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FOUNDATIONS FOR FAMILY HOUSING

ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY

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	20 ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents in abbreviated form information necessary to select appropriate foundations for family housing for various site conditions, climates, and construction methods. Included are a comprehensive survey of foundations presently used for family housing, a review of the soil mechanics used in foundation design, a discussion of current forms of house construction, and examples of cost computations for some typical foundations. Also included are several		

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tables which facilitate the selection of an appropriate foundation type.

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FOREWORD

This investigation was performed under Project 4A664717D895, "Military Construction Systems Development," Task 03, "Military Housing," Work Unit 003, "Systems Approach to Site Development." The work was performed under the direction of the Office of the Chief of Engineers (OCE), Directorate of Military Construction. The OCE Technical Monitor was Mr. D. Swanson.

The study was conducted under the general supervision of the Construction Engineering Research Laboratory (CERL), Facilities Habitability and Planning Division. Dr. R. M. Dinnat is Division Chief.

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FOUNDATIONS FOR FAMILY HOUSING

1 INTRODUCTION

General. Family housing fund appropriations for military personnel are lower priority than military hardware, therefore making it imperative that maximum value be obtained from the limited funds available. The maximum return on the expenditure may take the form of more housing units or the same number of units of better living and/or comfort quality.

The problem of obtaining maximum value per dollar invested is not unique with military housing procurement personnel; in fact, builders and developers are concerned. There are many methods for lowering construction costs.^{1, 2, 3, 4}

Maximum investment returns may be obtained in such ways as attention to construction details, careful planning, worker motivation, use of time-and-motion study data, use of engineered designs rather than rule-of-thumb techniques which often result in over-design, adequate construction supervision, careful site and foundation engineering, and other factors which may be peculiar to a locale.

Military family housing for a particular site may have a short programmed life such as temporarily reactivated bases, missile sites, and radar bases. Housing design for these type locations may be on the basis of a short service life, or as an alternative, may be designed to be relocatable. Housing which is relocatable from a site must be readily transportable, easily separable from the foundation system, and have sufficient structural integrity to absorb movements over considerable distances without damage to the various building elements. It may also be advantageous for the building foundation to be easily removable. Family housing at permanent installations would be expected to have about the same service life as the civilian counterpart.

¹R. J. Johnson, "Home Building Productivity Research," *Proceedings, Third CIB Congress for Building Research 1965* (Rotterdam: Elsevier Publishing Co., 1966), pp 142-145.

²E. G. Stern, *Novel Wood Foundation-Framing System*, Wood Research and Wood Construction Laboratory Report No. 82 (Virginia Polytechnic Institute, 1969).

³O. Ural, *Proceedings, Second International Symposium on Low Cost Housing Problems Related to Urban Renewal and Development* (University of Missouri, 1970), p 243.

⁴O. Ural, *Proceedings, Second International Symposium on Low Cost Housing Problems Related to Urban Renewal and Development*, p 289.

This report will be concerned with foundations for military family housing. It should be recognized, however, that the material contained in this report is equally applicable for civilian family housing. The foundation alternatives to be considered are limited to one- and two-family dwelling units. High-rise and multi-family apartment units are specifically excluded from this study.

Foundations for Housing Units. The foundation for a family housing unit usually receives little attention from the designer or builder, instead local practices are often followed. This can easily result in over-design. Johnson⁵ reports on a situation of a slab-on-grade house being built twice, the first time using observers to note where savings could be made, the second time built identically, but with savings made where possible. A savings of \$150.41 was realized in the foundation by engineering the footing sizes and by giving careful attention to grading the soil prior to pouring the slab. Since labor on this project was paid at a rate of \$3.00 per hour, current costs reflecting increases in both materials and labor could easily increase this saving to \$200 to \$250.

While it should be apparent that savings may be obtained by careful design and construction control of a selected foundation system, considerable economy might also be obtained by an alternative foundation system. This report is concerned with this latter aspect. One should be aware, further, that while economics may be affected in the foundation and additional economy may be obtained from an alternative foundation scheme, the total cost savings will be relatively small compared to cost savings which might be obtained from other parts of the dwelling unit. Of the dwelling units considered in this report, it would be rare that the most expensive foundation system would be over 10 to 15 percent of the total construction cost of the structure including the foundation. Any alternatives are not likely to reduce this cost over 20 percent maximum and most probably the reduction will be about 8 to 12 percent (savings of \$150 to \$250). This is illustrated in the appendix where several typical cost estimates for foundation types are shown.

Scope. This report considers those evaluations needed to effect adequate performance and economy in the foundation elements of the family dwelling unit, specifically--site, performance, and economics.

A site analysis is the first step in the decision-making process of foundation selection. Certain site constraints such as topography, ground-water table, and type of soil, may eliminate some foundation systems from further consideration. Almost any land site can be used for residential construction using some kind of foundation system, therefore, economics will be the major factor in the foundation selection process. The flow

⁵R. J. Johnson, "Home Building Productivity Research," *Proceedings, Third CIB Congress for Building Research (1965)*, (Rotterdam: Elsevier Publishing Co., 1966).

chart of Figure 1 indicates site constraints as a major factor in the initial selection process. The other major input during the "initial considerations" consisting in building codes, user, budget, and other are not considered in this report.

Performance is taken to be the interaction of the superstructures and the foundation system to produce a dwelling unit which will require a minimum of maintenance caused by excessive total, or intolerable differential, settlements. At this point, Figure 1 indicates that revisions may be required, such as using different construction methods or materials, or modification of user requirements, to obtain a dwelling unit which will have adequate service performance.

The alternative foundation systems (see Chapter 2) having adequate performance characteristics are evaluated based on economic considerations. Since there are many cost variables involved, the only really practical method at present is to estimate the construction cost for all the acceptable foundation systems. All those systems which do not exceed some predetermined costs are possible foundation systems for the project.

As an example of the magnitude of the problem, consider the following: one foundation on which a small home, 25 by 40 ft, can be supported is a series of isolated columns or piers. The following are some of the factors affecting the foundation cost:

- a. Is the crawl space open or enclosed?
- b. If the crawl space is enclosed, is it cheaper to enclose the space with skirting or use a perimeter foundation wall?
- c. Are the piers:
 - Wood
 - Masonry: brick
 - concrete block
 - Poured-in-place concrete: round (use fiber tube forms)
 - square
 - Pre-cast concrete
 - Metal: bare
 - painted
 - Cast-in-concrete for corrosion protection and appearance
- d. Is the house to be built on site, by using components, or modular construction? (See Chapter 4 for information on several types of construction for family units.)
- e. If the house is modular construction, how will the costs be allocated so that a legitimate cost comparison can be made between various foundation alternatives? For example, a slab-on-ground is the subfloor of one foundation system, whereas, with piers

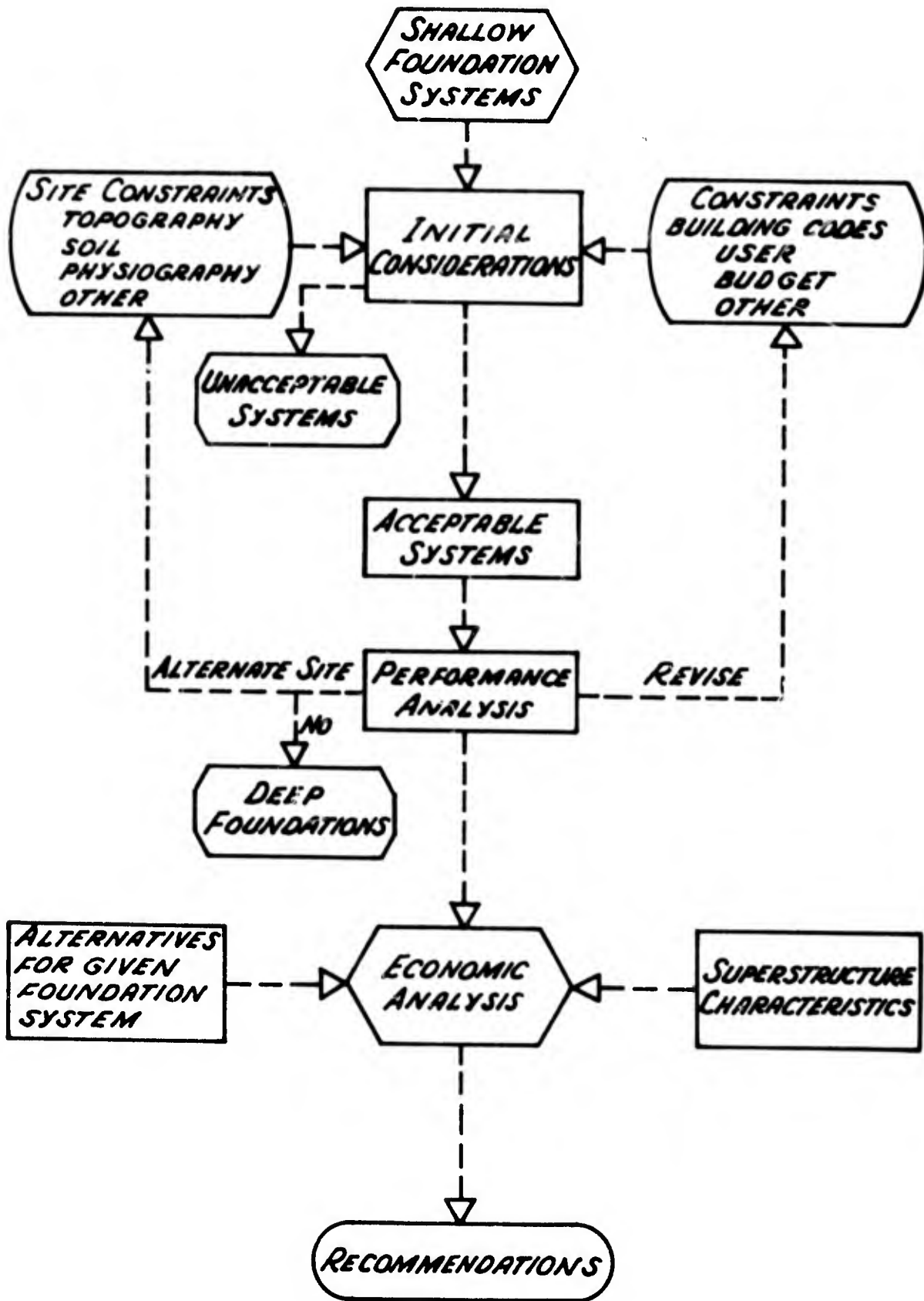


Figure 1. Foundation selection process flow chart.

the beams running from pier to pier for the module base may make up the remainder of the foundation cost--the subfloor being part of the modular unit.

- f. Does the local contractor(s) favor a particular foundation system? Is he equipped for precasting, etc?

Thus, while it may be evident that the general system of this example of isolated piers can be the most economical foundation system for the site, this will be true if the final specific scheme or alternative within this general system is also more economical than any alternative general foundation system, e.g., a combination of strip footings and pads, a slab-on-ground, etc.

When one considers two foundation systems of different costs and any special construction or site problems, e.g., delays due to weather or labor problems (including motivation), or differences in materials and construction methods, the cost differential can easily be reduced to zero or even reversed.

In this report the foundation will be considered as all of those structural elements including the subfloor and floor joist and beam system for post and pier foundations, and slab-on-ground type construction necessary to transmit the superstructure loads to the underlying soil. Where basements are a part of the dwelling, the basement walls and floors will be considered part of the foundation along with the subfloor and joist system of the ground floor. It is necessary to make this assumption in order to make legitimate cost comparisons between various foundation systems.

Site preparation costs such as grading, cut-and-fill, dewatering, drainage, roads, and streets, are not considered in the economic evaluation of the foundation.

Objectives. This report outlines a procedure for selecting a suitable foundation scheme for a specific site. Foundation schemes to be considered must be capable of satisfactory performance in carrying the superstructure and of being constructed within project budget limitations.

The general procedure for selection of the most suitable foundation system(s) is as follows (Figure 1):

- a. Identify all the possible general foundation configurations which could be considered for the project.
- b. Consider the various project constraints such as soil, site, climate, type of structure, local conditions, budget and building costs, and eliminate those foundation configurations which are not practical.
- c. Check the foundation systems for adequate performance or interaction with soil and superstructure and eliminate those which are unsatisfactory.

- d. Estimate costs for the remaining schemes.
- e. Select the foundation scheme of least cost, of the various alternatives which satisfy budget and performance criteria.

Using the Report. This report is not intended to be a complete source book on small home construction, soil mechanics, and cost estimating. Rather it is intended to provide an overview of the various foundation systems together with a limited amount of soil mechanics background oriented toward obtaining sufficient field information to make a foundation selection decision.

2 FOUNDATIONS FOR FAMILY HOUSING UNITS

Types of Foundations. The foundation of the housing unit is a structural system (member or group of members) whose function is to transfer the loads derived from the superstructure to a sufficiently large area of soil so that the resulting soil pressure does not cause settlements large enough to cause superstructure damage. Damage for family dwellings would normally take the form of sticking doors and windows, cracks in masonry, cracks in wall board or plaster, and in some cases broken windows. One does not normally have a building collapse in this type of construction because of the small loads on foundations. The resilient nature of residential construction as characterized by generally large deformations would, in any case, provide adequate warning prior to collapse.

A foundation is shallow if the depth, D_f , to the interface of the footing and soil is not more than the width, B , of the footing ($D_f \leq B$). This definition (Figure 2) will include spread footings, slab-on-grade, deep-beam footings, and footings underlying basement areas, and will be extended in this report to include short-post and pier foundations. All other are classified as *deep* foundations.

Piles, piers, and caissons are deep foundations. These foundations tend to dissipate the applied superstructure load vertically through a soil mass of low strength via a vertical structural member, the pile, pier, or caisson. The primary difference between the shallow and deep foundation is the manner of load transference: horizontally for the shallow and vertically for the deep foundation.

Deep foundations may be necessary for residential housing in river delta areas, in coastal regions, or where a very high groundwater table exists. Wood piling is commonly used in the New Orleans, LA, area in residential house construction to support the floor slab grade beams,⁶ though with a careful application of soil mechanics ordinary footings might be used. Where wood is located below the permanent water table its service life is indefinite.

Generally, the caisson or pile foundation is so expensive that it will not be considered as an alternative. It is considered only where the site is so poor in load-carrying capacity or the water table so high that the deep foundation is the only possible foundation system.

Further information on the two basic types of foundation systems is presented in the following sections.

⁶Irving B. Rau, "Telephone Poles Used as Piles in New Orleans Area," *Civil Engineering* Vol. 29, No. 4 (American Society of Civil Engineers [ASCE], April 1959), pp 47-49.

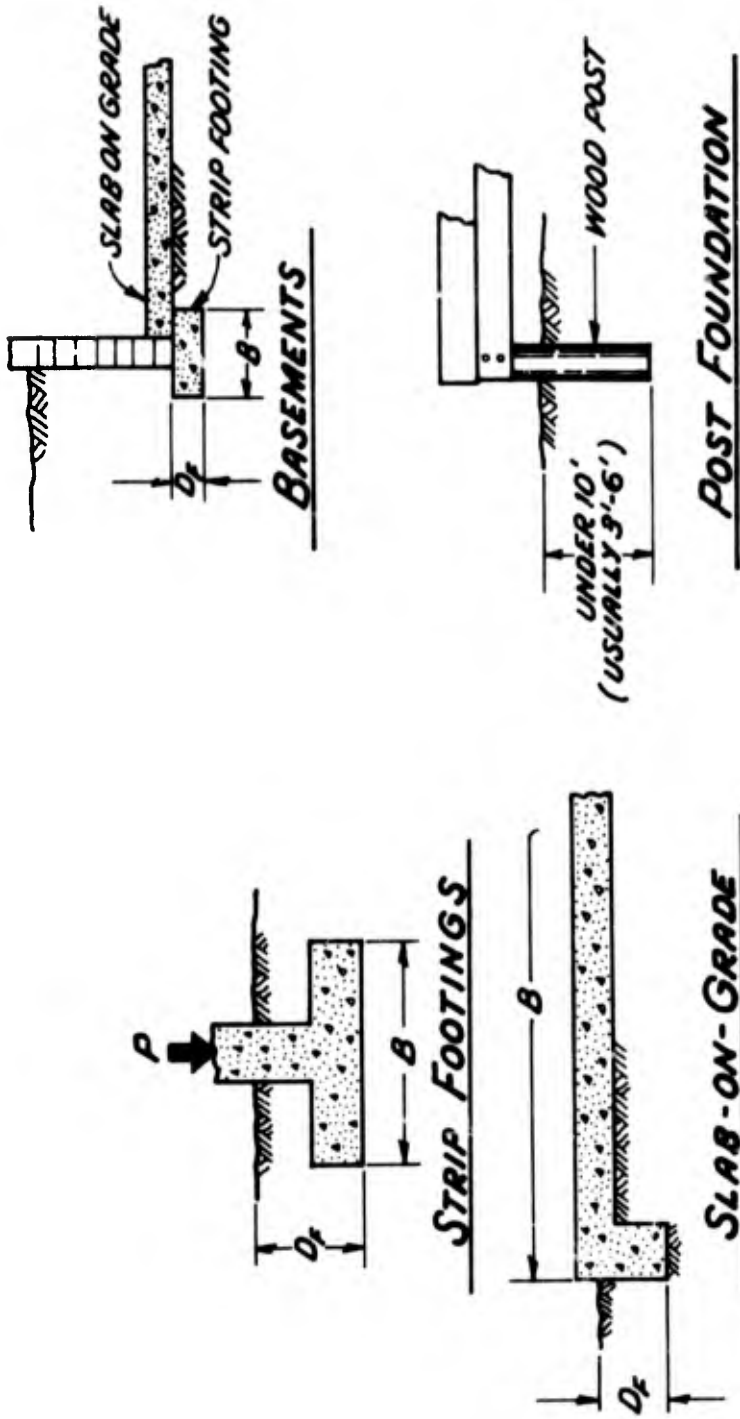


Figure 2. Shallow footings as applicable to family housing.

Shallow Foundations. Shallow foundations are also termed "spread" foundations because they spread the load intensity of the superstructure to a larger resisting soil area. This class of foundations may be a strip or continuous footing beneath the exterior walls or cross walls of the dwelling. Footings which carry the load from the superstructures through pedestals, short columns also called "piers", at selected locations beneath the floor beams are called pads, spot footings, spread footings, or simply footings. These isolated load spreading members are commonly rectangular, but may also be circular. The pedestal, or pier, may be a cast-in-place or precast round or square concrete member. It may also be built of brick, concrete block, or treated timber. Figures 3 through 6 illustrate several types of footings.

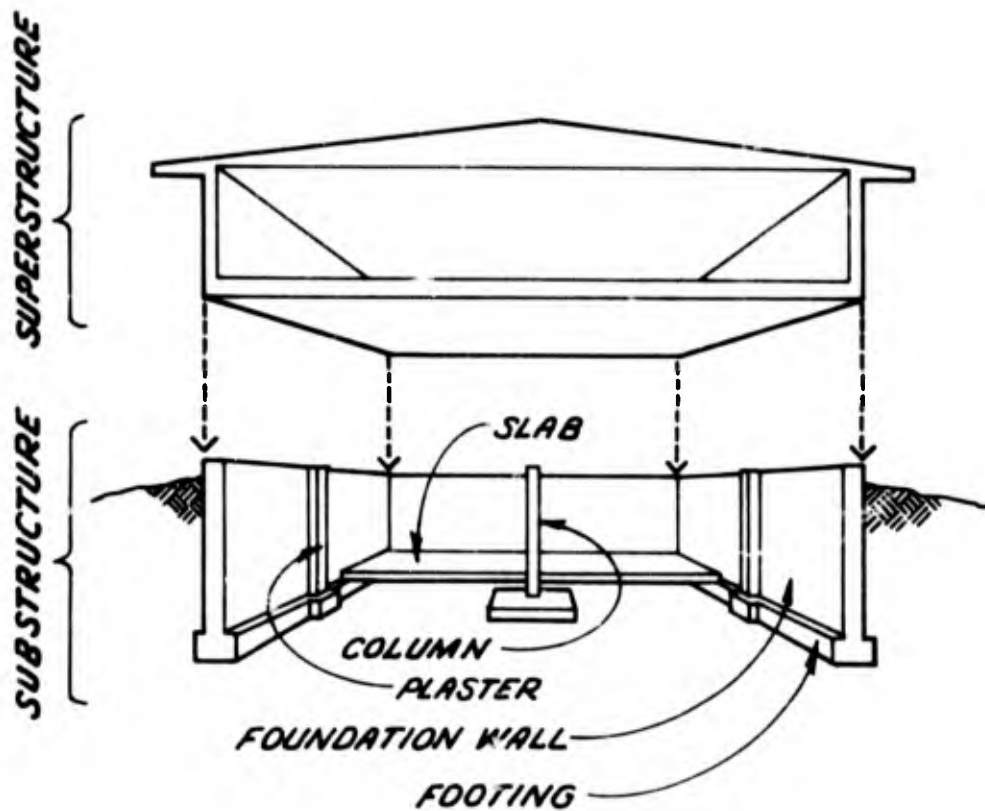


Figure 3. Substructure of a building. The superstructure loads are transmitted to the soil using foundation walls, pilasters, piers, columns, and footings. Other elements such as grade beams and piles may also be used but are not shown here.

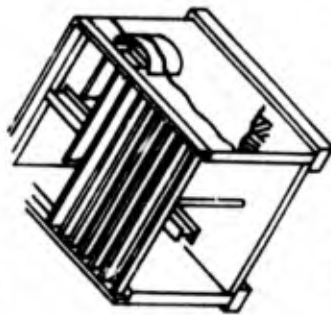
Post foundations for residential construction are included in the shallow foundation classification for this report. The post type foundation consists of placing a series of short posts 3 to 6 ft (1 to 2 meters) into the ground, with 1 to 6 ft (.3 to 2 meters) exposed above ground (Figure 7). The posts may be treated wood, cast-in-place or precast concrete, or steel. These structural members may be driven or placed in preaugured holes. The post foundation cost compares favorably with the other classes of shallow foundations in this section and since the posts are much shorter than the usual pile foundation it is appropriate to include this foundation system here.

Grade beams (Figures 4d and e) are often used to carry the superstructure loads to pier, post, and pile foundations. A grade beam spans two or more posts or piers and is in close proximity to or even below the ground surface. The soil beneath beams, in contact with the ground, should be loosened. Where beams are in soil susceptible to volume change, a void should be left beneath the beam.

The geometric properties of these foundations will depend on the type of superstructure, loads, soil conditions, local practices and building codes. The engineered design may not be more economical than one following the local building code, but will invariably contain more system reliability.

Strip Footings. These footings are almost universally used to support the exterior foundation or basement walls and are sometimes termed "load bearing walls" since the principal superstructure loads are loaded on these walls. The load carried per linear ft of wall is usually quite low and the width is governed by the minimum width in which the mason can lay the wall course, or some rule-of-thumb method, rather than by the bearing capacity of the soil. This type of footing can be formed in many ways. A simple method used in early construction was to use masonry (Figure 8) corbeled out at 45° or 60° from either edge of the wall until the desired depth and width was obtained. This type of construction can be used with either brick or concrete block units. Most strip footings beneath the foundation walls are currently constructed using concrete, either plain or reinforced, poured in a prepared trench excavation since these footings tend to be more structurally reliable than masonry footings. Obviously the strip should be somewhat wider than the foundation wall--how much wider depends on if the wall is to be of masonry or concrete construction, and the allowable bearing capacity of the soil. Table 1 provides the minimum dimensions accepted by FHA. Good engineering practice requires the use of a minimum amount of reinforcing steel in the footing strip (Figure 4).

BASEMENT

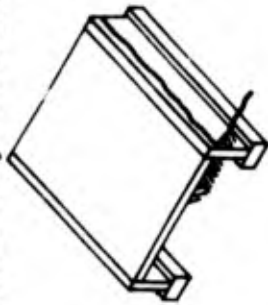


a STEEL BEAM & WOOD JOISTS

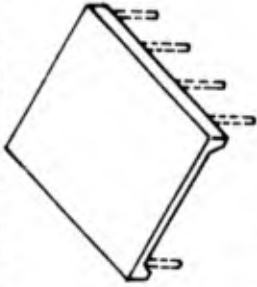
SLABS-ON-GROUND

MAY BE SUPPORTED ON:

GROUND, FOUNDATION WALLS, OR GRADE BEAMS W/PILES

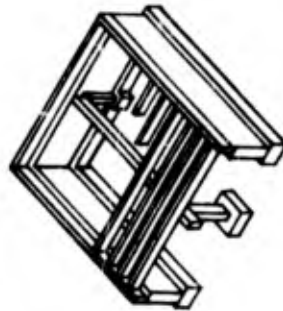


b



c

CRAWL SPACES



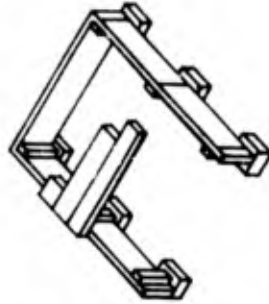
d

CONC. OR MASONRY



e

STEEL

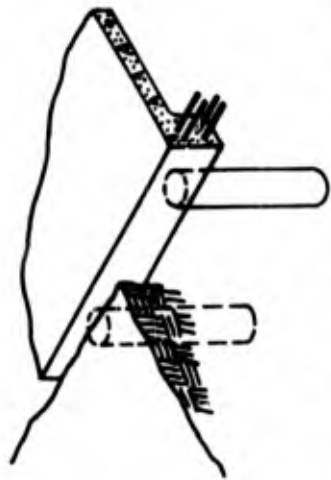


f

PRE-CAST CONCRETE

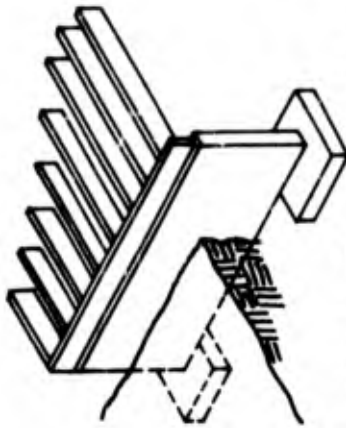
Figure 4. Typical methods and systems as used in building construction to transmit superstructure loads to the soil. (a) Foundations incorporating a basement; (b,c) slabs-on-ground and may use spread footings and/or grade beams or piles; (d,e,f) foundations utilizing crawl space and may rest on perimeter walls and interior piers or use perimeter walls only, may also use all piers, if (f) precast material is used.

g



GRADE BEAM SUPPORTED ON PILES

h



GRADE BEAM SUPPORTED ON FOOTINGS

Figure 4 (cont'd). (g,h) Use of grade beams to transmit superstructure loads to soil via either piles or spread footings.

