10

Mats

The mere formulation of a problem is far more often essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks real advances in science.

Albert Einstein

The second type of shallow foundation is the *mat foundation*, as shown in Figure 10.1. A mat is essentially a very large spread footing that usually encompasses the entire footprint of the structure. They are also known as *raft foundations*.

Foundation engineers often consider mats when dealing with any of the following conditions:

- The structural loads are so high or the soil conditions so poor that spread footings would be exceptionally large. As a general rule of thumb, if spread footings would cover more than about one-third of the building footprint area, a mat or some type of deep foundation will probably be more economical.
- The soil is very erratic and prone to excessive differential settlements. The structural continuity and flexural strength of a mat will bridge over these irregularities. The same is true of mats on highly expansive soils prone to differential heaves.
- The structural loads are erratic, and thus increase the likelihood of excessive differential settlements. Again, the structural continuity and flexural strength of the mat will absorb these irregularities.

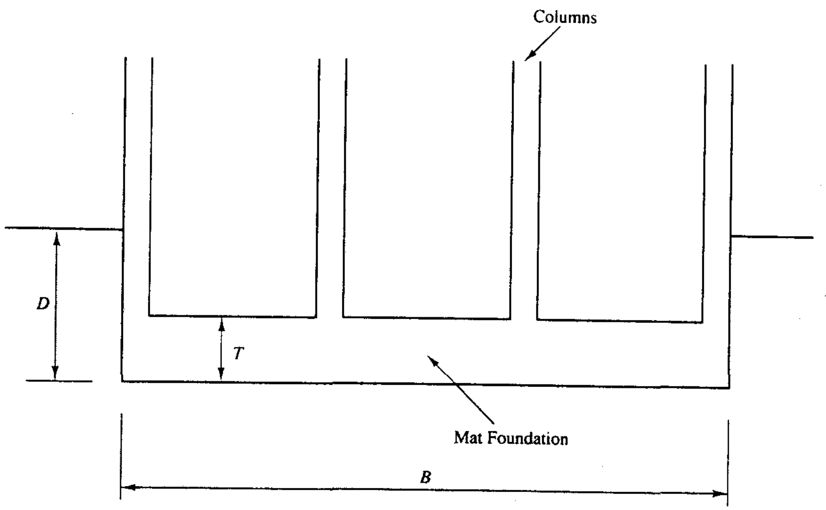

Figure 10.1 A mat foundation supported directly on soil.

- Lateral loads are not uniformly distributed through the structure and thus may cause differential horizontal movements in spread footings or pile caps. The continuity of a mat will resist such movements.
- The uplift loads are larger than spread footings can accommodate. The greater weight and continuity of a mat may provide sufficient resistance.
- The bottom of the structure is located below the groundwater table, so waterproofing is an important concern. Because mats are monolithic, they are much easier to waterproof. The weight of the mat also helps resist hydrostatic uplift forces from the groundwater.

Many buildings are supported on mat foundations, as are silos, chimneys, and other types of tower structures. Mats are also used to support storage tanks and large machines. Typically, the thickness, T, is 1 to 2 m (3–6 ft), so mats are massive structural elements. The seventy five story Texas Commerce Tower in Houston is one of the largest mat-supported structures in the world. Its mat is 3 m (9 ft 9 in) thick and is bottomed 19.2 m (63 ft) below the street level.

Although most mat foundations are directly supported on soil, sometimes engineers use pile- or shaft-supported mats, as shown in Figure 10.2. These foundations are often called *piled rafts*, and they are hybrid foundations that combine features of both mat and deep foundations. Pile- and shaft-supported mats are discussed in Section 11.9.

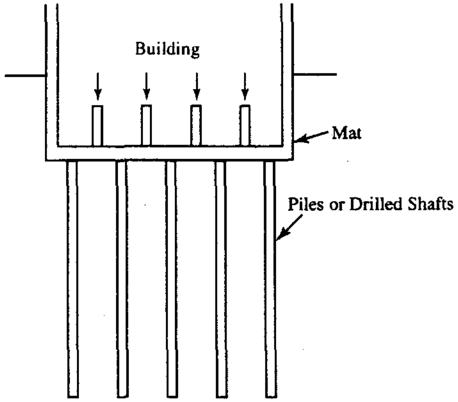

Figure 10.2 A pile- or shaft-supported mat foundation. The deep foundations are not necessarily distributed evenly across the mat.

Various methods have been used to design mat foundations. We will divide them into two categories: Rigid methods and nonrigid methods.

