# CHAPTER 10

## SPREAD FOOTINGS AND MAT FOUNDATIONS

**10-1. General.** When required footings cover more than half the area beneath a structure, it is often desirable to enlarge and combine the footings to cover the entire area. This type of foundation is called a raft or mat foundation and may be cheaper than individual footings because of reduced forming costs and simpler excavation procedures. A mat foundation also may be used to resist hydrostatic pressures or to bridge over small, soft spots in the soil, provided the mat is adequately reinforced. Although mat foundations are more difficult and more costly to design than individual spread footings, they can be used effectively.

**10-2. Adequate foundation depth.** The foundation should be placed below the frost line (chap 18) because of volume changes that occur during freezing and thawing, and also below a depth where seasonal volume changes occur. The minimum depth below which seasonal volume changes do not occur is usually 4 feet, but it varies with location. If foundation soils consist of swelling clays, the depth may be considerably greater, as described in TM 5-818-7. On sloping ground, the foundation should be placed at a depth such that it will not be affected by erosion.

### 10-3. Footing design.

*a. Allowable bearing pressures.* Procedures for determining allowable bearing pressures are presented in chapter 6. In many instances, the allowable bearing pressure will be governed by the allowable settlement. Criteria for determining allowable settlement are discussed in chapter 5. The maximum bearing pressure causing settlement consists of dead load plus normal live load for clays, and dead load plus maximum live loads for sands. Subsoil profiles should be examined carefully to determine soil strata contributing to settlement.

*b. Footings on cohesive soils.*

(1) If most of the settlement is anticipated to occur in strata beneath the footings to a depth equal to the distance between footings, a settlement analysis should be made assuming the footings are independent of each other. Compute settlements for the maximum bearing pressure and for lesser values. An example of such an analysis is shown in figure 10-1. If significant settlements can occur in strata below a depth equal to the distance between footings, the settlement analysis should consider all footings to determine the settlement at selected footings. Determine the vertical stresses beneath individual footings from the influence charts presented in chapter 5. The footing size should be selected on the basis of the maximum bearing pressure as a first trial. Depending on the nature of soil conditions, it may or may not be possible to proportion footings to equalize settlements. The possibility of reducing differential settlements by proportioning footing areas can be determined only on the basis of successive settlement analyses. If the differential settlements between footings are excessive, change the layout of the foundation, employ a mat foundation, or use piles.

