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RESIDENTIAL AND LIGHTLY LOADED FOUNDATIONS: DESIGN PARAMETERS AND PROCEDURES

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SECTION 5
RESIDENTIAL AND LIGHTLY LOADED FOUNDATIONS

ROBERT B. ANDERSON

5.1 SLAB-ON-GROUND CONSTRUCTION

One of the most common forms of residential foundations is the slab-on-ground. This encompasses slabs both at the surface, which are common in most warmer climates, and below-surface slabs, which form basements. The concept is essentially the same from a design standpoint. In referring to slab-on-ground construction, the name says it all. *The slab is supported on the ground.* This means that a major focus of the design should be on the ground conditions and proper preparation of the ground for receiving a slab.

In most instances, the reinforcing associated with slab-on-ground is fairly minimal as compared to elevated slabs. This should highlight the importance of the supporting soil conditions and their affect on any slab-on-ground design. Paramount importance should therefore be placed on the identification of soil conditions prior to the undertaking of any foundation design, regardless of the size of the project. As a design professional, it is necessary to have proper identification of soil conditions either from personal experience, local code requirements, county soil surveys, or preferably a site-specific soils investigation. Failure to secure such information and citing its source on the design drawings is essential.

The choice of slab-on-ground construction is a function of architectural requirements and soil conditions. If the structure is to be elevated with a crawl space, the foundation will more than likely be pier supported with either spread footings, continuous strip footings, or a deep foundation. If soil conditions are poor either due to compressible clays or other deleterious conditions, structurally supported slabs may be in order.

Other options, depending on the nature of problem soils, are soil removal, soil improvement, or a stiffer and stronger slab-on-ground.

Essentially, residential foundations can be categorized as:

1. Supported on stable granular soils
2. Supported on plastic or compressible clay
3. Structurally supported

Each of these will be described. A fourth category, pier supported residences, will also be treated.

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5.1.1 Stable Granular Soil Conditions

5.1.1.1 Required Geotechnical Information

It is recommended that a soils investigation be conducted in order to determine the type of soil on the site, the thickness and distribution of each soil type, and the density of granular soils. Clay soils should also be described and their physical properties determined.

Soils investigation for residential design should be site-specific, with at least one test boring per slab site. In production housing sites, a test program may suffice with fewer borings; however, number and location should be established by the geotechnical engineer. In well-established neighborhoods with consistent soils, the presence of a soil test within 300 feet may be acceptable.

Soils should be classified under the Unified Soil Classification System, thereby delineating the acceptability of a lightly reinforced slab.

5.1.1.2 Minimum Reinforcement Requirements

The Building Research Advisory Board study for the Federal Housing Authority recommends that certain granular and dense materials may entertain an unreinforced slab. According to the BRAB Report, as a general guideline based on the Unified Soil Classification, GW and CP soil types as well as dense or medium dense GM, GC, SW, SP, SM, SC, ML, and MH may support an unreinforced slab-on-ground. Although allowable, such a design is not encouraged by the author. If such soils are encountered, it is recommended that either an appropriate dosage of synthetic fibers or a minimum of 6 × 6 W1.4/W1.4 welded wire reinforcement be used in a slab with a minimum thickness of 4 inches.

Table 5.1 below consists of a suggested modification of BRAB Report recommendations for the selection of slab type based on soil conditions.

TABLE 5.1 Slab-Type Recommendations Based on Soil Conditions[1]

Soil type[2]	Minimum density[3] or PI or q_u	Recommended slab type
GW, GP	All Densities	Minimum 4″ with synthetic fibers or 6 × 6 W1.4/W1.4 WWF
GM, GC, SW, SP, SM, SC, ML, MH	Dense or medium dense	Minimum 4″ with synthetic fibers or 6 × 6 W1.4/W1.4 WWF
GM, GC, SW, SP, SM, SC, ML, MH	Loose	Minimum 4″ with 0.1% steel
CL, OL, CH, OH	PI < 15 and $q_u \geq 2500$ psf	Minimum 4″ with 0.1% steel
	PI > 15 and $q_u < 2500$psf	Reinforced and stiffened
	$q_u < 1000$ psf	Structurally supported slab
Pt	All	Structurally supported slab

[1]Modified from *Criteria for Selection and Design of Residential Slab on Ground* (Table P11), Publication 1571, National Academy of Sciences, Washington, DC, 1968.
[2]As classified under the Unified Soil Classification System.
[3]Unconfined compression strength of undisturbed sample.

