TECHNICAL NOTE

A METHOD FOR ESTIMATING FOUNDATION
ULTIMATE CAPACITY

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ABSTRACT

In the load testing of a foundation or any other ground structure, the method of defining ultimate failure load depends on many factors which include the design criteria and the soil stress history. Some of the more commonly used methods are noted in this technical note. A graphical method is presented which harmonises three of these methods and thus makes it easier to make comparable safety factors between different loading test results.

Key words : bearing capacity, failure, foundation, load test, settlement (IGC : E 2/E 3)

INTRODUCTION

Before the design load of a ground structure is determined, it is always necessary to estimate the maximum load that would cause its collapse so that the use of a meaningful safety factor can be effected. Unfortunately there is no one universally accepted method by which this collapse load can be estimated.

There are many different ways in which the ultimate load capacity of a ground structure may be defined, depending on the peculiarities of the problem and the criteria governing its design and stability after construction. The shape of the load-displacement graph obtained for any such structure depends largely on the properties and initial stress history of the soil. The most commonly used methods for ultimate load definition include the following:

1. The load on a load-displacement plot after which there is no change in load with increasing displacement.
2. The maximum load on a load-displacement plot after which the load falls with increasing displacement, therefore, exhibiting strain softening.
3. The constant residual load after the peak has been passed on a load-displacement plot.
4. The load on a load-displacement plot after which the soil undergoes a constant rate of strain hardening.
5. The load at which the tangent defining the strain hardening phenomenon in 4 intersects the load-axis. This corresponds to an assumption that the soil is instantaneously sheared to its ultimate capacity to be followed by strain hardening.
6. The load corresponding to the end of

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Fig. 1. Typical load-displacement curves

the initial linear portion of the load-displacement curve (that is, the elastic limit).

7. The load carried by the ground structure when its displacement equals a pre-set percentage of a dimension of the structure (for example, the shorter width of a footing or the diameter of a pile or an anchor) or when the displacement equals a pre-set absolute value.

Fig. 1. shows definitions 1 through 6 with numbers indicating corresponding definitions.

The use of definition 3 is usually in situations when a soil has a post-yield brittle behaviour. In using definition 5, problems of ambiguity often arise. For example, in the load testing of horizontal and inclined anchors such as are used with diaphragm or sheet pile walls, two different anchors could be found to exhibit strain hardening post-failure behaviours. However, a situation could arise whereby the one with the obviously higher pullout capacity shows a higher rate of strain hardening than the other in such a way that its pullout capacity as defined by definition 5 is underestimated even below that of the other anchor.

Ultimate soil resistances as are obtained with definitions 6 and 7 are usually necessary in cases, as in retaining wall designs, where the displacements govern all considerations.

The purpose of this paper is to describe a method of ultimate load estimation that harmonises the commonest failure occurrences

Fig. 2. Construction for ultimate load estimation

as typified by definitions 1, 2 and 4. The main considerations on which this method is based are as follows.

DESCRIPTION OF METHOD

Consider the load-displacement curve shown in Fig. 2. Divide the displacement-axis into very small but equal segments each of length k and draw lines parallel to the load-axis from these segment points to meet the curve at points 1, 2, 3, ..., n as shown. Let the lengths of these lines be respectively $l_1, l_2, l_3, \dots, l_n$ and the angles they respectively make with the tangents to the curve at the points be $\theta_1, \theta_2, \theta_3, \dots, \theta_n$. If the segments on the displacement-axis are sufficiently small, the tangents are approximately coincident with the curve proper. Thus, the inverse slopes of the curve are respectively

$$\cot \theta_1 = l_1/k \quad (1a)$$

$$\cot \theta_2 = (l_2 - l_1)/k \quad (1b)$$

$$\cot \theta_3 = (l_3 - l_2)/k \quad (1c)$$

⋮

$$\cot \theta_n = (l_n - l_{n-1})/k \quad (1n)$$

Eqs. 1 thus indicate that $\cot \theta_i$ is directly proportional to $(l_i - l_{i-1})$. Plot the values of $(l_i - l_{i-1})$ above every point $(i-1)=0, 1, 2, \dots, (n-1)$ as shown.

To obtain the ultimate load by definition 1, extrapolate the $(l_i - l_{i-1})$ -load curve, if necessary. The load corresponding to $\cot \theta_i = 0$ is the required ultimate load. Also, for the case characterised by definition 2, $\cot \theta_i = 0$ defines failure even though some of the points on the curve have negative values. Where a constant rate of strain hardening is obtained, $\cot \theta_i$ is always greater than zero and failure is defined as the load corresponding to the beginning of the constant (minimum) value of $\cot \theta_i$.

The ultimate collapse load of a foundation can thus be defined as that load on a plot such as is in Fig. 2 at which $\cot \theta_i = 0$ or at which $\cot \theta_i$ reaches a constant minimum value.

APPLICATION

The simplicity of the construction method described in this note is obvious as it does not depend on the physical characteristics of the soil or the ground structure. The smaller the segments on the displacement-axis the better the fit on the graph. The method was tested on results of some published materials (Aldrich and Pickering, 1959; Hanna, 1963; Mohan et al., 1963; Coyle and Reese, 1966; Akinmusuru, 1973, 1978; Neeley et al., 1973). In each case, the portion of the graph used was up to the load corresponding of 50% of the measured ultimate capacity. The construction method was then applied from this point until estimate ultimate capacity. The results showed that the estimated ultimate capacities for different types of ground structures were

between 90%-105% of the measured ultimate capacities thus implying a very good agreement between estimated and measured values of ultimate capacity as typified by definitions 1, 2 and 4 in Fig. 1.

CONCLUSIONS

A method has been described in this paper for estimating the ultimate load capacity of a foundation or of any other subsurface structure in a way that is compatible with the most commonly used ultimate load definitions. The advantage of this graphical method is that it provides the much needed consistent basis required in design for obtaining comparable safety factors.

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