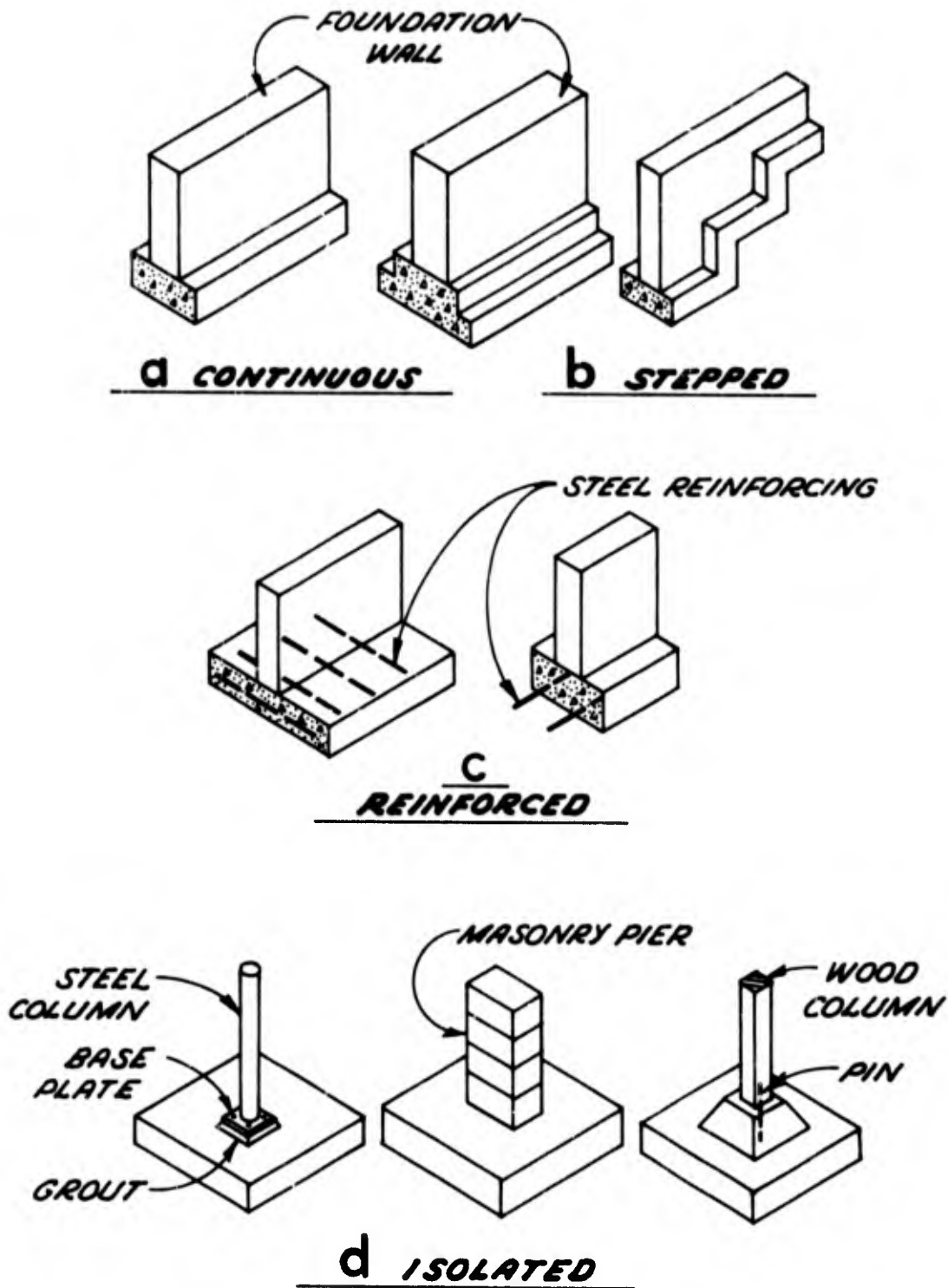
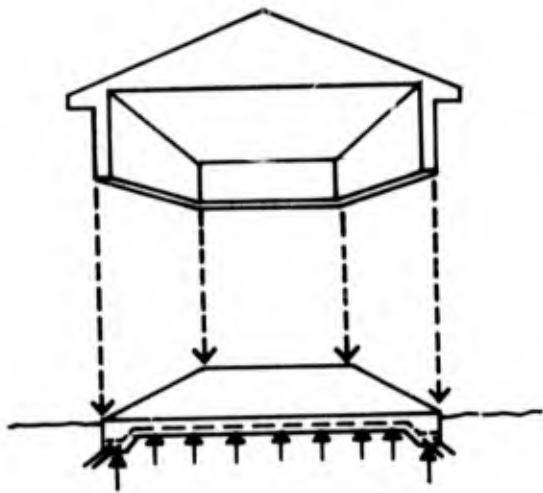
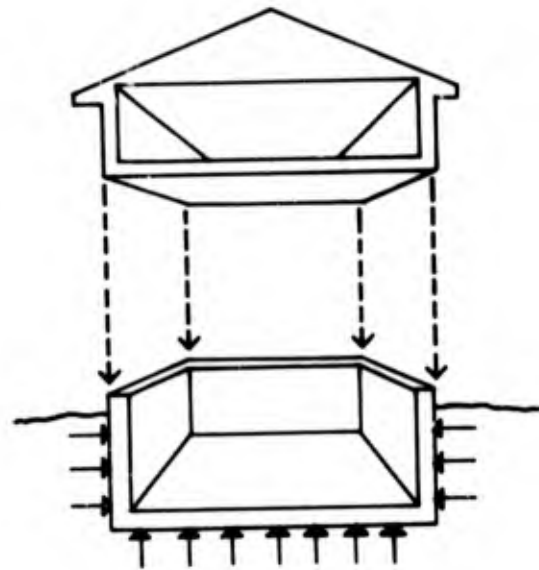


Figure 5. Various types of spread footings. These are used to spread the building load over larger soil areas so that the soil can carry the load without undergoing detrimental settlement.



a ***MAT FOUNDATION***



b ***RAFT FOUNDATION***

Figure 6. Floating foundations. The entire foundation acts as a unit to support the superstructure and is used on relatively weak soils or soils subject to volume change.

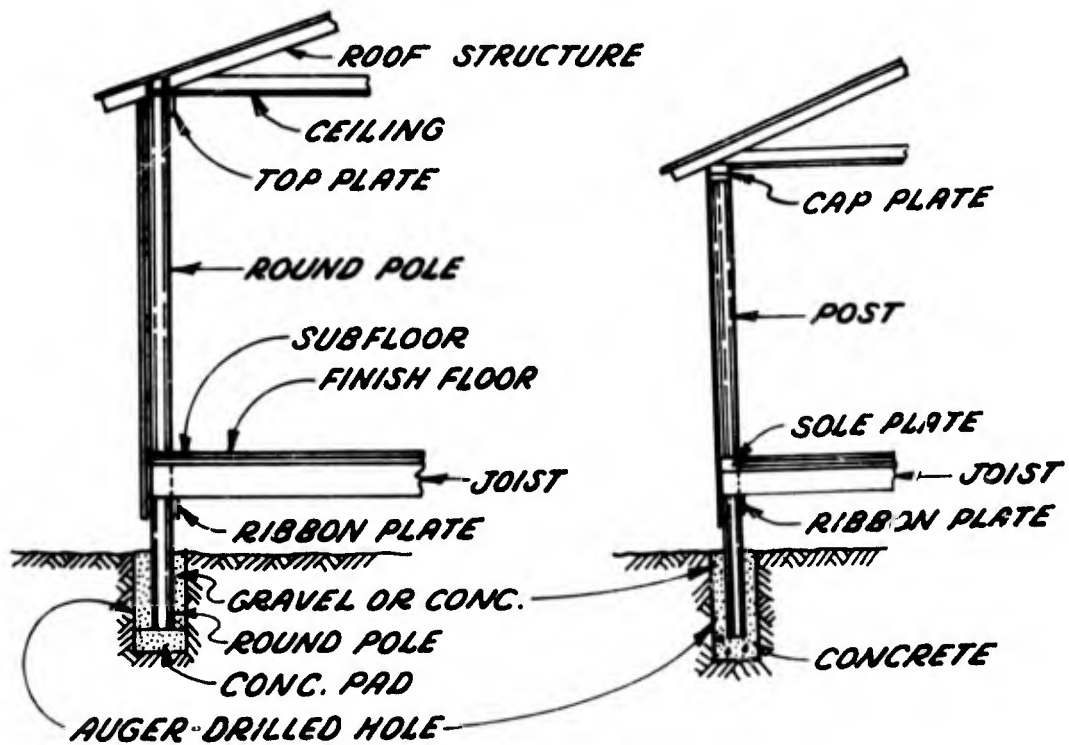
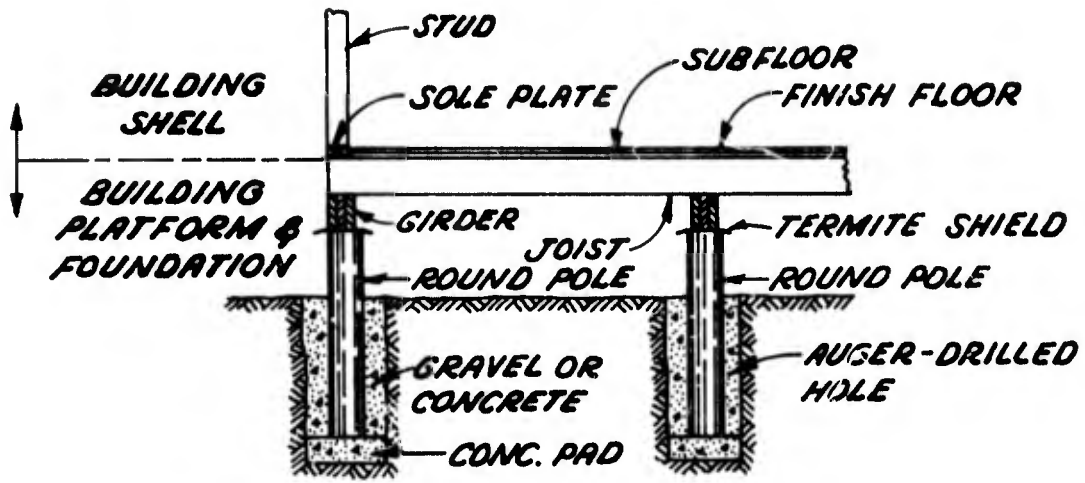
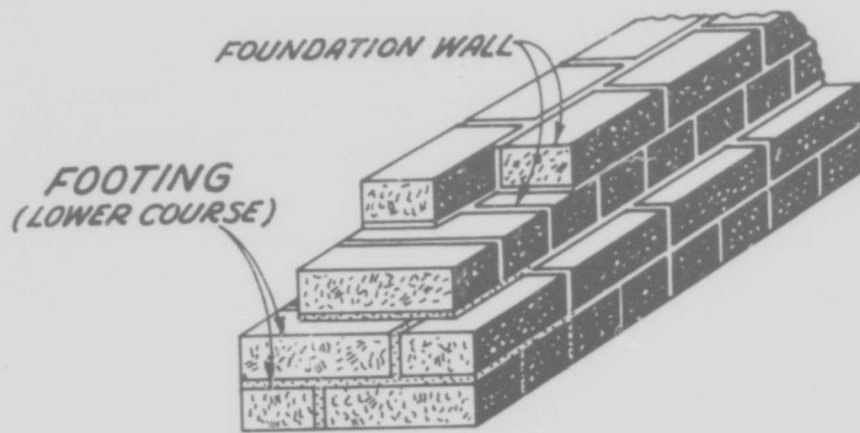
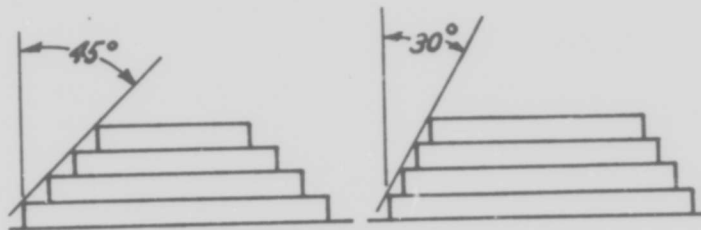


Figure 7. Typical details for post and pole foundations.



12" BRICK FOOTING SUPPORTING 8" FOUNDATION WALL.



BRICK FOOTINGS WITH 45° & 30° STEPPING.

Figure 8. Masonry footings. Concrete block may be used instead of brick.

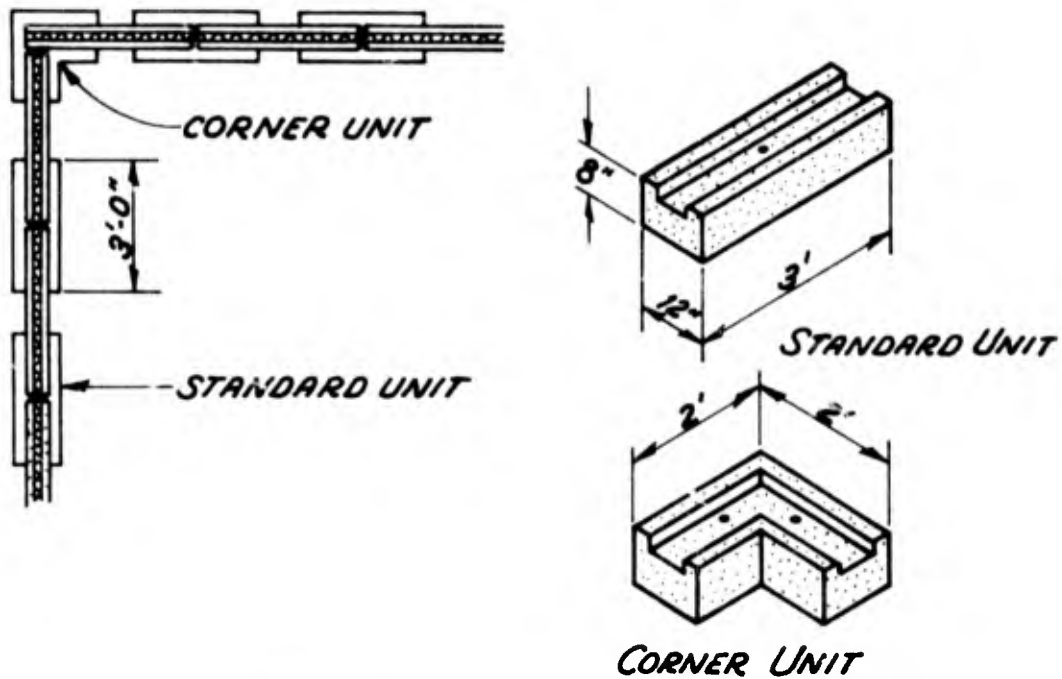
Table 1
Footing Sizes as Recommended by FHA

Number of stories	Frame		Masonry or masonry veneer	
	Min thickness (inches)	Projection each side of wall (inches)	Min thickness (inches)	Projection each side of wall (inches)
One story:				
No basement---	6	2	6	3
Basement-----	6	3	6	4
Two story:				
No basement---	6	3	6	4
Basement-----	6	4	8	5

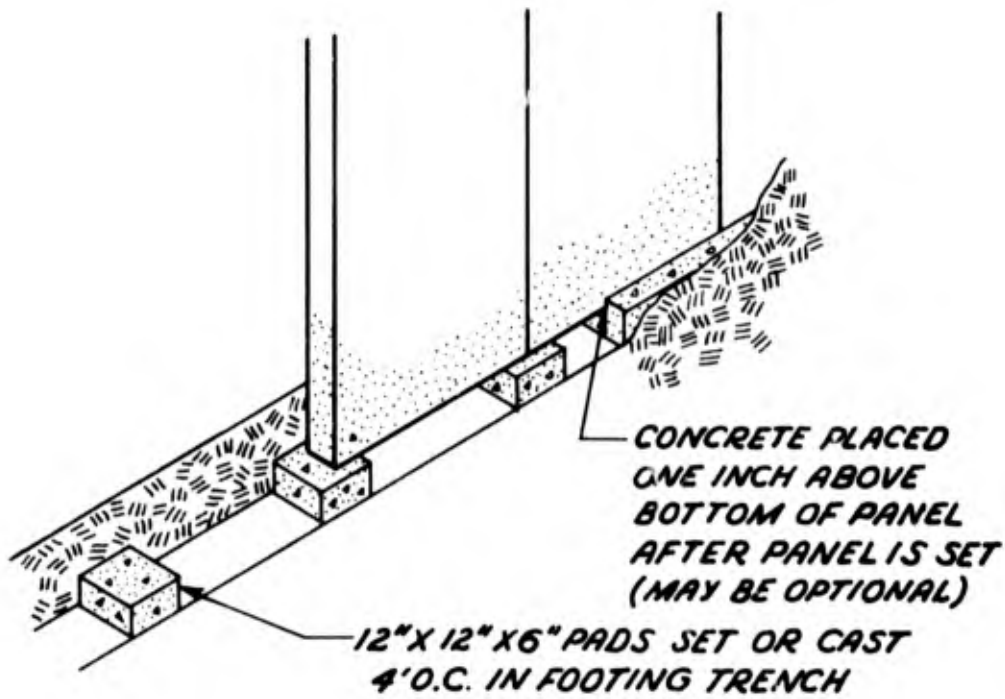
In areas of high seasonal soil volume change, or deep frost penetration the necessity of placing the footing on good soil can result in large amounts of excavation. For these two situations it may be advantageous to use precast foundation walls in a structural scheme as shown in Figures 4 and 9. Precast foundation walls can also be used by housing developers to facilitate winter construction in colder climates. In these circumstances the foundation wall is precast off-site, trucked to the site, and lowered onto precast leveling blocks placed in the bottom of a mechanically excavated, deep, narrow trench. Footing concrete can then be poured into the trench to fill the space beneath the foundation wall from use of the leveling blocks in the bottom of the trench. Should it be necessary, the freshly poured concrete can be easily protected against freezing. A main characteristic of this type foundation is that the footing trench is dug only wide enough to set and align the wall, place the leveling blocks, and pour the strip footing which is as wide as the trench. This reduces the amount of soil excavated to a minimum. The construction method precludes the use of longitudinal reinforcing steel in the footing, however, this type construction is rigid enough that reinforcing would rarely be required.

As the average small- to medium-sized home will weigh about 100 kips (live and dead loads), in soil of a bearing capacity of 4 to 6 ksf, about 25 sq ft of footing area would be required. This amount of area may be obtained from the leveling blocks without need of additional concrete poured in the footing trench.

If the soil conditions at a site are poor or irregular in character such as partly cut and partly filled or variable in bearing capacity, longitudinal reinforcing steel should be used in potential tension zones to assist the footing in resisting flexural stresses due to unequal settlement. Note that the tension zone is more likely to be in the top than in the bottom of the strip, contrary to most architectural sketches.



DETAILS FOR PRECAST CONCRETE FOOTINGS



ALTERNATE FOOTING CONSTRUCTION

Figure 9. A precast foundation wall and wall-footing system for residential construction.

Due to the narrow width of strip footings and the small projections beyond the foundation wall, transverse reinforcement in the footing for bending and shear is seldom required.

When differential settlement is likely to be excessive, the footing can be formed with the lower part of the wall to form an inverted T-beam (Figure 10). The use of longitudinal reinforcing steel with increased footing depth is preferred because, in addition to structural benefits, there is less additional formwork for the T-beam.

On sloping terrain the strip footing does not have to be at the same level around the structure; the footings can be stepped as shown in Figure 11. Stepping the footing may also provide an economical means of transferring the superstructure loads to a greater depth where soils of varying bearing capacity are encountered on the site.

Where a principal load-carrying beam frames into the foundation wall, a pilaster may be added with an increase in the footing strip width at that point (Figure 3).

Pad Footings. These are footings used to support individual floor support columns or piers. The simplest pad footing is a pyramid of masonry, usually corbeled out at a 45° angle from the column. If reinforced concrete is employed a simple rectangular or circular block is used (Figures 12 and 13). If large footings greater than 3 ft or 1 m square are used, reinforcement may be needed to keep the quantity of concrete economical, though with the light loads usually encountered, reinforcing steel and its placement may result in a trade-off in favor of using extra concrete. Pad footings are often square, but in cohesive soil, a round pad, obtained by using a large diameter earth auger to excavate the footing outline, and possibly with a large diameter fiber tube (conotube) as a form, may be the most economical.

The pedestal or pier which carries the superstructure load to the pad is designed to satisfy the structural strength of the material. Minimum design standards adopted by FHA⁷ also include the following considerations:

For masonry or concrete piers (see Table 2 for minimum dimensions):

- a. Piers shall extend at least 12 in. above grade.
- b. Exterior or interior piers subject to wind shall be solid concrete, solid masonry, or hollow masonry with the cells filled with concrete.
- c. Maximum height above grade shall be not more than three times the least dimension unless reinforced.

⁷*Minimum Property Standards for One and Two Living Units* (U. S. Government Printing Office, 1960), p 315.

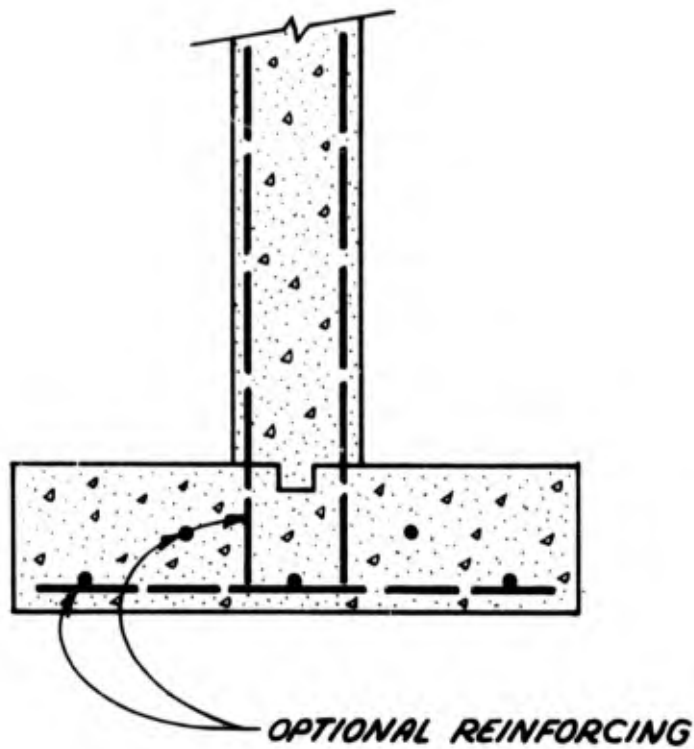


Figure 10. Inverted T-beam wall strip footing.

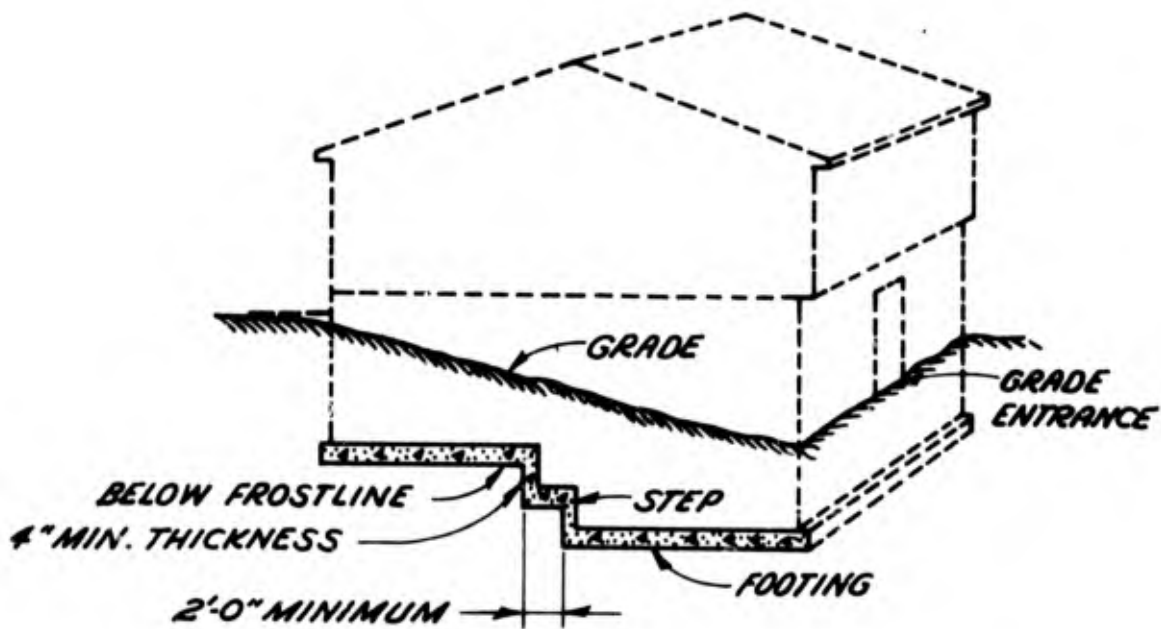
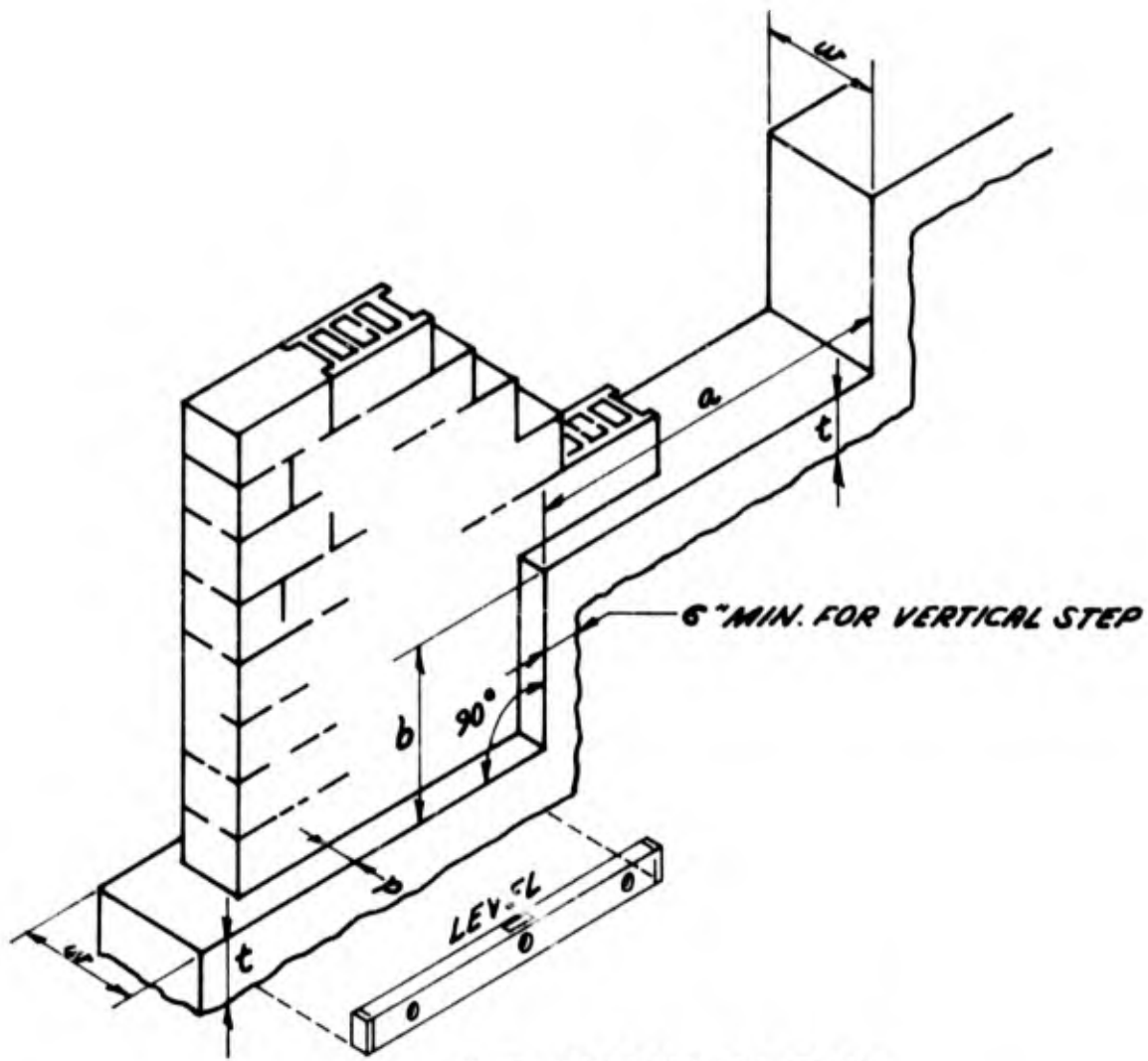


Figure 11a. Stepping of strip footings on sloping sites. The general case where stepping is required.