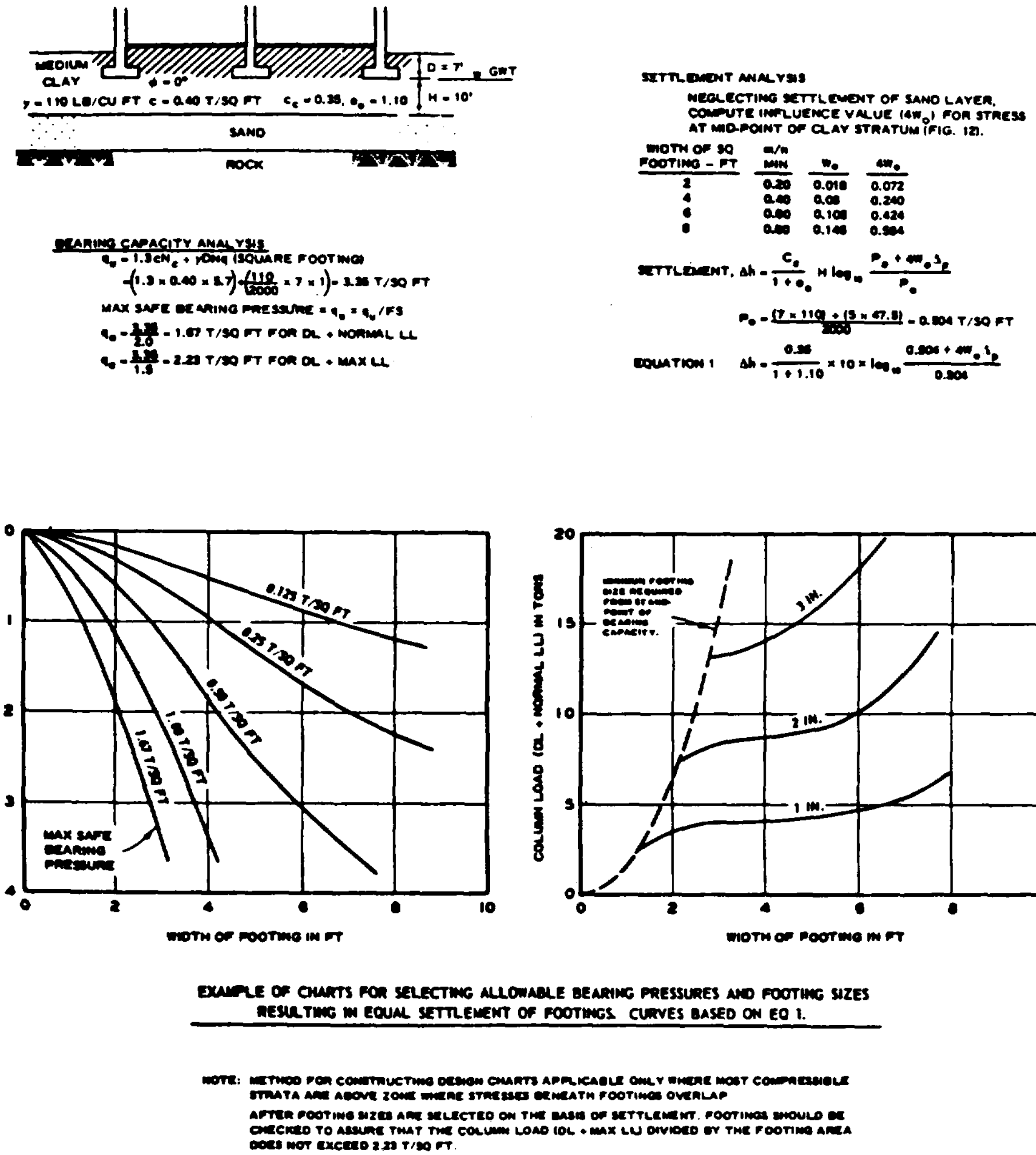
(2) If foundation soils are nonuniform in a horizontal direction, the settlement analysis should be made for the largest footing, assuming that it will be founded on the most unfavorable soils disclosed by the borings and for the smallest adjacent footing. Structural design is facilitated if results of settlement analyses are presented in charts (fig 10-1) which relate settlement, footing size, bearing pressures, and column loads. Proper footing sizes can be readily determined from such charts when the allowable settlement is known. After a footing size has been selected, compute the factor of safety with respect to bearing capacity for dead load plus maximum live load condition.

*c. Footings on cohesionless soils.* The settlement of footings on cohesionless soils is generally small and will take place mostly during construction. A procedure for proportioning footings on sands to restrict the differential settlement to within tolerable limits for most structures is given in figure 10-2.

*d. Foundation pressures.* Assume a planar distribution of foundation pressure for the structural analysis of a footing. This assumption is generally conservative. For eccentrically loaded footings, the distribution of the bearing pressure should be determined by equating the downward load to the total upward bearing pressure and equating the moments of these forces about the center line in accordance with requirements of static equilibrium. Examples of the bearing pressure distribution beneath footings are shown in figure 10-3.

