# Evaluation of Ultimate Vertical Capacity of Pile From Full Scale Pile Load Test

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**Abstract.** To validate the theoretical pile capacity, full scale pile load test is the most common approach. It is often not possible to test the pile up to failure. It was often observed that under the test load the pile does not reach ultimate pile capacity. Hence in such cases extrapolation of load-settlement curve is required to arrive at ultimate load. Various methods were proposed in the past by researchers such as Chin Kondner, Decourt, Davisson, Brinch Hansen etc. to evaluate extrapolated ultimate pile capacity. Data from 14 pile load tests were analyzed using above methods to estimate ultimate pile capacity. Based on the comparison, it has been observed that, each method estimated different values of ultimate load under different test loads and no specific method can be recommended based on accuracy to evaluate the ultimate pile capacity.

**Keywords:** Pile load test, Ultimate pile capacity, Load-settlement curve

## 1 Introduction

Static load test are used to confirm the actual ultimate load capacity of pile with respect to theoretical ultimate capacity. The ultimate capacity of pile can be defined as the load for which the rapid settlement occurs or when the pile plunges. However, often the ultimate load is not established during the test. Therefore the ultimate capacity of pile can be obtained with some criteria using load-settlement data. Past researchers suggested different method to determine ultimate pile capacity.

As per Fellenius (2001), 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.

It is of utmost importance to arrive at ultimate capacity for the design purpose based on some methods. Few of these methods are Davisson offset limit, Hansen ultimate load, the Chin-Kondner extrapolation, Decourt methods etc. However, IBC 2003 permits to evaluate the ultimate load by Davisson Offset method, Brinch Hansen Criterion and Chin-Konder Extrapolation method. The above mentioned methods have been considered to evaluate ultimate pile capacities using load-settlment curve from static pile load test.

## 2 The Davisson Offset Limit Load

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 a load-settlement curve of 750mm diameter pile for the site Bibiyana III, Bangladesh. The Davisson ultimate load is also depicted in **Fig. 1**.

It can be noticed that the offset limit load is not 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.

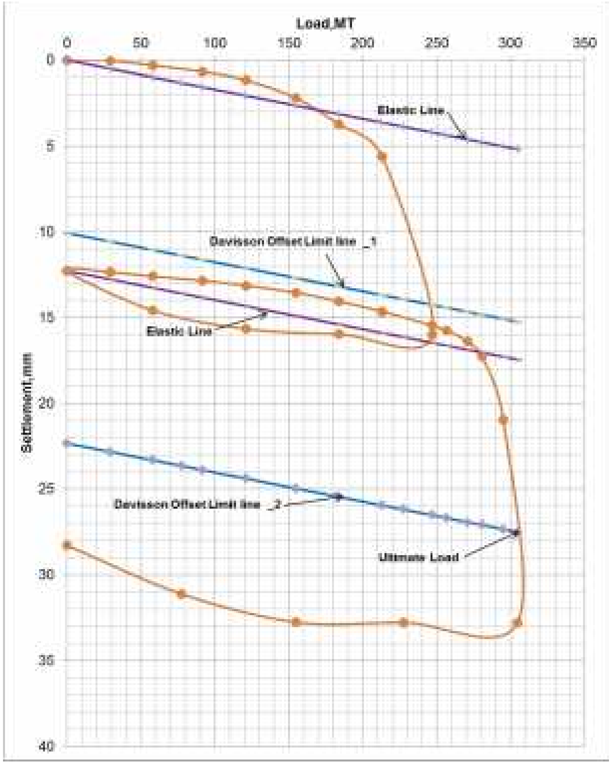

**Fig. 1.** Davisson's offset limit load method

## 3 The Hansen 80-% Criterion (Fellenius, 2001)

J. Brinch Hansen in year 1963, proposed a definition for pile capacity as the load that gives four times the movement of the pile head as obtained for 80% of that load. This '80%- criterion' can be estimated directly from the load movement curve, but 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 as shown in **Fig. 2** for a load-settlement curve of 750mm diameter pile for the site Bibiyana III, Bangladesh.

