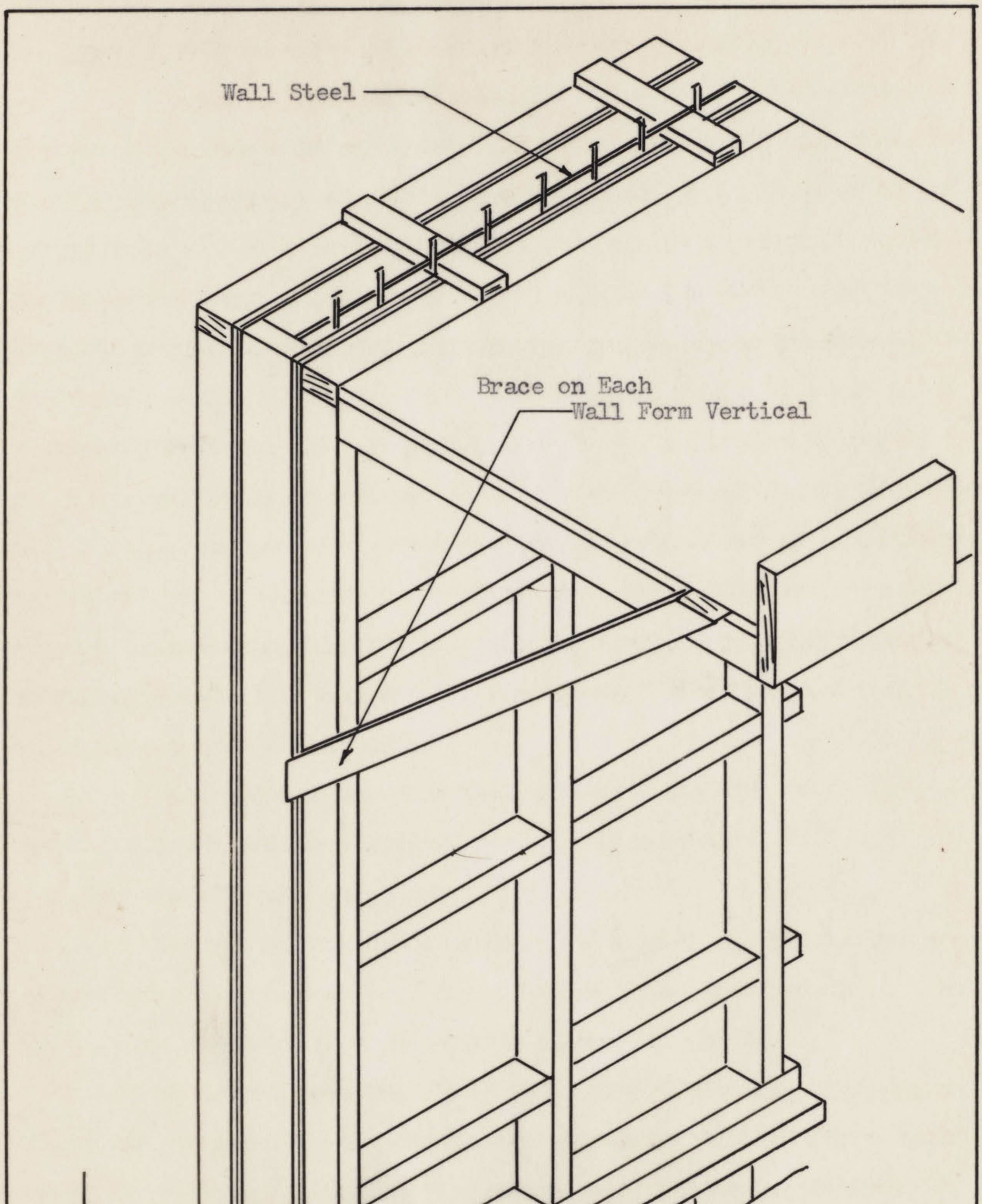


Figure 21. Typical Roof Form

Forms: The forms used in this process are not unique in their design. They are the usual 2" x 4" plywood combination. Typical panels are shown in Figures 17 to 21. It is suggested that the individual wall panels be made as long as possible. In this manner most of the walls will require only one form panel for each side of the wall. The forms must be sturdily constructed and braced as shown in Figures 17 to 21 to provide the expected service. If properly constructed and carefully assembled and removed, it is believed that they will serve for the placing of at least twelve houses.

The forms are secured to the floor by means of concrete anchors, and to adjoining panels by means of interior cross bracing. This system is believed to be a unique use of the actual floor structure as a support for the balance of the building. Thus the customary slant bracing together with the usual dead men are eliminated. This makes for a more sturdy and compact form design.

The use of countersunk wood screws in the individual form panels makes for sturdy construction, and if properly assembled, will last for the expected twelve projects.

The use of through bolts in all corner joints eliminates nails being used each time the forms are assembled, thus eliminating the usual nail damage and increasing the useful life of the forms.

It is believed that this combination of plywood, bracing, and floor anchors forms a well-integrated and compact manner of form assembly that will result in a neater, faster, and more economical assembly procedure. A separate cost analysis of the form construction is given on page 59.

Quantities Survey:

Concrete:

Floor beams	315 x 1	x 1		315 cu. ft.
Floor slabs	28 x 40	x 4/12		373
Garage slab	36 x 10	x 7/12		210
Exterior walls	164 x 8	x 4/12	438	
Less openings	250 x 4/12		83	355
Interior walls	127 x 8	x 6/12	508	
Less openings	84 x 6/12		42	466
Roof slab	28 x 40	x $4\frac{1}{2}$/12		420
Garage roof slab	36 x 10	x $6\frac{1}{2}$/12		195
Total concrete				2,334 cu. ft.
				87 cu. yd.