10.1 RIGID METHODS

The simplest approach to structural design of mats is the *rigid method* (also known as the *conventional method* or the *conventional method of static equilibrium*) (Teng, 1962). This method assumes the mat is much more rigid than the underlying soils, which means any distortions in the mat are too small to significantly impact the distribution of bearing pressure. Therefore, the magnitude and distribution of bearing pressure depends only on the applied loads and the weight of the mat, and is either uniform across the bottom of the mat (if the normal load acts through the centroid and no moment load is present) or varies linearly across the mat (if eccentric or moment loads are present) as shown in Figure 10.3. This is the same simplifying assumption used in the analysis of spread footings, as shown in Figure 5.10e.

This simple distribution makes it easy to compute the flexural stresses and deflections (differential settlements) in the mat. For analysis purposes, the mat becomes an inverted and simply loaded two-way slab, which means the shears, moments, and deflections may be easily computed using the principles of structural mechanics. The engineer can then select the appropriate mat thickness and reinforcement.

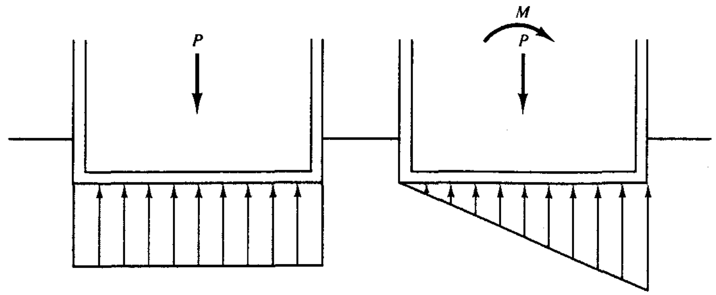

Figure 10.3 Bearing pressure distribution for rigid method.

Although this type of analysis is appropriate for spread footings, it does not accurately model mat foundations because the width-to-thickness ratio is much greater in mats, and the assumption of rigidity is no longer valid. Portions of a mat beneath columns and bearing walls settle more than the portions with less load, which means the bearing pressure will be greater beneath the heavily-loaded zones, as shown in Figure 10.4. This redistribution of bearing pressure is most pronounced when the ground is stiff compared to the mat, as shown in Figure 10.5, but is present to some degree in all soils.

Because the rigid method does not consider this redistribution of bearing pressure, it does not produce reliable estimates of the shears, moments, and deformations in the mat. In addition, even if the mat was perfectly rigid, the simplified bearing pressure distributions in Figure 10.3 are not correct—in reality, the bearing pressure is greater on the edges and smaller in the center than shown in this figure.

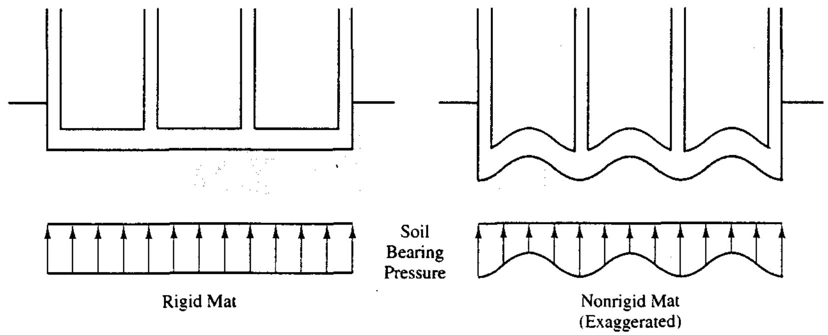

Figure 10.4 The rigid method assumes there are no flexural deflections in the mat, so the distribution of soil bearing pressure is simple to define. However, these deflections are important because they influence the bearing pressure distribution.

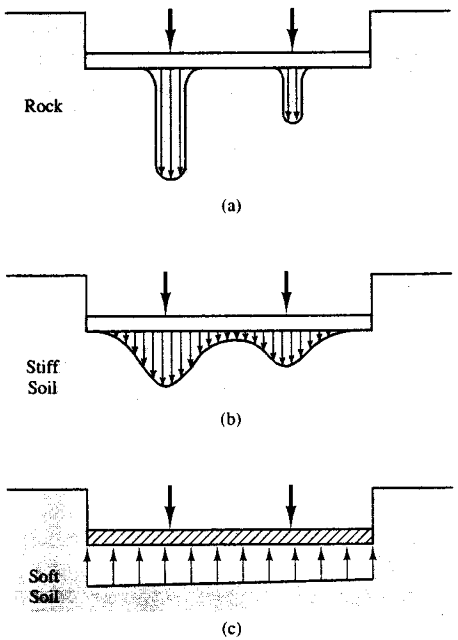

Figure 10.5 Distribution of bearing pressure under a mat foundation; (a) on bedrock or very hard soil; (b) on stiff soil; (c) on soft soil (Adapted from Teng, 1962).