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For minimum reinforcement of a conventional nature, ACI 360 at the time of this writing recommends a value of 0.1% of the cross-sectional area of concrete. For a 4″ thick slab, this results in 0.048 in^2 per foot or 6 × 6 W2.5/W2.5. A more common selection would be 6 × 6 W2.9/W2.9, which is more popularly designated as 6 × 6 6/6 WWF.

The welded wire reinforcement is preferred in sheets to rolls in order to insure its proper placement in the slab, which is to be no lower than mid-height, but preferably 1½″ from the top.

Loads in excess of 500 psf and point loads should be addressed with supplemental reinforcement or slab thickness to accommodate their function. Static analysis based on the bearing capacity of the soil may be utilized.

5.1.1.3 Sample Problem

A single story residence has the footprint shown in Fig. 5.1. The soil classification is SW Loose with a recommended bearing capacity of 2000 psf. Frost depth is 13″ and distance from ground to top of slab is 8″. No loads except the perimeter shall exceed 500 psf.

1) Select a 4″ thick slab:

$$\text{Area of steel } (A_s) = 4 \times 12 \times 0.001 = 0.048 \text{ in}^2$$

Use 6 × 6 W2.9/W2.9 WWF – $A_s = 0.058 \text{ in}^2/\text{ft} > 0.048$

2) Select perimeter grade beam:

$$8'' \text{ freeboard} + 13'' = 21''$$

Use 24″ deep grade beam for perimeter

The author recommends a minimum reinforcing for the grade beam of 0.25% in order to comply with the intentions of ACI 318.

Minimum steel = 12 × 24 × 0.0025 = 0.72

Use 4 #4 bars (2 top and 2 bottom)

$A_s = 0.80 \text{ in}^2 > 0.72 \text{ in}^2$

5.1.1.4 Suggested Layout and Details (see Fig. 5.2):

Note: Alternate exterior grade beams for this design may consist of filled concrete masonry units for greater depth requirements as shown in Fig. 5.3.

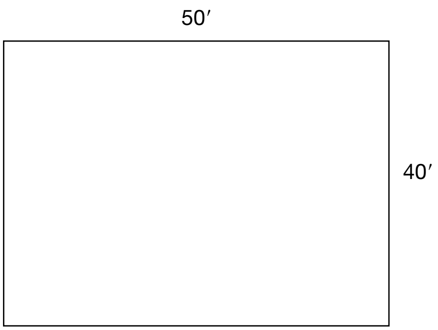

FIGURE 5.1.

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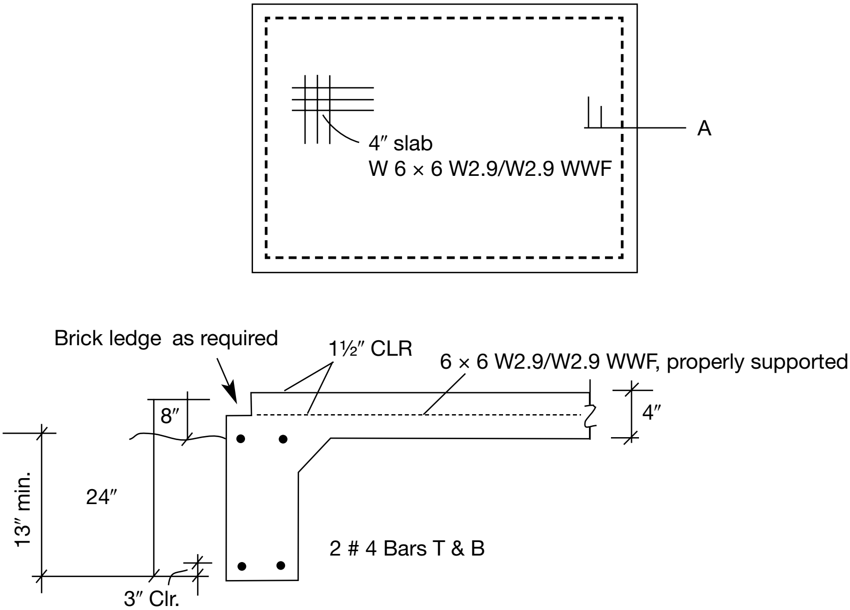