Vermiculite concrete:

Floor slab	28 x 40	x 2/12		187 cu. ft.
Exterior walls	164 x 8	x 2/12	219	
Less opening	250 x 2/12		42	177
Interior walls	10 x 8	x 2/12		13
Roof slab	28 x 40	x 2/12		186
Total vermiculite concrete				563 cu. ft.
				21 cu. yd.

Reinforcing steel:

Bars: 1" square

Garage floor	14 x 20	280 ft.
Garage roof	10 x 20	200
Living room	12 x 22	264
Dining room	12 x 15	180
Total 1" square		924 ft.
Weight = 924 x 3.4		3,140 lbs.

Reinforcing steel:

Bars: ½" round

Garage floor	22 x 10	220 ft.
Garage roof	20 x 10	200
Storage roof	5 x 10	50
Storage roof	10 x 5	50
Porch roof	20 x 10	200
Living room roof	22 x 12	264
Dining room roof	15 x 10	150
Bedrooms - roof	16 x 24	384
Bedrooms - roof	24 x 12	288
Kitchen roof	16 x 16	256
Kitchen roof	16 x 8	128
Bath; heating roof	6 x 16	96
Bath; heating roof	16 x 6	96
Cantilever roof	40 x 4	160
Cantilever roof	4 x 80	320
Total ½" round		2,862 ft.
Weight = 2,862 x 0.66		1,890 lbs.
Total steel weight		5,030 lbs.

Mesh - Type 7-A

Exterior wall area	164 x 8	1,312 sq. ft.
Less opening		- 250
Total steel mesh		1,062 sq. ft.

Heating piping:	
$\frac{1}{2}$" Type K copper tubing (see page xv for details)	947 ft.
Tar & gravel roofing: Area: 40 x 28 = 1,120 sq. ft.	
10 x 36 = 360	1,480 sq. ft.
Windows:	
Type 3524	4
Type 3323	6
Double-hung sash (2'6" x 4')	1
Doors:	
Exterior (3' x 7')	3
Interior (2'6" x 7'0")	5
Garage	1
Plumbing facilities and piping:	
Bathtub	1
Toilet	1
Wash bowl	1
Kitchen sink	1
Hot water tank - 300 gal.	1
Roof drain	1
Drain pipe 4" C.I.	20 ft.
Galvanized water pipe	40 ft.
Vent 6" C.I.	10 ft.
Electrical facilities	
Total outlets	21
Bell	1
Buzzer	1
Heating facilities	
Boiler unit	1
Radiant heating valves	6

Form materials				
3/4" plywood	2 x 391 x 8 =	6,256 sq. ft.		
Less openings	334 x 2 =	668		5,588 sq. ft.
2" x 4" braces	5 x 291 x 2 =		2,910 ft.	
	2 x $\frac{291}{4}$ x 8 =		1,164	4,074 lin. ft.
2" x 6"	100 + 28 + 36 =			164 lin. ft.
2" x 8"	100 + 28 + 36 =			164 lin. ft.
Fastenings				
Nails				200 lbs.
$\frac{1}{2}$" bolts	6 x $\frac{291}{4}$			500
Concrete anchors				200
Hardware				
Mortised locks - exterior				3
Mortised locks - interior				5
Hinges				16
Cinders:	40 x 28 = 1,120			
	10 x 36 = 360			1,480 cu. ft.
				55 cu. yd.
Insulation				
Sisalkraft				1,480 sq. ft.
Floor covering				
Asphalt tile				1,120 sq. ft.
Interior finish				
Window jambs				136 lin. ft.
Door jambs				131 lin. ft.

COST

General: The following section is devoted to a cost analysis of the proposed residence. The unit prices are from several sources. Those for concrete, reinforcing steel, lumber, plywood, and the hourly labor rates are taken from the March 17, 1949, issue of the Engineering News-Record. This issue contains the annual summary of construction costs. The unit labor rates are those prevailing in the Boston area and represent a typical cross section of those prevailing over the country. Unit prices for the ordinary materials are from the manufacturer's catalog. In the case of items subject to frequent fluctuation in price, such as steel windows, plumbing and heating facilities and piping, the most recent quotations were obtained by contacting the manufacturers or distributors. The unit prices for the plumbing facilities and the garage door include all the fittings necessary for installation. The usual 37% discount for window prices between $1 and $1000 has been deducted from the price of the steel windows. The electrical estimate is based on a charge of $7.50 per outlet, which is the usual method for determining the cost of electrical installations; however, in this estimate the total price thus obtained has been split into the portion chargeable to labor and the portion applicable to the cost of materials. The concrete quotation is based on the price for ready-mixed concrete.

It is believed that this combination of prices and methods represents an accurate as well as a fair procedure for estimating the cost of construction. The total figure thus obtained is a true measure of the cost to be incurred in this type of project.