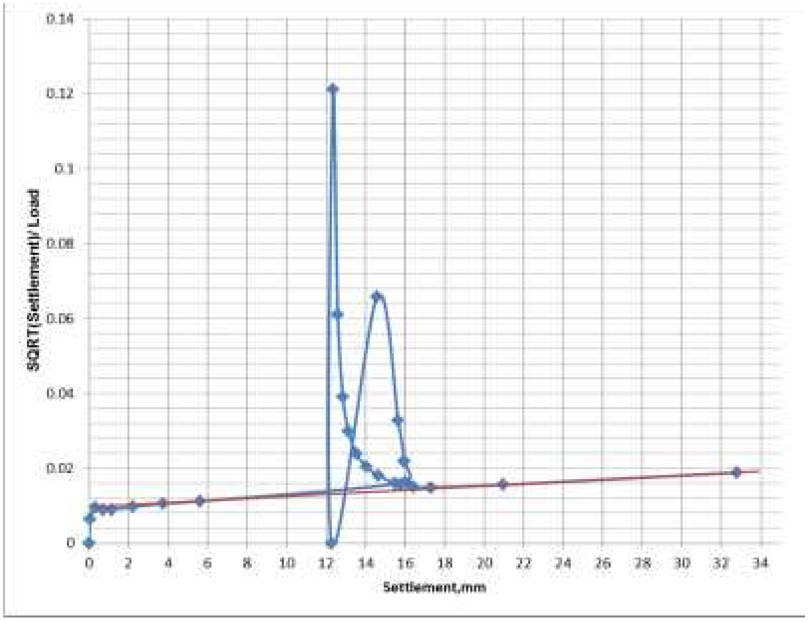

**Fig. 2.** Hansen's 80% criteria

Following relation can be derived for computing ultimate load:

$$Q_u = 1/2*(C_1*C_2)^{0.5} = ½* \mathrm{SQRT}\ (0.00025*0.01) = 316\mathrm{MT} \quad (1)$$

$$\delta_u = C_2 / C_1 = 0.01/0.00025 = 40\mathrm{mm} \quad (2)$$

Where $Q_u$ = Ultimate load; $C_1$= slope of the straight line; $C_2$= Y-intercept of the straight line; $\delta_u$ = settlement at the ultimate load

Equation 1 implies that Hansen Ultimate load is 316 MT which is slightly more than applied load of 305MT. It is utmost important to check the point 0.80 $Q_u$ – 0.25 $\delta_u$ lies on or near to measured load-settlement curve as shown in **Fig. 3**. The Hansen curve and measure curve should preferably be in close proximity between the load equal to about 80 % of the Hansen ultimate load and the ultimate load itself.

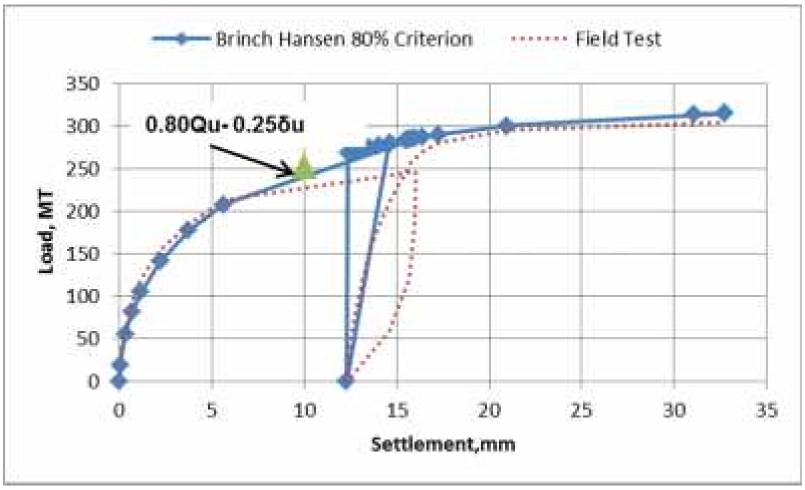

**Fig. 3.** Hansen Curve and Measured Curve

## 4 Chin-Kondner Extrapolation

Chin (1970) proposed an application to piles of the general work by Kondner (1963). Chin assumes that the relationship between load and settlement is hyperbolic. The method is similar to the Hansen method. To apply the Chin-Kondner method, divide each settlement with its corresponding load and plot the resulting value against the settlement. As shown in **Fig. 4**, 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.

$$Q_u = 1/C_1 = 1/\ 0.00333 = 300\ \text{MT} \tag{3}$$

The equation of the ‘ideal’ curve is given in below equation

$$Q = C_2\delta\ /\ (1 - C_1\delta) \tag{4}$$

Where Q = applied load; $C_1$= slope of the straight line; $C_2$= Y-intercept of the straight line

The Chin-Kondner Extrapolation method can be used to determine load-settlment curve as shown in Fig.5.