10.2 NONRIGID METHODS

We overcome the inaccuracies of the rigid method by using analyses that consider deformations in the mat and their influence on the bearing pressure distribution. These are called *nonrigid methods*, and produce more accurate values of mat deformations and stresses. Unfortunately, nonrigid analyses also are more difficult to implement because they require consideration of *soil-structure interaction* and because the bearing pressure distribution is not as simple.

Coefficient of Subgrade Reaction

Because nonrigid methods consider the effects of local mat deformations on the distribution of bearing pressure, we need to define the relationship between settlement and bearing pressure. This is usually done using the *coefficient of subgrade reaction*, k_s (also known as the *modulus of subgrade reaction*, or the *subgrade modulus*):

$$\boxed{k_s = \frac{q}{\delta}} \qquad (10.1)$$

Where:

k_s = coefficient of subgrade reaction
q = bearing pressure
δ = settlement

The coefficient k_s has units of force per length cubed. Although we use the same units to express unit weight, k_s is not the same as the unit weight and they are not numerically equal.

The interaction between the mat and the underlying soil may then be represented as a "bed of springs," each with a stiffness k_s per unit area, as shown in Figure 10.6. Portions of the mat that experience more settlement produce more compression in the "springs," which represents the higher bearing pressure, whereas portions that settle less do not compress the springs as far and thus have less bearing pressure. The sum of these spring forces must equal the applied structural loads plus the weight of the mat:

$$\Sigma P + W_f - u_D = \int q\,dA = \int \delta\, k_s\, dA \qquad (10.2)$$

Where:

ΣP = sum of structural loads acting on the mat
W_f = weight of the mat

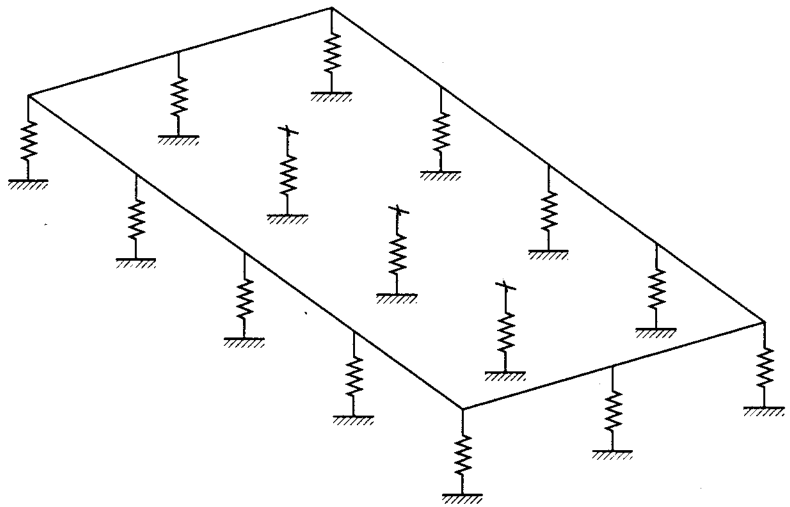

Figure 10.6 The coefficient of subgrade reaction forms the basis for a "bed of springs" analogy to model the soil-structure interaction in mat foundations.

u_D = pore water pressure along base of the mat
q = bearing pressure between mat and soil
A = mat–soil contact area
δ = settlement at a point on the mat

This method of describing bearing pressure is called a *soil-structure interaction analysis* because the bearing pressure depends on the mat deformations, and the mat deformations depend on the bearing pressure.

Winkler Method

The "bed of springs" model is used to compute the shears, moments, and deformations in the mat, which then become the basis for developing a structural design. The earliest use of these "springs" to represent the interaction between soil and foundations has been attributed to Winkler (1867), so the analytical model is sometimes called a *Winkler foundation* or the *Winkler method*. It also is known as a *beam on elastic foundation* analysis.

In its classical form the Winkler method assumes each "spring" is linear and acts independently from the others, and that all of the springs have the same k_s. This representation has the desired effect of increasing the bearing pressure beneath the columns, and thus is a significant improvement over the rigid method. However, it is still only a coarse representation of the true interaction between mats and soil (Hain and Lee, 1974; Horvath, 1983), and suffers from many problems, including the following:

1. The load-settlement behavior of soil is nonlinear, so the k_s value must represent some equivalent linear function, as shown in Figure 10.7.
2. According to this analysis, a uniformly loaded mat underlain by a perfectly uniform soil, as shown in Figure 10.8, will settle uniformly into the soil (i.e., there will be no differential settlement) and all of the "springs" will be equally compressed. In reality, the settlement at the center of such a mat will be greater than that along the edges, as discussed in Chapter 7. This is because the $\Delta\sigma_z$ values in the soil are greater beneath the center.
3. The "springs" should not act independently. In reality, the bearing pressure induced at one point on the mat influences more than just the nearest spring.
4. Primarily because of items 2 and 3, there is no single value of k_s that truly represents the interaction between soil and a mat.

