

7.12 FOUNDATION DESIGN

other methods described below. Probably because of its infrequent use, ASTM withdrew this test from publication in December 2002.

Modulus of Subgrade Reaction. The plate load test can also be used to calculate the modulus of subgrade reaction, also known as the subgrade modulus K_v . The procedure (per NAVFAC DM-7.1, 1982) is to plot the stress exerted by the plate versus the penetration of the plate. Using this plot, the yield point at which the penetration rapidly increases is estimated. Then the stress q and depth of penetration of the plate (δ) corresponding to half the yield point are determined from the plot and the subgrade modulus K_v is defined as:

$$K_v = \frac{q}{\delta} \quad (7.4)$$

Assuming the modulus of elasticity increases linearly with depth, the settlement S caused by a uniform vertical footing pressure q can be estimated from the following equations (NAVFAC DM-7.1, 1982):

For shallow foundations with $D \leq B$ and $B \leq 20$ ft:

$$S = \frac{4qB^2}{K_v(B+1)^2} \quad (7.5)$$

Using SI units, for shallow foundations with $D \leq B$ and $B \leq 6$ m:

$$S = \frac{4qB^2}{K_v(B+0.3)^2} \quad (7.6)$$

For shallow foundations with $D \leq B$ and $B \geq 40$ ft:

$$S = \frac{2qB^2}{K_v(B+1)^2} \quad (7.7)$$

Using SI units, for shallow foundations with $D \leq B$ and $B \geq 12$ m:

$$S = \frac{2qB^2}{K_v(B+0.3)^2} \quad (7.8)$$

where S = settlement of the footing (ft or m)

q = vertical footing pressure (psf or kPa)

B = footing width (ft or m)

K_v = subgrade modulus from the plate load test (pcf or kN/m³)

D = depth of the footing below ground surface (ft or m)

It is necessary to interpolate between Eqs. 7.5 and 7.7 for shallow foundations having a foundation width B between 20 and 40 ft. Eqs. 7.7 and 7.8 can also be used for deep foundations having $D \geq 20$ ft and $B \leq 20$ ft (6 m).

Besides the plate load test, the subgrade modulus can also be obtained from Fig. 7.7. The values K_v from Fig. 7.7 apply to dry or moist cohesionless (granular) soil with the groundwater table at a depth of at least 1.5 B below the bottom of the footing. If a groundwater table is at the base of the footing, then $1/2 K_v$ should be used in computing the settlement. For continuous footings, the settlement calculated earlier should be multiplied by a factor of 2. The relative density D_r can be estimated from the standard penetration test N value (see Table 2.6). Equations 7.5 to 7.8 may underestimate the settlement in cases of large footings where soil deformation properties vary significantly with depth or where the thickness of granular soil is only a fraction of the width of the loaded area.

Example Problem 7.1 A site consists of a sand deposit where the standard penetration test N value corrected for field testing procedures and overburden pressure $[(N_1)_{60}]$ is equal to 20. The groundwater table is well below the bottom of the footing and the total unit weight γ_t of the sand = 120 pcf (18.9 kN/m³). For a square footing that is 10 ft (3 m) wide and at a depth of 5 ft (1.5) below ground surface, determine the settlement if the footing exerts a vertical pressure of 6600 psf (320 kPa) onto the sand.

Solution From Table 2.6, for $(N_1)_{60} = 20$, the relative density D_r of sand is at the junction between medium and dense and hence D_r is approximately 65 percent.

Entering Fig. 7.7 at $D_r = 65$ percent, the value of $K_v = 190$ tons/ft³ (380,000 pcf or 60,000 kN/m³).

It is the net pressure exerted by the footing on the soil that will cause settlement, or:

$$q = 6600 \text{ psf} - (5 \text{ ft})(120 \text{ pcf}) = 6000 \text{ psf} (290 \text{ kPa})$$

Since $D \leq B$ and $B \leq 20$ ft, use Eq. 7.5:

$$\begin{aligned} S &= (4qB^2)/[K_v (B + 1)^2] \\ &= [(4)(6,000)(10)^2]/[(380,000)(10 + 1)^2] = 0.052 \text{ ft} = 0.63 \text{ in.} \end{aligned}$$

Using Eq. 7.6:

$$\begin{aligned} S &= (4qB^2)/[K_v (B + 0.3)^2] \\ &= [(4)(290)(3)^2]/[(60,000)(3 + 0.3)^2] = 0.016 \text{ m} = 1.6 \text{ cm} \end{aligned}$$

Terzaghi and Peck Empirical Chart. Figure 7.8 shows a chart by Terzaghi and Peck (1967) that presents an empirical correlation between the standard penetration test N value and the allowable soil pressure (tsf) that will produce a settlement of the footing of 1.0 in. (2.5 cm). Terzaghi and Peck (1967) developed this chart specifically for the standard penetration test (i.e., $E_m = 60$, and $C_b = 1.0$).