- a* = HORIZONTAL STEP
- b* = VERTICAL STEP
- t* = FOOTING THICKNESS
- p* = PROJECTION OF FOOTING
- w* = WIDTH OF FOOTING

*ALL FOOTINGS & STEPS SHALL BE LEVEL.
 STEP (b) SHALL NOT EXCEED 3/4 OF STEP (a).*

Figure 11b. Stepping of strip footing on sloping sites. Usual dimensions used in stepping a strip footing.

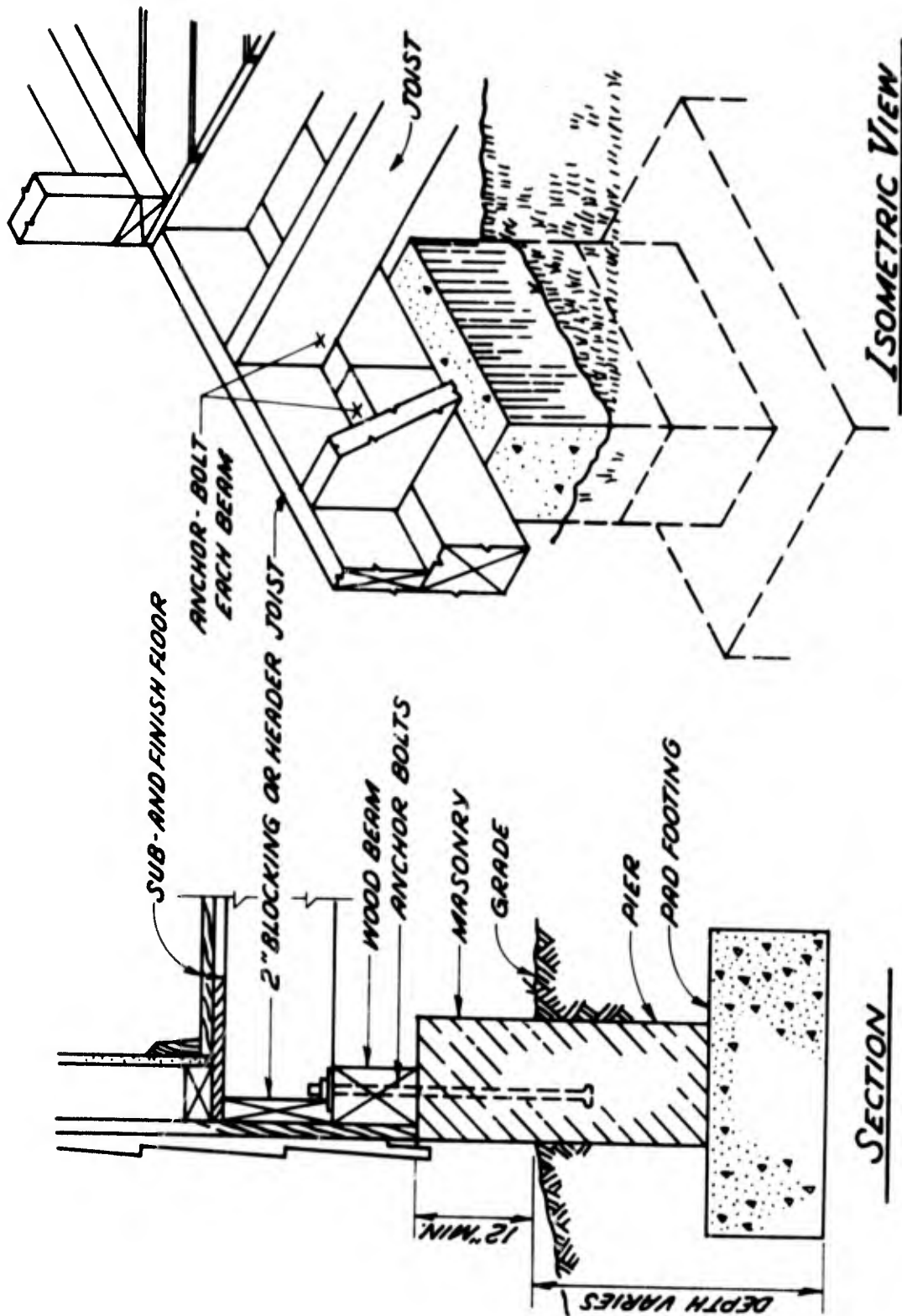


Figure 12. Common pier-on-pad foundation.

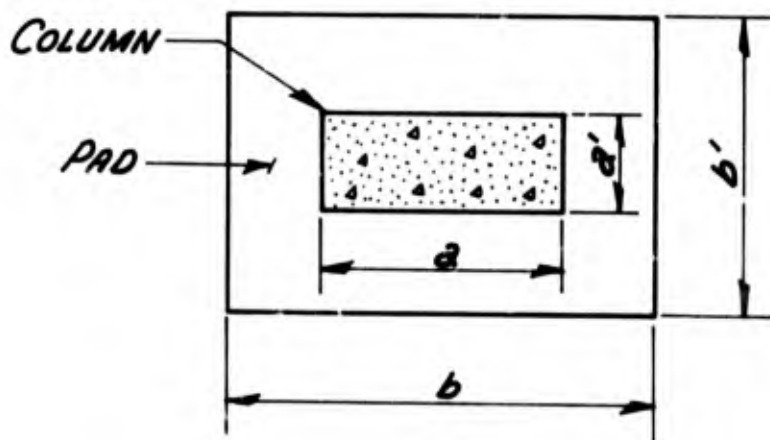
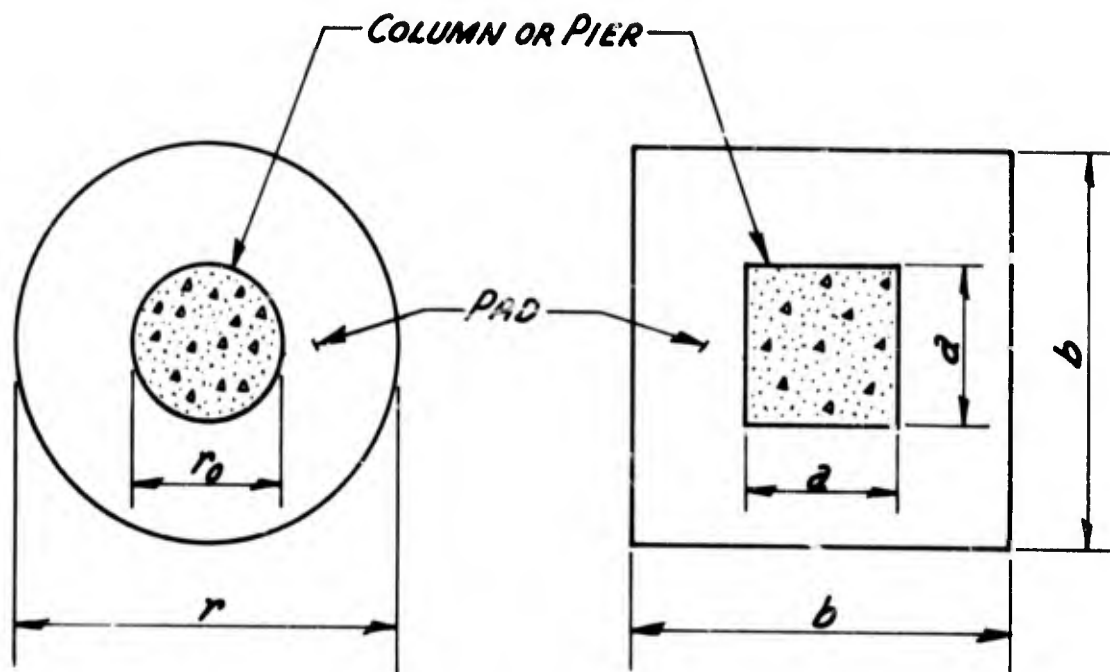


Figure 13. Typical pad footing shapes.

- d. Interior piers not subject to wind may be of hollow masonry.
- e. Interior piers not subject to wind may have a height above grade of:
 1. If solid, 10 times least dimension.
 2. If hollow, four times least dimension.

For wood piers:

- a. Top of concrete base on which column rests shall be at least 3 in. above floor in basements or 8 in. above grade in areas without a basement. (Pressure-treated wood piers may be used both above and below grade in carrying the superstructure loads to the concrete pad. Note this difference between piers of this section and in *Post Foundations*.)
- b. The members shall be cut square and at least 6 by 6 in.

Table 2

Foundation Piers as Recommended by FHA

Pier material	Minimum pier size (inches)	Minimum footing size (inches)	Pier spacing	
			Right angles to joists	Parallel to joists
Solid or grouted masonry	8 x 12	16 x 24 x 8	8 feet o.c.	12 feet o.c.
Hollow masonry*	8 x 16	16 x 24 x 8		
Plain concrete	12" dia. or 10 x 10	20 x 20 x 8		

*Interior pier not subject to wind.

This type foundation configuration for basementless structures provides a crawl space (Chapter 3, *Drainage*) beneath the floor. If the exterior walls are carried on piers as well as the interior floor loads, a perimeter skirt may be required in colder climates to reduce heat loss.

Mat Foundation. These are continuous foundations beneath the entire dwelling which support the several independent loads, both the interior, load-bearing walls and any interior columns which may carry part of the superstructure loads. The exterior wall loads are transmitted to strip footings around the perimeter of the mat unless the mat edge is thickened to carry the additional loads. If the edge were not thickened or

surrounded by a foundation wall the soil could erode from beneath the slab edges creating voids and resulting in the slab cracking. For family housing considerations, this type of foundation is the slab-on-ground or basement floor support.

Criteria for slab-on-ground selection, design, and construction is covered in considerable detail in a report prepared by the Building Research Advisory Board (BRAB).⁸ This report classified slabs from the standpoint of performing one or both of the following objectives: serve as a separating element between the ground and the habitable space; serve as a structural element to receive and transmit superstructure loads to the underlying soil.

Depending upon soil types and conditions, climate at the site, type of superstructure, and quality control during construction, the BRAB report⁹ considers four types of slabs.

Type I Unreinforced

Type II Lightly reinforced against shrinkage and temperature cracking

Type III Reinforced and stiffened

Type IV Structural (not directly supported on the ground).

These slab types are illustrated in Figures 14 through 16.

Type I and II slabs are generally 4 in. or more in thickness, and the primary function is to separate the habitable space from the ground. However, interior building partitions carrying part of the superstructure loads often rest on the slab, if the partition load does not exceed 500 lbs/linear ft. The exterior walls carry the major part of the superstructure dead load to the perimeter footing (generally a strip).

Type III carries all the superstructure loads to the underlying soil. This slab is often used where the soil may undergo substantial volume change with time. These slabs are designed to bridge local soft spots in the underlying soil. Where uneven volume change occurs, the slab provides for a leveling action within the building. These slabs are semi-designed for structural resistance. This type of slab may also be termed a "waffle slab" depending on how it is formed. Figure 15 illustrates several schemes of incorporating this type of slab into the site.

⁸*Criteria for Selection and Design of Residential Slabs-on-Ground* (National Academy of Sciences, 1968), p 268.

⁹*Criteria for Selection and Design of Residential Slabs-on-Ground.*

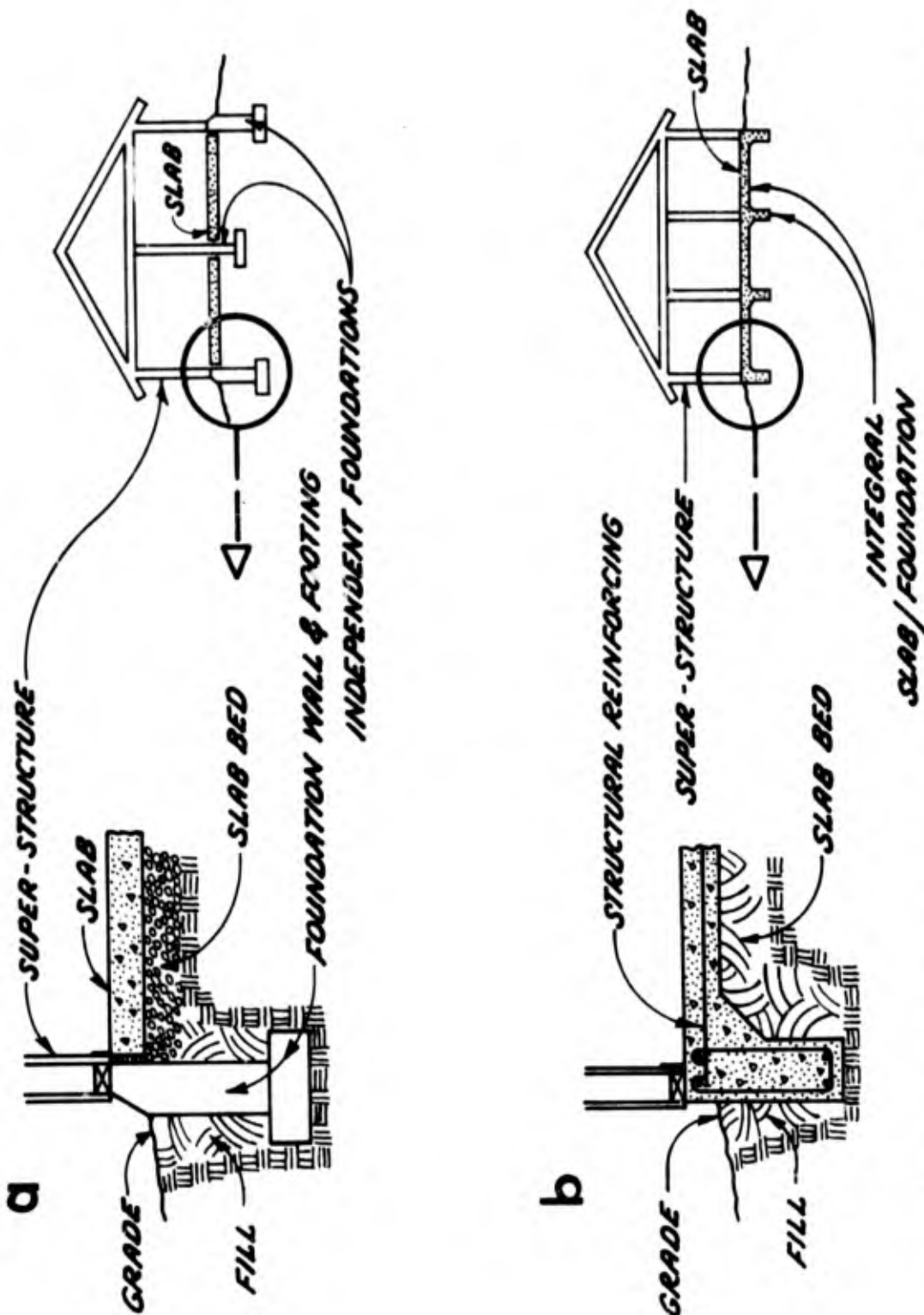


Figure 14. Typical slab-on-ground details. (a) Slab is independent of superstructure and foundation walls; (b) slab is integral with foundation perimeter wall.

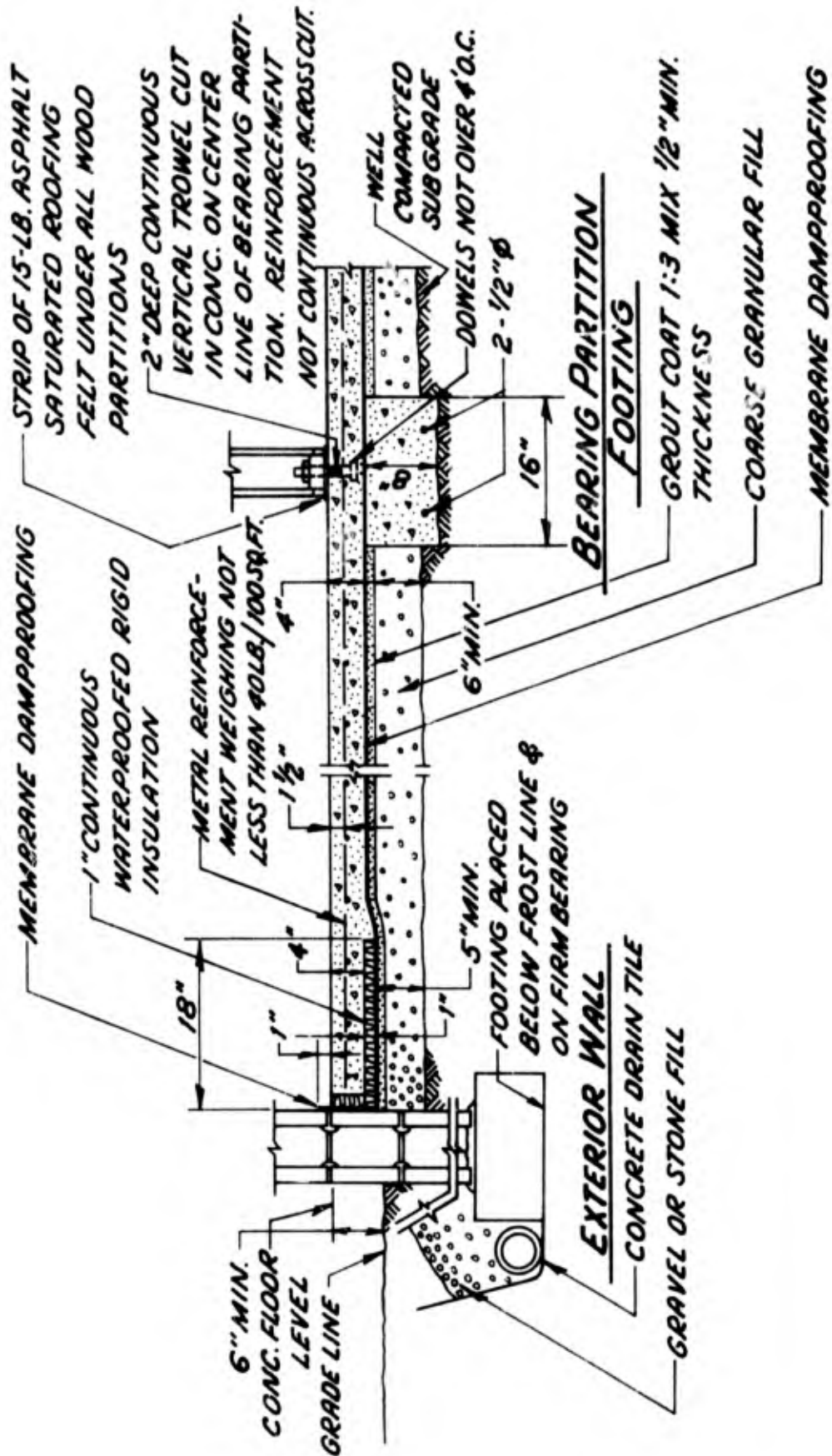


Figure 14 (cont'd). (c) Construction details.

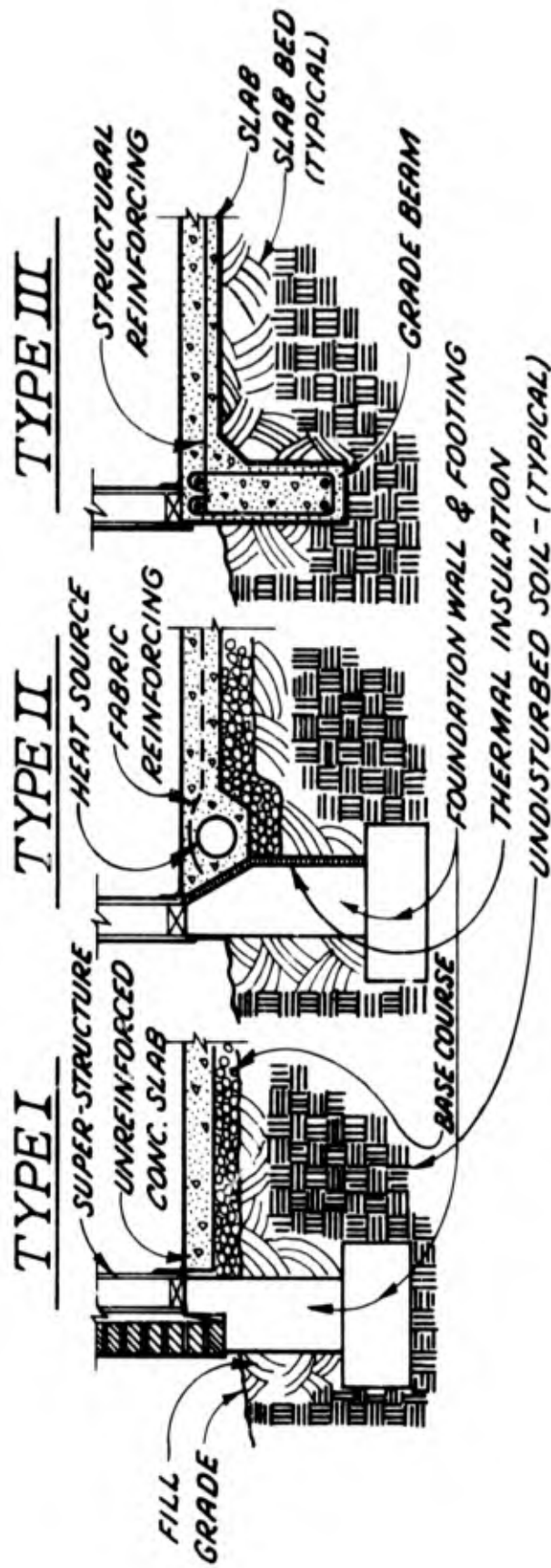
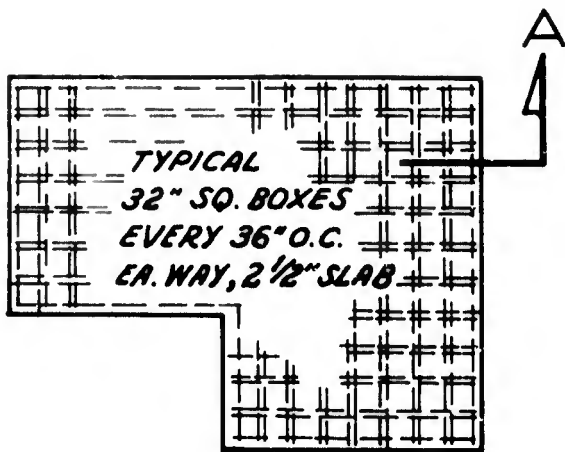
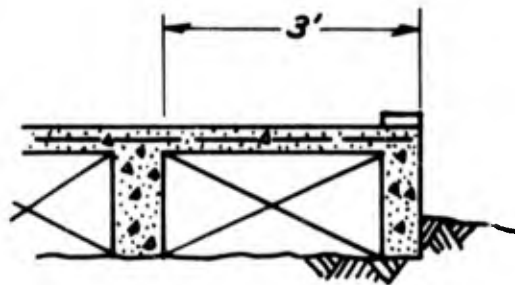


Figure 15. Typical details for slabs-on-ground of types shown. (a) Typical reinforcing.



FLOOR PLAN



SECTION A

VALUES AND DIMENSIONS ARE FOR ILLUSTRATIVE PURPOSES ONLY

Figure 15 (cont'd). (c) A waffle slab using collapsible boxes as forms to make the cavities beneath the floor slab as shown.

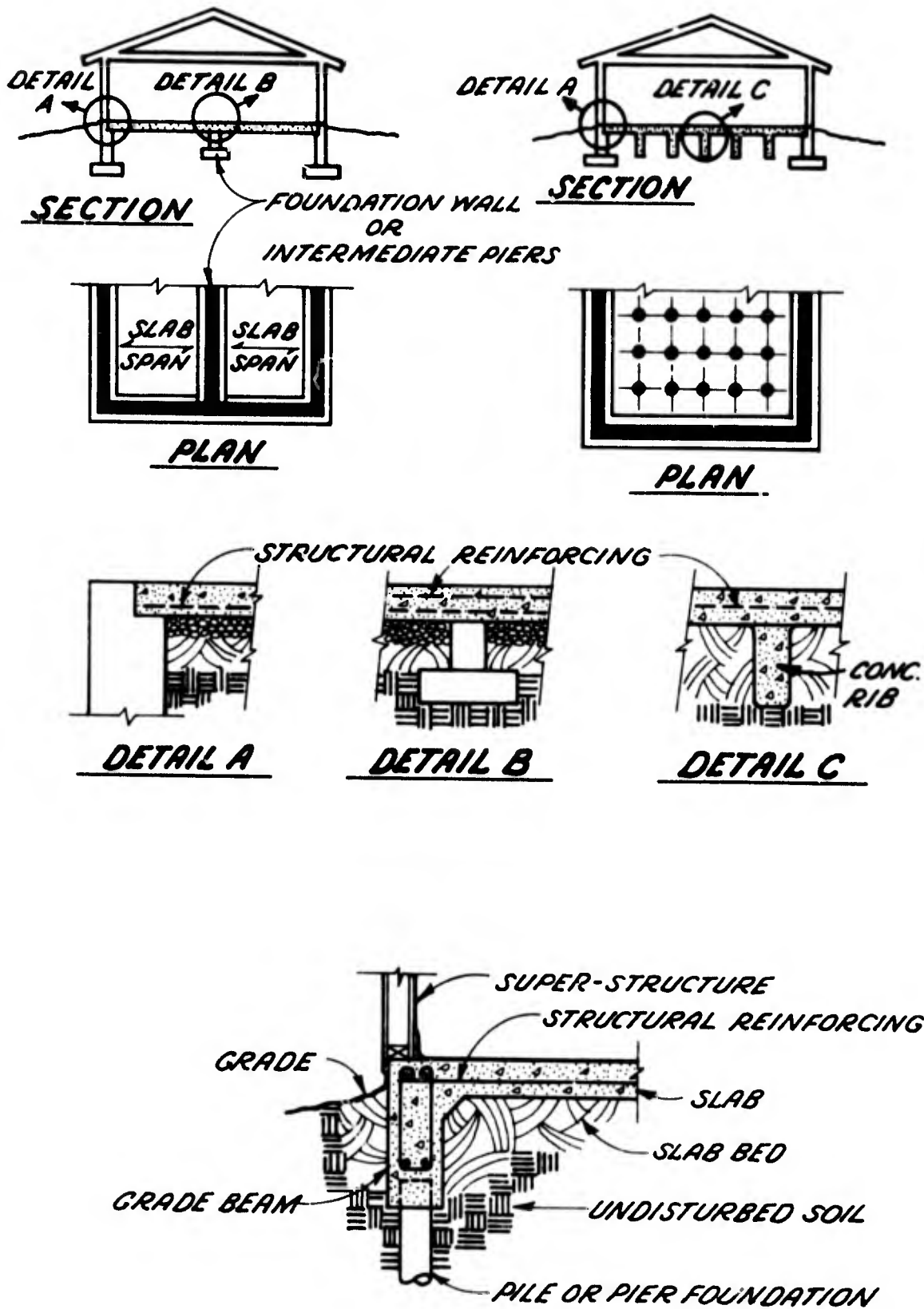


Figure 16. Type IV slab-on-ground. Typical construction details shown. Note that the use of a pile or pier foundation may be optional.