Items 2 and 3 are the primary sources of error, and this error is potentially unconservative (i.e., the shears, moments, and deflections in the mat may be greater than those predicted by Winkler). The heart of these problems is the use of independent springs in the Winkler model. In reality, a load at one point on the mat induces settlement both at that point and in the adjacent parts of the mat, which is why a uniformly mat exhibits dish-shaped settlement, not the uniform settlement predicted by Winkler.

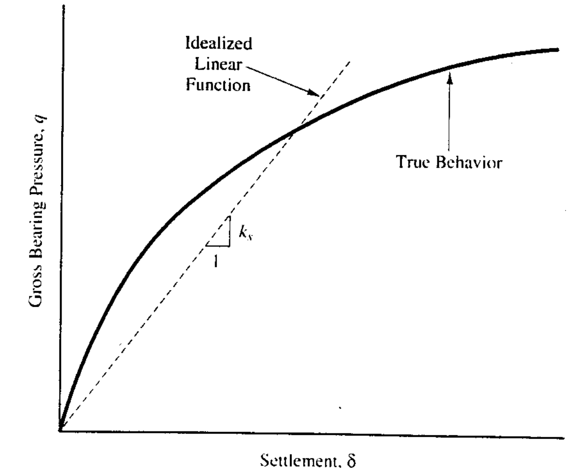

Figure 10.7 The q-δ relationship is nonlinear, so ks must represent some "equivalent" linear function.

Coupled Method

The next step up from a Winkler analysis is to use a *coupled method,* which uses additional springs as shown in Figure 10.9. This way the vertical springs no longer act independently, and the uniformly loaded mat of Figure 10.8 exhibits the desired dish shape. In principle, this approach is more accurate than the Winkler method, but it is not clear how to select the k_s values for the coupling springs, and it may be necessary to develop custom software to implement this analysis.

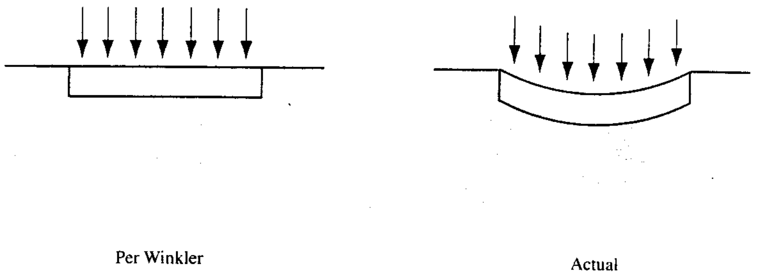

Figure 10.8 Settlement of a uniformly-loaded mat on a uniform soil: (a) per Winkler analysis, (b) actual.

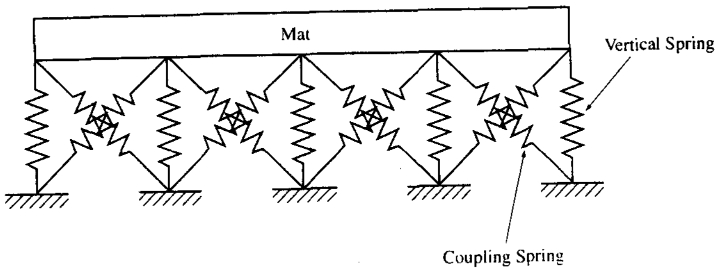

Figure 10.9 Modeling of soil-structure interaction using coupled springs.

Pseudo-Coupled Method

The *pseudo-coupled method* (Liao, 1991; Horvath, 1993) is an attempt to overcome the lack of coupling in the Winkler method while avoiding the difficulties of the coupled method. It does so by using "springs" that act independently, but have different k_s values depending on their location on the mat. To properly model the real response of a uniform soil, the "springs" along the perimeter of the mat should be stiffer than those in the center, thus producing the desired dish-shaped deformation in a uniformly-loaded mat. If concentrated loads, such as those from columns, also are present, the resulting mat deformations are automatically superimposed on the dish-shape.

Model studies indicate that reasonable results are obtained when k_s values along the perimeter of the mat are about twice those in the center (ACI, 1993). We can implement this in a variety of ways, including the following:

1. Divide the mat into two or more concentric zones, as shown in Figure 10.10. The innermost zone should be about half as wide and half as long as the mat.
2. Assign a k_s value to each zone. These values should progressively increase from the center such that the outermost zone has a k_s about twice as large at the innermost zone. Example 10.1 illustrates this technique.
3. Evaluate the shears, moments, and deformations in the mat using the Winkler "bed of springs" analysis, as discussed later in this chapter.
4. Adjust the mat thickness and reinforcement as needed to satisfy strength and serviceability requirements.

ACI (1993) found the pseudo-coupled method produced computed moments 18 to 25 percent higher than those determined from the Winkler method, which is an indication of how unconservative Winker can be.