FIGURE 5.2.

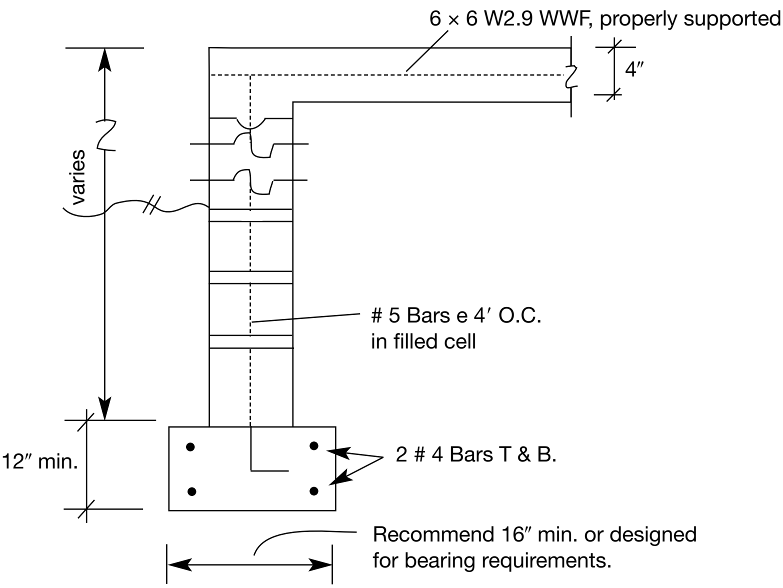

FIGURE 5.3.

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5.2.1 Plastic or Compressible Clay Conditions

5.2.1.1 Required Geotechnical Information

As with any residential geotechnical report, the guidelines set forth in Section 5.1.1 should be followed. In plastic or compressible clay conditions, the soil is generally classified as fine-grained, and therefore falls into the category of CL, OL, CH, or OH. The geotechnical investigation should make recommendations relative to bearing capacity, and state if the soil is susceptible to volume change with moisture content or surcharge. Table 5.1 offers a guideline as to what types of information should be present.

In relatively stable high compressive strength clays with a low plasticity index (PI), a slab similar to the one shown in Fig. 5.2 is acceptable. Such recommendations should be made by the geotechnician.

With higher plasticity indices, a reinforced and stiffened slab may be required. It is desirable for the geotechnicial engineer in this instance to provide more detailed information relative to the potential change in volume of the soil. This information is critical in both dry and wet climates for the purpose of evaluating the stiffness necessary for a slab. Two of the more common delineations made in geotechnical investigations are to describe: 1) the potential vertical rise (PVR) of the soil, and 2) recommended values for e_m and y_m in plastic design procedure. A third property that may be reported in highly compressible clays is differential and total settlement.

When a slab is supported on a fine-grained soil (clay), or a collapsing soil (such as silt), the responsibilities of both the structural engineer and the geotechnical engineer become more acute. Care must be taken to anticipate any change in moisture content and drainage as well as irrigation that might affect the characteristics of the soil. The structural engineer may no longer be dealing with a static load being placed on an isotropic homogeneous material. The soil could very well be imposing an uneven load on the slab. This implies use of a reinforced and stiffened slab.

