Lecture – 5
Pile Load Test

Vertical capacity from Load test

9.12 BEARING CAPACITY OF A SINGLE PILE BY LOAD TEST

9.12.1 Introduction

Pile load test is the most acceptable method to determine the load carrying capacity of a pile. The load test may be carried out either on a driven pile or a *cast-in-situ* pile. Load test may be made either on a single pile or a group of piles. Load test on a pile group is very costly and may be undertaken only in very important projects.

Pile load tests on a single or a group of piles might be for the determination of

1. vertical load bearing capacity,
2. uplift load capacity,
3. lateral load capacity.

Generally load tests are made to determine the bearing capacity and to establish the load settlement relationship under compression load. The other two types of tests may be carried out only when piles are required to resist large uplift or lateral forces.

Usually the pile foundations are designed on an estimated capacity which is arrived from a thorough study. At the beginning of construction, load tests are made for the purpose of verifying the adequacy of the design capacity. If the test results show an inadequate factor of safety or excessive settlement, the design must be revised before construction is under way.

Load tests may be carried out either on

1. a working pile or 2. a test pile.

A *working pile* is a pile driven or *cast-in-situ* along with the other piles to carry the loads from the superstructure. The maximum test load on such piles should not exceed one and a half times the design load.

A *test pile* is a pile which does not carry the loads coming from the structure. The maximum load that can be put on such piles may be about 2 1/2 times the design load or the load imposed must be such as to give a total settlement not less than one-tenth the pile diameter.

9.1 AXIAL COMPRESSION PILE LOAD TESTS

9.1.1 Test Equipment and Instruments

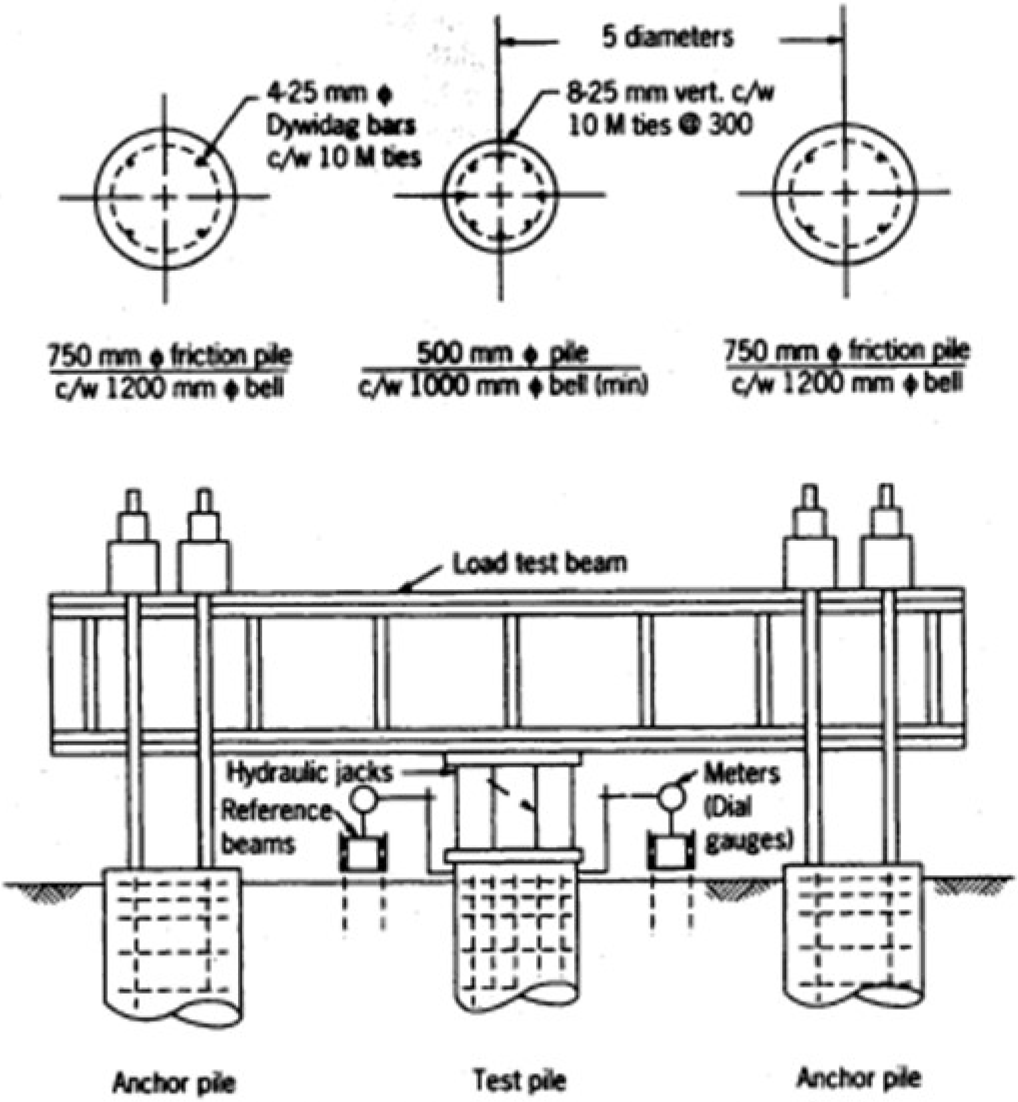


Figure 9.1a An example of a typical axial compression load application arrangement (Sharma et al., 1984).