Most commercial mat design software uses the Winkler method to represent the soil-structure interaction, and these software packages usually can accommodate the

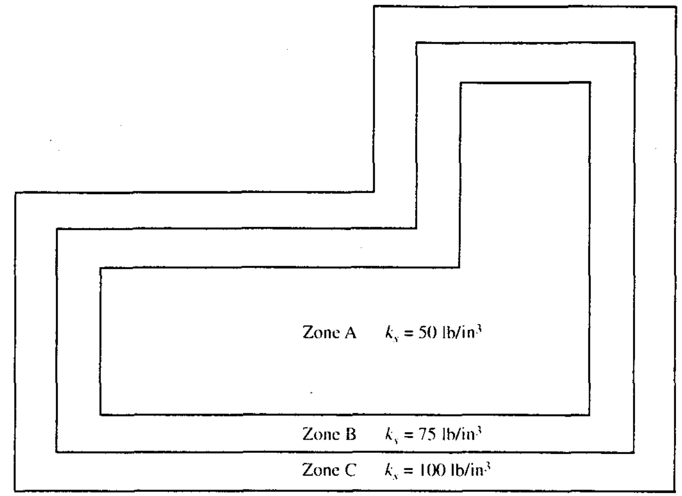

Figure 10.10 A typical mat divided into zones for a pseudo-coupled analysis. The coefficient of subgrade reaction, k_s, progressively increases from the innermost zone to the outermost zone.

pseudo-coupled method. Given the current state of technology and software availability, this is probably the most practical approach to designing most mat foundations.

Multiple-Parameter Method

Another way of representing soil-structure interaction is to use the *multiple parameter method* (Horvath, 1993). This method replaces the independently-acting linear springs of the Winkler method (a single-parameter model) with springs and other mechanical elements (a multiple-parameter model). These additional elements define the coupling effects.

The multiple-parameter method bypasses the guesswork involved in distributing the k_s values in the psuedo-coupled method because coupling effects are inherently incorporated into the model, and thus should be more accurate. However, it has not yet been implemented into readily-available software packages. Therefore, this method is not yet ready to be used on routine projects.

Finite Element Method

All of the methods discussed thus far attempt to model a three-dimensional soil by a series of one-dimensional springs. They do so in order to make the problem simple enough to perform the structural analysis. An alternative method would be to use a three-dimensional mathematical model of both the mat and the soil, or perhaps the mat, soil, and superstructure. This can be accomplished using the *finite element method.*

This analysis method divides the soil into a network of small elements, each with defined engineering properties and each connected to the adjacent elements in a specified way. The structural and gravitational loads are then applied and the elements are stressed and deformed accordingly. This, in principle, should be an accurate representation of the mat, and should facilitate a precise and economical design.

Unfortunately, such analyses are not yet practical for routine design problems because:

1. A three-dimensional finite element model requires tens of thousands or perhaps hundreds of thousands of elements, and thus place corresponding demands on computer resources. Few engineers have access to computers that can accommodate such intensive analyses.
2. It is difficult to determine the required soil properties with enough precision, especially at sites where the soils are highly variable. In other words, the analysis method far outweighs our ability to input accurate parameters.

Nevertheless, this approach may become more usable in the future, especially as increasingly powerful computers become more widely available.

This method should not be confused with structural analysis methods that use two-dimensional finite elements to model the mat and Winkler springs to model the soil. Such methods require far less computational resources, and are widely used. We will discuss this use of finite element analyses in Section 10.4.

10.3 DETERMINING THE COEFFICIENT OF SUBGRADE REACTION

Most mat foundation designs are currently developed using either the Winkler method or the pseudo-coupled method, both of which depend on our ability to define the coefficient of subgrade reaction, k_s. Unfortunately, this task is not as simple as it might first appear because k_s is not a fundamental soil property. Its magnitude also depends on many other factors, including the following:

- **The width of the loaded area**—A wide mat will settle more than a narrow one with the same q because it mobilizes the soil to a greater depth as shown in Figure 8.2. Therefore, each has a different k_s.
- **The shape of the loaded area**—The stresses below long narrow loaded areas are different from those below square loaded areas as shown in Figure 7.2. Therefore, k_s will differ.
- **The depth of the loaded area below the ground surface**—At greater depths, the change in stress in the soil due to q is a smaller percentage of the initial stress, so the settlement is also smaller and k_s is greater.

- **The position on the mat**—To model the soil accurately, k_s needs to be larger near the edges of the mat and smaller near the center.
- **Time**—Much of the settlement of mats on deep compressible soils will be due to consolidation and thus may occur over a period of several years. Therefore, it may be necessary to consider both short-term and long-term cases.

