STABILITY OF FOUNDATIONS

STABILITE DES FONDATIONS
УСТОЙЧИВОСТЬ ОСНОВАНИЙ

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SYNOPSIS. The three "conventional" steps of stability analysis, i.e. checking the load bearing capacity of the subsoil, the safety against sliding and tilting of the structure may be combined into a single, complex procedure, eliminating some contradictions inherent to former methods. The degree of safety cannot, in general, be given with a single number, but it has to be demonstrated that the critical resultant equals the ultimate capacity to inclined-eccentric loads at a specified low probability. This study considers the fundamentals of this interpretation of the safety, without getting involved in the theoretical problems of the bearing capacity of foundations under inclined-eccentric loads. The approximation proposed as a first step is likely to be in need of further examination.

An adequate stability of engineering structures re-
653 quires safety against ground failure, sliding, overturning (or tilting) and floating up. In order to secure economical construction, the lowest possible safety factor has to be selected.

This seemingly simple problem involves rather complex basic principles and even new considerations arise in connection with stability analyses. The safety against floating up will not be considered here. The safety against ground failure, sliding and overturning should be treated as a complex problem, they cannot be dealt with separately, as was demonstrated earlier (Kézdi, 1961).

As for the definition of the safety factor, there are suggestions which call for the ratio of stabilizing moments to overturning moments, others consider the eccentricity of the resultant. Objections may be made to both, because - as will be demonstrated - they do not take correctly the load bearing capacity of the soil into consideration.

It has to be emphasized that stability against inclined and eccentric loads should primarily be examined on the basis of the loads bearing capacity of the soil.

For stability analysis Meyerhof replaced the actual surface L x B under eccentric load by a reduced surface L' x B' under central load (Fig. 1). The same is adopted by the Hungarian Standard, and also test results by Muhs and Weiss (1970) have led to the same conclusion. For calculations with the reduced surface, the contact pressure distribution beneath the base is assumed to be symmetrical.

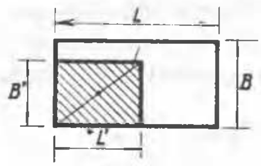

FIG. 1

Several authors have investigated the load bearing of bases acted upon by a central but inclined load which makes an angle μ with the perpendicular. Based on the theories furnishing the limit load, bearing capacity factors can be developed.

According to these, eccentric, inclined ultimate loads for strip foundations are expressed by:

$$R_\mu = B'\left(\frac{B'\gamma N_\gamma'}{2} + d\gamma N_q' + c N_c'\right) \quad (1)$$

where B' width of the reduced surface,
d foundation depth,
γ soil density,
c' soil cohesion,
N' dimensionless bearing capacity factors.

The practical use of Eq. (1) will be illustrated by a numerical example developed for a fictitious case in Fig. 2. Remember that in the given case the resistance of the earth mass down to depth t - the passive earth pressure - cannot be considered separately since, once the sliding surface has developed and failure caused by the resultant R_μ takes place, the mass referred to moves together with the entire mass bounded by the sliding surface - thus, it cannot separately resist either slipping, or tilting.

The ultimate value of the inclined force R may be reduced by using an arbitrary safety factor, or a reduction based on the scatter of soil mechanical and other data may be applied (Varga, 1965). Let us introduce the reduction factor α = 0,5. Now, the diagram in Fig. 2 for inclined-eccentric ultimate load bearing capacity may be plotted, as defined by the given conditions.

This load bearing capacity is to be confronted to the acting forces, i.e. the inclined eccentric load resulting from their most adverse coincidence should equal the ultimate load bearing capacity according to Fig. 2 only at a specified low probability.

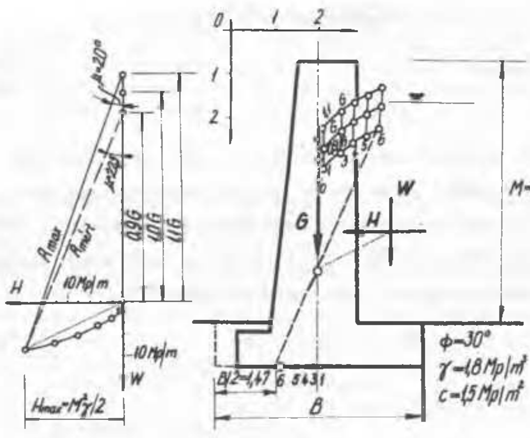

FIG. 2

This train of thought will be set forth on the example in Fig. 3, where a cantilever wall is shown. Let the wall - for the sake of simplicity - retain water. Water depth is seen to vary from 0 to 5 m in normal service conditions. At a low probability, however, the basin may be entirely filled to a depth of M = 6 m. Any uncertainty in the wall weight is allowed for by using the factors 0,9 and 1.1. The vertical component of the resultant force contains also the water weight W above the cantilever in accordance with the horizontal water pressure H, in dependence of the water level. (A mechanistic consideration of relevant standard specifications would involve different factors for H and W.)