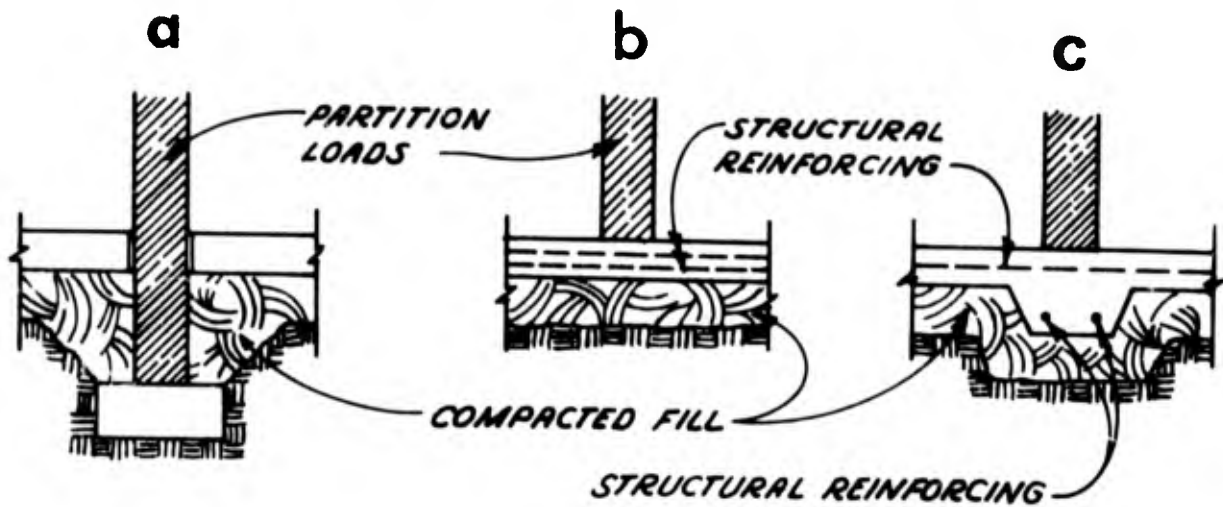


Figure 16 (cont'd). Footing details for Type I and II slabs for heavy partitions loads "a", and alternatives "b" and "c" when the slab has been designed for the partition loads and the amount of steel reinforcing selected on this basis.

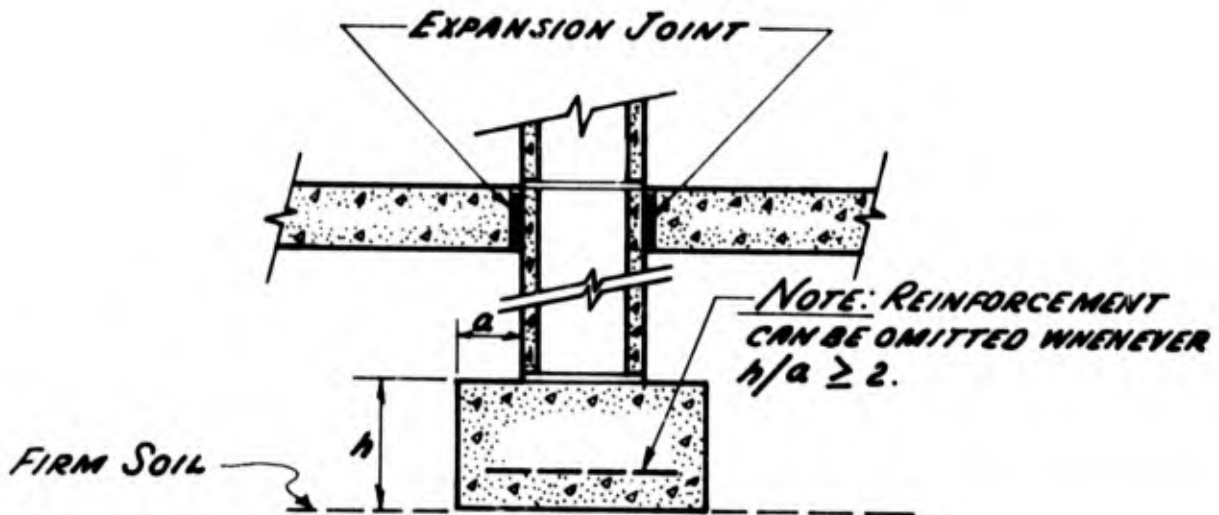


Figure 16 (cont'd). A further alternative for partition loads when the partition load is in excess of 500 lbs/lineal ft.

Type IV slabs are similar to Type III slabs (Figure 16) except that they do not transmit the foundation load directly to the soil. These slabs transmit the superstructure loading to beams which in turn rest on caissons, piles, or footings which carry the loads to solid, undisturbed ground at some depth below the slab level. This type slab would be used for soils that are susceptible to large volume change, have negligible bearing capacity, or are high in organic content.

Basement Foundations. These will be considered part of the foundation system for the purposes of this report. Today's trend in home construction, especially in cold climates, is to build a finished basement which can be used as a recreation room, workshop, or storage area. In cold climates it is necessary to go below the frost zone for the footings and for water and sewer service. To take advantage of machine excavation it is often easier to excavate the entire house outline rather than just the footing plan--especially for spot footings, therefore, the basement can be obtained for a modest increase in cost. This is especially true if the storage space in the basement removes the need for external storage facilities and if the site is such that the extra excavation can be used in the housing development area for landscaping.

From a technical viewpoint, excavation for the basement area reduces structural loads on the underlying soil mass by the weight of the excavated soil. In most cases this results in a zero net increase in soil pressure due to the weight of the building. It should be noted that if both cut and fill are involved at a site the net pressure in the fill zones may not be zero. In fact, differential settlement in these areas may be aggravated. Footings for basement walls are similar to normal wall footings with the size usually set by construction methods. A Type I or II slab is cast separately from the wall and footing for the basement area floor as illustrated in Figure 17.

Interior columns, also called posts, may be required to carry floor loads where large, unsupported span lengths are developed. An increase in floor slab thickness at these points should be made and/or the amount of reinforcement increased (Figure 16). Extra reinforcing steel should be placed closer to the bottom of the slab but 3 in. of concrete should be left between steel and granular backfill.

If the basement is to serve as useful space for the inhabitants it must be kept dry. In low-lying areas where the groundwater level is near the ground surface it may not be feasible to construct a basement. If a hydrostatic pressure exists on the basement it may float the structure out of the ground or be difficult-to-impossible to waterproof. Rarely will it be possible or practical to lower the groundwater level to below the basement floor in cohesionless soils. In cohesive soils it may be possible to maintain a dry basement through use of drain tiles (Figure 18), around the perimeter of the basement, that empty into a sump pit which can be periodically pumped. This scheme is not practical in cohesionless soils as too much water must be removed.

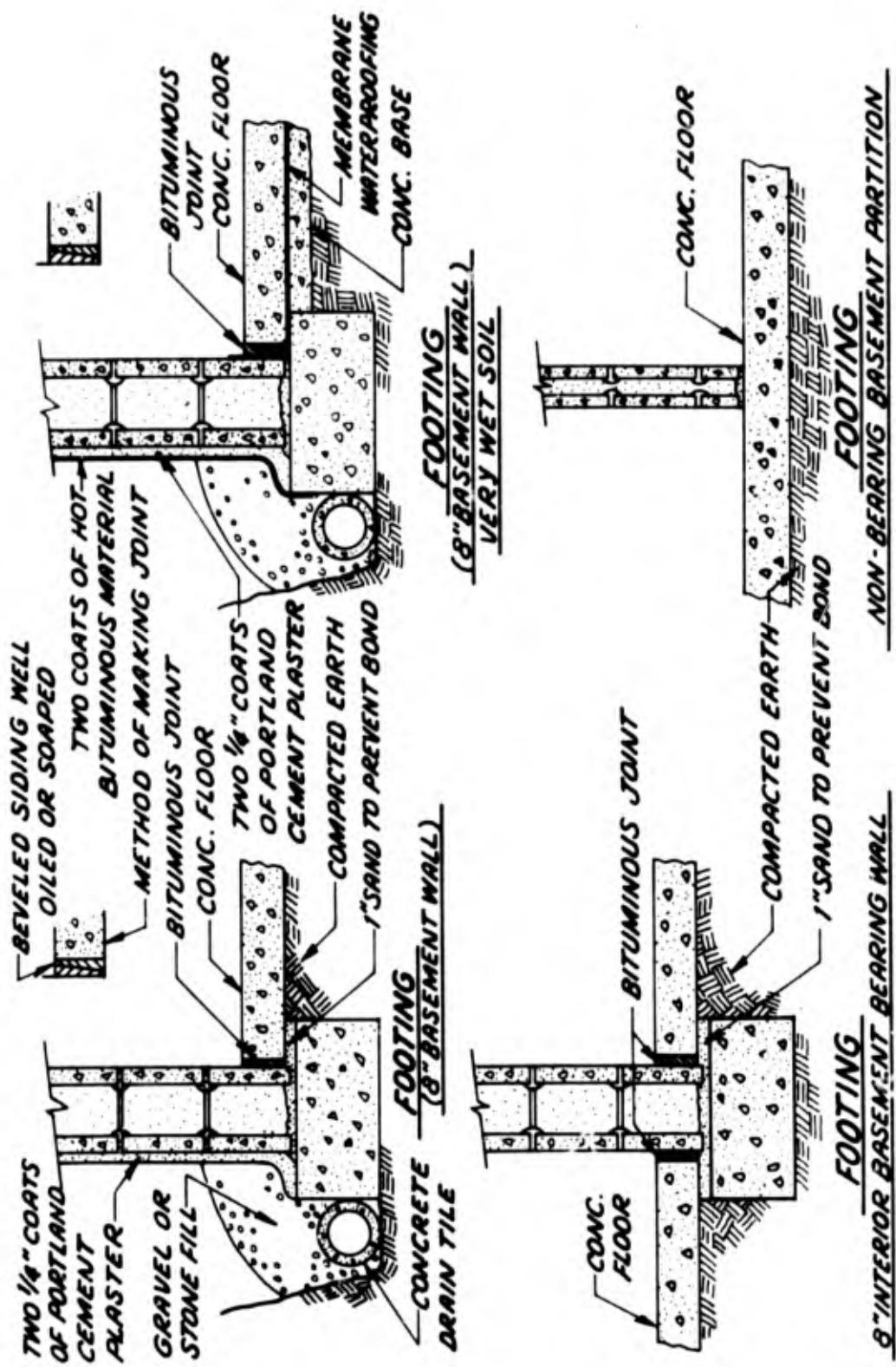


Figure 17. Footing designs for various foundation walls. If reinforcing is used in any of the above slabs the slab is designated a Type II slab.

Drainage tiles should be laid around the periphery of the basement walls at a level below the floor slab. The tile is placed on the ledge formed by the footing extension beyond the exterior wall or adjacent to the footing in the excavated trench (Figure 18) on which a bedding of granular material has been placed. The drain is laid with a 1/4 in. gap between sections of tile and is covered with building paper; the space between the wall and excavation is backfilled with 12 to 18 in. of a coarse sand-gravel mixture to affect free drainage of the intercepted groundwater. The tile is sloped at least a 1/2 percent grade to facilitate drainage. The tiling is terminated into the storm drainage system or to a convenient location on the site where advantage can be taken of natural drainage, or to a sump where it is periodically pumped.

The soil beneath the floor slab should be graded, compacted and sloped to a low point, a corner, the center, etc., then backfilled with 3 to 6 (usually 4) in. of granular material and covered with a vapor barrier prior to pouring the floor slab. Where practical a tile from the low point beneath the slab should connect with the exterior drain tiling.

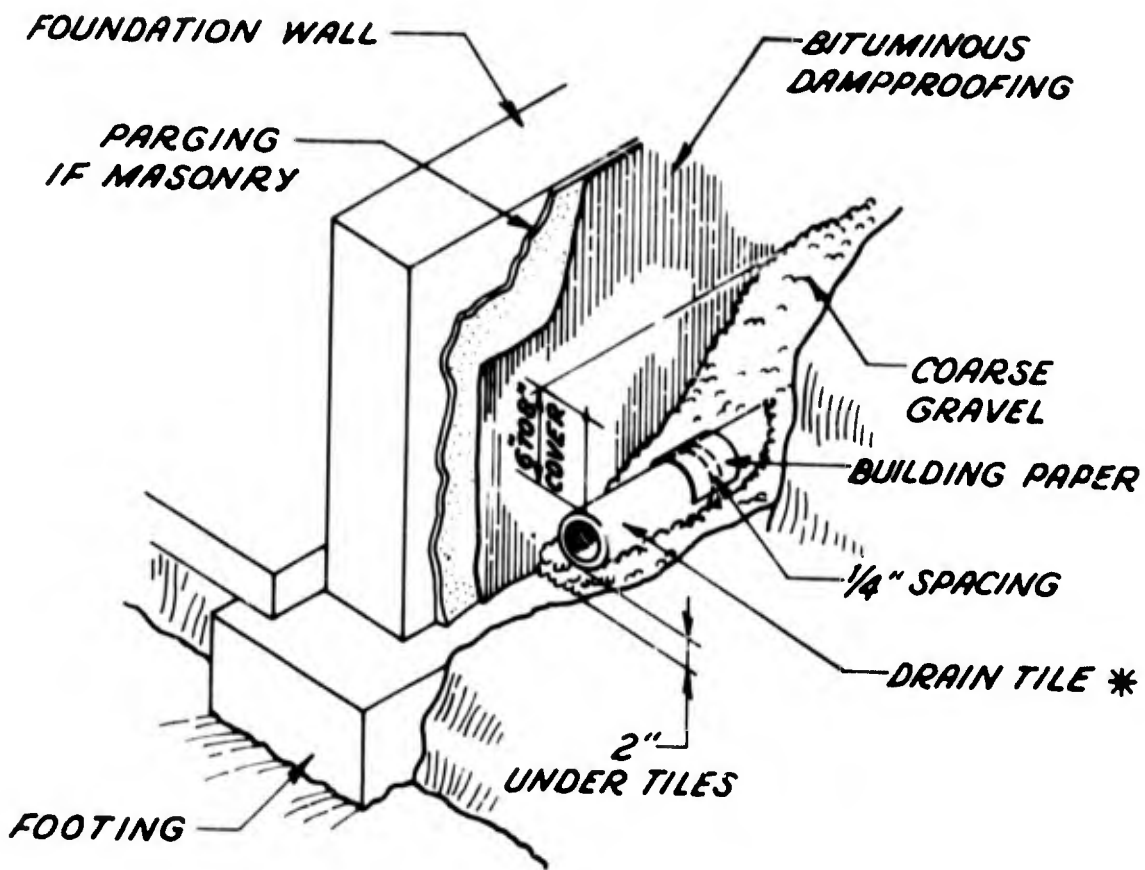
Concrete block masonry walls are coated with 3/8 to 3/4 in. of portland cement mortar (parging) below the ground line and then sprayed or mopped with a bituminous waterproofing material. Cast concrete walls are simply sprayed or mopped with waterproofing material to stop water movement through the walls. Figure 18 illustrates a typical basement wall system carried by a strip footing.

Using wood instead of concrete block basement walls resulted in a considerable savings. The wood wall system uses a compacted gravel base on which the wall sole plates rest (Figure 19).

Several precast wall foundation systems are presented in Ural's 1970 report.¹⁰ These are cited as typical of many which are, or will be, available during the service life of this report.

The basement wall must be adequate to resist vertical loads as well as to provide adequate lateral resistance to soil and/or water pressure. The wall also provides anchorage of the building against overturning. This is shown in Figure 20. Table 3 provides minimum FHA data on wall thickness.

¹⁰O. Ural, *Proceedings, First International Symposium on Low Cost Housing Problems Related to Urban Renewal and Development* (University of Missouri, 1970), p 243.



* TILES SHOULD BE LAID WITH A MINIMUM SLOPE OF ONE INCH IN TWENTY FEET AND CONNECTED TO A POSITIVE OUTFALL OR STORM SEWER.

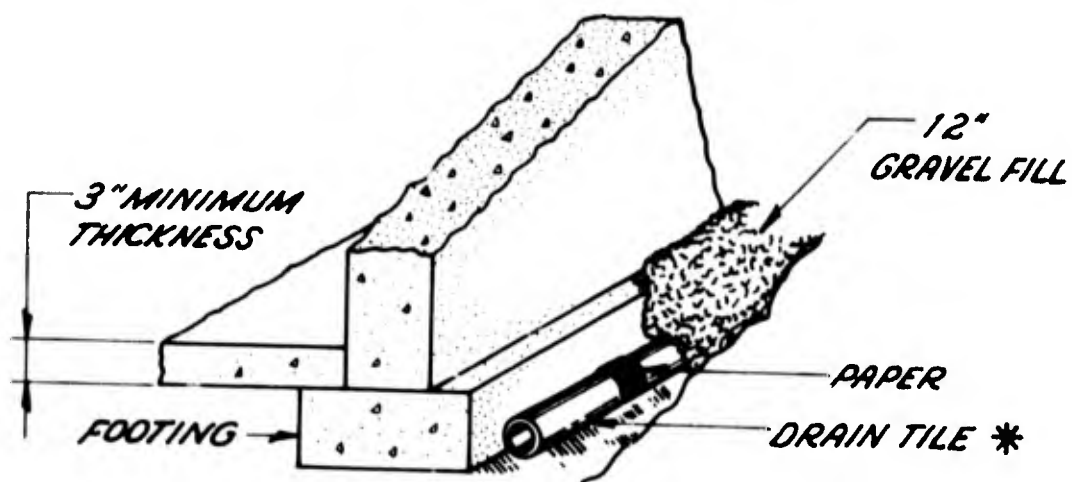


Figure 18. Foundation drainage. Alternative locations for drain tile are shown above.

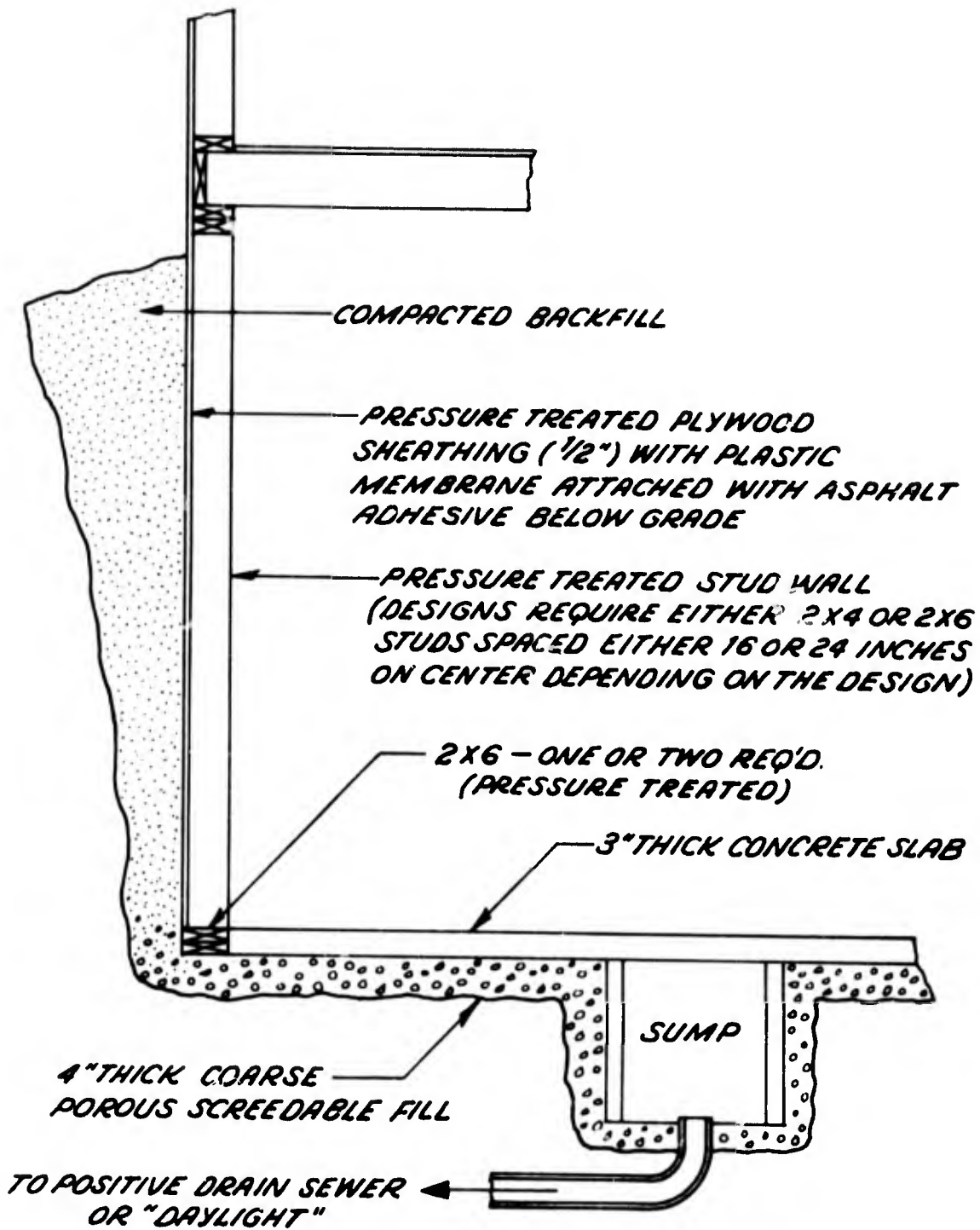


Figure 19. A treated wood basement foundation.

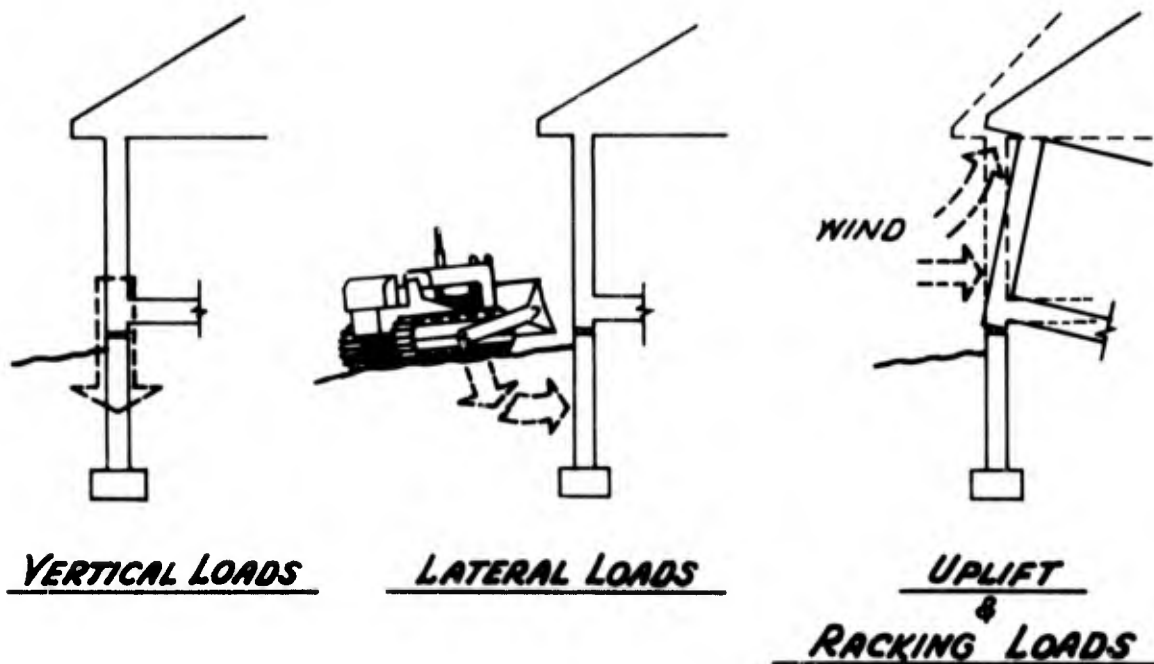


Figure 20. Foundation wall loads. Note that the lateral load can be developed from trucks, piles materials, etc.

Table 3
 Wall Thickness for Various Heights of Unbalanced Backfill
 (Foundation Walls for Several Types of Wall Construction)

Foundation wall construction	Maximum height of unbalanced fill (feet)*	Minimum thickness (inches)	
		Frame	Masonry or veneer
Hollow masonry	3	8	8
	5	8	8
	7	12	10
Solid masonry	3	6	8
	5	8	8
	7	10	8
Plain concrete	3	6**	8
	5	6**	8
	7	8	8

*Height of finish grade above basement floor or inside grade.
 **Provided forms are used both sides full height.

Post Foundations. Conventional and semi-conventional post foundations utilize posts which may be treated wood or precast, reinforced concrete. Post foundations differ from the pad and pedestal footings of the post directly on soil. A small amount of side resistance may be developed, but with the small depths of penetration (around 3 to 5 ft) side resistance is probably negligible. This provides an essential difference between post foundations and the pile foundations of the next section. Due to the fact that posts will generally be under 15 in. (commonly 8 to 10 in.) in diameter, a relatively large number will be required beneath a dwelling unit. Based on the limited data currently available it appears that a 6 x 6 in. wood post embedded about 3 ft should be able to carry 1 to 2 kips in firm soil. It should be noted that this type of unit has been used for some time for guard rail supports in highway construction. Mechanical driving units capable of driving 10 to 20 posts per hour (developed for highway work) can be used for driving these foundations. Sometimes preaugering may be helpful in placing the posts.

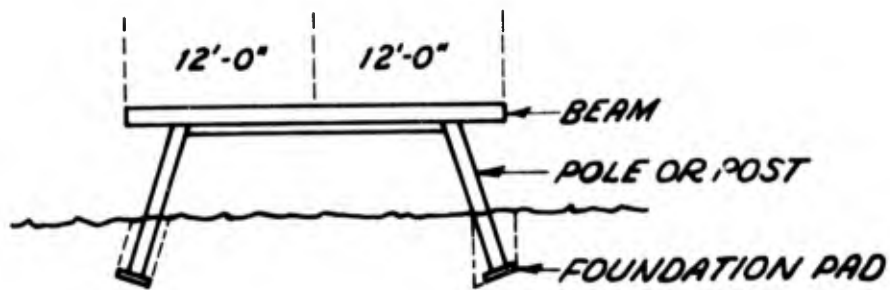
The use of leveling beams or ribbon plates (Figure 7) is necessary since the driving process will generally require that the top posts be cut due to brooming or inability to drive the post to the required depth, or be exactly vertical. The cut surface should be painted because studies have shown that painting increases service life.

Alternative post-with-leveling-beam schemes may be developed. Figure 21¹¹ indicates such an alternative.