5.2.1.2 Consideration of Stiffened Slab Sections

The reinforced and stiffened slab tends to be a fairly complex design problem if done properly. This type of slab may be either conventionally reinforced or posttensioned. The preferable design procedure is that of the Post Tensioning Institute (PTI). More detailed design examples are found in *Designing Floor Slabs On Grade*, published by the Aberdeen Group, Addison, IL (1996).

It is suggested that the following two publications be referenced for a detailed design analysis for reinforced and stiffened slabs-on-ground:

1. *Design and Construction of Post-Tensioned Slabs-on-Ground*, 2nd ed., Post-Tensioning Institute, Phoenix, AZ, 1995.
2. *Designing Floor Slabs-on-Grade*, Boyd C. Ringo and Robert B. Anderson, 2nd ed., The Aberdeen Group, Addison, IL, 1996.

A simple to follow calculation procedure is considered too lengthy for this publication, and is better dealt with in the latter publication, which devotes 100 pages to two sample problems.

It is recommended that the designer at least become familiar with the Post Tensioning Institute design procedure prior to buying any software for problem solving. Software sources are provided through the Post Tensioning Institute.

5.2.1.3 Design Concept for Stiffened Slabs

The concept behind the PTI design procedure and least acceptable standard conventional designs is that the slab be capable of resisting both an edge lift condition and a center lift condition due to the normal seasonal volume change in the soil. This results in either a positive moment or a negative moment in the slab. This is schematically shown in Fig. 5.4.

Not only must the slab resist both positive and negative moments based on e_m and y_m design parameters, but it must also be stiff enough to function adequately by not inducing cracks in walls and ceilings due to this movement. Therefore, adequate stiffness is the governing concern of this design

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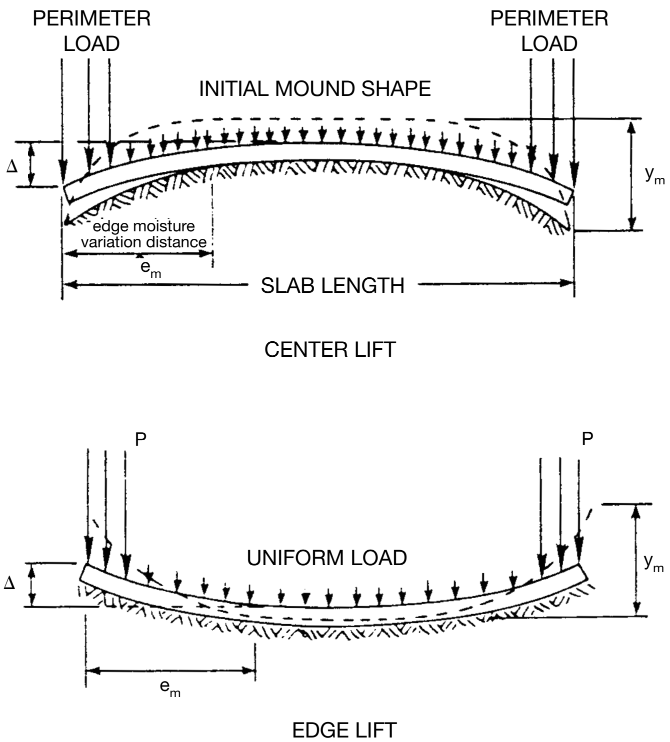

FIGURE 5.4.

procedure. Slabs must be either sufficiently thick or have adequate stiffening beams to control center lift and edge lift movement.

5.2.1.4 Compressible Clays

Slabs placed on compressible clays are designed very similar to those on expansive clays, provided the soil differential settlement is acceptable for ground support. The geotechnical report should predict both maximum settlement and maximum differential settlement. It has been the author's experience that if the predicted differential is less than 2″ or less than a deflection ratio of 1/300 measured from the center of the slab to the edge, with 2″ as the maximum limit, the slab can potentially be ground supported. The clay material must, however, be free of organics, and the procedure must be approved by the geotechnical engineer

Moments and deflections are primarily positive, due to the saucering of the slab associated with consolidation.