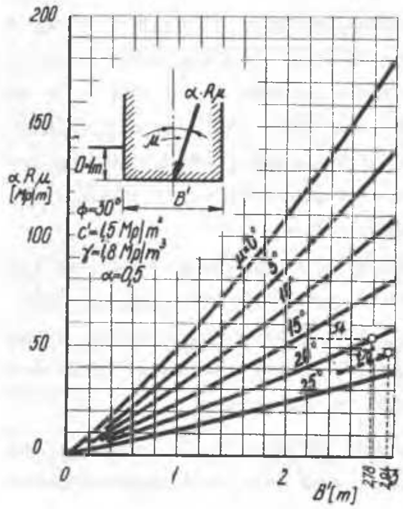

FIG. 3

Variation of the magnitude, direction and position of the components of forces G, H and W as a function of the dead weight factor G and the water depth is presented in detail in Fig. 3. The resultant force intersects the base plane at points 1, 3, 4, 5 and 6 as the water depth increases from 0 to 1, 3, 4, 5 and 6 m respectively. (The greater circle 6 indicates that all lines of action not specified above pass almost through the same point.) The other end points of the actual resultant forces are indicated by small circles on the upper right part of the wall. Of course, maximum resultant corresponds to maximum water depth; it is, however, not directly evident whether the resultant whose absolute value is maximum or a somewhat smaller but more inclined resultant (R = 54 Mp/m, μ_o = 20° and R = 47,5 Mp/m, μ = 22,5°, respectively) will be critical. This problem can be be solved by means of Fig. 2, plotting the data B' = 2,78 m and B' = 2,94 for the first and the second case, respectively. Accordingly, the smaller resultant making a smaller angle with the horizontal determines the required base width. Half of the size B' = 2,94 m is measured from the point of application of the resultant R_m (left to the circle 6) so that the total width of the base increases from the originally assumed 4,25 m to B = 4,80 m. (For the given example the slight increase in weight G and the modification of the position of the resultant have been neglected.)

Another problem consists in the impossibility to indicate the safety margin by a unique number, since the safety is governed by the reduction factor α introduced into the calculation of the soil load bearing capacity, and by the probability of occurrence of the critical load. These, however, do not lend themselves to form simply an "overall" safety factor.

For circumstances shown in Fig. 3, no special consideration was required for the assumption of the maximum water level in connection with the risk, since the possible load was limited by geometry. In some cases, however, such limits may not exist, and the critical load may be the resultant of different, independent random effects, such as wind load, ice load, forces transmitted by floating objects, seismic forces etc. For example, it is interesting to note that - to the author's knowledge - chimney shafts or TV towers are never designed for the combined total effect of critical seismic forces plus maximum wind gusts characteristic of that area since their coincidence is of a low probability. The critical combination of loads or the justified assumption of risks should be considered in each case separately, depending on the character of the load and the importance of the structure. Therefore the other component of the "overall safety" may be reckoned with only if the following requirement is fulfilled:

- the resultant of an adverse combination of components is permitted to equal the ultimate load bearing capacity under inclined-eccentric loads only at a specified low probability.

This procedure may lead to an adequate safety against both ground failure and overturning. However, sliding safety should be checked separately, since in the case of firm subsoils sliding is likely to occur on the lower surface of the base. Therefore, with the size B determined in the described manner, also the "conventional" safety, i.e. fulfilment of the requirement

$$\frac{\alpha\,(N \tan\varphi + A \cdot F + E_p)}{T} = n \qquad (2)$$

has to be verified (φ = angle of surface friction between the base and the soil; A = adhesion if any, F = base surface of the foundation; E_p = passive earth pressure; ΔX = reduction factor; and n = safety factor required in the given case, generally, n = 1,5).

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