FUNDAMENTALS OF

SOIL MECHANICS

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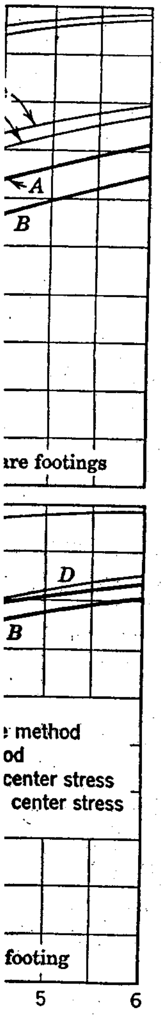

on buried strata.

and for a long footing the expression is

$$\frac{q_k}{q_0} = \frac{\dfrac{b}{d}}{\dfrac{b}{d} + \tan \beta} \qquad (19 \cdot 29)$$

wherein q_k is the stress on the central portion of the buried stratum and the spread angle β recommended by Kögler is 55 degrees. In Fig. 19·17 curves representing the above equations with the 55-degree spread angle are labeled B.

The light curves of Fig. 19·17 are for the elastic cases represented in Fig. 19·16 (a), the intensity of q being the maximum intensity at depth d. It is seen from Fig. 19·17 that the Boussinesq formula gives relatively large values of q/q_0 but that the other three approaches are in reasonable agreement with each other. Use of any one of these three approaches is probably conservative and sufficiently accurate for the rough indications usually desired from such a method.

For square or round footings Fig. 19·17 shows that the stress on the buried stratum is about one-fifth that at the surface when the breadth-depth ratio is 1; this figure is worth remembering.

19·29 Pressure Distributions and Differential Settlements

The distribution of pressure is very different below footings on cohesionless soil from that below footings on cohesive soil. The distribution also depends greatly on the rigidity of the footing, being entirely different below rigid and below flexible footings. The pattern of the differential settlement of flexible footings is also dependent on the type of soil below the footing. Little has been said in the preceding pages about these important variations, the intensities of loading and the settlements considered up to this point being the average values.

The policy of first developing concepts for limiting cases will be continued in this section, and perfectly flexible and perfectly rigid footings will be studied relative to pressure distributions and differential settlements. Separate studies of these items will be carried out for cohesionless and for highly cohesive soils.

The general concepts arrived at are valid for square, round, or long footings.

Consider first a *flexible footing on the surface of a cohesionless soil,* carrying a *uniformly distributed load.* Since the footing is completely flexible the uniform distribution of pressure also acts on the surface of the soil. The soil just outside of the edge of the footing is not under pressure and has no strength. Therefore, when the given intensity of load is applied, the outer edge of the footing undergoes a relatively large settlement. Below the center of the footing the soil develops strength and rigidity as fast as it is loaded from above and from surrounding points, and because of this the settlement is relatively small. Figure 19·18 (*a*) shows the uniform loading diagram for this case, with the curve of settlement shown by heavy dashed lines.

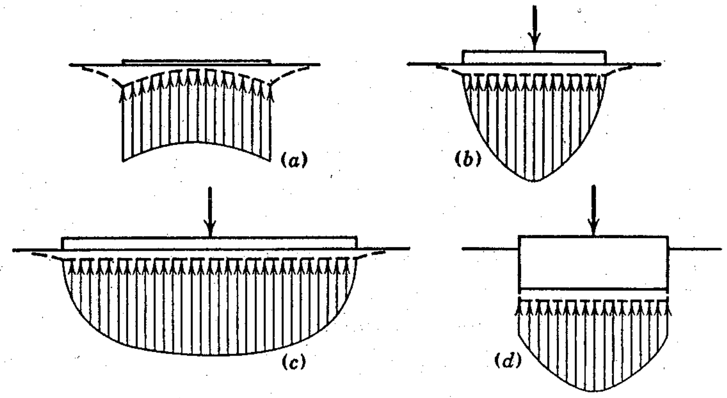

Fig. 19·18 Pressure distributions and differential settlements in cohesionless soils.

For a *rigid footing resting on cohesionless soil* the settlement must be uniform. Under uniform settlement the high resistance to compression in the soil below the center of the footing, as compared to the lack of resistance to compression below the edge, must result in a relatively large pressure under the center and no pressure at the edge. This case with constant settlement and an approximately parabolic pressure distribution is shown in Fig. 19·18 (*b*). If the average pressure is relatively small, or if the width of the footing is large, this pressure distribution is some-for square, round, or

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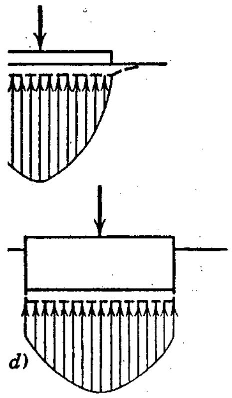

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what flatter over the central portion of the footing, as shown in Fig. 19·18 (*c*), being nearer ellipsoidal than parabolic in shape but still having zero pressure at the edges.

For *rigid footings founded below the surface of a cohesionless deposit* there is some strength below the edge of the footing and, therefore, the pressure is not zero at the edge but is more like that shown in the distribution curve in Fig. 19·18 (*d*). For very deep rigid footings on sand the distribution may be more like that discussed below for cohesive soils.

