WHAT CAPACITY VALUE TO CHOOSE FROM THE RESULTS OF A STATIC LOADING TEST

by Bengt H. Fellenius, Urkkada Technology Ltd., Ottawa, Ontario, Canada

1. Introduction

For pile foundation projects, it is usually necessary to confirm capacity and to verify that the behavior of the piles agrees with the assumptions of the design. Frequently, this is achieved by means of performing a static loading test, and, normally, determining the capacity is the primary purpose of the test. The capacity can crudely be defined as the load for which rapid movement occurs under sustained or slight increase of the applied load - the pile plunges. This definition is inadequate, however, because large movements are required for a pile to reach plunging mode and large movements are often governed less by the capacity of the pile-soil system and more by the capacity of the man at the pump. On most occasions, a distinct plunging ultimate load is not obtained in the test and, therefore, the pile capacity or ultimate load must be determined by some definition based on the load-movement data recorded in the test.

An old definition of capacity has been the load for which the pile head movement exceeds a certain value, usually 10 % of the diameter of the pile, or a given distance, often 1.5 inch. Such definitions do not consider the elastic shortening of the pile, which can be substantial for long piles, while it is negligible for short piles. In reality, a movement limit relates only to a movement allowed by the superstructure to be supported by the pile, and it does not relate to the capacity of the pile in the static loading test. As such, the 10 % or any other ratio to the pile diameter is meaningless from both the point-of-view of the pile-soil behavior and the structure. Similarly, 1.5-inch maximum movement criterion can be just right for the structure, but it has nothing to do with the pile-soil behavior. The question could be: "Should the definition consider the structure that is going to be supported by the pile"?

For now, let's restrict ourselves to a definition of capacity in the geotechnical sense of the word. Sometimes, the pile capacity is defined as the load at the intersection of two straight lines, approximating an initial pseudo-elastic portion of the curve and a final pseudo-plastic portion. This definition results in interpreted capacity values, which depend greatly on conjecture and on the scale of the graph. Change the scales and the perceived capacity value changes also. A loading test is influenced by many occurrences, but the draughting manner should not be one of these.

Without a proper definition, capacity interpretation becomes meaningless for cases where obvious plunging has not occurred. To be 'proper,' a definition of pile capacity must be based on a mathematical rule and generate a repeatable value that is independent of scale relations and eye-balling ability of the interpreter.

There is more to a static loading test than analysis of data obtained. As a minimum requirement, the test should be performed in accordance with the ASTM guidelines (D 1143 and D 3689) for axial loading (compression and tension, respectively), keeping in mind that the guidelines refer to routine testing. Tests involving instrumented piles may well need stricter performance rules.

Some time ago, the author presented nine different definitions of pile capacity evaluated from load-movement records of a static loading test (Fellenius, 1975; 1980). Four of these have particular interest, namely, the Davisson Offset Limit, the DeBeer Yield Limit, the Hansen Ultimate Load and the Chin-Kondner Extrapolation. Recently, a fifth method was proposed by Luciano Decourt in Brazil (Decourt, 1999). The methods, including the Decourt Extrapolation are presented in the following.

2. The Davisson Offset Limit Load

The Offset Limit Method is probably the best known and widely used method in North America. The method was proposed by Davisson (1972) as the load corresponding to the movement that exceeds the elastic compression of the pile (taken as a free-standing column) by a value of 0.15 inch (4 mm) plus a factor equal to the diameter of the pile divided by 120. *Fig. 1* shows an example of a load-movement diagram from a static loading test on a 12-inch precast concrete pile. (The method of testing this pile is the constant-rate-of-penetration method, which is why the load-movement curve shows so many plotted points). The Davisson limit load is added to the curve presented in *Fig. 1*. For the 12-inch diameter example pile, the offset value is 0.25 inch (6 mm) and the load limit is 375 kips.

Notice that the Offset Limit Load is not necessarily the ultimate load. The method is based on the assumption that capacity is reached at a certain small toe movement and tries to estimate that movement by compensating for the stiffness (length and diameter) of the pile. It was developed by correlating — to one single criterion — a large number subjectively determined pile capacities for a data base of pile loading tests. It is primarily intended for test results from driven piles tested according to quick methods and it has gained a widespread use in phase with the increasing popularity of wave equation analysis of driven piles and dynamic testing.