Materials and Equipment:

Concrete	87 cu. yds. @ $10.00/cu. yd.	$ 870.00
Vermiculite concrete	21 cu. yds. @ $17.12/cu. yd.	359.52
Reinforcing steel:		
1" square	3,140 lbs. @ $8.00 per 100 lbs.	251.20
½" round	1,890 lbs. @ $10.00 per 100 lbs.	189.00
Mesh	1,062 sq. ft. @ $3.00 per 100 sq. ft.	31.86
Heating piping	947 lin. ft. @ $0.1046 per lin. ft.	99.05
Tar & gravel roofing	1,480 sq. ft. @ $6.95 per 100 sq. ft.	102.86
Windows:		
Type 3524	4 @ $17.64	70.56
Type 3323	6 @ $15.00	90.00
2'4" x 4'6" double-hung wood	1 @ $3.00	3.00
Doors:		
Exterior 3'0" x 7'0"	3 @ $14.50	43.50
Interior 2'6" x 7'0"	5 @ 7.00	35.00
Garage 8'0" x 8'0" x 1-3/4"	1 @ 29.00*	29.00
Plumbing facilities & piping		
Bathtub		105.00
Toilet		34.65
Wash bowl		32.65
Kitchen sink		37.50
Hot water tank - 300 gal.		41.00
Roof drain		6.50
Drain pipe 4" C.I.	20 ft. @ $0.23 per ft.	4.60
Galvanized water pipe	40 ft. @ 0.37 per ft.	14.80
Vent pipe 6" C.I.	10 ft. @ 0.41 per ft.	4.10
Valves & fittings		15.00

*Includes all necessary hardware.

Electrical facilities:		
Outlets	21 @ $7.50 per outlet	57.50
Bell		2.00
Buzzer		2.00
Heating facilities:		
Boiler-burner unit		130.00
Radiant heating valves & fittings		25.00
Hardware:		
Mortised locks - exterior	3 @ $9.95 each	29.85
Mortised locks - interior	5 @ $3.29 each	16.45
Hinges	8 pairs @ $0.83 per pair	6.64
Fastenings:		
Concrete anchors	200 @ $10.00 per 100	20.00
Cinders	55 cu. yds. @ $ 0.50 per cu. yd.	27.50
Insulation:		
Sisalkraft	1,480 sq. ft. @ $ 3.00 per 100 sq. ft.	44.40
Floor covering:		
Asphalt tile	1,120 sq. ft. @ $ 8.00 per 100 sq. ft.	89.60
Interior finish:		
Window jambs	136 lin. ft. @ $14.00 per 100 ft.	19.04
Door jambs	131 lin. ft. @ $14.00 per 100 ft.	18.34

Vermiculite fabrication:

Volume of vermiculite concrete required = 563 cu. ft.

For 2" panel thickness: 563 cu. ft. = 6,756 bd. ft.

6,756 board ft. @ $0.052 per bd. ft. 351.31

Total cost of materials and equipment $3,152.48

Forms:

Material

3/4" plywood	5,588 sq. ft.	@ $0.20 per sq. ft.	$1,117.60
2" x 4" braces	4,074 lin. ft.	@ $0.08 per lin. ft.	325.92
2" x 6" floor forms	164 lin. ft.	@ $0.10 per lin. ft.	16.40
2" x 8" floor forms	164 lin. ft.	@ $0.10 per lin. ft.	16.40
Nails	200 lbs.	@ $0.02 per lb.	4.00
Bolts	500 - ½"	@ $5.00 per 100	25.00
Total cost of material			$1,505.32

Labor: (per 100 sq. ft. of forms)

Carpenter	2 hrs. @ $2.10	$4.20
Labor	2 hrs. @ $1.55	3.10
Labor cost/100 sq. ft.		$7.30

Total labor costs:

5,580 sq. ft. @ $7.30 per 100 sq. ft. 407.34

Total cost of form material and labor $1,912.66

Note: The above computations give the entire cost of building the forms.

If the forms are used 12 times only, $159.39 of the cost is applicable to each house. The cost of setting up and removing the forms is given in the Labor section of this Cost Analysis section. See page 62

Labor:

Site layout and placement of batterboards			
Superintendent	1 hr. @ $3.00 per hr.		
Labor	1 hr. @ 1.55		4.55
Site grading and placement of cinder fill			
Labor	8 hr. @ 1.55		12.40
Trench excavation (floor beams, pipes, etc.)			
Labor	4 hr. @ 1.55		6.20
Placement of sub-soil piping and utilities outlets			
Plumber	4 hr. @ 2.30		9.20
Erection of floor slab forms			
Carpenter	3 hr. @ 2.10	$6.30	
Labor	1 hr. @ 1.55	1.55	7.85
Placing Sisalkraft "Blanket"			
Labor	2 hr. @ 1.55		3.10
Pouring first layer of concrete (except garage)			
Labor	16 hr. @ 1.55	$24.80	
Cement finisher	8 hr. @ 2.50	20.00	44.80
Placing vermiculite insulation (floor slab)			
Labor	8 hr. @ 1.55		12.40
Placing radiant heating pipes			
Steamfitters	16 hr. @ 2.30	$36.80	
Labor	8 hr. @ 1.55	12.40	49.20
Construction & placing anchor bolt planking			
Carpenter	3 hr. @ 2.10	$ 6.20	
Labor	2 hr. @ 1.55	3.10	9.30
Placing garage slab steel			
Labor	3 hr. @ 1.55		4.65

Pouring top layer of concrete and garage slab			
Labor	16 hr. @ $1.55	$24.80	
Cement finisher	8 hr. @ 2.50	20.00	$ 44.80
Removal of anchor bolt planking			
Labor	2 hr. @ 1.55		3.10
Placement of wall & roof slab forms (interior & exterior)			
Carpenter	50 hr. @ 2.10	$105.00	
Labor	25 hr. @ 1.55	38.75	143.75
Placing vermiculite wall insulation panels			
Labor	24 hr. @ 1.55		36.80
Placing wall mesh reinforcing			
Labor	16 hr. @ 1.55		24.80
Placing wall concrete (Gunite)			
Nozzleman	16 hr. @ 2.50	$ 40.00	
Gunman	16 hr. @ 2.00	32.00	
Labor	8 hr. @ 1.55	12.40	84.40
Placing roof slab steel			
Labor	16 hr. @ 1.55		24.80
Pouring roof slab			
Labor	10 hr. @ 1.55	$ 24.80	
Cement finisher	8 hr. @ 2.50	20.00	44.80
Placing roof slab vermiculite insulation			
Labor	8 hr. @ 1.55		12.40
Pouring and sloping roof slab top layer			
Labor	16 hr. @ 1.55	$ 24.80	
Cement finisher	12 hr. @ 2.50	30.00	54.80
Applying tar and gravel roofing			
1,480 sq. ft. @ $4.10 per 100 sq. ft.			50.68