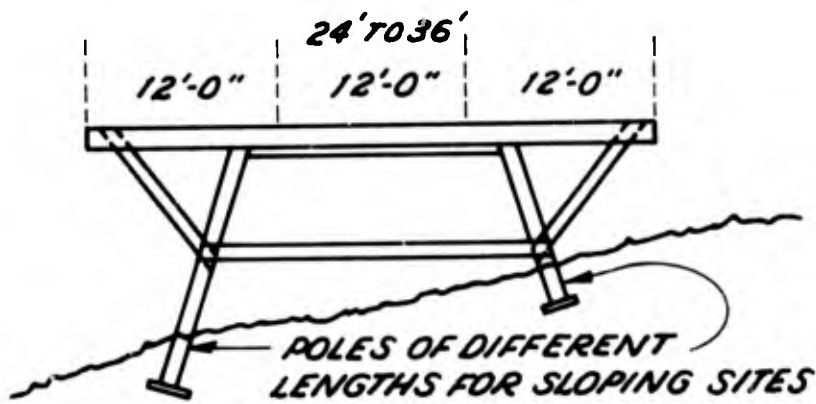
A post foundation has several advantages:

1. Reduction of site preparation--especially on sloping ground.
2. Rapid installation.
3. Where frost depth is 4 to 5 ft posts can be driven to below frost penetration when the ground is frost free.
4. Weather is not a factor as long as ground is not frozen.
5. Effective to control uplift and overturning of lightweight structures, especially mobile homes.
6. Removal cost is minimum.
7. Relative ease in releveling a structure in the event of settlement since a crawl space is always beneath the structure.

¹¹J. E. Bowles, *Engineering Properties of Soils and Their Measurement* (McGraw-Hill Book Co., 1970), p 189.



(a) STANDARD FOUNDATION BENT FOR 24 FT. WIDE HOUSE.



(b) EXTENDED FOUNDATION BENT FOR HOUSES UP TO 36 FT. WIDE.

Figure 21. Foundation bent using pole-and-beam construction.

The fact that wood posts cannot be driven in soil where large stones will be encountered appears to be a principal disadvantage. This type foundation structure may require skirting around the dwelling perimeter to reduce heat loss in colder climates or to improve appearance of the structure.

Other Post Foundations. Two other post-type foundation schemes will be considered. These two foundation types may be used in conjunction with Type IV slabs on overlying soils subject to large volume changes as well as with conventional wood framing utilizing a crawl space beneath the dwelling unit.

One of these foundation schemes has been reported by Parcher and Means¹² and earlier by Means¹³ and Dawson¹⁴. This consists of drilling a shaft to a depth below the potential zone of volume change, belling the base and casting an in-place pier or post. The belled portion is to resist the uplift forces developed as the soil expands. Various methods may be used to reduce the uplift force on the shaft such as casting a small pier shaft or casting it smaller than the drilled shaft hole. Post depths may range from 10 to 30 ft (3 to 9 m) for this type solution.

The second scheme has been reported by Donaldson¹⁵. This method consists of using small diameter steel rods or pipes containing 1 to 1 1/2 sq in. of steel area and a length of 6 to 12 ft. Loads for these members is limited to a maximum of 8 to 12 kips in compression and pullout forces may be on the order of 4 to 8 kips. Actual load capacities must be determined by a load test and may be quite small in some soils. The shaft is made small to reduce the forces developed during soil volume changes. The rods reported in the cited reference were driven with Standard Penetration Test equipment. The problem of corrosion was not considered in the cited references.

¹²J. V. Parcher and R. E. Means, *Soil Mechanics and Foundation* (Charles Merrill Publishing Co., 1968), p 573.

¹³R. E. Means, "Buildings on Expansive Clay," *Proceedings, First Soil Mechanics Conference: Theoretical and Practical Treatment of Expansive Soil* (Colorado School of Mines, 1959), pp 1-31.

¹⁴R. F. Dawson, "Modern Practices Used in Design of Foundations for Structures on Expansive Soils," *Proceedings, First Soil Mechanics Conference: Theoretical Practical Treatment of Expansive Soil* (Colorado School of Mines, 1959), pp 66-88.

¹⁵G. W. Donaldson, "The Use of Small Diameter Piles in Expansive Soil," *Proceedings, Fourth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Vol 1* (1967), pp 249-252.

Deep Foundations. Piles may be necessary to support family dwelling units in areas where the top several feet of soil are very low bearing capacity and/or the water table is very near the ground surface. Many coastal or delta housing areas may require piles. The piles may extend above ground several feet so that the dwelling may be supported entirely off the ground. This type of construction is particularly applicable in coastal areas where hurricanes may inundate the area.

Piles are the most expensive type of foundation and will be required only in areas of poor soil and adverse ground/surface conditions; this selection is based on necessity and not as an alternative. For this reason, any further discussion of piles is omitted.

3 SITE FACTORS, SOIL ENGINEERING, AND FOUNDATION DESIGN

Introduction. Chapter 1 outlined the general problem and objectives. Chapter 2 described the various possible foundation systems. This chapter will discuss factors which can eliminate certain types of foundation systems. Among the several factors are: topography, drainage, physiography (geography, climate, etc.), and site soils.

An evaluation of existing, and preferably similar, structures at or near the site for settlement distress such as cracks, sticking doors and windows, and cracked plaster, may be most informative in determining if the site contains problem soils. In any case, the engineer responsible for the project should make a personal, on-site inspection to supplement the topographic maps and soil-boring information.

Topography. Site topography can be an important consideration in selecting an economical foundation system. Whether the site is level, gently rolling, or steep will give an indication of the amount of grading required and whether adequate drainage can be provided.

At this point a serious question must be answered by the engineer or designer, namely, how are the site preparation costs to be allocated to the project? For example, either a post, pad, or spot footing type foundation can be built on a hillside location, but skirting may be required in colder climates requiring minimal grading. For additional costs, a full or split-level type basement may be incorporated into the structure with excavation limited mostly to the basement. With some additional grading and footing excavation, continuous strip footings with interior pier-on-pad footings may be used. Finally, with considerable site grading, one may utilize slab-on-ground foundations in addition to the sub-structure systems previously cited; thus, a careful investigation of the site and cost allocations must be made when comparing various foundation system alternatives.

For comparative purposes a qualitative site description is the following:

- level - less than 1 percent grade across the development area
- rolling - between 1 and 4 percent grade across the development area
- hilly - greater than 4 percent grade across the development area.

Leveling a site where a 4 percent grade is parallel to the long dimension of the building could result in nearly 2 ft of fill on the low side if only fill is used to level the area. It should be noted that this small

amount of fill probably weighs more than the house--unfortunately the fill is not uniform, thus, settlement due to fill weight will most likely not be uniform.

Note that as site grading costs increase, excavation costs for any of the possible foundation alternatives decrease. An exception is the basement system in which the basement excavation may even increase if a side hill excavation is possible before the site is graded.

Where the site contains trees, it is desirable to limit cut and fill to a minimum to retain as many of the trees as possible. This ecological aspect may be an important factor in the foundation selection process.

Drainage. Requirements of FHA¹⁶ are that the ground level shall be at least 18 in. below the bottom of the floor joists and 12 in. below the bottoms of girders. To facilitate drainage FHA further requires that the interior ground level be higher than the exterior ground level so that water does not stand beneath the house.

In any case, site grading and landscaping should be such that all surface water drains away from the house. This will avoid the problem of erosion around foundation walls and footings in addition to eliminating wet or damp floors. In the case of homes with basements, draining surface water away from the house would aid in keeping the basement dry. In many instances where basements were wet initially, changing the draining pattern has resulted in removing the problem.

Removal of subsurface water, except as incidental to the tile drainage system around the footings of the basement dwellings, will not be considered a factor in an economic selection of foundation systems. Surface drainage provided by grading and landscaping may reduce subsurface water, but elaborate subsurface drainage facilities should be considered in the same context as pile foundations. Pile foundations may be required where subsurface water exists near the ground surface. Capillary water will be considered in the section on *Capillary Water and Soil Moisture Change*.

Physiography. Physiography is a description of features of the earth's surface to include both geologic and geographic features. Geological features would include items such as flood plains, valleys, coastal plains, deltas, marshes, desert areas, glacial deposits, and sand dunes.

Geographic features include both continental location, i.e., southeast, northeast, north central, southwestern parts of the United States, and corresponding locations on other continents. Geographic features would also include temperature and rainfall.

¹⁶*Minimum Property Standards for One and Two Living Units* (U. S. Government Printing Office, 1960).

Physiographic information can give some indication of types of soils to be expected such as residual soils in the southeast, glacial deposits across much of the northern tier of states, loess of soils in parts of the Midwest, and soils with large volume change potential in the Southwest.

Geographic location will give an indication of potential frost depth and permafrost zones and may aid in prediction of rainfall quantities, potential for earthquakes, hurricanes, and tornadoes.

A combination of physiographic and topographic data may indicate the possibilities of landslides and mudflows.

Site Soils. In order to obtain maximum economy in foundation selection the foundations should be designed on the basis of an engineering evaluation of soils at the development site.

The minimum amount of required soil information would be obtained from a number of soil borings on the site. The actual number of borings may be from one to three where the site is reasonably level and soil deposits are relatively uniform, to one per dwelling unit where there is considerable lateral soil and topographic variation. Where the soil deposits are extremely erratic, especially in the vertical direction, large numbers of borings will contribute little to the overall design except increase its cost.

These borings may be taken using power drilling equipment, but may also be augured using either portable gasoline-powered or hand augers, since for residential construction the borings will rarely extend over 15 to 20 ft in depth. The boring information will provide data for a soil profile. Soil samples collected from the borings are used to identify physical properties of the various layers of soils. The location of the water table should be determined if it is within a zone to influence the type of foundation.

Generally the soil tests would include natural moisture content w_n , liquid limit w_L and plastic w_p , and grain size analysis. The second and third tests are sufficient, together with a visual examination, to classify the soil in the Unified Classification System. (The Unified Soil Classification system should be used for classifying soil since this system is widely used by U. S. Government agencies such as FHA, Corps of Engineers, and Bureau of Reclamation, as well as most consulting foundation engineering firms. The Building Research Advisory Board also uses this system.)

Other soil test which may be required are: standard penetration test (SPT), unconfined or confined compression tests, consolidation test,

compaction and field density tests, shrinkage limit w_s , and permeability.

Natural Moisture Content. This measurement (w_N) may indicate the type or state of the soil. For example, dense soil at full saturation will have a lower water content than less dense soil. Clay soils which are saturated are normally considered consolidated if the natural moisture content is closer to the liquid than plastic limit. A normally consolidated soil is one in which the present overburden pressure is the greatest apparent pressure to which the soil has been subjected. Soils susceptible to volume change may shrink or swell if w_N is not at the shrinkage limit, and the further w_N is from w_s , the greater the amount of potential volume change. If the natural moisture content is less at lower depths in the soil mass but above the water table, this may be due to cohesive soil overlying the soil being tested. It may also be due to recent precipitation. The water content in the vicinity of the groundwater table may give an indication of the height of capillary rise.

Liquid (w_L) and Plastic (w_p) Limit Tests. These are consistency index tests useful in:

a. Identification of the minus No. 200 sieve fraction (clay and silt) of the soil mass. This fraction is identified as clay (CL, CH) silt (ML, MH) or organic (OL, OH) depending on whether the liquid limit is less than 50 percent (L) or greater than 50 percent (H). The organic description is based on odor and visual appearance of the material.

b. Estimation of volume change. This estimate is made based on the Plasticity Index ($I_p = w_L - w_p$) of the soil as shown in Table 4 from Holtz's paper on expansive clays.¹⁷ This estimation may be supplemented with shrinkage limit (w_s) tests to place a quantitative estimation of the amount of volume change to be expected. It is more important and easier to recognize that a potential for volume change exists than to attempt to quantify it, the latter may be nearly impossible.

Estimate of Consolidated Settlement. Consolidation settlements are a phenomena of fine-grained deposits which contain water. As the structure readjusts under load the readjustment displaces water from soil voids. Settlement cannot be accomplished until the displaced water reaches equilibrium. The time to reach equilibrium depends on whether the soil mass is saturated and/or how far the displaced water must flow.

¹⁷W. G. Holtz, "Expansive Clays--Properties and Problems," *Proceedings, First Soil Mechanics Conference: Theoretical and Practical Treatment of Expansive Soil* (Colorado School of Mines, 1959), pp 89-126.

Table 4

Soil Data for Making Estimates of Probable
Volume Change for Expansive Materials.

Data from index tests*				
Colloid content (% minus 0.001 mm)	Plasticity index	Shrinkage limit (%)	Probable expansion** of total volume change (dry to saturated condition)	Degree of expansion
>28	>35	<11	>30	Very high
20-31	25-41	7-12	20-30	High
13-23	15-28	10-16	10-20	Medium
<15	<18	>15	<10	Low

*All three index tests should be considered in estimating expansive properties.

**Based on a vertical loading of 1.0 psi.

An estimate for the time required for consolidation is not reliable when the soil is saturated. The estimate is even less reliable when the soil is non-saturated.

The amount of consolidation settlement (S) can be computed using an equation in the form

$$S = \frac{C_c H}{1 + e_0} \text{Log} \frac{P_0 + \Delta P}{P_0} \quad [\text{Eq 1}]$$

where C_c = compression index

H = thickness of stratum

e_0 = in-situ void ratio

P_0 = average overburden pressure in thickness H

P'_0 = preconsolidation pressure at same location as P_0
(and for normally consolidated soils $P'_0 = P_0$)

ΔP = average change in pressure throughout stratum due to surface loadings (building, fill, water table drawdown, etc.)

The term C_c may be obtained from a consolidation test or estimated as

$$C_c = a(w_L - b) \quad [\text{Eq 2}]$$

where a and b are coefficients which depend upon the clay characteristics. Terzaghi and Peck¹⁸ recommended

$$a = .009$$

$$b = 10$$

for clays of medium to low sensitivity as found in large areas of the Midwest. The reliability of Eq 2 is on the order of ± 30 percent.

The liquidity index, I_w , is useful in estimating whether a saturated, cohesive soil is normally consolidated or preconsolidated. The liquidity index is defined as

$$I_w = \frac{w_L - w_N}{w_L - w_p} \quad [\text{Eq 3}]$$

If I_w is less than 0.5, the natural moisture is closer to the liquid than plastic limit and the soil is normally consolidated. If I_w is greater than 0.5 the natural moisture is closer to the plastic limit and the soil is probably preconsolidated. Thus soils with $I_w < 0.5$ are more likely to be settlement problems than soils of $I_w > 0.5$. If $I_w < 0$, the soil is in an unstable state. It should be noted, however, that Eq 3 is only applicable to cohesive soils below the water table, since the natural moisture content is a transient phenomena for soils above the water table.

Grain Size Analysis. This test is used to classify the soil in the Unified Classification System as either a coarse-grained (more than 50 percent retained in the No. 200 sieve) or a fine-grained soil as follows:

a. If more than 50 percent is retained on the No. 4 sieve the soil is a gravel (symbol G) and is

1. well or poorly graded if less than 5 percent passes the No. 200 sieve
Symbol: GW or GP
2. silty or clayey if more than 12 percent passes the No. 200 sieve
Symbol: GM or GC

b. If more than 50 percent passes the No. 4 and is retained on the No. 200 sieve the soil is a sand (symbol S) and is

¹⁸K. Terzaghi and R. B. Peck, *Soil Mechanics in Engineering Practice*, (John Wiley, 1967), p 729.

1. well or poorly graded if less than 5 percent passes the No. 200 sieve
Symbol: SW or SP
2. silty or clayey if more than 12 percent passes the No. 200 sieve
Symbol: SM or SC

c. If more than 50 percent of the soil passes the No. 200 sieve the soil is fine-grained and is a silt, clay, or organic soil depending on the liquid and plastic limit values and in case of organic soils, the odor and visual appearance

Symbols: ML, CL, OL
MH, CH, OH.

The grain size analysis is useful in indicating the coefficient of permeability and in identifying granular soil of relatively high-bearing capacity depending on the density, soils not susceptible to volume change, and soils which may be frost susceptible (more than about 10 percent silt sizes).

Standard Penetration Test (SPT). This test, routinely done as a part of the soil boring/exploration operation, consists of counting the blows (N) necessary to drive a standard 2-in. O.D. by 1 3/8-in. I. D. sampler 12 in. using 140 lb drive weight falling 30 in.

This test is widely used in cohesionless soils to indicate relative density and bearing capacity (Table 5). The allowable bearing capacity can be approximated in cohesionless soils using the standard penetration number, N, and footing width B as

$$q_a = 1.2(N - 3)\left(\frac{B + 1}{2B}\right)^2 \quad [\text{Eq 4}]$$

where q_a is in kips/sq ft. Sometimes N is corrected for depth effects, however, for residential construction this may be an unwarranted refinement.

The SPT test is also used in cohesive soils, but is somewhat less reliable. If the soil sample recovered from the boring is not too damaged, an unconfined compression test can be performed to supplement the penetration number N (Table 6).

Where cohesive soil samples removed by the standard penetration test sampler are excessively disturbed, thin-walled tube samples may be obtained for strength testing.

Unconfined Compression Test. This test evaluates the shear strength of cohesive soils. The test compresses a cylindrical soil specimen with a length/diameter ratio somewhat greater than two and computes the failure stress, q_u .

Table 5

Relative Density and Penetration Number for Cohesionless Soils

Description	Very Loose	Loose	Medium	Dense	Very Dense
Field Identification	as dumped from truck	easily shoveled	shovel with some difficulty	may require pick to loosen	
Penetration No. N		4	10	30	50
Relative Density	0	.15	.35	.65	.85 1.00
Approx. ϕ angle of internal friction, ϕ	25-30	27-32	30-35	35-40	38-43
Moist	70-100	90-115	110-130	110-140	130-150

Table 6

Consistency versus Strength of Cohesive Soils in Lieu of Unconfined Compression Tests

Consistency	q_u , ksf	Approximate Field Ident.	N Blows/ft
Very soft	0.5	sags under weight	0-1
Soft	.50-1.0	very easily indented between thumb and finger	2-4
Firm	1.0-2.0	easily indented between thumb and finger	5-8
Stiff	2.0-4.0	considerable effort to indent with fingers	9-15
Very stiff	4.0-8.0	very considerable effort to indent with fingers	16-30
Hard	>8.0	cannot be indented with fingers	>30

The cohesion (c) of the soil is taken as

$$c = q_u/2$$

and insertion into the usual bearing capacity equation of the form

$$q_{ult} = 1.3cN_c + qN_q. \quad [\text{Eq 5}]$$

Using a safety factor of 3, $N_c = 5.74$, and $N_q = 1$ (assuming $\phi = 0^\circ$), the allowable soil pressure, q_a , is approximately

$$q_a = q_u. \quad [\text{Eq 6}]$$

Table 6 gives typical consistency-strength relationships which may be used in lieu of, or in conjunction with, unconfined compression tests.

Where the soil strength is less than 1000 psf, confined compression (triaxial tests) should be performed on carefully recovered thin-walled tube samples. When the soil strength is this low, a performance evaluation will consider pile foundation and extreme caution should be used so as not to eliminate other foundation systems in favor of this expensive alternative, when an additional expenditure of a few hundred dollars on soil engineering could make a profound difference in the selection.

Consolidation Test. This test is to obtain somewhat more refined values of the compression index (C_c) than the estimate obtained in Eq 2 from the liquid limit test. Data from a plot of void ratio versus log pressure will indicate whether the soil is normally consolidated or pre-consolidated. Preconsolidated soils are not likely to settle as much under new load conditions as normally consolidated soils. Time-versus-settlement data from this test can be used to estimate the time rate of settlement.

Ordinarily, family dwelling units of the type considered in this report are not likely to induce consolidation settlements unless the troublesome layer is located near the ground surface. Using the theory of elasticity, the load dissipation, with depth of footings, indicates that at a depth of about twice the footing width (least dimension) the pressure is about 0.1 of the contact pressure. With dwelling unit footings of sizes generally under 2 ft in width, the corresponding maximum influence depth will be under 5 ft, therefore, only shallow deposits are likely to be troublesome.

The consolidation problem is most likely to exist beneath fills where landscaping operations take place. Generally the loads will be larger and extend to greater depths due to large lateral dimensions of the fill so that footings either on, in, or beneath fills may undergo settlement--not from the structure weight but due to the fill weight. Thus, in fill zones or potential fill zones, borings will be needed to extend to greater depths to properly assess this problem.

Compaction and Field Density Test. Where fill is required in the building area, the fill should be placed in accordance with guidelines

given by BRAB.¹⁹ This criteria requires that compaction tests be performed on the soil or the several different soils making up the fill to obtain the maximum dry density and optimum moisture content. Where several soils are blended to make up the fill, a compaction test should be performed on the blended material. For this type construction the standard compaction test, ASTM D698-66T (American Society for Testing and Materials), will usually provide an adequate control density.

Field density tests should be performed to check the in-situ compacted density and water content of the fill at the time of the test. These control tests may be the widely used sand-cone or balloon density²⁰ methods or a nuclear method. If the fill sites are limited in area, the sand-cone and balloon methods may be preferable.

Shrinkage Limit. This test may be used as a supplement to the liquid and plastic limit test to better identify volume change potential.^{21, 22} The shrinkage limit is defined as that water content (at 100 percent saturation), below which no further volume change occurs. With this definition it follows that the smaller the shrinkage limit the more susceptible the soil to volume change and the smaller the amount of water required to affect a volume change.

It is difficult to quantify the amount of volume change to be expected directly from this test. A PVC meter was developed for the FHA as an aid in evaluating amount of volume change as well as expansion pressures. This device has received only limited acceptance, however, and an alternative procedure is to do the shrinkage limit test on several samples at different dry densities and plot a curve of dry density versus percent volume change. (The percent volume change and dry density can be computed for a particular test since known volumes and weight are available.) Extrapolation or interpolation to the field density would provide a volume indicative of the amount of volume change to be expected. The necessity for the plot is that the shrinkage limit test must start with a fully saturated soil because of the definition of the limit, often at a water content well above the liquid limit such that the soil is a viscous fluid.

Any predictions of the amount of field volume change from using a laboratory test in which the soil can expand and contract with little restriction are considerably in error (generally on the conservative side) due to field restrictions. In the field, normally the shrinkage and swell is primarily in the vertical direction. The building weight provides a surcharge effect and the soil provides its own surcharge on the soil at greater depths in the mass; both of these effects reduce swell potential of the soil mass.

¹⁹*Criteria for Compacted Fills* (National Academy of Sciences, 1965).

²⁰J. E. Bowles, *Engineering Properties of Soils and Their Measurements* (McGraw-Hill Book Co., 1970).

²¹Bowles, *Engineering Properties of Soils and Their Measurements*.

²²*Laboratory Soils Testing*, EM 1110-2-1906 (Department of the Army, 1965).

Permeability. Where dewatering or subsurface drainage is a problem, the coefficient of permeability of the soil may be required. Generally the solution of these problems would be part of the site development costs and rarely would this test be involved as a factor in a foundation selection scheme.

In the unlikely situation of building on a marshy site where considerable fill is used to elevate the site, permeability of the consolidating marsh deposit to estimate length of time involved for settlements to take place would most likely be determined from consolidation test data. If sand drains were used to speed the process of consolidation, it would not be necessary to determine permeability of the sand.

Capillary Water and Soil Moisture Change. Water will rise in a tube of diameter d to an approximate height of

$$h_c = \frac{4T \cos \alpha}{\gamma_w d} \quad [\text{Eq 7}]$$

where T = surface tension of water or approximately 0.075 gm/cm for soil-water temperature between 50 to 60°F

γ_w = unit weight of water

α = angle of intersection of surface film and conduit usually taken as 0°.

The interconnected soil voids form the capillary tube of diameter (d), which can be approximated as

$$d = 0.2D_{10}$$

where D_{10} is the approximate grain size diameter corresponding to the 10 percent finer soil fraction by weight from a sieve analysis.

Eq 7 indicates that water can rise considerably above the water table. Practically, it is doubtful if the capillary height ever exceeds 6 to 9 ft even over extended time spans. Capillary heights of 3 to 4 ft are common. The significance of the capillary height is that the soil has the potential for a degree of saturation (S) of 100 percent in this zone. If a slab-on-ground is within this zone it will become damp unless precautions are taken. These precautions include a vapor barrier of some waterproof material overlying a layer of coarse, granular material. The coarse, granular material is used to increase the effective soil pore diameter (d) of Eq 1, thus lowering the height of capillary rise. Care must be taken, however, that the capillary zone in the soil adjacent to the structure is not higher than that beneath the dwelling; the water will flow laterally in the zone below the height of capillary rise.

Where the dwelling unit encloses its perimeter or crawl space, or where a slab-on-ground is built either on the ground surface or as the basement floor, the upward flow of water vapor from the water table will

eventually saturate the soil beneath the slab or dwelling. In the case where the crawl space is enclosed, floor dampness is avoided by incorporating adequate ventilation with openings in the perimeter walls. A vapor barrier may be used either above soil or beneath the subfloor. Eventual soil saturation cannot be avoided beneath slabs-on-ground due to condensation of the water vapor flowing upward from the water table, but the floor can be kept dry by using a vapor barrier which keeps the water from contact with the bottom face of the slab.

Change in soil moisture beneath the structure can cause considerable volume change in soils susceptible to volume change. The problem is aggravated by the differential in moisture content from the perimeter to the interior of the structure as occurs during dry periods. Note that the phenomena of soil saturation beneath slabs will exist if there is a water table at any depth below the foundation unless an impervious material exists between the water table and foundation soil.

Frost Depth, Permafrost. In much of the United States ground freezing occurs during late fall through early spring. Ground freezing introduces two problems for consideration:

- a. Vertical and/or horizontal expansion of the soil as the pore water turns to ice and increases in volume.
- b. Melting of the top during thawing, but with underlying frozen material preventing drainage. This trapped water can cause a large decrease in soil support value.

Frost heave or expansion is caused by formation of ice in soil pores. The problem is magnified by upward flow of capillary water from the water table which increases ice crystals below the height of capillary rise by the continuous upward flow of water. Water vapor can contribute to the problem, but the principal factor in ice lens formation is capillary water.

Ice lenses tend to form primarily in finegrained soils where approximately 10 percent is between 0.074 and 0.002 mm silt sizes. It is necessary to have simultaneously, a soil which can support a significant height of capillary rise and one where the pores are large enough to transmit a significant quantity of water. Sand meets the second criteria but not the first; clay meets the first criteria but not the second.