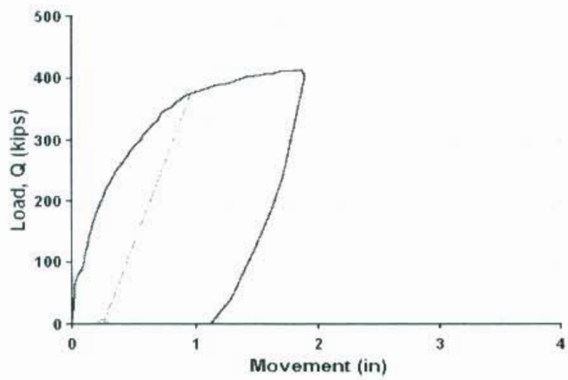

Fig. 1 The Offset Limit Method

3. De Beer Yield Load

If a trend is difficult to discern when analyzing data, a well known trick is to plot the data to logarithmic scale rather than to linear scale. Then, provided the data spread is an order of magnitude or two, all relations become more or less linear. (Determining the slope and location of the line and using this for some mathematical truths is rarely advisable; the linearity has more the effect of hiding details than revealing them). DeBeer (1968) made use of the logarithmic linearity by plotting the load-movement data in a double-logarithmic diagram as shown in *Fig. 2*.

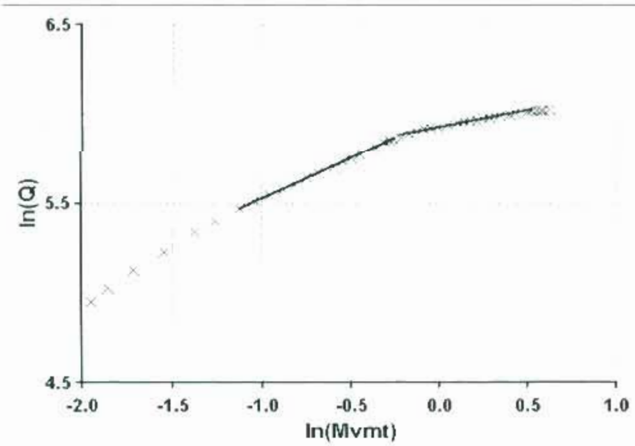

Fig. 2 DeBeer's Double-Logarithmic Method

If the ultimate load was reached in the test, two line approximations will appear; one before and one after the ultimate load (provided the number of points allow the linear trend to develop). The slopes are meaningless, but the intersection of the lines is useful as it indicates where a change occurs in the response of the piles to the applied load. DeBeer called the intersection the Yield Load. It occurs at a load of 360 kips for the example.

4. The Hansen 80%-Criterion

J. Brinch Hansen (1963) proposed a definition for pile capacity as the load that gives four times the movement of the pile head as obtained for 80 per cent of that load. This '80 %-criterion' can be estimated directly from the load-movement curve, but it is more accurately determined in a plot of the square root of each movement value divided by its load value and plotted against the movement.

Normally, the 80 %-criterion agrees well with the intuitively perceived 'plunging failure' of the pile. The following simple relations can be derived for computing the capacity or ultimate resistance, Q_u, according to the Hansen 80%-criterion for the ultimate load:

(1) $$Q_u = \frac{1}{2\sqrt{(C_1 C_2)}}$$

(2) $$\delta_u = \frac{C_2}{C_1}$$

DeBeer Yield Load

Where Q_u = capacity or ultimate load
δ_u = movement at the ultimate load
C_1 = slope of the straight line
C_2 = y-intercept of the straight line

The Hansen method is applied to the example case, as illustrated in *Fig. 3*. *Eq. 1* indicates that the Hansen Ultimate Load is 418 kips, a value slightly smaller than the 440-kip maximum test load applied to the pile head.