5.2 STRUCTURALLY SUPPORTED SLABS

When soil conditions are such that a ground-supported slab is not feasible, it may be necessary to structurally support the slab. This condition could arise if the soils is too weak to support the load.

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Highly compressible clays would pose such a difficulty. Another reason to use structurally supported slabs may be extremely high volume change clays. In such instancess, slabs may have to be supported on drilled shafts with voids on the underside to accommodate volume change.

If a concrete slab is used under either of these circumstances, the slab must be designed in accordance with ACI 318. This document addresses elevated slabs. By being structurally supported on either piling or drilled shafts, such residential slabs fall under this code requirement. Failure to completely meet the steel requirements for slabs and beams in ACI 318 for structurally supported slabs is more than likely a concern with of most local code requirements within the United States. The designer should confirm that the minimum requirements of Chapter 7.12 of ACI 318 are met regardless of moment and shear requirements. There is a precedent for deleting minimum bonded steel if ultimate moment fails to produce stresses above $7.5\sqrt{f_c'}$.

5.3 PIER SUPPORTED RESIDENTIAL CONSTRUCTION (PIER-AND-BEAM FOUNDATIONS)

In many areas throughout the country, pier supported construction is both commonplace and desirable. It offers the homeowner a greater ease of access for plumbing and electrical modifications and repairs. The crawl space also maybe used as a heating and air conditioning plenum with some additional work.

Pier supported structures require essentially two design procedures. First, a pier design must be designed. A perimeter beam is then designed whose function is to transfer the perimeter loads to the pier system. This may be either on spread footings, a chain wall, or on a deep foundation. Subsequently a floor system and beams must be designed to transfer the interior load to the piers.

Floor systems may consist of wood floor joists, steel joists, or occasionally a concrete slab. Beams (or girders) transferring the load to piers may also be wood, steel, or concrete.

Care should be taken to ascertain that a pier supported floor meets governing code requirements for clearance from the ground. In many coastal areas, the minimum clearance is a function of flood water elevation, and refers to the lowest elevation of the lowest structural member of the floor.

There are several variations of pier-and-beam design other than those mentioned. One such design, popular in the southern United States is the “low profile” pier-and-beam foundation. Here the crawl space is excavated to permit a low silhouette comparable to the slab foundation.

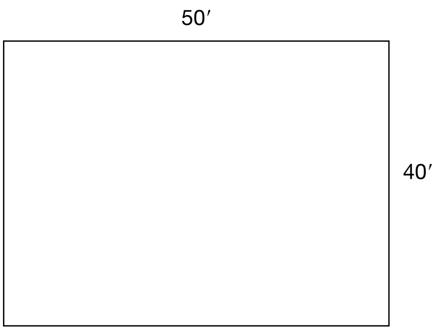

FIGURE 5.5.

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Sample Problem

A single-story residence has the footprint shown in Fig. 5.5. The residence is wood frame. The soil classification is SW Loose with a recommended bearing capacity of 1500 psf for strip footings. There is no frost depth concern. Design a pier foundation with 24″ clear from ground level to underside of structural members. Wood construction is acceptable. The roof is wood truss design.

Step 1: Determine strip footing layout (see Fig. 5.6). Determine maximum load on piers that will be 6′3″ on center.

1. *Exterior loading.*

$$\text{Roof truss} = \frac{40}{2} \times (20 \text{ L.L.} + 15 \text{ D.L.})$$

$$= 20 \times 35 \qquad = 700\ \#/\text{l}'$$

$$\text{Floor load} = \frac{13.33}{2}(40 \text{ L.L.} + 20 \text{ D.L.}) \qquad = 400\ \#/\text{l}'$$

$$\text{Allow exterior wall} = 100\ \#/\text{l}' \qquad = \underline{100\ \#/\text{l}'}$$