Form removal			
Labor	24 hr. @ $1.55		$ 37.20
Install windows			
Carpenter	7 hr. @ 2.30	$16.10	
Glazier	7 hr. @ 2.00	14.00	30.10
Install doors and door hardware			
Carpenter	14 hr. @ 2.30		32.20
Surfacing concrete walls and ceilings			
Operator	24 hr. @ 1.75		42.00
Installation of plumbing facilities			100.00
Installation of electrical facilities			100.00
Filling concrete anchor holes			
Labor	2 hr. @ 1.55		3.10
Installation of asphalt tile floor covering			
Tile setter	28 hr. @ 2.25		63.00
Painting and landscaping			200.00
Total cost of labor			$1,296.38

Summary

Materials and equipment	$3,152.48
Forms	159.39
Labor	1,296.38
	4,608.25
Overhead and contingencies	460.83
	$5,069.08

COMPARATIVE COSTS

Since the time allotted for this investigation does not permit compiling separate cost analyses for wood, brick, concrete-block, and other types of construction, it is necessary to employ several available indices to obtain the comparative figures.

The digest of indices chosen is the Boeckh Index of Construction Costs, developed by E.H. Boeckh & Associates, Inc., Consulting and Valuation Engineers of 1406 M Street, N.W., Washington, D.C. Their system is based on a United States Average for 1926-29 of 100. This comparison is based on 1948 data given for the Boston Area.* The indices used are

Brick	226.2
Frame	227.5
Concrete	205.3

No index is available for concrete block or other types of construction.

Basing our comparison on a $5000 concrete house (approximately the cost of the house under consideration in this report), we obtain

For brick $\quad \$5000 \times \frac{226.2}{205.3} = \$5,500.$

For frame $\quad \$5000 \times \frac{227.5}{205.3} = \$5,600.$

Thus it is shown that a concrete house of this type construction would cost $5500 if built of brick and $5600 if of wood. It might be pointed out that the saving is small, but it must be considered that the required construction time is much greater for the brick or frame dwelling than it would be for the concrete house, and that the construction technique described in this paper is more readily adapted to mass production, multiple-family dwellings, and housing projects.

*"Construction Costs," Engineering News-Record, CXLII (March 17, 1949), 159-207.

SUMMARY

The purpose of this section is to analyze and evaluate the construction technique and the costs; to weigh the advantages; to cite possible means of further reducing the cost of construction; and to suggest other improvements.

<u>Conclusions</u>: The use of prefabricated plywood panels and reinforced concrete results in a decided reduction in construction time, as compared to the relatively slow assembly of brick or frame structures. It is estimated that this reinforced concrete house would require about five days to construct, using the methods outlined in this paper, and no more than the average number of workmen required for dwelling house construction. The method employed is simple, and with the exception of the suggested use of the Gunite process, requires no unusual equipment or skilled workmen.

The estimated cost of construction for this two-bedroom house, with garage, is considerably lower than the current listed price of the same type house of conventional construction. The use of radiant heating eliminates the usual excavation cost. The poured concrete shell eliminates the necessity and cost of interior plastering, woodwork, and other interior trim. The labor cost is considerably lower in this project due to the saving in construction time. Possible means of further reducing the time and costs are given below in the recommendations for improvement.

The advantages of this type construction are many: considerable reduction in construction time; low cost; simple technique; fire resistance; wide adaptability of design; comfort; low maintenance and compactness of the radiant heating provided; and low upkeep, among other factors. The design selected provides efficient and compact layout with larger than average-size rooms, adequate storage space, the possibility of future enlargement, and can be adapted to any type furnishings, geographic location, or neighborhood. In addition to housing, the technique described can be modified for the construction of any one-story building, such as garages, light-aircraft hangars, motor courts, roadside stands, service stations, multiple-family dwellings, housing projects, and various one-story mercantile buildings.

Recommendations: It is possible to improve this technique and to further reduce the cost of construction by

1. the use of a prefabricated concrete panel, thereby eliminating all forming;
2. a re-arrangement of the rooms to reduce roof span, thereby saving considerable steel;
3. inducing the manufacturer to produce prefabricated panels of vermiculite concrete by providing him with a volume outlet;
4. lowering the unit price through mass production;
5. decreasing the construction time by building multiple-family one-story dwellings;
6. the use of steel instead of plywood forms (if further investigation proves that the increase in the useful life of the forms justifies the higher initial cost);
7. the use of a cheaper insulating material;
8. the replacement of steel casement windows with wood sash;
9. perfecting the adaptation of the Gunite process to this construction technique, thereby reducing labor costs; and by
10. the addition of cement coloring during mixing to eliminate interior and exterior painting.