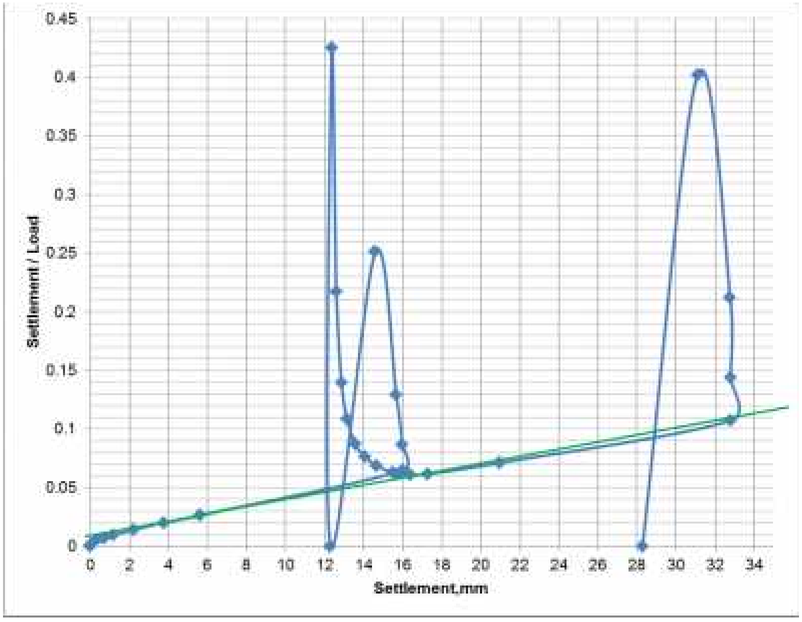

**Fig. 4.** Chin-Kondner Extrapolation

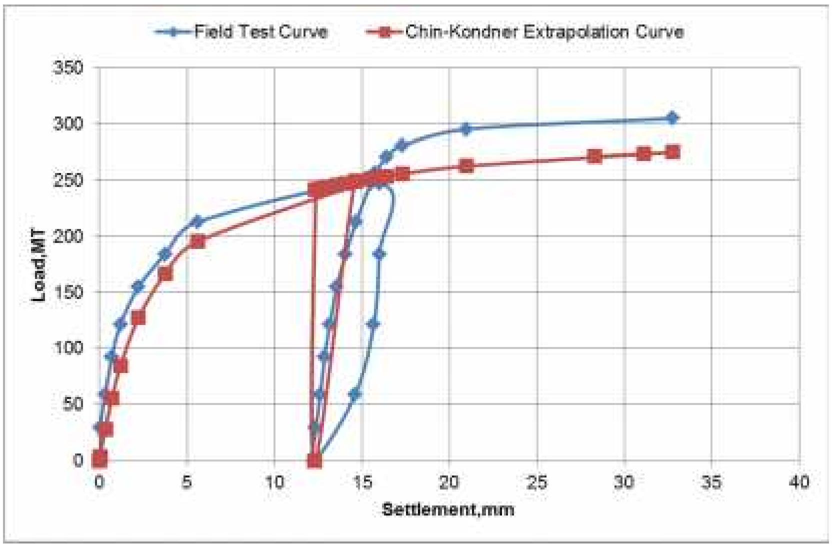

**Fig. 5.** Chin-Kondner Curve and Measured Curve

## 5 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 settlement and plot the resulting value against the applied load. The Decourt extrapolation load limit is equal to the ratio between the Y- intercept and the slope of the line as given in the equation below.

$$Q_u = C_2 / C_1 = 200/ 0.67 = 300 \text{ MT} \tag{5}$$

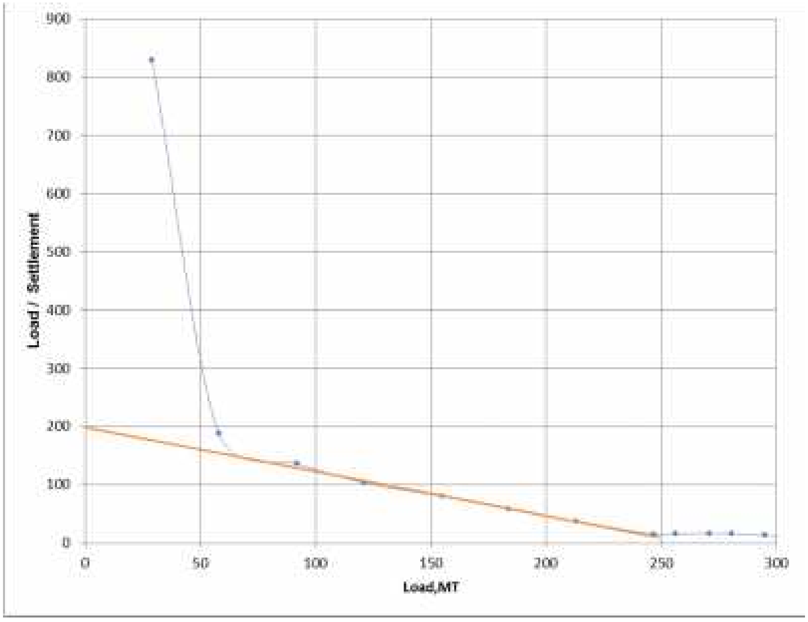

**Fig. 6.** Decourt Extrapolation

## 6 Static pile load test data

The load-settlement data are from different projects located in Bangladesh. These data are analyzed using different extrapolation methods. **Table 1** summarizes the pile load test results. The test load has been applied is 2.5 times the design load.