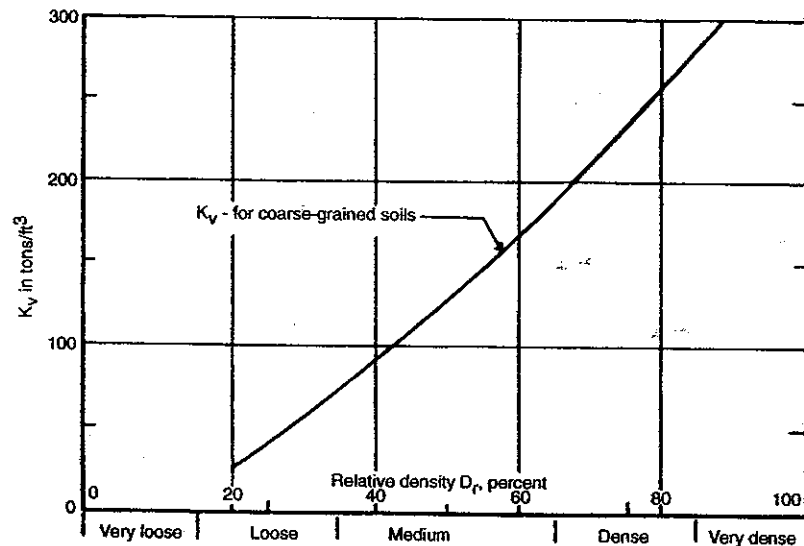


FIGURE 7.7 Correlation between relative density D_r and subgrade modulus K_v for cohesionless soil. (Adapted from NAVFAC DM-7.1, 1982.)

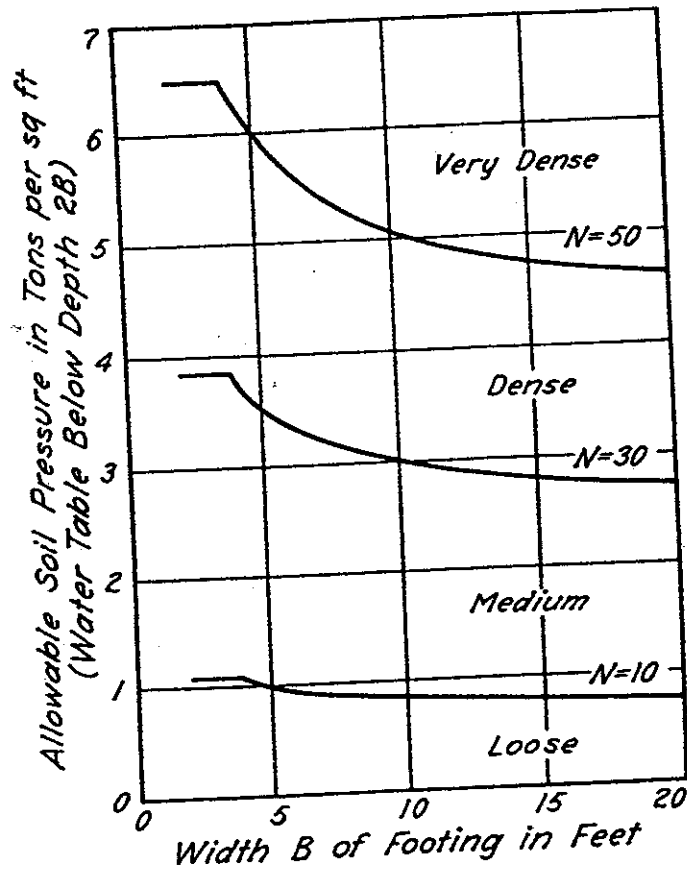


FIGURE 7.8 Allowable soil bearing pressures for footings on sand based on the standard penetration test. Note: assume N refers to the N_{60} value from Eq. 2.4. (From Terzaghi and Peck, 1967; reprinted with permission of John Wiley & Sons.)

Hence as a practical matter, the N value referred to in Fig. 7.8 can be assumed to be essentially equivalent to the N_{60} value calculated from Eq. 2.4. Terzaghi and Peck (1967) defined the soil density states versus N_{60} as follows:

Soil density	N_{60} value
Very loose	Less than 4
Loose	4-10
Medium	10-30
Dense	30-50
Very dense	Greater than 50

Thus the curves in Fig. 7.8 are at the boundaries between different soil density states. For N_{60} values other than those for which the curves are drawn in Fig. 7.8, the allowable soil pressure can be obtained by linear interpolation between curves. According to Terzaghi and Peck (1967), if all of the footings are proportioned in accordance with the allowable soil pressure corresponding to Fig. 7.8, then the total settlement ρ_{max} of the foundation should not exceed 1.0 in. (2.5 cm) and the maximum differential settlement Δ should not exceed $3/4$ in. (2 cm). Figure 7.8 was developed for the ground-water table located at a depth equal to or greater than a depth of $2B$ below the bottom of the footing.