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Radiant Heating Design

The following procedure is based on the second edition of "A Graphical Design Procedure for Radiant Panel Heating" by F.W. Hutchinson, prepared for Revere Copper and Brass Incorporated

The formulas used are:

$$U = \frac{1}{\frac{1}{f_i} + \frac{1}{f_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3}}$$

$$U_e = \frac{U_g A_g + U_w A_w + U_i A_i + U_c A_c + U_f A_f}{A_t}$$

In which:

K_c = Thermal conductivity of concrete

K_v = Thermal conductivity of vermiculite concrete

U_f = Coefficient of transmission of floor

U_c = Coefficient of transmission of ceiling

U_w = Coefficient of transmission of exterior wall

U_i = Coefficient of transmission of interior wall

U_g = Coefficient of transmission of glass

U_e = Overall coefficient of transmission

A_t = Total unheated surface area

V = Ventilation rate in air changes per hour

A_g = Area glass

A_w = Area exterior wall

A_i = Area interior wall

A_c = Area ceiling

A_f = Area floor

x = Thickness of material in inches

f_i = Inside surface conductance coefficient

f_o = Outside surface conductance coefficient

The following abbreviations are also used in this procedure:

V_c = Ventilation correction factor

K = Geometry correction factor

Q_p = Panel rating

t_a = Comfort air temperature

Calculation of Coefficients of Transmission (U):

For Floor (assume 2" of vermiculite concrete between two 2" layers of concrete):

$$*U_f = \frac{1}{\frac{1}{*f_1} + \frac{1}{*f_o} + \frac{2}{*k_c} + \frac{2}{**k_v} + \frac{2}{k_c}}$$

$$U_f = \frac{1}{\frac{1}{1.65} + \frac{1}{\text{inf.}} + \frac{2}{12} + \frac{2}{1.2} + \frac{2}{12}}$$

$$U_f = \frac{1}{0.606 + 0.00 + 0.167 + 1.67 + 0.167} = \frac{1}{2.61}$$

U_f = 0.38 Btu per hour per square foot per degree (F) difference in temperature

For Ceilings and Exterior Walls (assume 2" of vermiculite concrete between two 2" layers of concrete):

$$U_c = U_w = \frac{1}{\frac{1}{f_i} + \frac{1}{f_o} + \frac{2}{k_c} + \frac{2}{k_v} + \frac{2}{k_c}}$$

$$U_c = U_w = \frac{1}{\frac{1}{1.65} + \frac{1}{6.0} + \frac{2}{12} + \frac{2}{1.2} + \frac{2}{12}}$$

$$U_c = U_w = \frac{1}{0.606 + 0.167 + 0.167 + 1.67 + 0.167} = \frac{1}{2.78}$$

$U_c = U_w$ = 0.36 Btu/hr./sq. ft./°F

For Inside Partitions:

6" concrete

$***U_i = 0$

For Glass:

$****U_g = 0.45$

*Charles Merrick Gay and Charles De Van Fawcett, Mechanical and Electrical Equipment for Buildings (New York, 1945), pp. 101-3.

**"Vermiculite Concrete," California Stucco Products of N.E., Inc., 169 Waverly Street, Cambridge, Massachusetts (1949), p. 4.

***F.W. Hutchinson, A Graphical Design Procedure for Radiant Panel Heating (Revere Copper and Brass Incorporated, New York, 1948), p. 14.

****Gay and Fawcett, op. cit., p. 108.

Heating Design:

For Living Room (including entryway):

Ceiling area	= 27 x 12	=		324 sq. ft.
Floor area	= 27 x 12	=		324
Exposed wall	= 51 x 8	= 408 sq. ft.		
Glass area	= 12 x 5.5	= 66	=	66
Net exposed wall =		342 sq. ft.	=	342
Interior partition =	27 x 8	=		216
Total surface area		=		1,272 sq. ft.
*Unheated floor area	324 - (0.2 x 1,272)		=	70
Total unheated surface	.8 x 1,272		=	1,018

Design temperature outside air	0°F
Design temperature under floor	30°F
Design temperature panel surface	85°F
Assumed air changes per hour	1

$$**U_e = \frac{U_gA_g + U_wA_w + U_iA_i + U_cA_c + U_fA_f}{A_t}$$

$$U_e = \frac{(0.45x66)+(0.36x342)+(0x216)+(0.36x324)+(0.38x\frac{68-30}{68-(0)}x70)}{1018}$$

$$U_e = \frac{29.7 + 123.0 + 0 + 1170 + 14.8}{1018} = \frac{284.5}{1018} = 0.28$$

*An explanation for the 20% deduction in surface area is given in Hutchinson, op. cit., p. 14.

**Ibid., p. 8: "If outside air is tempered before admission an approximate ventilation rate - based on equivalent untempered outside air - can be calculated from the equation, $V = \frac{(68 - t_x)}{(68 - t_o)} V_a$ where V_a is the actual ventilation rate and t_x is the temperature of the tempered air. This equation is set up for a room from which all transmission losses are based on the same value of outside air temperature. If the design outside air temperature for any part of the enclosure (as the floor) differs from t_o, the term for that surface in the numerator of equation 1 should be corrected by a factor $\frac{68 - t_y}{68 - t_o}$ in which t_y is the design exterior air temperature for the area in question."

From Geometry Chart $K = 4.0$ $V_c = 2.0$

From Floor Panel Chart 85° and 0°

Q_p = Panel Rating = 44.0 Btu(hr)(sq. ft.)

Percent of floor to be heated = 75%

t_a = Comfort air temperature = 70°F

Total Btu(hr) output of panel 324x0.75x44.0 = 10,700 Btu(hr)

From Table 1,	tube size	and spacing	and mean water temp.
	$\frac{1}{2}$"	on 9" centers	121.9°F

Length of pipe required $27 \times \frac{12}{9} \times 11 = 396'$

\+ Bends $2(36 \times 1.2) = 86$

$482' \times .75 = 362'$

Panel area = 27 x 12 x .75 = 243 sq. ft.