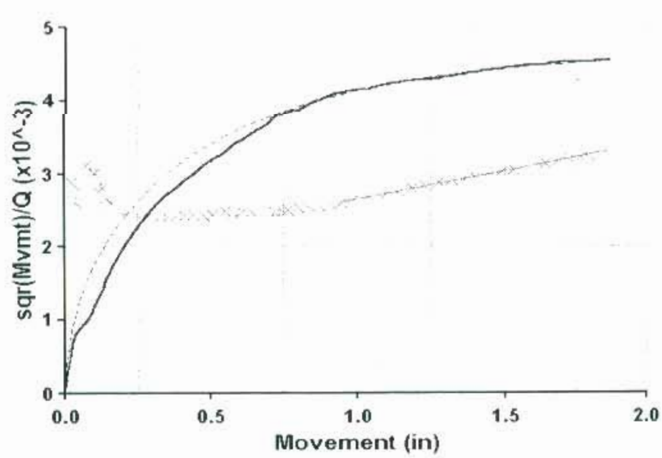

Fig. 3 Hansen 80 %-Criterion

The 80 %-criterion determines the load-movement curve for which the Hansen plot is a straight line throughout. The equation for this 'ideal' curve is shown as a dashed line in *Fig. 3* and *Eq. 3* gives the relation for the curve.

(3) $$Q = \frac{\sqrt{\delta}}{C_1\delta + C_2}$$

Where Q = applied load
δ = movement
C_1 = slope of the straight line
C_2 = y-intercept of the straight line

When using the Hansen 80%-criterion, it is important to check that the point $0.80\ Q_u/0.25\ \delta_u$ indeed lies on or near the measured load-movement curve. The relevance of evaluation can be reviewed by superimposing the load-movement curve according to *Eq. 3* on the observed load-movement curve. The two curves should preferably be in close proximity between the load equal to about 80 per cent of the Hansen ultimate load and the ultimate load itself.

5. Chin-Kondner Extrapolation

Chin (1970; 1971) proposed an application to piles of the general work by Kondner, (1963). The method is similar to the Hansen method. To apply the Chin-Kondner method, divide each movement with its corresponding load and plot the resulting value against the movement. As shown in *Fig. 5*, after some initial variation, the plotted values will fall on straight line. The inverse slope of this line is the Chin-Kondner Extrapolation of the ultimate load.

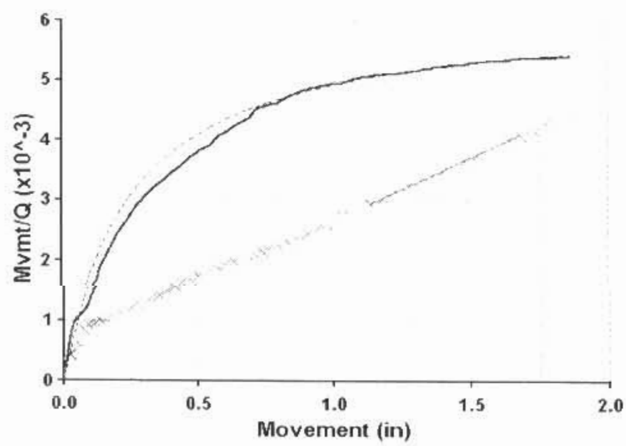

Fig. 5 Chin-Kondner Extrapolation Method

For the example case, the inverse slope of the straight line indicates a Chin-Kondner Extrapolation Limit of 475 kips, a value exceeding the 440-kip maximum test load applied to the pile head.

Also the Chin-Kondner criterion can be used to determine the load-movement curve for which the Chin-Kondner plot is a straight line throughout. The equation for this 'ideal' curve is shown as a dashed line in *Fig 5* and *Eq. 4* gives the relation for the curve.

(4) $$Q = \frac{\delta}{C_1\delta + C_2}$$

If during the progress of a static loading test, a weakness in the pile would develop in the pile, the Chin-Kondner line would show a kink. Therefore, there is considerable merit in plotting the readings per the Chin-Kondner method as the test progresses. Moreover, the Chin-Kondner limit load is of interest when judging the results of a static loading test, particularly in conjunction with the values determined according to the other two methods mentioned.