The depth of frost penetration is a geographic factor over which the builder has no control. The best solution is to go below the frost zone. Figure 22 indicates approximate frost depths for the United States. Figure 22 was obtained by a post card survey of foundation practice in selected cities in the United States, plotting the frost depths being used and interpolating contours. Where a conflict between the map and local practice exists local practice should be followed. The amount of frost heave can be controlled by incorporating a water

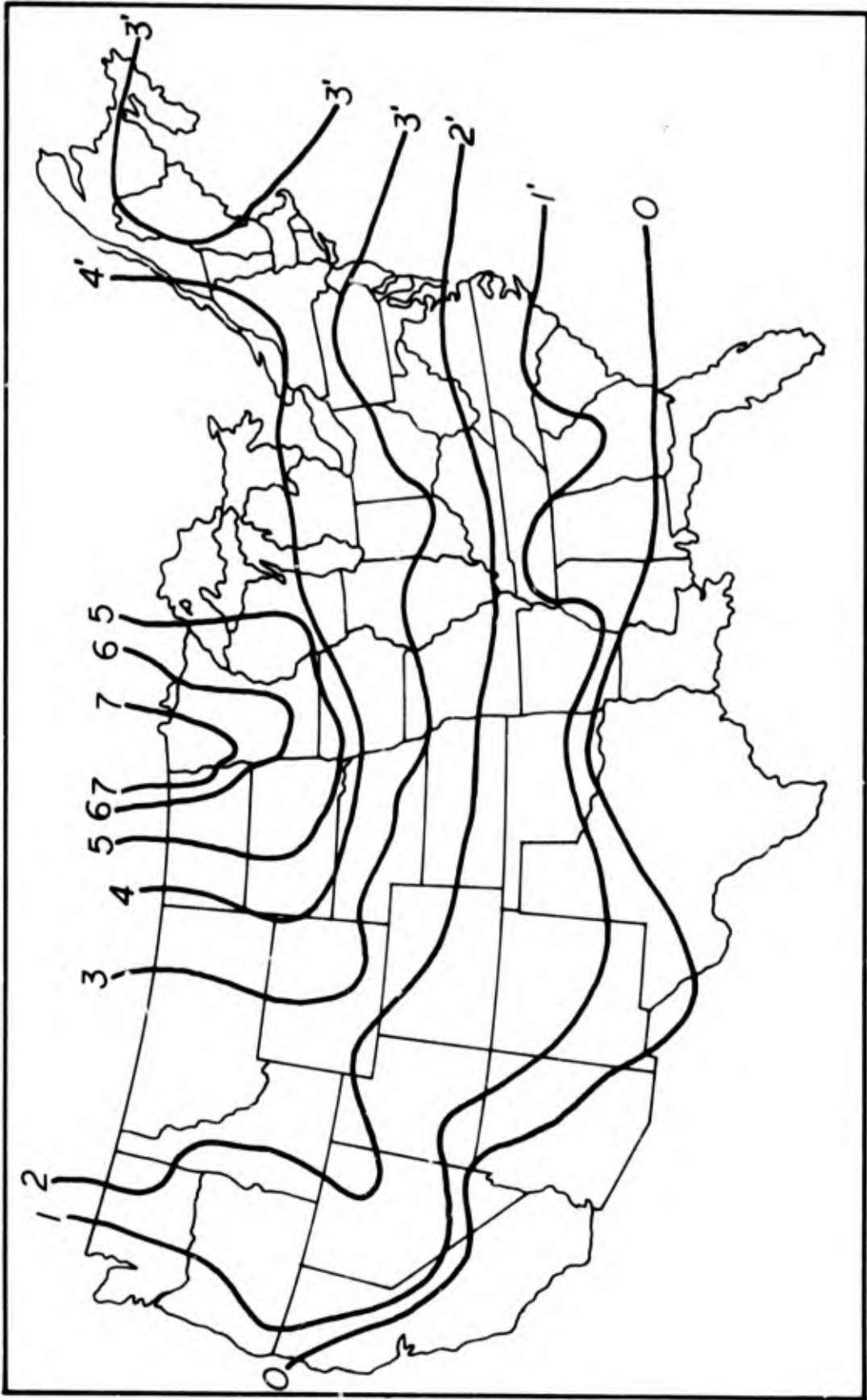


Figure 22. Approximate frost depth contours for the United States.

barrier between the water table and the depth of freezing so that an upward flow is not available to support the growth of large ice lenses.

Permafrost is a special condition of ground frost where the ground remains permanently frozen the year around. Permafrost exists in certain geographic areas (such as northern Canada, Alaska, Antarctica, Greenland, parts of Siberia). In many other areas the top several inches to several feet of soil annually thaw (termed the active layer) and refreeze.

Sandy or coarsegrained soils are not considered to be a problem in permafrost areas as they drain easily, have a low capillary rise, and only the pore water expands upon freezing. Since freezing water expands about 10 percent and soil grains make up much of the frozen mass, little heave is encountered. This material performs satisfactorily for building foundations. One solution in permafrost areas is to build up granular fill on top of the permafrost as an insulator, then construct the building.

When the soil is a silty sand, fine sand, or in general contains more than about 3 to 4 percent silt and has a water content above 30 percent, detrimental heave is possible. The situation is considerably aggravated if a water source is available to feed the ice crystals via capillary flow.

Designing Footings for Family Home Construction. Foundations for residential construction must be the same as for any other construction when considering bearing capacity and settlement. Two factors make the problem easier for major structures, namely, light unit loads on the soil and greater tolerance of soils to distortion. Table 7 may be used as a guide for tolerable allowable differential settlements in residential construction. If settlement at a point does not exceed the range of values shown for type of foundation, differential settlement can generally be tolerated.^{23, 24}

A 28 by 40 ft house with 1120 sq ft of plan area (no reduction in live load, 30 psf snow and no wind) would weight approximately:

	Aluminum siding	Brick veneer
Minimum, kips	90.5	127.5
Maximum, kips	117.4	153.3

²³J. E. Bowles, *Engineering Properties of Soils and Their Measurements* (McGraw-Hill Book Co., 1970).

²⁴R. F. Dawson, "Modern Practices Used in Design of Foundations for Structures on Expansive Soils," *Proceedings, First Soil Mechanics Conference: Theoretical and Practical Treatment of Expansive Soils* (Colorado School of Mines, 1959).

Table 7

Tolerable Differential Settlements of Buildings in Inches

Soil	Δ/L	<u>Spread Footings</u>		<u>Slabs</u>	
		1/200	1/400	1/200	1/400
Cohesionless		3	1 1/2	4	2
Cohesive		5	2 1/2	6	3

The following categorizes a house that weighs 80 to 150 kips:

Type	Load, psf
Life floor loads*	30 - 40
Dead loads	
Floor	6 - 10
Ceiling	4 - 8
Roof	3 - 6
Partitions	2 - 4
Wind**	15 - 20 either inward or outward on any surface
Snow***	20 - 30 horizontal projection
Exterior walls	
Brick (including wood sheating etc.)	40 (wall surface)
Standard wood with aluminum siding	6 - 7 (wall surface)

*Most building codes allow live load reductions when the live load is less than 100 psf if the room area is 150 sq ft or more by the least of the following percentages (but not less than 60 percent):

$$R = 0.08A$$

$$R = \frac{(DL + LL)(100)}{4.33LL}$$

Example: Room 15 x 12, DL incl snow = 45 psf, LL = 30 psf, A = 180 sq ft

$$R = .08(180) = 14 \%$$

$$R = \frac{(45 + 30)100}{4.33(30)}$$

$$R = \leq 60$$

Use 14 percent reduction since this is the smallest percent of the three. The reduced load is:

$$LL = 30(100 - 14) = 25.8$$

For family housing 0.084 usually controls.

**The Uniform Building Code varies wind from 15 to 20 psf depending on building height and geographic location.

***The Uniform Building Code allows as little as 12 psf snow load depending on roof slope.

The house perimeter is 136 ft and the resulting pressure, if all the load is carried by a perimeter wall footing, is between 0.7 kips per lineal ft (klf) and 1.1 klf, respectively for the minimum and maximum conditions above.

Most soils can easily carry footing loads as small as these with neither a bearing failure nor excessive settlements. This situation is considerably improved by the necessity of placing the footings in the ground below frost or seasonal volume changes. First, this puts the footings on firm ground taking care of both settlement and bearing capacity and, secondly, the bearing capacity generally increases with depth. Note that one key to the problem is firm ground, thus if excavations are accidentally carried too deep, they should be carefully backfilled and compacted. Should poured concrete footings be used, the excess excavated depth is left and backfilled with concrete.

It is because of small loads that the post foundation, generally with frame construction, can be made to work with relatively small numbers of posts required for support. Depending on the soil and post size, 16 to 30 posts may be adequate to carry the average small home.

With the lighter loads of frame construction a careful soil investigation will determine:

- a. That precast foundation walls might be placed in a trench on a prepared and compacted stone base without leveling blocks;
- b. That leveling blocks may be the only necessity for a building using precast wall construction;
- c. That pressure treated wooden sole plates (2 by 6 in. or 2 by 8 in.) can rest directly on a prepared and compacted stone base where wooden foundation walls are used (Figure 19);
- d. That a concrete strip footing may not be required beneath a masonry foundation wall if the first course of blocks can be adequately levelled.

Mat Foundations for Family Home Construction. Slab-on-ground foundations may be used on any flat ground surface although they may not be the most economical system. They may be a necessary alternative, however, where the soil is expansive. Table 8²⁵ lists the conditions for which various slab-on-ground foundations are recommended. It is self-evident that even under the most severe service conditions, i.e., where differential swell or settlement shrinkage has taken place such that only partial slab-to-ground contact is made, soil pressure will be low. Where partial slab contact exists the slab must bridge the voids and maintain structural integrity, thus, it may require rather massive ribs.

²⁵*Criteria for Selection and Design of Residential Slab-on-Ground* (National Academy of Sciences, 1968).

Table 8

Slab-Type Recommendations Based on Soil Type at Site and Climatic Rating from Figure 23

Soil Type*	Minimum Density** or PI or q_u	Climatic Rating	Recommended Slab Type
GW, GP	All Densities	ALL	I
GM, GC, SW, SP, SM, SC, ML, MH	Dense or medium dense	ALL	I
GM, GC, SW, SP, SM, SC, ML, MH	Loose	ALL	II***
CL, OL, CH OH	PI < 15 and $q_u/q_c \geq 7.5$	ALL	II
	PI > 15 and $q_u/q_c \geq 7.5$	$C_w > 45$ $C_w < 45$	II III
All q_u/w to q_u/q_c	$7.5 > q_u/q_c > 2.5$	ALL	III
	$q_u/q_c < 2.5$	ALL	IV
Pt	ALL	ALL	IV

*As classified under the Unified Soil Classification System.

**Unconfined compression strength of undisturbed sample.

***Type I slab may be used if soil is densified by compaction to a depth-slab width.

Figure 23 presents climatic ratings developed for use with Table 8. This rating system takes a $C_w = 45$ or above ideal, that is, small variation in normal precipitation and dry periods, generally under 4 weeks. The poorest climatic rating C_w is 15 for large variations in precipitation and quite long drought periods; $C_w = 15$ applies to the lower Southwest and $C_w = 45$ defines the northeastern states and a small part of the upper Northwest. The rest of the United States lies in climatic ratings between these two extremes. Where soil is susceptible to volume change, the largest volume changes will be caused by a long dry or wet period followed by a wet or dry period (see *Capillary Water and Soil Moisture Change*). Generally when the plasticity index I_p is less than 15, the volume change is not very critical if the average actual soil pressure ($q_c = DL + LL$) to q_u ratio

is

$$q_u/q_c \geq 7.5.$$

$\overline{A}_{\text{foot}}$

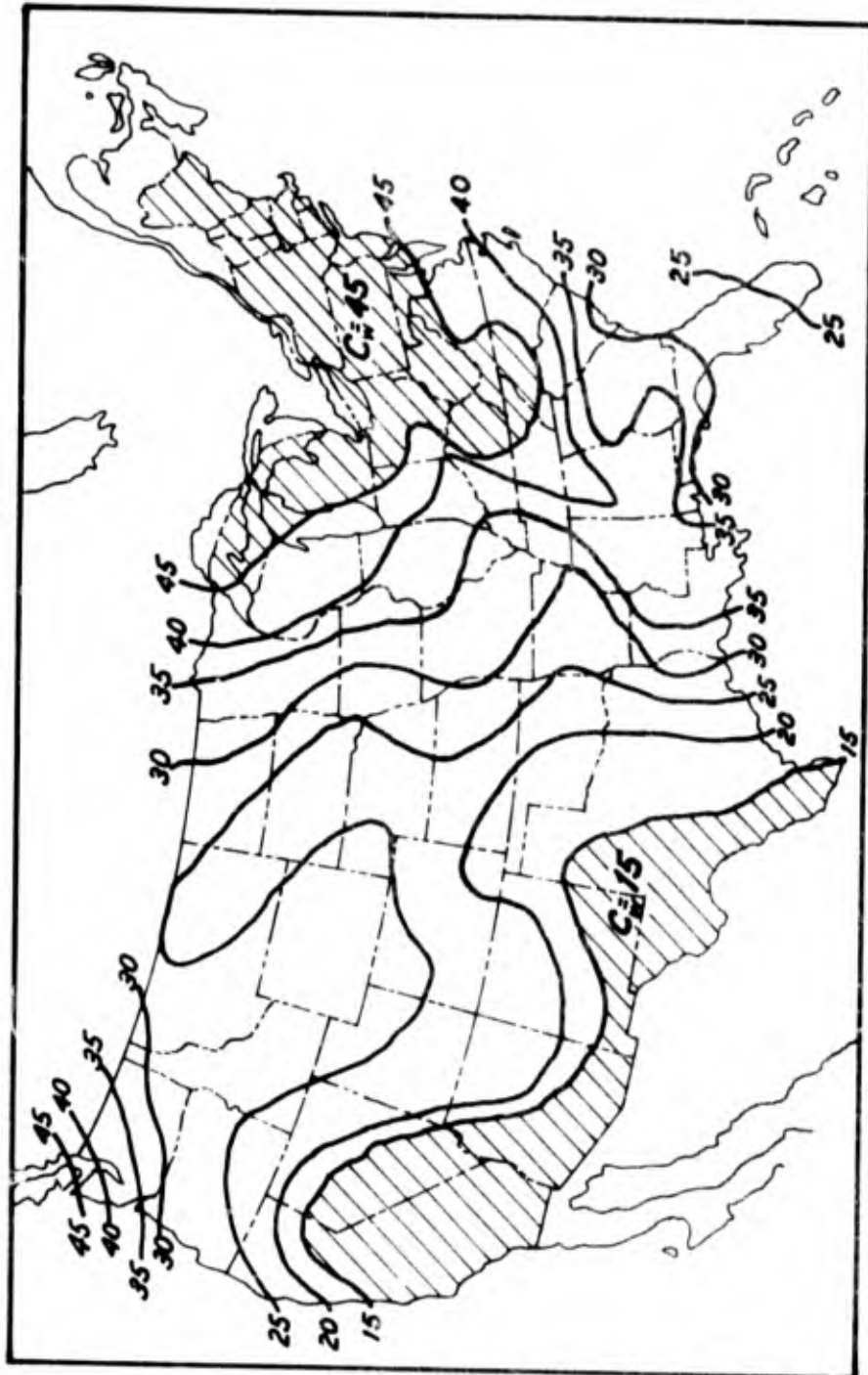


Figure 23. Climatic ratings (C_w) for the United States.

This condition allows the use of Type II slabs.

Type II slabs can be used for soils more susceptible to volume change ($I_p > 15$) if $C_c > 45$ and the ratio $q_u/q_c \geq 7.5$. Type III slabs are recommended if $C_w < 45$ for $I_p > 15$ even though $q_u/q_c \geq 7.5$.

If the soil strength q_u is such that

$$7.5 > q_u/q_c > 2.5$$

regardless of the values of I_p and C_w , a Type III slab is recommended. If the soil strength to load ratio is

$$q_u/q_c \leq 2.5$$

a Type IV slab is recommended. These slabs are illustrated in Figures 14 through 16.

It has been found that soil volume change can be reduced by forcing the soil to expand laterally rather than vertically or by applying sufficient load to confine the expansion. The structural configuration of the Type III and IV slabs is such that ribs or beams carry the total load. This results in a higher intensity of pressure beneath the ribs. With voids on either side and a high intensity of pressure beneath the rib, the wet soil can flow up along either side of the rib with total vertical movement greatly reduced.

Structural design of the Type III and IV slabs using the BRAB method also involves using the climatic rating. The rating is used with volume change data to compute a support index. The support index relates to the amount of mat area estimated to be in contact with the soil when volume changes occur. Structural design of the slab-on-ground foundation is beyond the scope of this report.

Wind Loads. Wind is seldom a problem in residential home construction. Usual construction practices in a given area should be adequate to insure proper lateral support for the superstructure. New methods, especially in prefabricated or modular construction, may require that the builder specifically provide for attaching the superstructure to the foundation.

Mobile homes may require additional anchorage since they are much lighter in total weight even though the weight per square foot may be nearly equal.

Records indicate that overturning or sliding off the foundations does not occur for residential dwellings except in the paths of hurricanes and tornadoes. Figures 24 and 25 illustrate typical methods of anchoring the superstructure to the foundation.

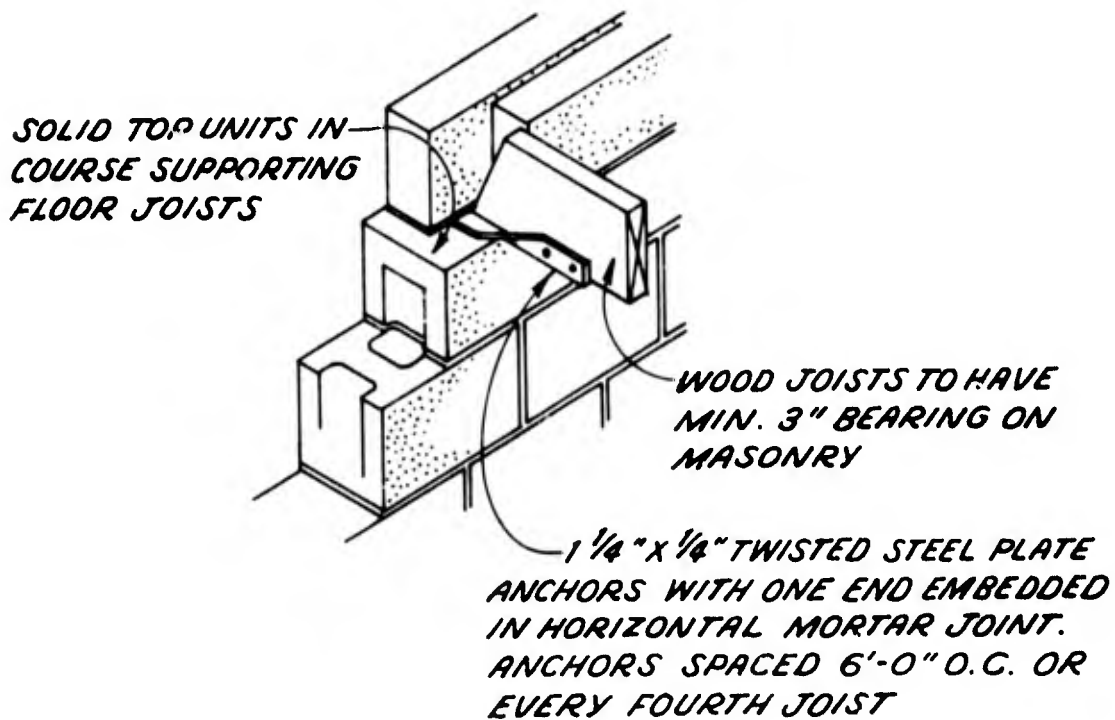
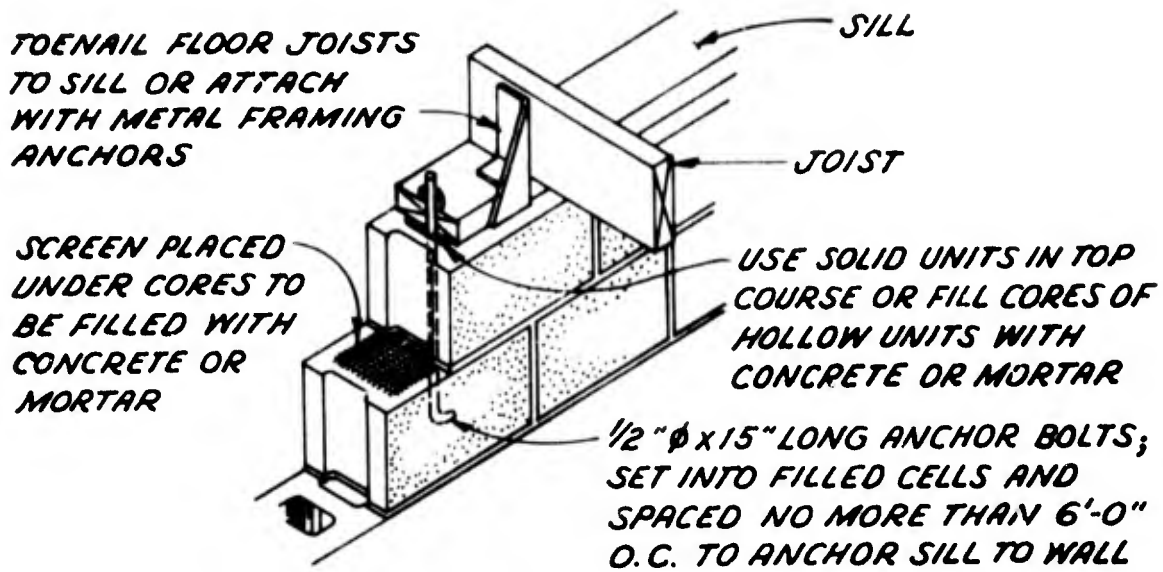


Figure 25. Typical anchorage details for attaching superstructure to concrete block masonry foundation walls.

The FHA²⁶ requires that buildings be designed for at least 20 lbs/sq ft wind load on the gross area of vertical projection for overturning or racking. In hurricane areas a wind load of 30 lb/sq ft may be used. Since single family housing units are relatively low structures, 20 lb/sq ft is probably adequate.

Settlements. Soil settlements are of two general types. Those which occur over a long period of time are consolidation settlements for which Eq 1 is applicable. Those which occur immediately upon applying the load are termed immediate.

Immediate settlements are computed as:

$$S_i = q_c B \frac{1 - \mu^2}{E_s} \psi \quad [\text{Eq 8}]$$

where q_c = contact pressure, kips/sq ft

B = footing width, ft

μ = Poisson's ratio (range of 0 to 0.5 and usually between 0.2 and 0.35)

E_s = stress-strain modulus (Modulus or Elasticity), kips/sq ft

ψ = shape of factor; $\psi=0.88$ for round; 0.82 for square; 1.06 for rectangle of $L/B = 1.5$ to 3.5 for continuous strip. These values are for rigid footings. Flexible footings are some 7 percent larger than rigid footing values.

For housing units, Eq 8 may be applied, using stress-strain data from an unconfined or confined compression test to obtain E_s . Most of the settlements which occur using this type of equation will be built out of the structure as construction proceeds and the building weight is added. Under this situation Eq 8 will overestimate the settlement and is not recommended for normal use.

Immediate settlements due to fill made prior to construction of the housing unit will have already occurred prior to construction. Immediate settlements due to fill placed after the structure has been built, as for backfill around basements, landscaping, etc., may cause detrimental settlements unless this is considered in the site design.

Most of the consolidation settlement will occur sometime after the structure is built. Eq 1 may be used to estimate the amount of this settlement. When using Eq 1 due consideration must be made for soil loading caused by cut-and-fill operations as these may be, and often are the principal loads causing consolidation settlement.

²⁶ *Minimum Property Standards for One and Two Living Units* (U. S. Government Printing Office, 1960).

Subsidence of earth fill placed without compaction control is a vertical movement of the mass as it consolidates under its self weight. This movement will be relatively independent of building loads--though the building load may increase the amount. Where buildings are placed on a fill, settlement due to subsidence as the material consolidates is of major importance. This movement will occur more rapidly than consolidation settlements, but, in general, is not rapid enough to be complete prior to building the structure. The magnitude of these settlements cannot be estimated by using either Eq 1 or Eq 8. The only way this problem can be solved or controlled is to:

- a. Place the fill several years prior to construction of the dwelling unit. This will also reduce consolidation settlements of the underlying soil when the building is later constructed;
- or
- b. Place the fill using careful compaction control. "Criteria for Compacted Fills"²⁷ may be consulted as a guide for the placement of compacted fills.

Summary. This chapter has presented site, soil exploration, soil testing, and other factors which may require consideration in the foundation selection process for a housing development project. Table 9 summarizes the principal factors to be considered for the foundation, site, and site soil interaction. This is a convenient check list to rapidly evaluate the site for problems that may require additional consultation with a soil specialist, additional field data, or more detailed laboratory testing.

Some foundation systems are incompatible with certain soils and site conditions. This information is summarized in Table 10.

²⁷*Criteria for Compacted Fills* (National Academy of Sciences, 1965).

Table 9
Check List for Influence of Site and Site Characteristics on Foundation Selection
(Refer to Key Below for Identification or Table Number Entries)

Site Characteristics	FOUNDATIONS		
	Post	Spread	Slab-on-Grade (all)
<u>Natural Ground</u>			
<u>Grading</u>			
level	-	-	1,2,3,4,5
rolling	-	-	1,2,3,4,5
rolling cut & fill	-	1,2,3,4,5	requires grading 1,2,3,4,5
hilly	-	-	1,2,3,4,5
hilly cut & fill	-	1,2,3,4,5	requires grading 1,2,3,4,5
<u>Ground Water</u>			
surface	-	requires temporary lowering	do not use
footing level	-	-	use perimeter drainage
below footing level	-	-	-
<u>Climate</u>			
	-	-	check C_w
<u>Soil Type</u>			
GM,GP,GM,GC	1,2	1,2	1,2
SW,SP,SM,SC			
ML,CL,OL	3,4,5	3,4,5	3,4,5
MH,CH,OH			

- KEY**
1. Compaction control - increase density if required, use compaction control in fills.
 2. Check relative density of cohesionless (GM,GP,SM,SP) soils; generally based on standard penetration test number.
 3. Use unconfined compression strength, q_u to estimate bearing capacity and for stress ratios for slab design.
 4. Check if settlement is a problem.
 5. Check liquidity index as indication of normally or preconsolidated clay; since based on natural moisture content w_N , may be transient value unless below water table.

Table 10

Possible Foundation Systems Based on Soil and Site Conditions

Type of Soil*	GW-GP	GM,GC,SW,SP,SM,ML,MH	CL,OL,CH,OH	Peat				
Soil Density, pcf	All	Dense to Medium Dense	Loose	- - - -				
Consistency	-	-	-	Stiff to Hard	Soft to Very Soft	-		
Plasticity Index, I_p	-	-	-	<15	>15	<15	>15	-
Slab-on-Ground	yes	yes	yes	yes	yes	yes	yes	yes
Post Foundation	yes	yes	yes	yes	yes**	no	no	no
Strip Footing	yes	yes	yes***	yes	no	no	no	no
Piers on Pads	yes	yes	yes***	yes	no	no	no	no
Basement+	yes	yes	yes	yes	yes++	yes	yes++	yes

*Note that GM, GC, SM, SC soils are cohesive and the density is not a primary factor in footing selection

**Precautions will be necessary so that possible soil expansion does not damage structure.

***This foundation can be used for SW, SP soils if the loose material is densified.

+Select appropriate basement floor slab. Do not use basements if ground water table is 6 in. or more above basement floor.

++Basement walls will need protection against possible lateral soil expansion.

4 SUPERSTRUCTURE AND SUITABLE FOUNDATIONS

Introduction. When choosing a suitable type foundation for a structure, the designer is concerned not only with the performance of the foundation in relation to the earth and environment, but also with the superstructure interaction. The type of structure and the construction material utilized will determine the magnitude and distribution of the foundation load. The types of construction materials used will influence the maximum allowable settlement which can be tolerated.

It is expected that both new materials and construction methods will be proposed and/or used in the near future. Government efforts to develop low-cost housing have received considerable attention in recent years. In 1969, the Department of Housing and Urban Development (HUD) supported 22 industrialized (component, modular, and combinations of panel and modular) housing systems in "Operation Breakthrough." Private enterprise is also working on various systems.

Structural analysis and full-scale testing of family housing ranges from very limited to non-existent. However, Government concern for low-cost housing has encouraged much recent work, mainly in the private sector, in various designs which have been structurally tested. There has been considerable testing of structural components and a trend appears to be developing to increase the "engineering" of dwelling units. This work is either proprietary or is so recent that it has not been widely disseminated at present. Most current practices are based on accumulated practical experience, though it is expected that in the near future advantage will be taken of advances in engineering design and technology.

Superstructure Systems. The following construction systems are currently available in home construction:

Conventional

1. Frame (wood, metal)
2. Load bearing wall (brick, concrete)

Componentized

1. Components
2. Packaged or prefabricated
3. Shell

Modular

1. Sectional house
2. Sectional box
3. Sectional stuck-on
4. Mechanical cores

Mobile

1. Single-wide mobile home
2. Double-wide mobile home
3. Expandable mobile home

Conventional Housing. These are on-site constructed housing units built up from the basic building materials such as lumber and concrete blocks. Certain off-site prefabricated components such as pre-hung door and window units may be utilized. On occasion prefabricated components such as roof trusses and wall panels are used--generally built by the contractor at his own central plant or obtained from a local lumber company.