Flow rate = 8 gpm with 10° temperature drop

Heating Design:

For Dining Room:

Ceiling area	= 14.5 x 10	=		145.0 sq. ft.
Floor area	= 14.5 x 10	=		145.0
Exposed wall	= 10 x 8	=	80 sq. ft.	
Glass area	= 7 x 5.5	=	38.5	38.5
Net exposed wall	=		41.5 sq. ft.	41.5
Interior partition	= 39 x 8	=		312.0
Total surface area		=		682.0 sq. ft.
Unheated floor area	145 - (0.2 x 6820)			9.0
Total unheated surface	0.8 x 682.0			546.0
Design temperature outside air				0^oF
Design temperature under floor				30^oF
Design temperature panel surface				85^oF
Assumed air changes per hour				1

$$U_e = \frac{U_gA_g + U_wA_w + U_iA_i + U_cA_c + U_fA_f}{A_t}$$

$$U_e = \frac{(0.45x38.5)+(0.36x41.5)+(0x312)+(0.36x145)+(0.38x\frac{68-30}{68-0}x9.0)}{546.0}$$

$$U_e = \frac{17.3 + 14.9 + 52.2 + 2.0}{546.0} = \frac{86.4}{546.0} = 0.16$$

From Geometry Chart $K = 4.8$ $V_c = 1.7$

From Floor Panel Chart 85° and 0°

Q_p = Panel Rating = 41.5 Btu(hr)(sq. ft.)

% of floor to be heated = 65%

t_a = Comfort air temperature = 68°F

Total Btu(hr) output of panel = 145x0.65x41.5 = 3,920 Btu(hr)

From Table 1: tube size	and spacing	and mean water temp.
$\frac{1}{2}$"	on 9" centers	120.6°F

Length of pipe required $14.5 \times \frac{12}{9} \times 9 = 174'$

+ Bends $2(19 \times 1.2) = \underline{45}$

$219' \times .75 = 164'$

Panel area = $14.5 \times 10 \times .65$ = 95 sq. ft.

Flow rate = 8 gpm with 10° temperature drop

Heating Design:

For Master Bedroom:

Ceiling area	= 12 x 12 =		144 sq. ft.
Floor area	= 12 x 12 =		144
Exposed wall	= 24 x 8 =	192 sq. ft.	
Glass area	= 9.5x 3.5=	33	33
Net exposed wall	=	159 sq. ft.	159
Interior partition	= 24 x 8 =		192
Total surface area	=		672 sq. ft.

Unheated floor area	144 - (.2 x 672)	10
Total unheated surface	.8 x 672	538

Design temperature outside air	0°F
Design temperature under floor	30°F
Design temperature panel surface	85°F
Assumed air changes per hour	2

$$U_e = \frac{U_g A_g + U_w A_w + U_i A_i + U_c A_c + U_f A_f}{A_t}$$

$$U_e = \frac{(0.45x33)+(0.36x159)+(0x192)+(0.36x144)+(0.38x\frac{68-30}{68-0}x10)}{538}$$

$$U_e = \frac{14.8 + 57.3 + 51.8 + 2.1}{538} = \frac{126.0}{538} = 0.23$$

From Geometry Chart $K = 4.7$ $V_c = 5.4$

From Floor Panel Chart   85° and 0°

Q_p = Panel Rating = 46.5 Btu(hr)(sq. ft.)

% of floor to be heated = 55%

t_a = Comfort air temperature = 67°F

Total Btu(hr) output of panel = 144x0.55x46.5 = 3,690 Btu(hr)

From Table 1: tube size and spacing and mean water temp.

1/2" on 9" centers 122.8°F

Length of pipe required = $12 \times \frac{12}{9} \times 11$ = 176'

+ Bends = 2(16 x 1.2) = 38

214' x .55 = 118'

Panel area = 12 x 12 x .55 = 79 sq. ft.

Flow rate = 7 gpm with 10° temperature drop

Heating Design:

For Small Bedroom:

Ceiling area	= 10 x 12 =		120 sq. ft.
Floor area	= 10 x 12 =		120
Exposed wall	= 10 x 8 =	80 sq. ft.	
Glass area	= 9.5x 3.5=	33	33
Net exposed wall	=	47 sq. ft.	47
Interior partition	= 34 x 8 =		272
Total surface area	=		592 sq. ft.
Unheated floor area	120 - (0.2 x 592)		2
Total unheated surface	0.8 x 592		474
Design temperature outside air			0°F
Design temperature under floor			30°F
Design temperature panel surface			85°F
Assumed air changes per hour			2

$$U_e = \frac{U_gA_g + U_wA_w + U_iA_i + U_cA_c + U_fA_f}{A_t}$$

$$U_e = (0.45x33)+(0.36x47)+(0x272)+(0.36x120)+(0.38x\frac{68-30}{68-0}x2)$$

$$U_e = \frac{14.8 + 16.9 + 43.2 + 0.4}{474} = \frac{75.3}{474} = 0.16$$

From Geometry Chart $K = 5.0$ $V_c = 3.3$

From Floor Panel Chart 85° and 0°

Q_p = Panel Rating = 41.0 Btu(hr)(sq. ft.)

% of floor to be heated = 50%

t_a = Comfort air temperature = 65°F

Total Btu(hr) output of panel = 120x.50x41 = 2,460 Btu(hr)

From Table 1: tube size	and spacing	and mean water temp.
½"	on 9" centers	121.9°F

Length of pipe required = $12 \times \frac{12}{9} \times 9$ = 144'

+ Bends = 2 (16 x 1.2)= 38

182 x .50 = 91'

Panel area = 10 x 12 x .50 = 60 sq. ft.

Flow rate = 5 gpm with 10° temperature drop.