Actually, there is no single k_s value, even if we could define these factors because the q-δ relationship is nonlinear and because neither method accounts for interaction between the springs.

Engineers have tried various techniques of measuring or computing k_s. Some rely on plate load tests to measure k_s in situ. However, the test results must be adjusted to compensate for the differences in width, shape, and depth of the plate and the mat. Terzaghi (1955) proposed a series of correction factors, but the extrapolation from a small plate to a mat is so great that these factors are not very reliable. Plate load tests also include the dubious assumption that the soils within the shallow zone of influence below the plate are comparable to those in the much deeper zone below the mat. Therefore, plate load tests generally do not provide good estimates of k_s for mat foundation design.

Others have used derived relationships between k_s and the soil's modulus of elasticity, E (Vesić and Saxena, 1970; Scott, 1981). Although these relationships provide some insight, they too are limited.

Another method consists of computing the average mat settlement using the techniques described in Chapter 7 and expressing the results in the form of k_s using Equation 10.1. If using the pseudo-coupled method, use k_s values in the center of the mat that are less than the computed value, and k_s values along the perimeter that are greater. This should be done in such a way that the perimeter values are twice the central values, and the integral of all the values over the area of the mat is the same as the produce of the original k_s and the mat area. Example 10.1 describes this methodology.

Example 10.1

A structure is to be supported on a 30-m wide, 50-m long mat foundation. The average bearing pressure is 120 kPa. According to a settlement analysis conducted using the techniques described in Chapter 7, the average settlement, δ, will be 30 mm. Determine the design values of k_s to be used in a pseduo-coupled analysis.

Solution

Compute average k_s using Equation 10.1:

$$(k_s)_{avg} = \frac{q}{\delta} = \frac{120 \text{ kPa}}{0.030 \text{ m}} = 4000 \text{ kN/m}^3$$

Divide the mat into three zones, as shown in Figure 10.11, with $(k_s)_C = 2(k_s)_A$ and $(k_s)_B = 1.5(k_s)_A$

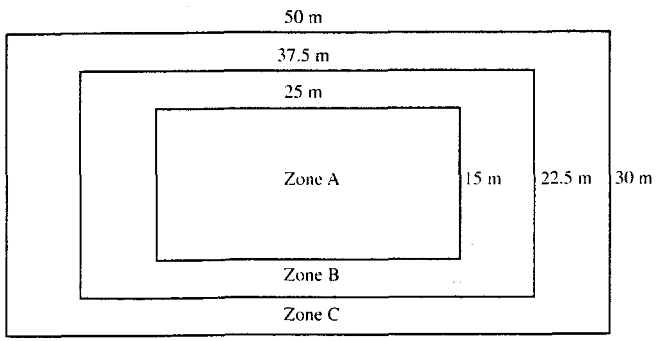

Figure 10.11 Mat foundation for Example 10.1.

Compute the area of each zone:

$$A_A = (25\text{ m})(15\text{ m}) = 375\text{ m}^2$$

$$A_B = (37.5\text{ m})(22.5\text{ m}) - (25\text{ m})(15\text{ m}) = 469\text{ m}^2$$

$$A_C = (50\text{ m})(30\text{ m}) - (37.5\text{ m})(22.5\text{ m}) = 656\text{ m}^2$$

Compute the design k_s values:

$$A_A\,(k_s)_A + A_B\,(k_s)_B + A_C\,(k_s)_C = (A_A + A_B + A_C)\,(k_s)_{avg}$$

$$375\,(k_s)_A + 469\,(1.5)(k_s)_A + 656\,(2)(k_s)_A = 1500\,(k_s)_{avg}$$

$$2390\,(k_s)_A = 1500\,(k_s)_{avg}$$

$$(k_s)_A = 0.627\,(k_s)_{avg}$$

$$(k_s)_A = (0.627)(4000\text{ kN/m}^3) = \mathbf{2510\text{ kN/m}^3} \quad \Leftarrow \textit{Answer}$$

$$(k_s)_B = (1.5)(0.627)(4000\text{ kN/m}^3) = \mathbf{3765\text{ kN/m}^3} \quad \Leftarrow \textit{Answer}$$

$$(k_s)_C = (2)(0.627)(4000\text{ kN/m}^3) = \mathbf{5020\text{ kN/m}^3} \quad \Leftarrow \textit{Answer}$$

Because it is so difficult to develop accurate k_s values, it may be appropriate to conduct a parametric studies to evaluate its effect on the mat design. ACI (1993) suggests varying k_s from one-half the computed value to five or ten times the computed value, and basing the structural design on the worst case condition.

This wide range in k_s values will produce proportional changes in the computed total settlement. However, we ignore these total settlement computations because they are not reliable anyway, and compute it using the methods described in Chapter 7. These changes in k_s have much less impact on the shears, moments, and deflections in the mat, and thus have only a small impact on the structural design.