$$\text{S/T} \qquad = 1200\ \#/\text{l}'$$

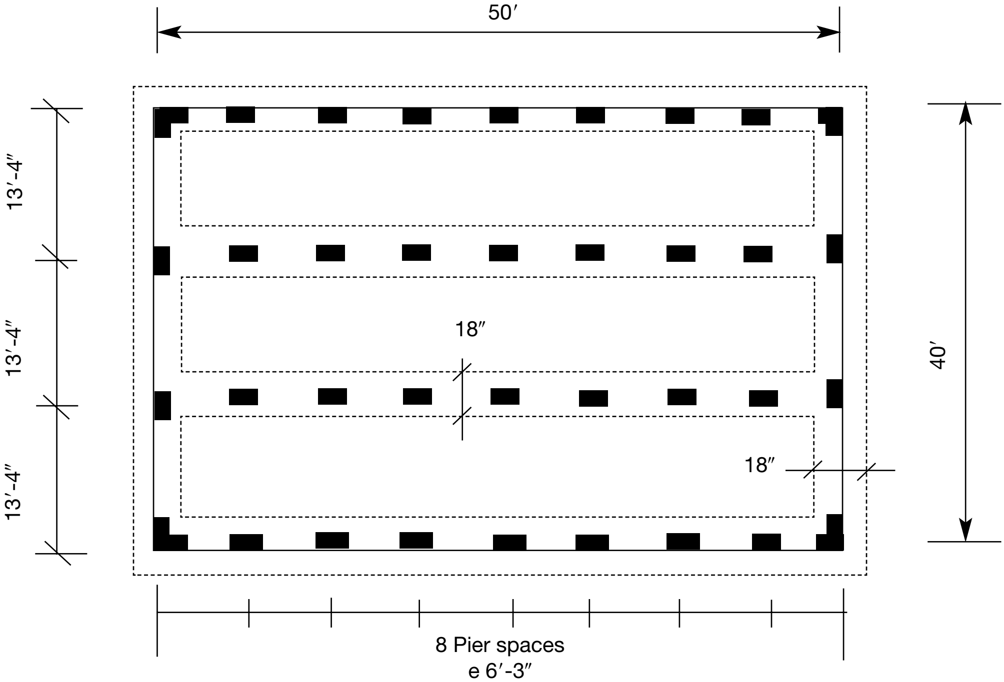

FIGURE 5.6.