**Table 1.** Pile Load Test Results

| Sr. No | Pile Dia, mm | Pile Length, m | Design load, MT | Test Load, MT | Max Settlement, mm | Davison, MT | Hasen -80%, MT | Chin-Kondner, MT | De-Court, MT |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 750 | 21 | 122 | 305 | 33 | 305 | 316 | 300 | 300 |
| 2 | 500 | 21 | 71 | 179 | 35 | 174 | 177 | 200 | 210 |
| 3 | 750 | 21 | 122 | 305 | 88 | 280 | 234 | 220 | 285 |
| 4 | 500 | 21 | 71 | 179 | 16.5 | 175 | 169 | 167 | 221 |
| 5 | 750 | 21 | 135 | 203 | 14 | 210 | - | - | - |
| 6 | 600 | 14.7 | 96 | 192 | 14 | 190 | - | - | - |
| 7 | 800 | 14.7 | 96 | 192 | 16.5 | 182 | 192 | 229 | 210 |
| 8 | 750 | 30 | 122 | 305 | 76 | 325 | 370 | 315 | 322 |
| 9 | 750 | 30 | 122 | 305 | 37.5 | 342 | 373 | 400 | 420 |
| 10 | 1200 | 38 | 280 | 700 | 72 | 530 | 560 | 500 | 540 |
| 11 | 350* x 350* | 27.4 | 35 | 88 | 35 | 84 | 77 | 100 | 97 |
| 12 | 305* x 305* | 27.4 | 30.4 | 76 | 40 | 64 | 78 | 71 | 60 |
| 13 | 305* x 305* | 24.4 | 40 | 100 | 27.5 | 92 | 96 | 100 | 105 |
| 14 | 355* x 355* | 24.4 | 40 | 100 | 41 | 76 | 89 | 100 | 110 |

Note:* represents Square Piles

## 7 Discussion and choice of evaluation method

It is difficult to choose the best method because the preferred method depends on one’s past experience and idea of what constitutes the ultimate capacity of pile.

The Davisson offset limit method is very sensitive to errors in the measurement of settlement and load and required well maintained equipment’s and accurate measurements. This method offers the benefit of allowing the engineer, when proof testing a pile for a certain allowable load, to determine in advance the maximum allowable movement for this load with consideration of the length and size of the pile.

The Davisson offset of 0.15 inch plus a value equal to the diameter divided by 120 from the elastic line represents the settlement necessary to mobilize toe resistance. The elastic deformation of soil proposed by Davisson is specifically for driven piles and is not appropriate where soil resistance beneath the pile toe has not been fully mobilized at the beginning of load testing. The Davisson study evaluated piles installed by driving where a compressed soil plug forms during placement. In contrast, cast-in-place piles and other types of drilled shafts do not compress the soil beneath the pile toe during installation. Thus, a greater downward movement of the pile toe would be required to mobilize the end resistance for cast-in-place piles if all other conditions are equal.

The Brinch-Hansen 80%-criterion usually gives a ultimate value ($Q_u$ value) which is close to what one subjectively accepts as the true ultimate resistance, determined from the results of the static loading test.

The Chin-Kondner Extrapolation and the Decourt Extrapolation limit load values are approached asymptotically. Therefore, these two methods are always obtained by extrapolation. It is a sound engineering rule never to interpret the results from a static loading test to obtain an ultimate load larger than the maximum load applied to the pile in the test. For this reason, an allowable load cannot, must not, be determined by dividing the limit loads according to Chin-Kondner and Decourt methods with a factor of safety (Fellenius, 2001).

# 8 CONCLUSION

For more accurate estimation of ultimate load, the pile must be loaded near to ultimate load. If the test load applied is less than ultimate load, then the variations in ultimate load can be obtained using different methods. Hence no conclusion can be drawn about the suitability of methods for ultimate load evaluation.

The result obtained from static loading test does not provide one simple answer at first may think. First the method of “Failure load” interpretation used in the industry is variable. Then the effect of degree of strain softening and residual load will affect the interpretation.

For non-complex and small projects, such lack is acceptable if the uncertainty is covered by large factor of safety. For larger and important projects, such approach will be costly. For these, the test pile should be instrumented and the test data evaluated carefully to work out the various influencing factors.

Combining an instrumented static loading test with dynamic testing, which can be performed on many piles at a relatively small cost, can extend the application of the more detailed results of the instrumented static test.

As per England (1994) and England & Fleming (1994), all pile testing methods for determining bearing capacity, from a continuous rate of penetration test to wave analysis system, appear to introduce complications related to inability of soils to reach a stable state in terms of effective stress during the load period. Hence, no specific method of failure load estimation is workable under all the circumstances.

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