### 10-4. Mat foundations.

*a. Stability.* The bearing pressure on mat foundations should be selected to provide a factor of safety of at least 2.0 for dead load plus normal live load and 1.5 for dead load plus maximum live load. By lowering the base elevation of the mat, the pressure that can be exerted safely by the building is correspondingly increased (chap 11), and the net increase in loading is reduced. The bearing pressure should be selected so that the settlement of the mat foundation will be within limits that the structure can safely tolerate as a flexible structure. If settlements beneath the mat foundation are more than the rigidity of the structure will permit, a redistribution of loads takes place that will change the pressure distribution beneath the structure, as subsequently described. The bearing capacity of loose sands, saturated silts, and low-density loess can be altered significantly as a result of saturation, vibrations, or shock. Therefore, the allowable bearing pressure and settlement of these soils cannot be determined in the usual manner for the foundation soils




U. S. Army Corps of Engineers

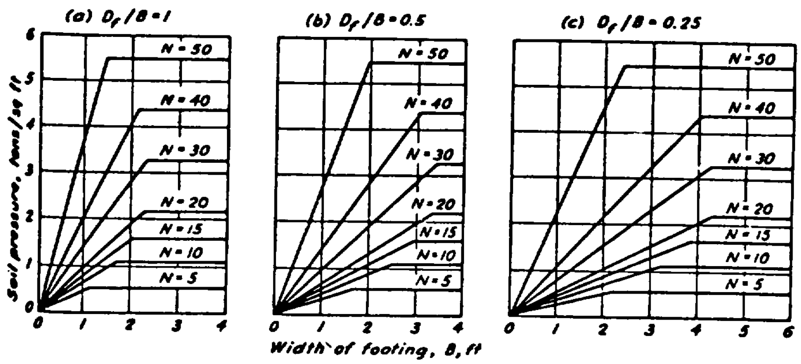
*Figure 10-1. Example of method for selecting allowable bearing pressure.*

may be subject to such effects. Replace or stabilize such foundation soils, as discussed in chapter 16, if these effects are anticipated.

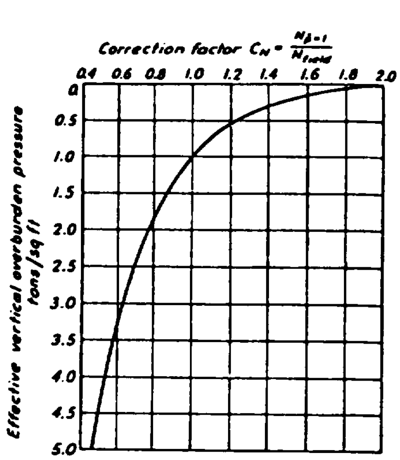
*b. Conventional analysis.* Where the differential settlement between columns will be small, design the mat as reinforced concrete flat slab assuming planar soil pressure distribution. The method is generally applicable where columns are more or less equally spaced. For analysis, the mat is divided into mutually perpendicular strips.

*c. Approximate plate analysis.* When the column loads differ appreciably or the columns are irregularly spaced, the conventional method of analysis becomes seriously in error. For these cases, use an analysis based on the theory for beams or plates on elastic foundations. Determine the subgrade modulus by the use of plate load tests. The method is suitable, particularly for mats on coarse-grained soils where rigidity increases with depth.

*d. Analysis of mats on compressible soils.* If the mat is founded on compressible soils, determination of the distribution of the foundation pressures beneath the mat is complex. The distribution of foundation pressures varies with time and depends on the construction sequence and procedure, elastic and plastic deformation properties of the foundation concrete, and




a. Design chart for proportioning shallow footings on sand.




b. Chart for correction of N-values in sand for influence of overburden pressure

1. Determine N values at 2-1/2-ft intervals between base of footing and depth B below base. Calculate average N value.

2. Select allowable soil pressure from design chart (a) based on settlement of 1 in.

3. If effective overburden pressure corresponding to depth of footing differs greatly from 1 ton/sq ft, adjust N value according to chart (b).