These housing units may be all wood frame, sometimes called post-and-beam construction, with wood exteriors. The wood exteriors may be wood siding, plank or plywood type, or shingles. Alternatively, the exterior may be metal or aluminum siding, either wood backed or plain, asbestos shingle siding, and brick or block veneer. Other exteriors may include stucco, stone, and imitation stone. In this type of construction the foundations would be one of the following:

- a. Strip footing, foundation wall of masonry or concrete and supplemented as necessary with interior piers and pads with either:
 1. A basement with Type I or II slab-on-ground
 2. Enclosed crawl space
- b. All piers and pads with either:
 1. Enclosed crawl space using skirting from sills to ground
 2. Open crawl space
- c. Post foundation with either:
 1. Enclosed crawl space
 2. Open crawl space
- d. Slab-on-ground:
 1. If Type I or II (depending on climatic rating and soil) uses perimeter wall footing and foundation wall
 2. If Type III or IV a ribbed (waffle) slab configuration
- e. Piles:
 1. Using grade beams
 2. Type IV slab.

Conventional housing may also take the form of concrete block or brick bearing walls and, depending on location, adobe, soil cement, or other

locally manufactured building blocks. This is termed load bearing wall construction, i.e., the wall starts on perimeter strip footing and is continuous to the roof line where rafters or roof trusses and ceiling joists carry roof and ceiling loads to the exterior walls. Interior partitions may be of either wood or exterior wall material. Foundations for these housing units would be one of the following:

- a. Strip footings with the exterior wall up to floor level as the foundation walls (this is necessary in order to make a realistic cost comparison) with either:
 1. Pier and pad interior footings if a wooden floor is framed into the exterior walls
 2. Type I or II slab-on-grade (depending on climatic rating and soil)
- b. Type III or IV slab-on-grade.

Soil pressure beneath strip footings carrying load bearing walls will be two to three times as great as for other siding materials due to the extra weight of the wall.

Componentized Construction. These structures are built from prefabricated components such as wall panels, roof trusses, partitions, and floor assemblies, as well as the preassembled window and door units. These several components are factory fabricated, identified, packaged, and transported to the building site. This construction system may also be one where the various parts, siding, studs, joists, rafters, etc., are factory precut, identified, bundled, and shipped to the site. If the entire building shell is factory cut, this is referred to as "shell home" construction.

The field erection crews then combine components to form the shell and basic structure. This flat panel or two-dimensional component system may occasionally include a modular unit such as a bathroom.

The major feature of component construction is that much of the field measuring and lumber cutting operation is transferred to the factory. Thus, the usual 16-in. to 24-in. on-center type construction practice used in conventional construction methods is retained (see section on *Superstructure Systems*).

Materials other than wood may be used in precast concrete walls and walls of sandwich construction. Sandwich construction uses wood, metal, or plastic skins with plastic or fiber fillers to improve strength, insulation, and sound proofing.

Foundation systems for this construction should be the same as for conventional housing. If the floor system is componentized, foundation tolerances will have to be more carefully controlled than in conventional on-site construction.

Modular Construction. Modules consist of box or three-dimensional units which are shipped preassembled to the development site. The required number of these units is placed into position, i.e., adjacent or stacked on the prepared foundation, and connected by on-site construction personnel.

A sectional house is formed if the units make the completed dwelling unit. Sometimes it is convenient to obtain those units with most of the mechanical equipment, such as bathrooms (mechanical cores), as a module and with most of the remainder of the dwelling unit being on-site construction.

These units must be of rigid enough construction to withstand transport from the factory to job site. This module rigidity will tend to reduce tolerable differential settlement of these dwelling units compared to post-and-beam construction.

Generally, foundations for these units must be more accurately aligned than post-and-beam construction. The foundation alternatives for these units would be the same as for conventional construction given in the previous section on *Superstructure Systems*.

Care must be taken to compare foundation systems on a legitimate basis. For example, if the module floor system is such that the unit is set in place on prepared supports then only the following are possible:

- a. Strip footings with perimeter walls, with or without interior piers.
- b. Isolated piers with pads and an open or enclosed crawl space.
- c. A post foundation with an open or enclosed crawl space.
- d. Piles with grade beams in soils susceptible to volume change.

In areas where soil is susceptible to volume change, the solution could also include Type III or Type IV slabs, but make-up of the module floor should be investigated to avoid the extra expense of a second floor system being used.

Note that where the module is lifted onto the foundation system it is not necessary to include floor joists, subfloor, etc., as part of the foundation system. If an economic analysis is made between both the foundation system and the superstructure alternatives there must be consideration of what constitutes the "foundation". Obviously, if the flooring is excluded in modular construction, but is included in conventional (post-and-beam) construction, the foundation of modular construction may cost much less than the alternative. The modular superstructure will cost more than conventional construction since it includes subfloor system costs.

Mobile Homes. A mobile home is a plant-manufactured living unit built to be towed to a designated site and set in place on a foundation. The unit

is entirely self-contained, requiring only electric, water, and sewage utilities. A gas connection may or may not be required since the unit may have its own propane gas system.

Mobile home ownership has increased considerably in recent years as a means of obtaining personal ownership of low-cost housing. There are different opinions about whether this is actually low-cost housing, however, there is little question that the initial purchase cost is generally less relative to other conventional houses. However, luxury mobile homes can be purchased costing well into middle-priced conventional housing. Part of the increase in luxury models is higher priced furniture since the mobile home costs generally reflect a furnished ready-to-live-in type housing.

These units come in sizes from 8 to 12 ft for small camping units, to 14 to 17 ft living units. The 12 and 14 ft wide units require special permits to be towed over public roads. Additionally two 12 ft wide units in certain models may be separately towed to a site and placed side-by-side on the foundation and securely attached to form a 24 ft wide living unit. Certain other units have provisions for a part of the length along one side to be expanded by simply pulling out the wall of a normally 10 or 12 ft wide unit to form 16 to 20 ft wide living areas.

Foundations for these units may consist of a few concrete blocks for blocking up the unit using a jack and an ordinary carpenter's level for alignment. Alternatively, six to 12 screw jacks are set on concrete blocks to level the unit and provide reasonable stability. In this case the jacks are left in place as foundation piers. Many mobile home parks pour concrete slabs, not considered slab-on-grade, on which the unit is parked.

To provide low-cost and/or temporary housing these mobile units may be permanently attached to foundations in a housing development. Permanent foundations would consist of:

- a. Strip footing with concrete masonry perimeter walls (interior piers not needed).
- b. Pier foundations with open or enclosed crawl space. Since a 14 by 70 mobile home would weigh, including a 30 psf snow load, about 50 kips, not more than 10 or 13 piers would be required. Skirting may be required to enclose the crawl space.
- c. Post foundation. Using 8 to 10 in. wood posts 5 to 6 ft long (3 to 4 ft in ground), about 16 to 26 would be required depending on mobile home size and soil (as measured by driving difficulty). Skirting may be required to enclose the crawl space.

Mobile home units are more vulnerable to lateral movement due to wind because of the small dead weight and the large surface area exposed to wind pressures; thus, provisions for wind anchorage should be provided if winds over about 50 MPH are expected. However, few private mobile home owners do this, simply taking a chance that the wind will not blow the unit off

the blocks or jacks. For post foundations this would entail attaching the unit to the posts. Where the units rest on masonry strip or pier footings, anchorage devices such as used by the electric power companies to anchor guy wires, can be used to provide wind anchorage. The cost of using these devices should be added to the masonry costs in evaluating foundation systems.

Structural Materials. The materials utilized in the construction of family housing affect the foundation in two ways. First, the load supported by the foundation is controlled by the weight of the materials utilized for the structure. This is known as the dead load, and is made up of elements such as the frame, walls, floors, ceiling, partitions, stairway, and insulation.

Secondly, the structural materials determine the amount of movement that can be withstood by the structure without suffering damage. Dwelling damage may be divided into two categories:

a. Structural or that which involves the frame.

b. Architectural, which involves the walls, floors, and finishes. The movement of principal concern is the differential settlement. Total settlement may be troublesome in a situation where the building moves vertically enough to collapse, requires ramps to effect entry, or damages the utility lines into the building. Differential settlements tend to warp the structure with the result that doors and windows stick and wall surfaces crack. In dwelling units the redistribution of load due to differential settlement generally does not result in a failure.

The allowable differential settlement is often expressed in terms of angular distortion as described by the difference in vertical movement between two points. This tacitly assumes a linear change in settlement between the two points measured. The actual differential settlement may not be linear between two measured points which have moved relative to each other. It is not practical to obtain the differential movement at every point between the end reference points. The angular distortion α , in terms of the differential movement (Δ) across a distance (L) in consistent units is

$$\alpha = \Delta/L. \quad [\text{Eq 9}]$$

Post-and-beam timber construction with external weather boards can accommodate comparatively large differential movements without structural damage. The maximum differential movement will be governed by the interior wall surfacing material such as plaster or wallboard. Sticking doors and windows are a nuisance, but they can easily be trimmed to fit. Sticking doors and windows may not be due to settlement. This is a phenomena also associated with periods of high humidity where the woodwork absorbs moisture and swells.

Wood is subject to termite damage (Figure 26) and precautions such as use of treated wood or termite shields may be necessary in areas subject to termite infestation.

NOTE: LINES DEFINING AREAS ARE APPROXIMATE ONLY. SEE LOCAL F. H. A. OFFICE FOR SPECIFIC AREAS. LOCAL CONDITIONS MAY BE MORE OR LESS SEVERE THAN INDICATED BY THE REGION CLASSIFICATION.

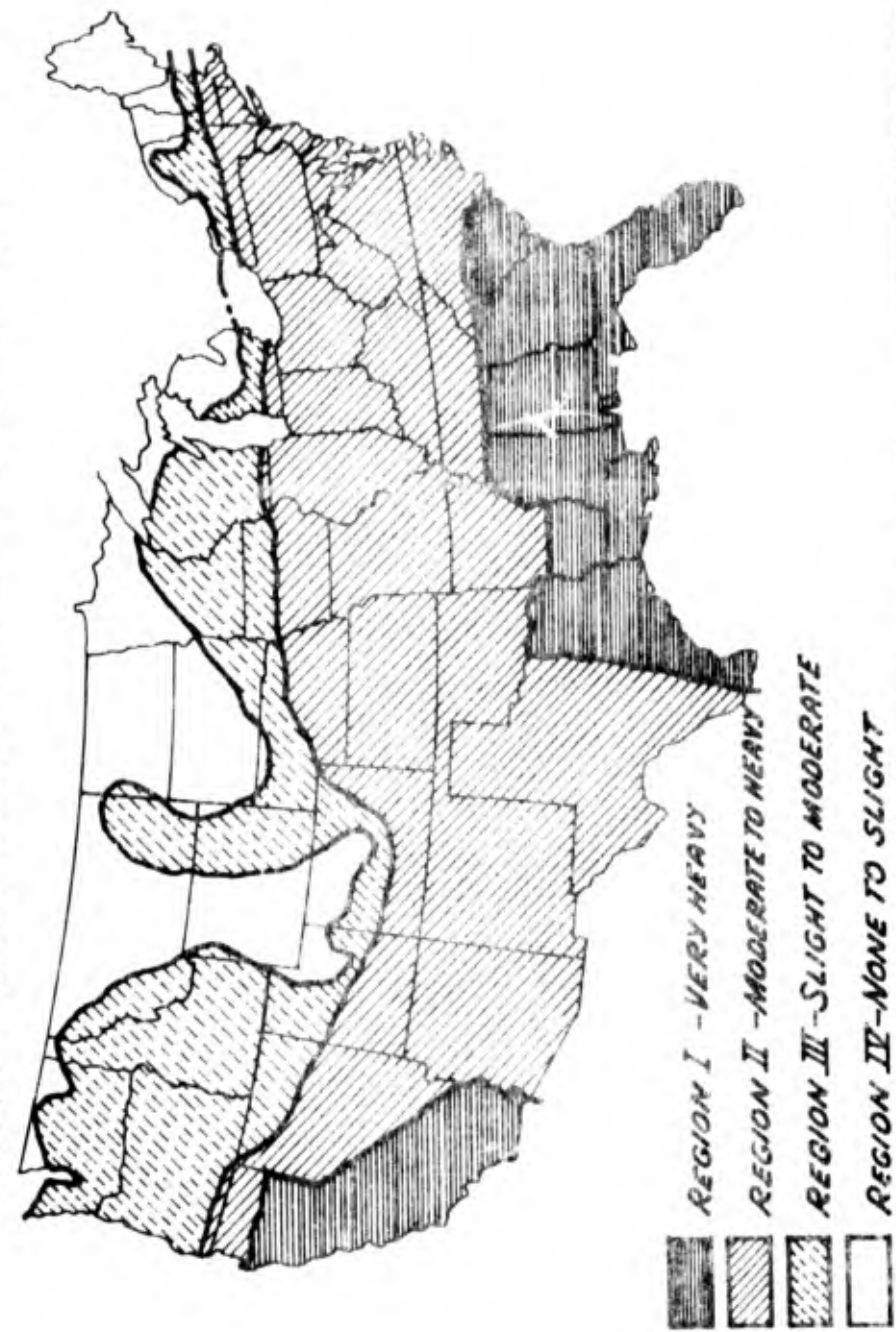


Figure 26. Geographic distribution of termite infestation.

The permissible differential settlement for various materials is given in Table 11.²⁸ If the superstructure contains one or more of the listed materials as an exposed finish, the most severe corresponding Δ/L ratio should apply. Table 11 should be used to supplement Table 7 which provides differential settlement values for the total structure.

Table 11

Permissible Differential Settlement for Foundations to
Minimize Damage to the Superstructure

Type of Construction (Materials Used)	Maximum Permissible Deflection (Ratio Δ/L)
Wood Frame	1/200
Unplastered Masonry or Gypsum (Wallboard)	1/300
Stucco, Plaster or Ceramic Tile	1/400

Structural Loads. The magnitude of the load which must be transmitted to the ground through the foundation is affected by the structural type, the construction material, and the live load. The soil must be capable of resisting all of the applied loads, generally vertical downward, but may be upward for post foundations in winds, or lateral components of loads on sloping sites. The basement walls must be capable of resisting lateral pressures of the soil and temporary hydrostatic pressures due to groundwater after rains.

The intensity of soil pressure generated by the building loads is more important than the magnitude of the load as described in the section entitled, *Designing Footings for Family Home Construction*. As shown in that section, soil pressure intensities for dwelling units can be expected to vary from about 200 to 1000 lbs/sq ft. Lower values are for wood construction, higher values are for load bearing wall construction.

The live loads on a structure consist of the weight of all moving and variable loads that may be placed in the dwelling unit including wind, and/or earthquake loads (Figure 27) which may act upon the structure.

Summary. The superstructure construction presently used in family housing is compatible with most foundation systems. This information is summarized in Table 12.

²⁸*Criteria for Selection and Design of Residential Slabs-on-Ground*
(National Academy of Sciences, 1968)

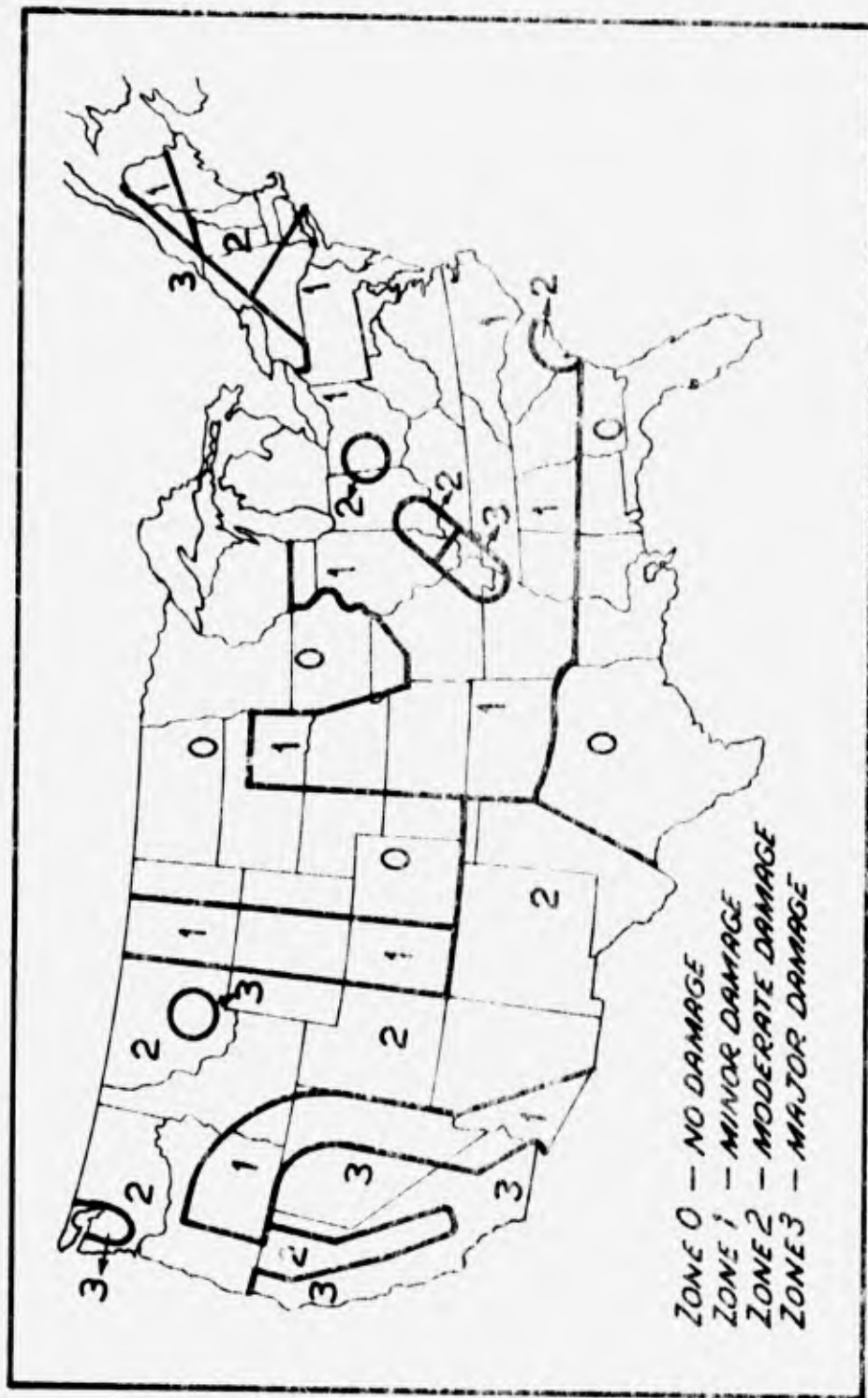


Figure 27. Zones of approximately equal seismic probability.

Table 12

Compatibility of Superstructure and Foundations Systems

Classification of Superstructure	Types of Foundation Systems				
	Post	Wall Strip	Individ. Piers	Slab-on-Grade	Basements
Conventional:					
Post-and-Beam	yes	yes	yes	yes	yes
Load Bearing Wall (any Masonry)	no	yes	no	yes	yes
Componentized					
Panels (wall units, etc)	yes	yes	yes	yes	yes
Wood					
Concrete	yes	yes	yes	yes	yes
Sandwich (not Conc)	yes	yes	yes	yes	yes
Other (shell, pre-packaged homes)	yes	yes	yes	yes	yes
Modular					
Wood frame	yes	yes	yes	yes	yes
Meta? frame	yes	yes	yes	yes	yes
Concrete	yes	yes	yes	yes	yes
Mobile					
	yes	yes	yes	no	no

5 FOUNDATION COSTS

Introduction. When one considers that almost any foundation system can be utilized at a site (see Table 10), it should be evident that cost is the primary factor in selecting a foundation system.

Considerations In Making Foundation Cost Estimates. Generally, to make valid comparisons of costs it will be necessary to limit the foundation elements to include, at most, the subflooring of the building. This may not be necessary depending on what the range of comparisons include and what types of systems are being compared. Consider the following examples:

a. Make a comparison of costs between a slab-on-ground and pier foundations. Solution: Include the subflooring for the pier foundations since the slab-on-ground will be the subfloor of that alternative.

b. Compare wall strip footings versus individual pier foundations. Solution: Use the subflooring as the cutoff. Although strictly this estimate could stop at the top of the piers or foundation wall, above that point the floor system for both alternatives is the same, including floor joists and subflooring.

c. Compare pier footings using conventional post-and-beam construction with the same foundation system using prefabricated modules. The modules will be brought to the site and set onto the piers. Solution: Here a particular difficulty arises in that the subfloor and floor joists must be incorporated into the structure on site for conventional construction where they are included in the base part of the prefabricated module units. For both systems, the estimate must include everything up to the tops of the piers.

Note whether a slab-on-ground foundation is also an alternative. With modular construction the cost comparison will be particularly difficult because the modules would rest directly on the concrete slab and normally would be prefabricated to eliminate floor joists and subflooring (or for economy should be). The conventional construction with piers would have to be estimated a second time to include subflooring costs for this latter comparison. These alternatives would require four cost estimates and some considerable judgement in making the economic evaluation.

d. Compare load bearing walls with strip footings with and without a basement and using, clear, unsupported floor spans. Solution: In both bases include the subflooring. A point of further consideration which will make the comparison difficult is how to compare unit costs since the floor area is twice as large with the basement. Since the basement area may not be used as much for living, but rather for storage and utilities, it might be questionable whether the floor area used to obtain unit costs should be twice that of the no-basement system or instead some factor, say, 1.60 to 1.75.

These four examples illustrate that the cost estimate will be considerably subjective. Each site and situation will have to be considered separately with any possible construction problems and site conditions peculiar to that site.

Foundation Cost Estimates. The foundation cost estimate is similar to other cost estimates. The various construction operations are considered and the cost of labor and materials is estimated. Obviously good cost data are essential for a valid construction estimate.

An estimate sheet should be used as a convenience in making orderly entries of items, dimensions, quantities, unit material and labor costs, and cost extensions. With the current widespread use of desktop electronic calculators, cost extensions should be carried to the nearest cent. Since this is an estimate, dollar fractions are for checking the extensions only and not for refinement in the cost estimates. Several cost estimate sheets are included in the Appendix (Figures A1 through A10).

The total cost of the foundation can be divided by the floor area, using exterior, overall dimensions, to obtain the unit cost of the foundation. Figure 28 illustrates a graphical display of unit costs for several foundations. Estimate sheets for part of the illustrated costs are included in Appendix A. In general, unit costs decline as the square footage increases for a basic foundation configuration, however, it would be expected that costs would approach an asymptote on either end of the cost curve.

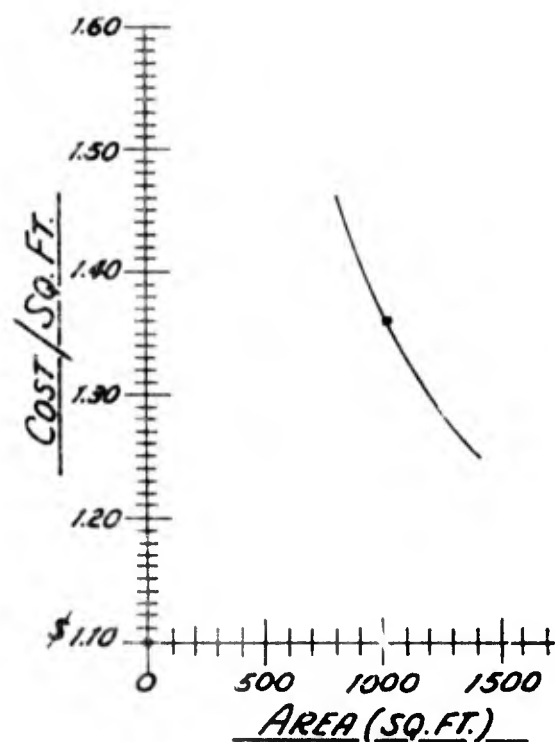
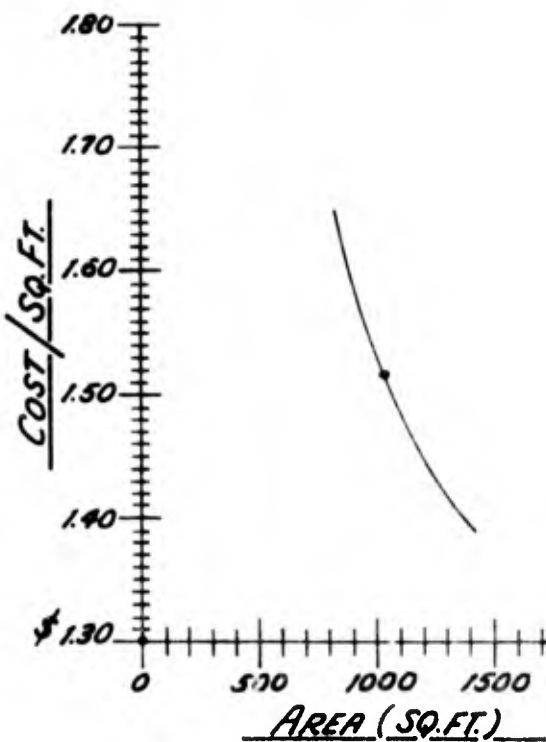
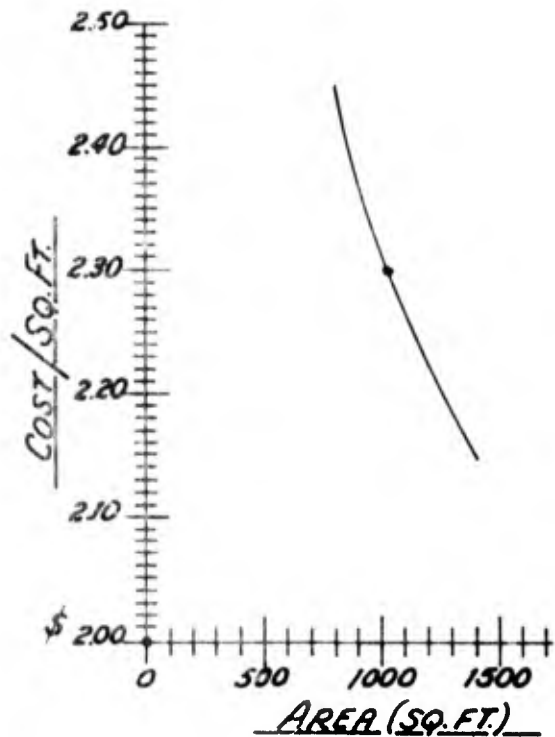
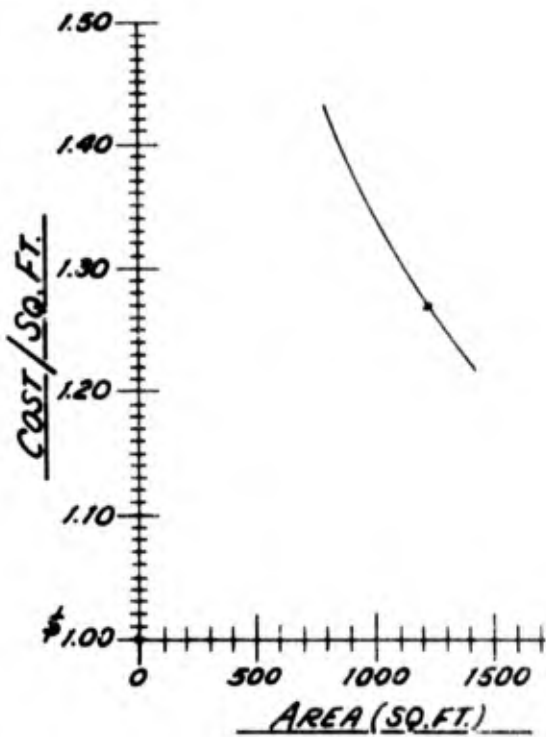


Figure 28. Cost versus floor area. The basic geometric shape of a rectangle is kept constant. Plotted points shown are from A1 through A4 in the Appendix.