Heating Design:

For Kitchen:

Ceiling area	= 16 x 8 =		128 sq. ft.
Floor area	= 16 x 8 =		128
Exposed wall	= 24 x 8 =	192 sq. ft.	
Glass area	= 9.5 x 3.5 =	33	33
Net exposed wall	=	159 sq. ft.	159
Interior partition	= 24 x 8 =		192
Total surface area	=		640 sq. ft.
Unheated floor area	128 - (0.2 x 640)		0
Total unheated surface	0.8 x 640		512
Design temperature outside air			0°F
Design temperature under floor			30°F
Design temperature panel surface			85°F
Assumed air changes per hour			$1\frac{1}{2}$

$$U_e = \frac{U_g A_g + U_w A_w + U_i A_i + U_c A_c + U_f A_f}{A_t}$$

$$U_e = (0.45x33)+(0.36x159)+(0x192)+(0.36x128)+(0.38x\frac{68-30}{68-0}x0)$$

$$U_e = \frac{14.8 + 57.3 + 46.1}{512} = \frac{118.2}{512} = 0.23$$

From Geometry Chart $K = 4.8$ $V_c = 2.4$

From Floor Panel Chart 85^{o} and 0^{o}

Q_p = Panel Rating = 45.5 Btu(hr)(sq. ft.)

% of floor to be heated = 57%

t_a = Comfort air temperature = 67^{o}

Total Btu(hr) output of panel = 128x.57x45.5 = 3,330 Btu(hr)

From Table 1: tube size and spacing and mean water temp.

$\frac{1}{2}$" on 9" centers 122.3°F

Length of pipe required = $16 \times \frac{12}{9} \times 7 = 150'$

+ Bends = 2(21 x 1.2) = 50

200 x .57 = 114'

Panel area = 16 x 8 x .57 = 73 sq. ft.

Flow rate = 7 gpm with 10° temperature drop

Heating Design:

*For Bathroom:

Ceiling area	= 8 x 6 =		48 sq. ft.
Floor area	= 8 x 6 =		48
Exposed wall	= 8 x 6 =	48 sq. ft.	
Glass area	= 2.5 x 3.5 =	9	9
Net exposed wall	=	39 sq. ft.	39
Interior partition	= 22 x 8 =		176
Total surface area	=		320 sq. ft.
Unheated floor area	48 -(0.2 x 320)		0
Total unheated surface	0.8 x 320		256
Design temperature outside air			0°F
Design temperature under floor			30°F
Design temperature panel surface			85°F
Assumed air changes per hour			2

$$U_e = \frac{U_g A_g + U_w A_w + U_i A_i + U_c A_c + U_f A_f}{A_t}$$

$$U_e = \frac{(0.45x9)+(0.36x39)+(0x176)+(0.36x48)+(0.38x\frac{68-30}{68-0}x0)}{256}$$

$$U_e = \frac{4.1 - 14.1 - 17.3}{256} = \frac{35.5}{256} = 0.14$$

*Note: Since the hallway is approximately the same size as the bathroom, the same arrangements and computations will be assumed.

From Geometry Chart $K = 7.0$ $V_c = 2.4$

From Floor Panel Chart 85^o and 0^o

Q_p = Panel Rating = 40.6 Btu(hr)(sq.ft.)

% of floor to be heated = 63%

t_a = Comfort air temperature = 68^oF

Total Btu(hr) output of panel = 48x0.63x40.6 = 1,230 Btu(hr)

From Table 1: tube size	and spacing	and mean water temp.
1"	on 9" centers	119.6^oF

Length of pipe required $= 8 \times \frac{12}{9} \times 5 = 54$ ft.

+ Bends $= 2(10 \times 1.2) = 24$

78' x .63 = 49'

Panel area = 8 x 6 x .63 = 30 sq. ft.

Flow rate = 3 gpm with 10^o temperature drop

Summary of Heating Design

Room	Q_t Btu/hr	Panel Area Sq. Ft.	Mean Water Temp. °F	Flow Rate gpm
Living Room	10,700	243	121.9	8
Dining Room	3,920	95	120.6	8
Master Bedroom	3,690	79	122.8	7
Small Bedroom	2,460	60	121.9	5
Kitchen	3,330	73	122.3	7
Bathroom	1,235	30	119.6	3
*Hall	1,235	30	119.6	3
Total	26,570	610	121.3 (Average)	41

Room	Pipe Type	Pipe Size Inch	Pipe Spacing Inches c to c	Pipe Length Feet	Comfort Temp. °F (10°F drop)
Living Room	K	$\frac{1}{2}$	9	362	70
Dining Room	K	$\frac{1}{2}$	9	164	68
Master Bedroom	K	$\frac{1}{2}$	9	118	67
Small Bedroom	K	$\frac{1}{2}$	9	91	65
Kitchen	K	$\frac{1}{2}$	9	114	67
Bathroom	K	$\frac{1}{2}$	9	49	68
Hall	K	$\frac{1}{2}$	9	49	68
Total				947	67.5 (Average)

*Note: Since the hallway is approximately the same size as the bathroom, the same arrangements and computations will be assumed.

Design Procedure for Roof Slabs:

Try 6" slab:

Assume: *Live load = 40 lbs. per sq. in.

Dead load = 75

W = 115 lbs. per sq. in.

Assume: f_c' = 3,000# per sq. in.

12" width = b   K = 236

Maximum Bending Moment = M = 1/8 WL^2

For Garage, Living Room, and Dining Room: Span = 20'0"

$M = \frac{1}{8} \times 115 \times (20)^2 = 5{,}750$ ft. lbs. $d = \sqrt{\frac{5{,}750 \times 12}{236 \times 12}} = 4.93"$

With ½" round bars: h = 4.93 + 0.25 + 1.0 = 6.18"

Therefore 6½" slab is indicated.   d = 6.5 - 1.0 - 0.25 = 5.25"

With 1" square bars: d = 6.5 - 1.0 - 0.5 = 5.0 "

Use 6½" slab for entire roof slab.