4. Multiply allowable soil pressure by correction factor for depth to water table $(D_w)$.

$$C_w = 0.5 + 0.5 \frac{D_w}{D_f + B}$$

*(Courtesy of R. B. Peck, W. E. Hanson, and T. H. Thornburn, Foundation Engineering, 1974, p 312. Reprinted by permission of John Wiley & Sons, Inc., New York.)*

*Figure 10-2. Proportioning footings on cohesionless soils.*

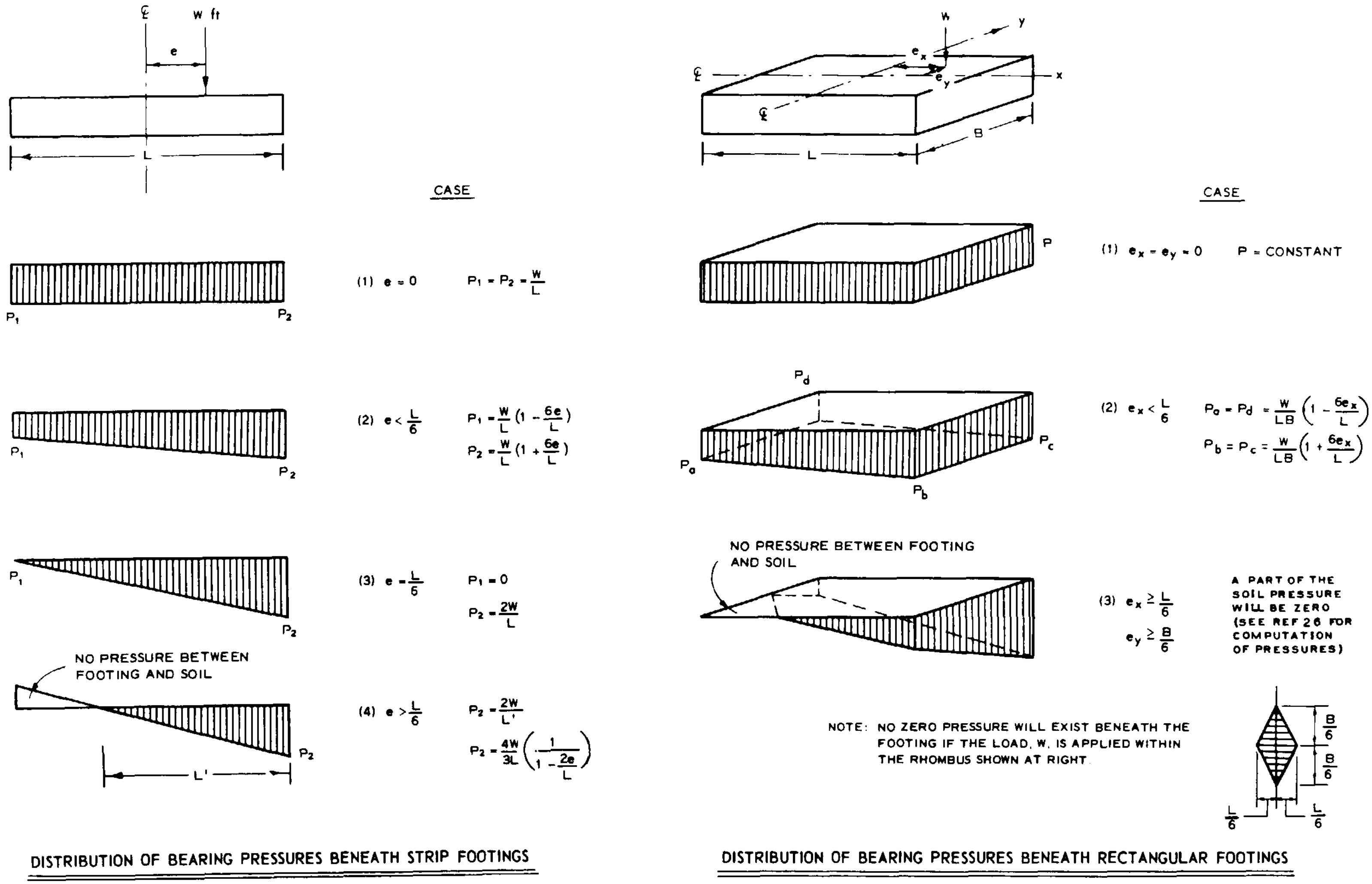



*Figure 10-3. Distribution of bearing pressures.*

time-settlement characteristics of foundation soils. As a conservative approach, mats founded on compressible soils should be designed for two limiting conditions: assuming a uniform distribution of soil pressure, and assuming a pressure that varies linearly from a minimum of zero at the middle to twice the uniform pressure at the edge. The mat should be designed structurally for whichever distribution leads to the more severe conditions.