APPENDIX A:

COST ESTIMATES

This section illustrates cost estimates for several foundations. These estimates are based on costs from the 1971 edition of *Building Construction Cost Data*²⁹. This was the latest available edition at the time this report was being written. These cost estimates are to be used as a guide and local conditions may require the inclusion of additional construction cost items.

In general one should accompany a cost estimate with a sketch of the principal geometric features of the foundation as illustrated in the five cost estimates displayed.

Note that data from Figures A1 through A4 are also plotted on Figure 28. The cost data for the remaining points used to plot Figure 28 are not included, but it involves making cost estimates of four rectangular structures (40 x 20, 38 x 27, 40 x 30, and 40 x 35 ft in plan).

²⁹R. S. Means, *Building Construction Cost Data* (R. S. Means Co., yearly revisions of costs).

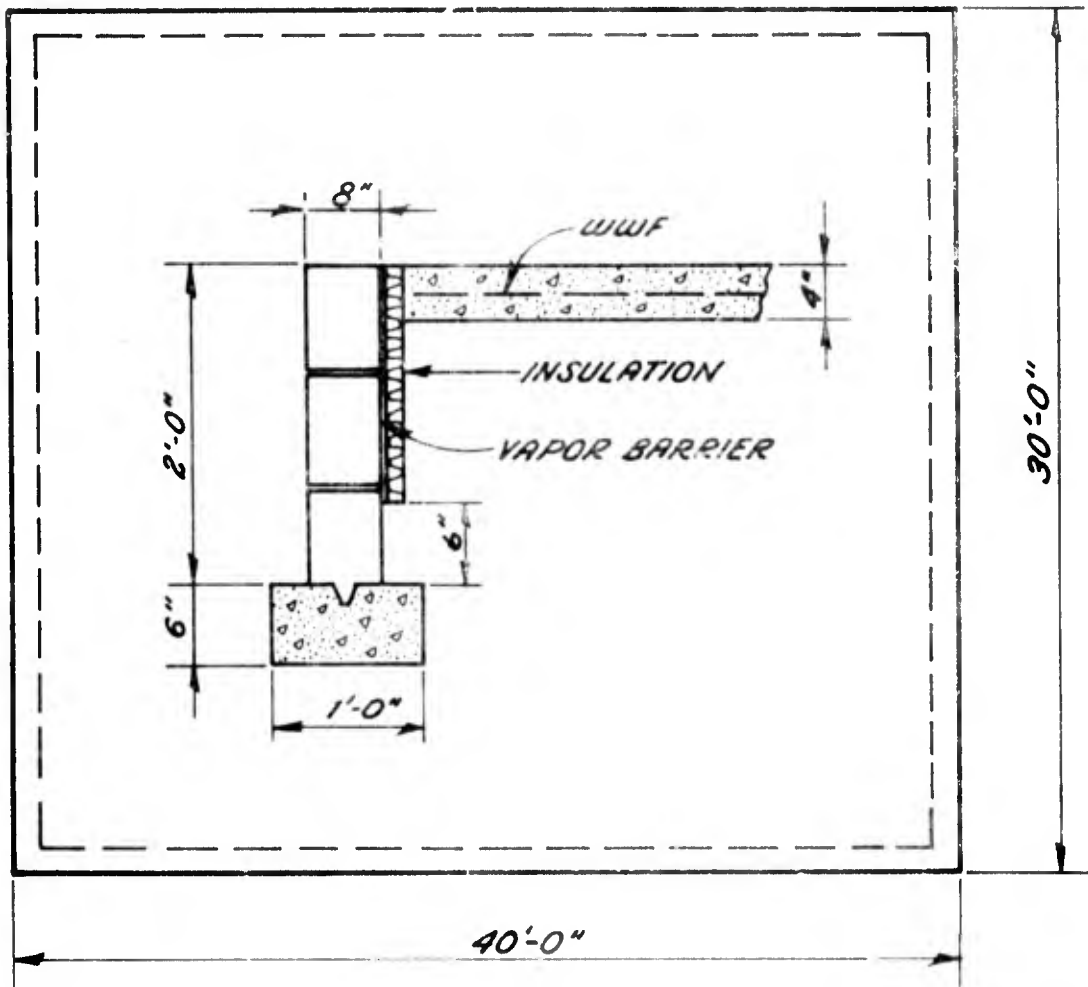


Figure A1. Foundation plan for general estimate sheet (Figure A2).

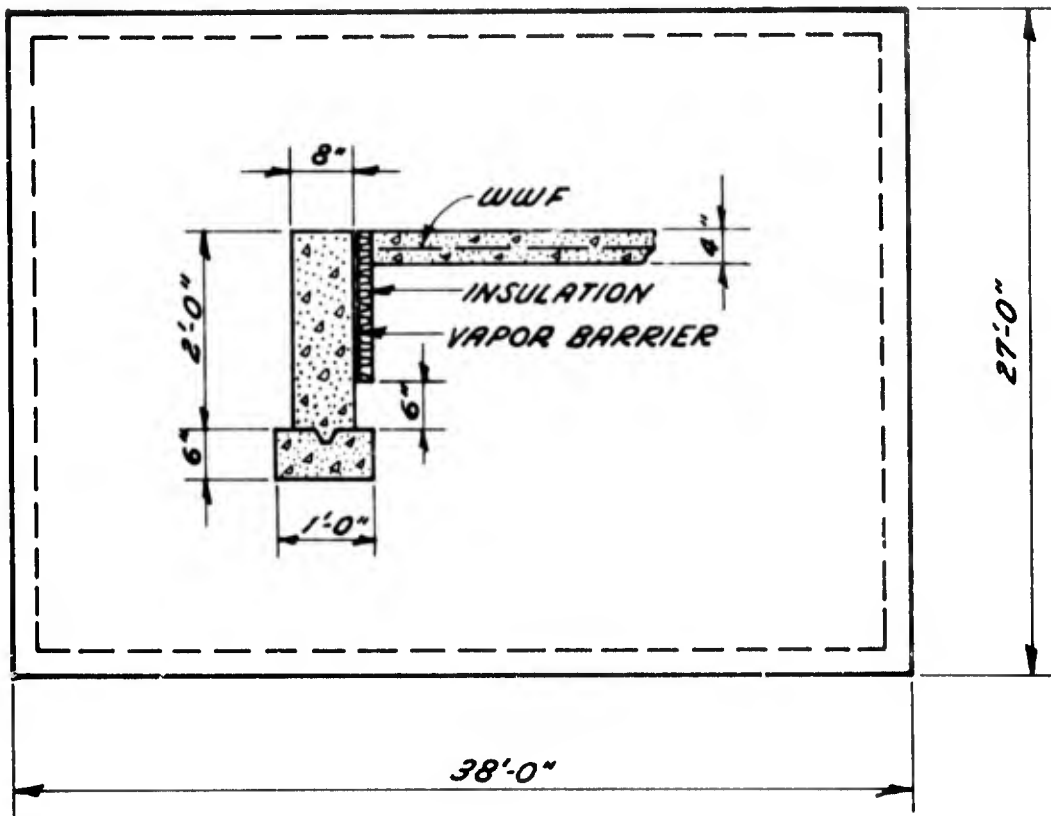


Figure A3. Foundation plan for general estimate sheet (Figure A4).

PROJECT DESCRIPTION Residence 3822'
Conc. Strip ftg, Conc. Found. wall
And TYPE II P. - slab, no termite

TOTAL PROJECT COST - \$1558.97
 COST/SQ FT - \$1.58

Description of Work	Quantity Units	Dimensions			Total Estimated Quantity	Unit Price Mat'l	Total Estimated Mat'l	Unit Price Labor	Total Estimated Labor	Total Estimated Labor & Material Cost
		L	W	D						
1 Dampproof flr slab										
6000' Polyeth	100 SF				10.76	3.35	33.35			33.35
2 Concrete 3500 psi										
Floor slab 4"	cy				12.0	21.00	272.00	5.00	65.00	338.00
Found Walls	cy				11.0	136.50	1501.50	2.25	24.75	160.25
Wall ftgs	cy				25	21.00	525.00	4.50	112.50	637.50
3 Reinf floor slab										
WWF	100 SF			(installed)	10.76	5.30	57.05			57.05
4 Insulation, Perim										
Walls, 1" Polysty	SF			(installed)	195	2.5	487.50			487.50
5 Excavation										
Wall	cy				19.3		76.06			76.06
Footings	cy				4.5	1.35	9.05			9.05
6 Gravel Backfill										
4" Compact (floor slab)	SF			(installed)	1026	1.4	1436.40			1436.40
7 Haul, 6 cy truck										
2 mi	cy				10	.80	8.00			8.00
8 Forms										
Wall (4 uses)	SFCA				520	.72	400.40			400.40
Footing (4 uses)	SFCA				120	.67	80.40			80.40
9 Travel Finish										
floor slab	SF				10.76			12	123.32	133.32
10 Backfill ftgs										
by hand	cy				5			3.25	16.25	16.25
backhoe	cy				.5	3.5	1.75			1.75
11 Fine Grade slab										
area	SF				114			20	211.00	211.00
Total =									\$	1558.97
Unit Cost =									$\frac{1558.97}{1026}$	\$1.58

Figure A4. General estimate sheet.

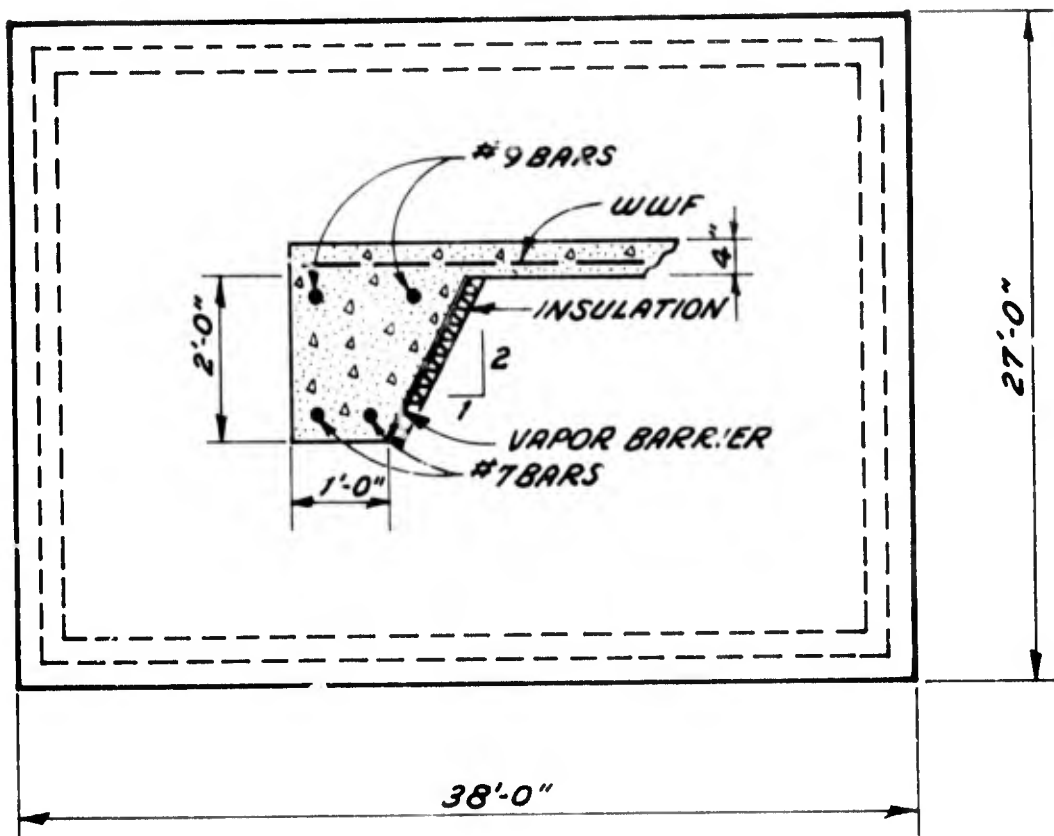


Figure A5. Foundation plan for general estimate sheet (Figure A6).

PROJECT DESCRIPTION Residence
no termites, 38x27' rectangle
Type II slab-on-grade

TOTAL PROJECT COST = \$1397.11
 COST/SQ FT = \$1.36

Description of Work	Quantity Units	Dimensions			Total Estimated Quantity	Unit Price Mat'l	Total Estimated Mat'l	Unit Price Labor	Total Estimated Labor	Total Estimated Labor & Material Cost
		L	W	D						
1. Waterproofing w/0.006" Polyeth	1026 SF				1026	3.25	333.35			333.35
2. Concrete slab 4" w/3500 PSI Conc	1026 SF				1026	2.71	2782.00	5.00	5130.00	3338.00
3. Conc. Perimeter footing	27 CY				145	2.10	304.50	3.25	87.75	358.85
4. Slab Reinf using WWF	1026 SF				1026	5.20	5335.20			5335.20
5. Insulation of Perim Footing 1" Polysty	513 SF				135	0.25	48.75			48.75
6. Footing Excav w/1/2 cy backhoe	27 CY				17.5	1.35	23.63			23.63
7. Gravel slab base 4" Compacted	1026 SF				1326	0.14	143.64			143.64
8. Hauling 2 mi w/6 cy truck	27 CY				10	0.80	8.00			8.00
9. Forms for wall footing (4 uses)	513 SF				200	0.22	200.00			200.00
10. Steel Trowel finish of slab	1026 SF				1026			0.13	133.38	133.38
11. Backfill Perim ftg trench (hand)	27 CY				5			3.25	16.25	16.25
12. Backfill Perim ftg trench/backhoe	27 CY				5	0.25	1.25			1.25
13. Fine Grade slab site	27 SF				114			0.30	34.20	34.20
Total =									\$1397.11	
					Unit Cost = $\frac{1397.11}{1026} = \$1.36/SF$					

Figure A6. General estimate sheet.

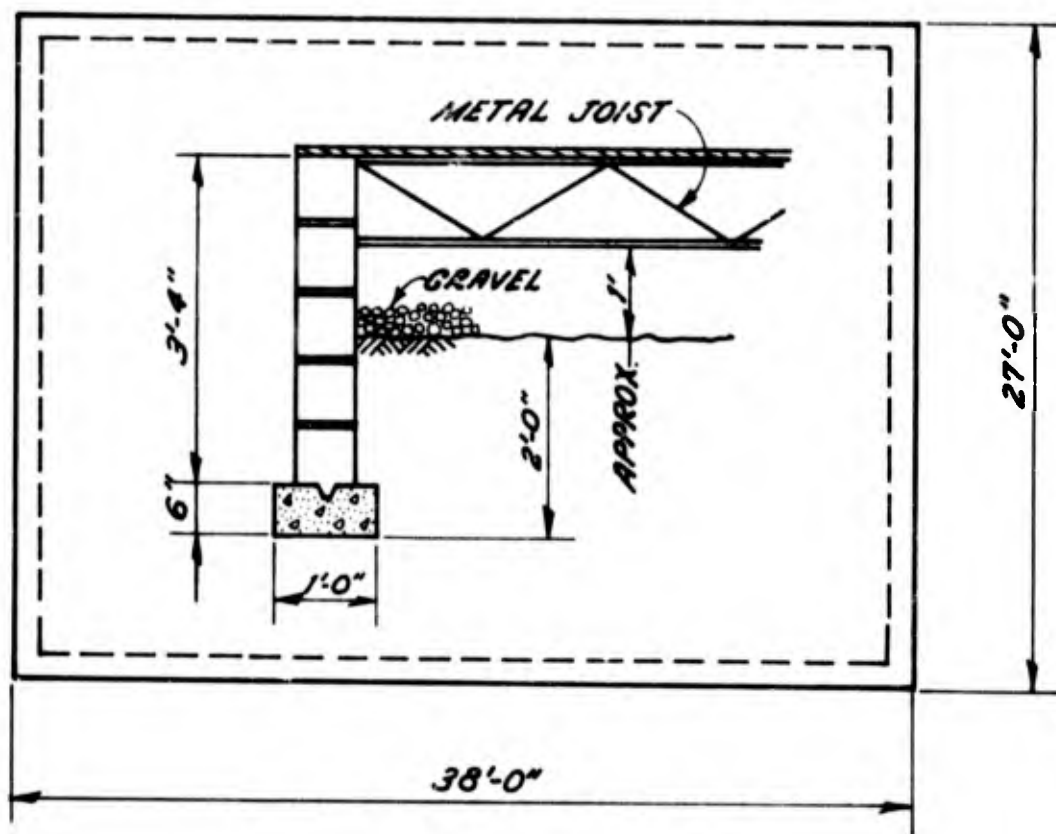


Figure A7. Foundation plan for general estimate sheet (Figure A8).

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PROJECT DESCRIPTION Residence 38x27'
Perim. strip footing with conc. block.
Perim. Wall. NO interior piers, no termites
Use steel floor joists

TOTAL PROJECT COST - \$2361.92
 COST/SQ FT - \$2.30

Description of Work	Sketch No. Units	Dimensions			Total Estimated Quantity	Unit Price Mat'l	Total Estimated Mat'l	Unit Price Labor	Total Estimated Labor	Total Estimated Labor & Material Cost
		L	W	D						
1 Excavation										
Wall	04	130'	2'	2'	284	.70		.65		37.00
Footing	04	130	3'	5'	73	1.45		1.25		13.80
Hauling w/6 cy truck 2 miles	04	130'	1'	2'	96	.30		.20		7.68
Backfill, by hand	04	130'	2'	1.5'	145	0.17		.15		5.08
Backfill, backhoe	04	130'	3'	1.5'	48			3.25		15.60
Fine Grading (site)	04	38'	27'		1140	0.15		.15		34.20
2 Concrete, wall ftg.										
3500 psi	04	130'	1'	5'	24	2.12		4.22		61.20
3 Masonry										
Block 8x8x16	SF	130'	3 1/2'	--	422.9	.36		1.04		606.06
4 Gravel fill 4"										
	SF	38'	27'	--	1076	.06		.08		143.64
5 Plywood subfloor										
3/4" thick	SF	38'	27'		1076	2.425		10.50		356.58
6 Formwork, footing										
(4 uses)	SFCA	130	--	1	130	.14		.53		87.40
7 Floor joists										
16JB @ 11.8 #/LF	Ton	2'	20 Joists 2222 #/LF 2000		3.2	215.00		25.00		942.00
									Total =	2361.92
										Unit Cost = $\frac{2361.92}{1026} = 2.30$

Figure A8. General estimate sheet.

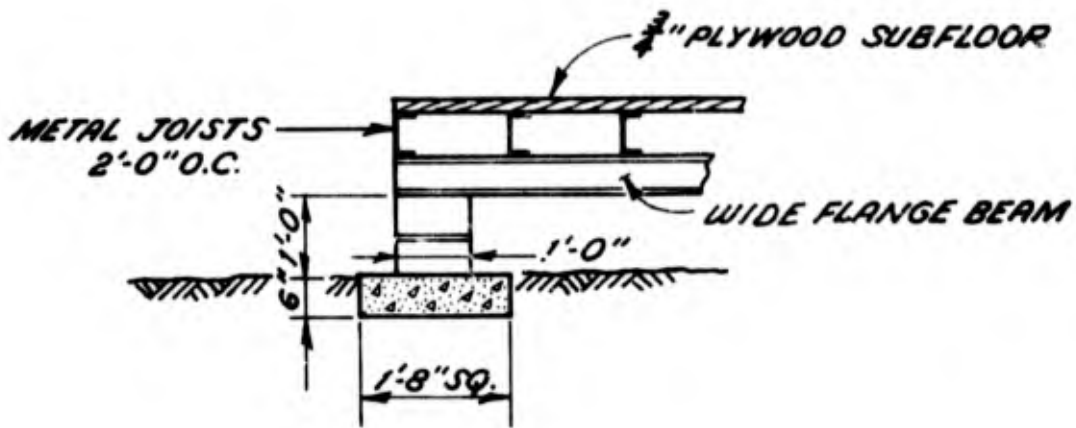
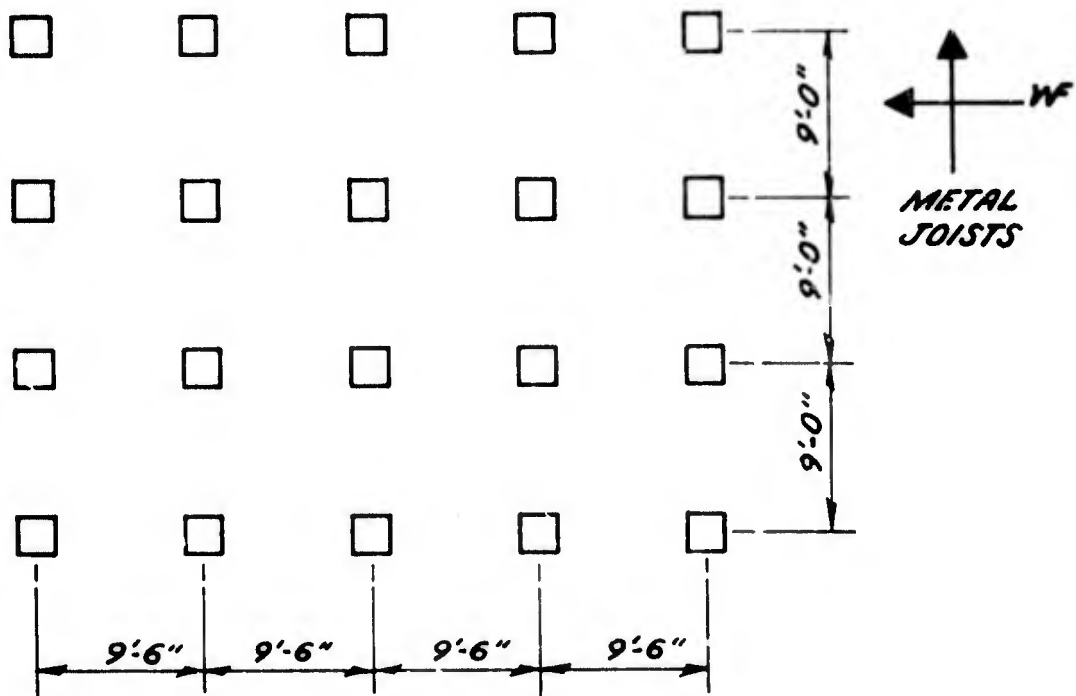


Figure A9. Foundation plan for general estimate sheet (Figure A10).

PROJECT DESCRIPTION Residence 28x27'
4 rows of piers using metal beams
& floor joists, & termites

TOTAL PROJECT COST = \$1402.90
 COST/SQ FT = \$137

Description of Work	Sketch No.	Dimensions			Total Estimated Quantity	Unit Price Mat'l	Total Estimated Mat'l	Unit Price Labor	Total Estimated Labor	Total Estimated Labor & Material Cost
		L	W	D						
1. Excavation										
Exc. w/ grader	cy	28'	27'		114	10		1140		25.05
Footings (hand)	cy	4.0'	1.67'	2.0'	132			10.00		10.20
2. Concrete ftgs										
3500 psi (chuted)	cy				102	21.00		3.00		24.90
3. Masonry (brick)										
	LF	1'	1'	1'	20	1.00		5.00		150.00
4. Steel										
Plates										179/9612
Wide Flange W6x20	Ton	28'	4'	100'	1.53	245.00		115.00		608.00
Open-web joists										
8J2 @ 4.2 lb/ft	Ton	9'	42'	100'	0.77	240.00		8.00		252.80
5. Plywood subfloor 3/4"										
	100SF	28'	27'		1076	15.25		16.00		294.90
6. Termite shields .020"										
	lf	20"	20"		67	3.0		.25		21.85
20x20x20 = 67										
10(12)										
								Total =	\$1402.90	
						unit Cost =	$\frac{1402.90}{10.26} =$	\$137		

Figure A10. General estimate sheet.

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SYMBOLS

U. S. units are generally used; for metric units substitute meters (m) for ft, centimeters (cm) for in., kiloNewtons for kips, and Pascals (Newton/sq m) for kips/sq ft.

A = floor area, sq ft

a = coefficient Eq 2

b = coefficient in Eq 2

B = footing width; least lateral footing dimension, ft

C = Unified Soil Classification symbol for clay

c = cohesion of soil, kips/sq ft

C_c = compression index (Eq 1,2)

C_w = climatic rating (see Figure 23 and Table 8)

d = diameter of capillary tube, cm (Eq 7)

D_f = depth of footing in soil, ft

D_r = relative density of soil (Table 8)

D_{10} = grain size for which 10 percent of sample is finer

DL = dead load, kips

e_0 = in-situ void ratio of soil

E_s = stress-strain (Modulus of Elasticity) modulus, kips/sq ft

G = Unified Soil Classification symbol for gravel

h_c = height of capillary rise in soil, cm (Eq 10)

H = thickness of soil stratum, ft (Eq 4)

I_p = plasticity index ($w_L - w_p$)

I_w = liquidity index

k = coefficient of permeability of soil, cm/sec

L = length, ft

LL = live load, kips
 M = Unified Soil Classification symbol for silt
 N = number of blows taken in a Standard Penetration Test
 N_c = bearing capacity factor for cohesive soil (Eq 5)
 N_q = bearing capacity factor for footing depth effect (Eq 5)
 O = Unified Soil Classification symbol for organic material
 P = Unified Soil Classification symbol for poorly graded soil
 P_o = in-situ overburden pressure, kips/sq ft (Eq 1)
 P'_o = in-situ preconsolidation pressure, kips/sq ft
 q = overburden pressure at footing depth ($q = \gamma D$), kips/sq ft (Eq 5)
 q_a = allowable soil pressure, kips/sq ft
 q_c = average footing contact pressure, kips/sq ft
 q_u = unconfined compression strength, kips/sq ft
 q_{ult} = ultimate soil pressure beyond which a shear failure occurs, kips/sq ft (Eq 5)
 R = live load reduction factor as allowed by most building codes
 S = Unified Soil Classification symbol for sand used as a prefix (SW,SP,SM,SC)
 S = standard symbol for degree of saturation of the soil
 S = settlement due to footing contact pressure, in Eq 1
 S_i = immediate settlement of a footing, in Eq 8
SPT = Standard Penetration Test
 T = surface tension of water, gm/cm (Eq 7)
 W = Unified Soil Classification symbol for well graded material
 w_L = liquid limit, percent (water content)
 w_N = natural water content of soil, percent
 w_p = plastic limit, percent (water content)
 w_s = shrinkage limit, percent (water content)

α = angle the meniscus makes with a capillary tube, deg (Eq 7)

ϕ = symbol for angle of internal friction of soil, deg

Δ = change in movement between two points, ft or in. (see Tables 7 and 11)

ΔP = increase in pressure within a soil mass due to footing loads, kips/sq ft (Eq 1)

γ = unit weight of soil, lb/cu ft or gm/cu cm

μ = Poisson's ratio

ψ = Shape factor

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