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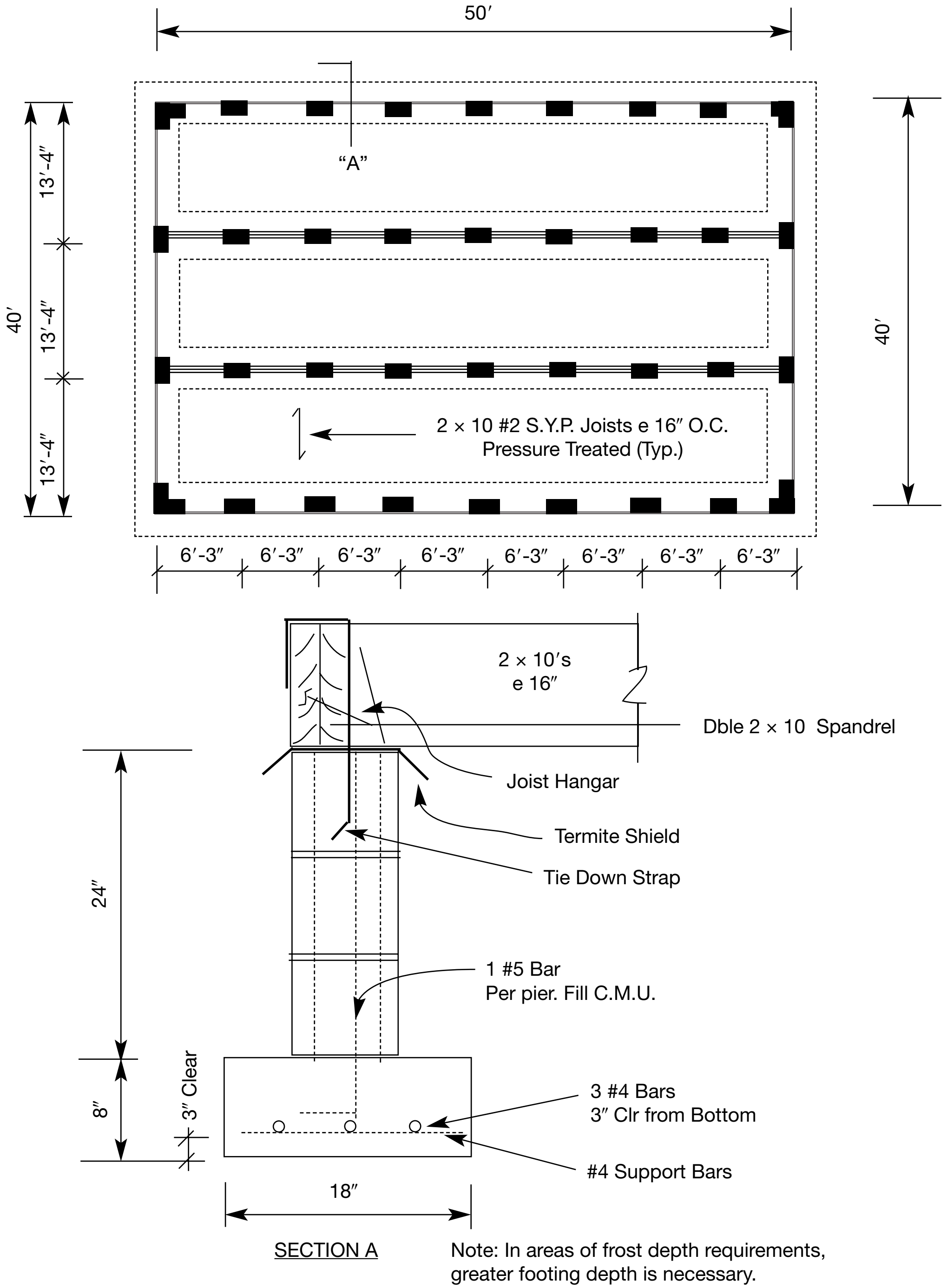

FIGURE 5.7.

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Assume 18″ wide × 8″ deep footing = 1.5 – 67 × 150 = 150 #/l′

Total load transferred to typical exterior pier T.L. = 1350 #/l′

1200 × 6.25 = 7500 #
Allow for Pier 150 #

Total load = 7650 #

2. *Check interior pier loading:*

Floor load = 13.33′ × (40 LL + 20 DL) = 800 #/l′
Allow for Interior Walls = 100 #/l′

Total Load = 900 #/l′

900 #/l′ < 1200 #/l′

∴ Use exterior strip footing design for all strip footings.

3. *Check steel requirements:*

For simplicity, assume a simple beam design to account for possible end rotation:

$M = \frac{1}{8} \times 1200 \times 6.25^2$
$M = 930'\#$
$M = 11.26''K$

Check minimum steel requirements:

$A_s = 0.002 \times 8 \times 18 = 0.288$ in^2

For an 18″ wide footing we recommend a minimum of 3 #4 bars. $A_s = 0.20 \times 3 = 0.60$. Use grade 40 deformed bars.

Check moment capacity of 3 #4's 3″ clear from bottom. Use 3000 psi concrete.

0.60 × 40 = 24K
0.85 × 3000 = 2550
Ultimate compression block = 24 ÷ 2.55 = 9.41″
$a = 18 \div 9.41 = 1.91$
$a/2 = 0.95$; use $d = 5''$
$M_u = 24K(5 - a/2) = 97.2''K$
Assume ultimate moment = 1.8 × 11.26 = 20.27″K
97.2 > 20.27 ∴ OK—Steel is more than sufficient

4. *Floor Design-Beams*

Maximum span = (6.25 – 1.33 for C.M.U.) = 4.92′
Maximum load = 1200 #/l′
$M = \frac{1}{8} \times 4.92^2 \times 1200$ #/l′ = 3630′#
Use two 2 × 10's with a joist hanger
Maximum capacity = 4312′# > 3630′# ∴ OK

The final detail is shown in Figure 5.7.

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