**10-5. Special requirements for mat foundations.**

*a. Control of groundwater.* Exclude groundwater from the excavation by means of cutoffs, and provide for temporary or permanent pressure relief and dewatering by deep wells or wellpoints as described in TM 5-818-5/AFM 88-5, Chapter 6. Specify piezometers to measure drawdown levels during construction. Specify the pumping capacity to achieve required drawdown during various stages of construction, including removal of the temporary system at the completion of construction. Consider effects of drawdown on adjoining structures.

*b. Downdrag.* Placement of backfill against basement walls or deep raft foundations constructed in open excavations results in downdrag forces if weight of backfill is significant with respect to structural loading. Estimate the downdrag force on the basis of data in chapter 14.

**10-6. Modulus of subgrade reaction for footings and mats.**

*a.* The modulus of subgrade reaction can be determined from a plate load test (para 4-6) using a 1- by 1- foot plate.

$$k_{sf} = k_{sl} B \qquad (10\text{-}1)$$

where

$k_{sf}$ = the modulus of subgrade reaction for the prototype footing of width B

$k_{sl}$ = the value of the 1- by 1-foot plate in the plate load test

The equation above is valid for clays and assumes no increase in the modulus with depth, which is incorrect, and may give k1, which is too large.

For footings or mats on sand:

$$k_{sf} = k_{sl} \left(\frac{B+1}{2B}\right) 2 \qquad (10\text{-}2)$$

For a rectangular footing or mat of dimensions of B x mB:

( 15m5)(10-3)

with a limiting value of $k_{sf} = 0.667k_{sl}$.

*b.* $k_s$ may be computed as

$k_s = 36q_a$. (kips per square foot)

(10-4)

which has been found to give values about as reliable as any method. This equation assumes $q_a$ (kips per square foot) for a settlement of about 1 inch with a safety factor, $F \cong 3$. A typical range of values of $k_s$ is given in table 3-7.

**10-7. Foundations for radar towers.**

*a. General.* This design procedure provides minimum footing dimensions complying with criteria for tilting rotations resulting from operational wind loads. Design of the footing for static load and survival wind load conditions will comply with other appropriate sections of this manual.

*b. Design procedure.* This design procedure is based upon an effective modulus of elasticity of the foundation. The effective modulus of elasticity is determined by field plate load tests as described in subparagraph *d* below. The design procedure also requires seismic tests to determine the S-wave velocity in a zone beneath the footing at least 1 1/2 times the maximum size footing required. Field tests on existing radar towers have shown that the foundation performs nearly elastically when movements are small. The required size of either a square or a round footing to resist a specific angle of tilt, α, is determined by the following:

$$B^3 = 4320(F)\ \frac{M}{\alpha}\left(\frac{1-M^2}{E_s}\right) \quad \text{(square footing)} \qquad (10\text{-}5)$$

$$D^3 = 6034(F)\ \frac{M}{\alpha}\left(\frac{1-M^2}{E_s}\right) \quad \text{(round footing)} \qquad (10\text{-}6)$$

where

B, D = size and diameter of footing, respectively, feet

F = factor of safety (generally use 2.0)

M = applied moment at base of footing about axis of rotation, foot-pounds

α = allowable angle of tilt about axis of rotation, angular mils (1 angular mil = 0.001 radian)

$E_s$ = effective modulus of elasticity of foundation soil, pounds per cubic foot

The design using equations (10-5) and (10-6) is only valid if the seismic wave velocity increases with depth., If the velocity measurements decrease with depth, special foundation design criteria will be required. The discussion of these criteria is beyond the scope of this manual.