10.4 STRUCTURAL DESIGN

General Methodology

The structural design of mat foundations must satisfy both strength and serviceability requirements. This requires two separate analyses, as follows:

Step 1: Evaluate the strength requirements using the factored loads (Equations 2.7–2.15) and LRFD design methods (which ACI calls *ultimate strength design*). The mat must have a sufficient thickness, T, and reinforcement to safely resist these loads. As with spread footings, T should be large enough that no shear reinforcement is needed.

Step 2: Evaluate mat deformations (which is the primary serviceability requirement) using the unfactored loads (Equations 2.1–2.4). These deformations are the result of concentrated loading at the column locations, possible non-uniformities in the mat, and variations in the soil stiffness. In effect, these deformations are the equivalent of differential settlement. If they are excessive, then the mat must be made stiffer by increasing its thickness.

Closed-Form Solutions

When the Winkler method is used (i.e., when all "springs" have the same k_s) and the geometry of the problem can be represented in two-dimensions, it is possible to develop closed-form solutions using the principles of structural mechanics (Scott, 1981; Hetényi, 1974). These solutions produce values of shear, moment, and deflection at all points in the idealized foundation. When the loading is complex, the principle of superposition may be used to divide the problem into multiple simpler problems.

These closed-form solutions were once very popular, because they were the only practical means of solving this problem. However, the advent and widespread availability of powerful computers and the associated software now allows us to use other methods that are more precise and more flexible.

Finite Element Method

Today, most mat foundations are designed with the aid of a computer using the *finite element method* (*FEM*). This method divides the mat into hundreds or perhaps thousands of elements, as shown in Figure 10.12. Each element has certain defined dimensions, a specified stiffness and strength (which may be defined in terms of concrete and steel properties) and is connected to the adjacent elements in a specified way.

The mat elements are connected to the ground through a series of "springs," which are defined using the coefficient of subgrade reaction. Typically, one spring is located at each corner of each element.

The loads on the mat include the externally applied column loads, applied line loads, applied area loads, and the weight of the mat itself. These loads press the mat downward,

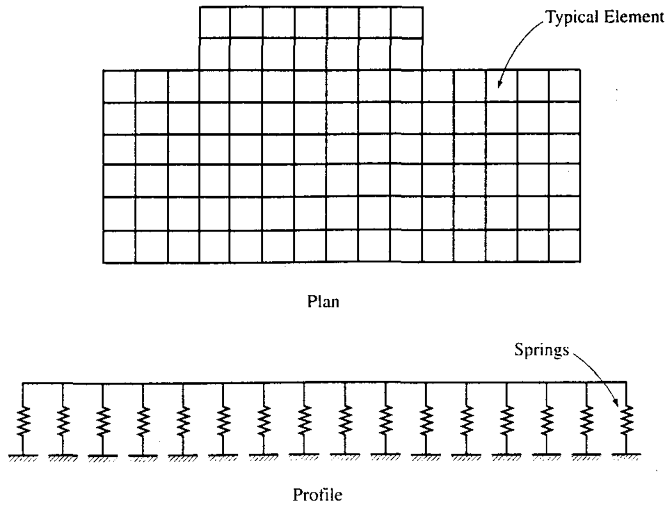

Figure 10.12 Use of the finite element method to analyze mat foundations. The mat is divided into a series of elements which are connected in a specified way. The elements are connected to the ground through a "bed of springs."

and this downward movement is resisted by the soil "springs." These opposing forces, along with the stiffness of the mat, can be evaluated simultaneously using matrix algebra, which allows us to compute the stresses, strains, and distortions in the mat. If the results of the analysis are not acceptable, the design is modified accordingly and reanalyzed.

This type of finite element analysis does not consider the stiffness of the superstructure. In other words, it assumes the superstructure is perfectly flexible and offers no resistance to deformations in the mat. This is conservative.

The finite element analysis can be extended to include the superstructure, the mat, and the underlying soil in a single three-dimensional finite element model. This method would, in principle, be a more accurate model of the soil-structure system, and thus may produce a more economical design. However, such analyses are substantially more complex and time-consuming, and it is very difficult to develop accurate soil properties for such models. Therefore, these extended finite element analyses are rarely performed in practice.

10.5 TOTAL SETTLEMENT

The bed of springs analyses produce a computed total settlement. However, this value is unreliable and should not be used for design. These analyses are useful only for computing shears, moments, and deformations (differential settlements) in the mat. Total settlement should be computed using the methods described in Chapter 7.

10.6 BEARING CAPACITY

Because of their large width, mat foundations on sands and gravels do not have bearing capacity problems. However, bearing capacity might be important in silts and clays, especially if undrained conditions prevail. The Fargo Grain Silo failure described in Chapter 6 is a notable example of a bearing capacity failure in a saturated clay.