Steel:

$A_s = \frac{M}{f_s jd} = \frac{5{,}750 \times 12}{20{,}000 \times 0.87 \times 5.0} = 0.78$ sq. in. per ft.

Use 1" square bars at 12" (A_s = 0.78 sq. in. per ft.)

Temperature Steel:

$A_t = 0.0025$ bd $A_t = 0.0025 \times 12 \times 5 = 0.15$ sq. in. per ft.

Use ½" round bars at 12" (A_t = 0.15 sq. in. per ft.)

For Kitchen: Span = 16'0"

$M = \frac{1}{8} \times 115 \times (16)^2 = 3{,}680$ ft. lbs.

$A_s = \frac{3{,}680 \times 12}{20{,}000 \times 0.87 \times 5.0} = 0.47$ sq. in. per ft.

Use ½" round bars at 5" (A_s = 0.47 sq. in. per ft.)

$A_t = 0.0025 \times 12 \times 5 = 0.15$ sq. in. per ft.

Use ½" round bars at 12"

*"Building Code," The National Board of Fire Underwriters (New York, 1943), p. 84, Section 703, 2.

For Bedrooms: Span = 12'0"

$M = \frac{1}{8} \times 115 \times (12)^2 = 2,070$ ft. lbs.

$A_s = \frac{2,070 \times 12}{20,000 \times 0.87 \times 5.0} = 0.26$ sq. in. per ft.

Use $\frac{1}{2}$" round bars at 9" ($A_s = 0.26$ sq. in. per ft.)

$A_t = 0.15$ sq. in. per ft.

Use $\frac{1}{2}$" round bars at 12" ($A_t = 0.15$ sq. in. per ft.)

For Bathroom and Hall: Span = 8'0"

$M = \frac{1}{8} \times 115 \times 8^2 = 920$ ft. lbs.

$A_s = \frac{920 \times 12}{20,000 \times 0.87 \times 5.0} = 0.12$ sq. in. per ft.

Use $\frac{1}{2}$" round bars at 12" ($A_s = 0.15$ sq. in. per ft.)

$A_t = 0.15$ sq. in. per ft.

Use $\frac{1}{2}$" round bars at 12" ($A_t = 0.15$ sq. in. per ft.)

For Cantilever Overhang:

Maximum Bending Moment = $M = \frac{WL}{2}$

$L = 4'0"$ $M = \frac{115 \times 4}{2} = 230$ ft. lbs.

$A_s = \frac{230 \times 12}{20,000 \times 0.87 \times 5.0} = 0.03$ sq. in. per ft.

Use $\frac{1}{2}$" round bars at 24" ($A_s = 0.08$ sq. in. per ft.)

$A_t = 0.15$ sq. in. per ft.

Use $\frac{1}{2}$" round bars at 12" ($A_t = 0.15$ sq. in. per ft.)

For bond: $L = \frac{f_s D}{4u} = \frac{20,000 \times 0.5}{4 \times 200} = 12\frac{1}{2}$"

Therefore run steel $12\frac{1}{2}$" into main slab

For Cantilever Porch:

$L = 10'0"$ $M = \frac{115 \times 10}{2} = 575$ ft. lbs.

$A_s = \frac{575 \times 12}{20,000 \times 0.87 \times 500} = 0.08$ sq. in. per ft. Use $\frac{1}{2}$" rd. bars @ 24"

$A_t = 0.15$ sq. in. per ft. Use $\frac{1}{2}$" rd. bars @ 12"

For bond: $L = \frac{20,000 \times 0.5}{4 \times 200} = 12\frac{1}{2}$"

Therefore run steel $12\frac{1}{2}$" into main slab

Design Procedure for Garage Floor Slab:

Try 6" slab:

Assume: Live load = 100 lbs. per sq. ft.

Dead load = 75

W = 175 lbs. per sq. ft.

Assume: Supports at end only   Span = 20'0"

$f_c' = 3{,}000$ lbs. per sq. in.

12" width = b   K = 236

Maximum Bending Moment = $M = \frac{1}{8} WL^2$

$$M = \frac{1}{8} \times 175 \times (20)^2 = 8{,}750 \text{ ft. lbs.}$$

$$d = \sqrt{\frac{M}{Kb}} = \sqrt{\frac{8{,}750 \times 12}{236 \times 12}} = 6.1"$$

With 1" square bars

$$h = 6.1 + 0.5 + 1.0 = 6.6"$$

Therefore 7" slab is indicated.

$$d = 7.0 - 0.5 - 1.0 = 5.5"$$

Check for Weight:

Live load = 100 lbs. per sq. ft.

Dead load = 87

187 lbs. per sq. ft.

$$M = \frac{1}{8} \times 187 \times (20)^2 = 9{,}350 \text{ ft. lbs.}$$

$$d = \sqrt{\frac{9{,}350 \times 12}{236 \times 12}} = 6.3"$$

With inch square bars: $h = 6.3 + 0.5 + 1.0 = 6.8"$

Therefore use 7" slab.

Steel:

$$A_s = \frac{M}{f_s jd} = \frac{9{,}350 \times 12}{20{,}000 \times 0.87 \times 5.5} = 1.18 \text{ sq. in. per ft.}$$

Use 1" sq. bars at 8"   (A_s = 1.18 sq. in. per ft.)

Temperature steel:

$A_t = 0.0025bd$ $A_t = 0.0025 \times 12 \times 5.5 = 0.17$ sq. in. per ft.

Use $\frac{1}{2}$" round bars at 12"   (A_t = 0.19 sq. in. per ft.)