*c. Effective modulus of elasticity of foundation soil ($E_s$).* Experience has shown that the design modulus of elasticity of in-place soil ranges from 1000 to 500, kips per square foot. Values less than 1000 kips per square foot will ordinarily present severe settlement problems and are not satisfactory sites for radar towers. Values in excess of 5000 kips per square foot may be encountered in dense gravel or rock, but such values are not used in design.

(1) Use equations (10-5) and (10-6) to compute-

(a) Minimum and maximum footing sizes using $E_s$ = 1000 and 5000 kips per square foot, respectively.

(b) Two intermediate footing sizes using values intermediate between 1000 and 5000 kips per square foot.

Use these four values of B or D in the following equations to compute the increase (or pressure change) in the live load, $\Delta L$.

$$\text{square footing } \Delta L = \frac{17.0M}{B^3} \text{ (pounds per square foot)} \quad (10\text{-}7)$$

$$\text{round footing } \Delta L = \frac{20.3M}{D^3} \text{ (pounds per square foot)} \quad (10\text{-}8)$$

(2) The $E_s$ value depends on the depth of the footing below grade, the average dead load pressure on the soil, and the maximum pressure change in the live load, $\Delta L$, on the foundation due to wind moments. A determination of the E, value will be made at the proposed footing depth for each footing size computed.

(3) The dead load pressure, $q_0$, is computed as the weight, W, of the radar tower, appurtenances, and the footing divided by the footing area, A.

$$q_0 = \frac{\Sigma W}{A} \quad (10\text{-}9)$$

The selection of loadings for the field plate load test will be based on qo and $\Delta L$.

*d. Field plate load test procedure.* The following plate load test will be performed at the elevation of the bottom of the footing, and the test apparatus will be as described in TM 5-824-3/AFM 88-6, Chapter 3.

(1) Apply a unit loading to the plate equal to the smallest unit load due to the dead load pressure $q_0$. This unit loading will represent the largest size footing selected above.

(2) Allow essentially full consolidation under the dead load pressure increment. Deformation readings will be taken intermittently during and at the end of the consolidation period.

(3) After consolidation under the dead load pressure, perform repetitive load test using the live load pressure $\Delta L$ computed by the formulas in paragraph 10-7c. The repetitive loading will consist of the dead load pressure, with the live load increment applied for 1 minute. Then release the live load increment and allow to rebound at the dead pressure for 1 minute. This procedure constitutes one cycle of live load pressure application. Deformation readings will be taken at three points: at the start, after the live load is applied for 1 minute, and after the plate rebounds under the dead load pressure for 1 minute. Live load applications will be repeated for 15 cycles.

(4) Increase the dead load pressure, $q_0$, to the second lowest value, allow to consolidate, and then apply the respective live load increment repetitively for 15 cycles.

(5) Repeat step 4 for the remaining two dead load pressure increments.

(6) An uncorrected modulus of elasticity value is computed for each increment of dead and live load pressure as follows:

$$E_s' = 25.5 \frac{\Delta L}{S} (1 - \mu^2)$$

$E_s'$ = uncorrected effective modulus of elasticity for the loading condition used, pounds per square foot

S = average edge deformation of the plate for the applied load, determined from the slope of the last five rebound increments in the repetitive load test, inches

$\mu$ = Poisson's ratio (see table 3-6).

(7) The above-computed uncorrected modulus of elasticity will be corrected for bending of the plate as described in TM 5-824-3/AFM 88-6, Chapter 3, where E' is defined above, and E, is the effective modulus of elasticity for the test conditions.

*e. Selection of required footing size.* The required footing size to meet the allowable rotation criteria will be determined as follows:

(1) Plot on log-log paper the minimum and the maximum footing size and the two intermediate footing sizes versus the required (four assumed values) effective modulus of elasticity for each footing size.

(2) Plot the measured effective modulus of elasticity versus the footing size corresponding to the loading condition used for each test on the same chart as above.

(3) These two plots will intersect. The footing size indicated by their intersection is the minimum footing size that will resist the specified angle of tilt.