We can evaluate bearing capacity using the analysis techniques described in Chapter 6. It is good practice to design the mat so the bearing pressure at all points is less than the allowable bearing capacity.

SUMMARY

Major Points

1. Mat foundations are essentially large spread footings that usually encompass the entire footprint of a structure. They are often an appropriate choice for structures that are too heavy for spread footings.
2. The analysis and design of mats must include an evaluation of the flexural stresses and must provide sufficient flexural strength to resist these stresses.
3. The oldest and simplest method of analyzing mats is the rigid method. It assumes that the mat is much more rigid than the underlying soil, which means the magnitude and distribution of bearing pressure is easy to determine. This means the shears, moment, and deformations in the mat are easily determined. However, this method is not an accurate representation because the assumption of rigidity is not correct.
4. Nonrigid analyses are superior because they consider the flexural deflections in the mat and the corresponding redistribution of the soil bearing pressure.
5. Nonrigid methods must include a definition of soil-structure interaction. This is usually done using a "bed of springs" analogy, with each spring having a linear force-displacement function as defined by the coefficient of subgrade reaction, k_s.
6. The simplest and oldest nonrigid method is the Winkler method, which uses independent springs, all of which have the same k_s. This method is an improvement over rigid analyses, but still does not accurately model soil–structure interaction, primarily because it does not consider coupling effects.
7. The coupled method is an extension of the Winkler method that considers coupling between the springs.
8. The pseudo-coupled method uses independent springs, but adjusts the k_s values to implicitly account for coupling effects.
9. The multiple parameter and finite element methods are more advanced ways of describing soil-structure interaction.
10. The coefficient of subgrade reaction is difficult to determine. Fortunately, the mat design is often not overly sensitive to global changes in k_s. Parametric studies are often appropriate.

11. If the Winkler method is used to describe soil–structure interaction, and the mat geometry is not too complex, the structural analysis may be performed using closed-form solutions. However, these methods are generally considered obsolete.
12. Most structural analyses are performed using numerical methods, especially the finite element method. This method uses finite elements to model the mat, and defines soil–structure interaction using the Winker or pseudo-coupled models. In principle, it also could use the multiple parameter model.
13. A design could be based entirely on a three-dimensional finite element analysis that includes the soil, mat, and superstructure. However, such analyses are beyond current practices, mostly because they are difficult to set up and require especially powerful computers.
14. The total settlement is best determined using the methods described in Chapter 7. Do not use the coefficient of subgrade reaction to determine total settlement.
15. Bearing capacity is not a problem with sands and gravels, but can be important in silts and clays. It should be checked using the methods described in Chapter 6.

Vocabulary

Beam on elastic foundation	Mat foundation	Rigid method
Bed of springs	Multiple parameter method	Shaft-supported mat
Coefficient of subgrade reaction	Nonrigid method	Soil–structure interaction
Coupled method	Pile-supported mat	Winkler method
Finite element method	Pseudo-coupled method	
	Raft foundation	

COMPREHENSIVE QUESTIONS AND PRACTICE PROBLEMS

10.1 Explain the reasoning behind the statement in Section 10.6: "Because of their large width, mat foundations on sands and gravels do not have bearing capacity problems."

10.2 How has the development of powerful and inexpensive digital computers affected the analysis and design of mat foundations? What changes do you expect in the future as this trend continues?

10.3 A mat foundation supports forty two columns for a building. These columns are spaced on a uniform grid pattern. How would the moments and differential settlements change if we used a nonrigid analysis with a constant k_s in lieu of a rigid analysis?

10.4 According to a settlement analysis conducted using the techniques described in Chapter 7, a certain mat will have a total settlement of 2.1 inches if the average bearing pressure is 5500 lb/ft^2. Compute the average k_s and express your answer in units of lb/in^3.

10.5 A 25-m diameter cylindrical water storage tank is to be supported on a mat foundation. The weight of the tank and its contents will be 50,000 kN and the weight of the mat will be 12,000 kN. According to a settlement analysis conducted using the techniques described in Chapter 7, the total settlement will be 40 mm. The groundwater table is at a depth of 5 m below the bottom of the mat. Using the pseudo-coupled method, divide the mat into zones and compute k_s for each zone. Then indicate the high-end and low-end values of k_s that should be used in the analysis.

10.6 An office building is to be supported on 150-ft × 300-ft mat foundation. The sum of the column loads plus the weight of the mat will be 90,000 k. According to a settlement analysis conducted using the techniques described in Chapter 7, the total settlement will be 1.8 inches. The groundwater table is at a depth of 10 ft below the bottom of the mat. Using the pseudo-coupled method, divide the mat into zones and composite each zone. Then indicate the high-end and low-end valves of k_s that should be used in the analysis.