Although some indeed use the Chin-Kondner Extrapolation Limit as the pile capacity established in the test (with an appropriately large factor of safety), this approach is not advisable. One should not extrapolate the results when determining the allowable load by dividing the extrapolated capacity value with a factor of safety. The maximum test load is also the maximum capacity value to use.

Generally speaking, two points will determine a line and third point on the same line confirms the line. However, it is very easy to arrive at a false Chin value if applied too early in the test. Normally, the correct straight line does not start to materialize until the test load has passed the Davisson Offset Limit. As an approximate rule, the Chin-Kondner Extrapolation load is about 20 to 40 per cent greater than the Davisson limit. When this is not a case, it is advisable to take a closer look at all the test data.

The Chin method is applicable on both quick and slow tests, provided constant time increments are used. The ASTM "standard method" is therefore usually not applicable. Also, the number of monitored values are too few in the 'standard test'; the interesting development could well appear between the seventh and eighth load increments and be lost.

6. Decourt Extrapolation

Decourt (1999) proposes a method, which construction is similar to those used in Chin-Kondner and Hansen methods. To apply the method, divide each load with its corresponding movement and plot the resulting value against the applied load. The left side diagram in *Fig. 4* shows the results: a curve that tends to a line that intersects with the abscissa. A linear regression over the apparent line (last five points in the example case) determines the line. The Decourt extrapolation load limit is the value of load at the intersection, 474 kips in the example case. As shown in the right side diagram of *Fig. 6*, similarly to the Chin-Kondner and Hansen methods, an 'ideal' curve can be calculated and compared to the actual load-movement curve of the test.

The Decourt extrapolation load limit is equal to the ratio between the y-intercept and the slope of the line as given in *Eq. 5*. The equation of the 'ideal' curve is given in *Eq. 6*.

(5) $$Q_u = \frac{C_2}{C_1}$$

(6) $$Q = \frac{\delta}{C_1\delta + C_2}$$

Where Q_u = capacity or ultimate load
Q = applied load
δ = movement
C_1 = slope of the straight line
C_2 = y-intercept of the straight line

Results from using the Decourt method are very similar to those of the Chin-Kondner method. The Decourt method has the advantage that a plot prepared while the static loading test is in progress will allow the User to 'eyeball' the projected capacity directly once a straight-line plot starts to develop.

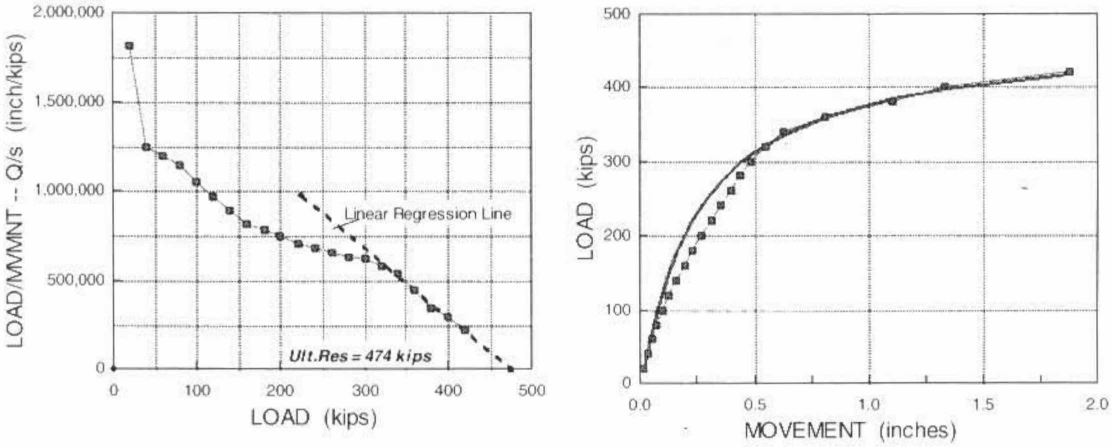

Fig. 6 Decourt Extrapolation Method

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It is the author's intent to present a future ***Fulcrum*** *article(s) discussing choice of factor-of-safety, LRFD approach, error sources, load-transfer behavior of a pile during the static test, methods of testing, instrumentation, how to apply the results to other piles at a site, etc.*