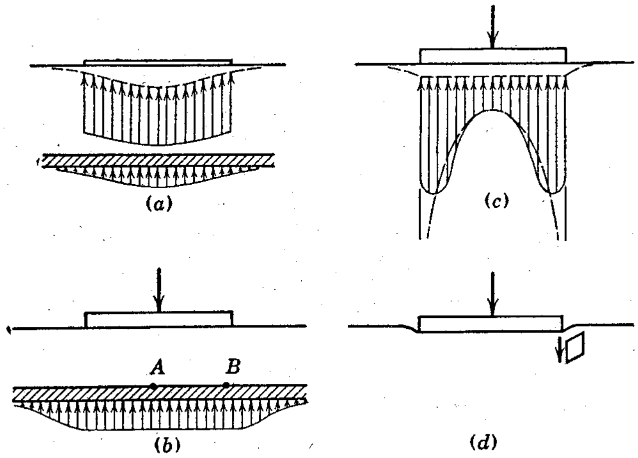

Fig. 19·19 Pressure distributions and differential settlements in highly cohesive soils.

A *uniformly loaded flexible footing on highly cohesive soil* gives conditions that can best be visualized by considering the stresses and strains caused in a typical thin horizontal layer of soil within the height of the pressure bulb. The uniform surface distribution transmits a bell-shaped distribution of pressure to this subsurface layer, as explained in Chapter 11 and as illustrated in Fig. 19·19 (*a*). The greater stress below the center of the footing at this subsurface layer must cause a greater compressive strain at this location. All horizontal layers below ground surface similarly show maximum compression below the center of the footing, and thus the surface settlement must have the dished pattern shown, with a much greater settlement under the center than under the edge of the footing.

A *rigid footing on highly cohesive soil* must undergo uniform settlement. Thus the underground horizontal layers discussed in the preceding paragraph must, on the average, be compressed nearly as much under the edges as under the center of the footing. The layer shown in (*b*) is at a depth of slightly less than $\frac{1}{2}b$ and may be accepted as representative of the average of all such layers. If the compression of this layer is nearly as large at point *B* as at point *A*, the pressure at this level must be nearly as large at *B* as at *A*, and the pressure distribution curve at this level must be about as shown. The pressure distribution at the base of the footing is best determined by a comparison of this case with the case of the flexible footing shown in (*a*). If the uniform surface distribution occurring in (*a*) causes the bell-shaped distribution shown on the buried layer, it can be reasoned that the surface distribution which causes a uniform distribution on the buried plane must, in comparison, be larger near the edges and smaller near the center, as shown in (*c*). For an elastic material of infinite strength, the distribution shown by the theory of elasticity is indicated in (*c*) by a light dashed line; this curve shows an infinite stress at the edge of the footing. Actually an infinite stress cannot occur, but the stress at the edges may be much larger than that at the center.

Another explanation of the large stresses under the edges of rigid footings on clay may be obtained by simple reasoning. The settlement of the footing forces the soil below the corner of the footing to subside, but the soil a short distance out from under the footing subsides much less. A little element of soil which was originally square must therefore be strained in shear to the shape shown in (*d*). A large vertical force is required to furnish the shearing stress that must exist on the left-hand face to cause the shearing strain of this highly cohesive element. This force must be provided by load from the footing, and it is this load that is resisted by perimeter shear and is the explanation of the larger edge pressure. Below the edges of rigid surface footings on sand this same shearing strain occurs, but it requires no force to cause it, owing to the lack of rigidity in the sand. However, in deeply buried, heavily loaded footings on sand a distribution similar to that in (*c*) may hold; this is not

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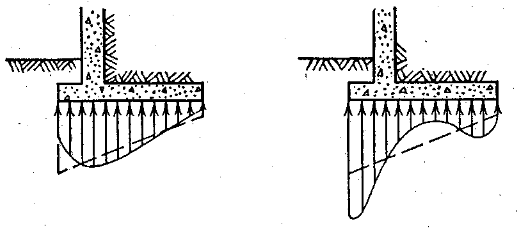
in disagreement with the concepts which have been developed because the sand in the bulb below a deeply buried footing may be essentially of constant strength and may thus resemble the character of a highly cohesive soil.

Numerical values of pressures for the variable distributions in Figs. 19·18 and 19·19 cannot be given because the actual magnitudes depend on numerous factors. However, a knowledge of the general forms of these distributions is very important to the structural designer. An assumption commonly used in the design of rigid footings is that the pressure is uniform, and no definite recommendation for a better procedure can be given. After a design has been prepared on this basis, however, it should be reviewed and should be strengthened at locations where the true distribution gives greater stresses than are given by the assumed distribution. For example, in Fig. 19·19 (*c*), the bending moment in the spread footing is much larger for the distribution shown than it is for a case of uniform soil reaction; additional reinforcing steel is needed to carry this greater moment, but the percentage to be added must be determined mainly by judgment since the actual distribution is known only qualitatively.

19·30 Pressure Distributions for Cases of Eccentric Loading

The common procedure for figuring pressures below eccentrically loaded areas involves the assumption of linear variation of pressure. A good example of such determinations, based on retaining walls, has already been given in Section 17·13. The dashed lines in Fig. 19·20 represent a typical eccentric case under this assumption. Pressure distribution diagrams on the basis



(*a*) Cohesionless soil **(*b*) Cohesive soil**

FIG. 19·20 Pressure distributions below retaining walls.