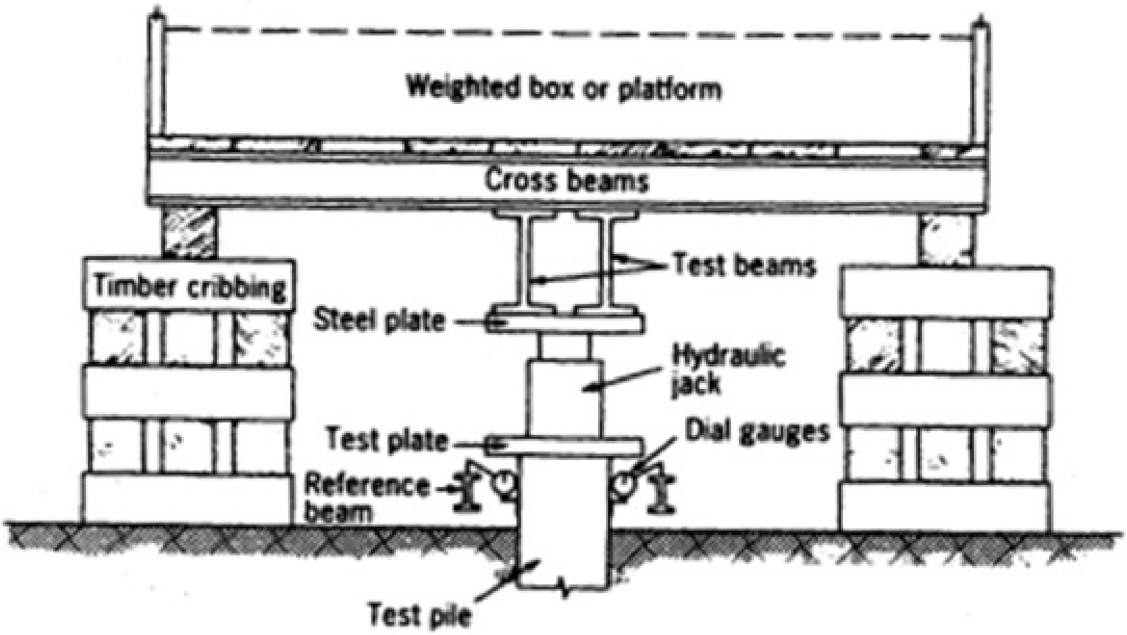


Figure 9.2 Axial compression load application arrangement using timber cribbing and the weighted box (ASTM, 1986).

9.1.2 Test Procedures

Practicing engineers and researchers have used many pile load test methods that have been reported in several publications (ASTM D1143-81, Butler and Hoy, 1977; Fellenius, 1975, 1980; Mohan et al., 1967; New York State DDT, 1974; Swedish Pile Commission, 1970; Weele, 1957; Whitaker, 1957, 1963; Whitaker and Cooke, 1961). From the available numerous load test methods the following four methods can be identified as the basic load test methods (Joshi and Sharma, 1987):

1. Slow Maintained Load Test Method (SM Test)
2. Quick Maintained Load Test Method (QM Test)
3. Constant Rate of Penetration Test Method (CRP Test)
4. Swedish Cyclic Test Method (SC Test)

1. **Slow Maintained Load Test Method (SM Test)** This test method, as recommended by ASTM D1143-81 (1989), consists of the following steps:

   (a) Load the pile in eight equal increments (i.e., 25 percent, 50 percent, 75 percent, 100 percent, 125 percent, 150 percent, 175 percent, and 200 percent) to 200 percent of the design load.

   (b) Maintain each load increment until the rate of settlement has decreased to 0.01 in./h (0.25 mm/h) but not longer than 2 h.

   (c) Maintain 200 percent load for 24 h.

   (d) After the required holding time, remove the load in decrements of 25 percent with 1 h between decrements.

   (e) After the load has been applied and removed, as above, reload the pile to the test load in increments of 50 percent of the design load, allowing 20 min between load increments.

   (f) Then increase the load in increments of 10 percent of design load until failure, allowing 20 min between load increments.

   This test method is commonly considered as the ASTM Standard Test method and is generally used for site investigation prior to installing contract piles and writing specifications. The main disadvantage of this test is that it is time consuming (e.g., a typical test period may last 40 to 70 h or more).

2. **Quick Maintained Load Test Method (QM Test)** This test method, as recommended by the New York State Department of Transportation, the Federal Highway Administration, and the ASTM 1143-81 (optional), consists of the following main steps:

(a) Load the pile in 20 increments to 300 percent of the design load (i.e., each increment is 15 percent of the design load).

(b) Maintain each load for a period of 5 min with readings taken every 2.5 min.

(c) Add load increments until continuous jacking is required to maintain the test load or test load has been reached.

(d) After a 5-min interval, remove the full load from the pile in four equal decrements with 5 min between decrements.

This test method is fast and economical. Typical time of test by this method is 3 to 5 h. This test method represents more nearly undrained conditions. This method cannot be used for settlement estimation because it is a quick method.

3. **Constant Rate of Penetration Test Method (CRP Test)** This method is recommended by Swedish Pile Commission, New York State Department of Transportation, and ASTM D1143-81 (optional). It consists of the following main steps:

(a) The pile head is forced to settle at 0.05 in/min (1.25 mm/min).

(b) The force required to achieve the penetration rate is recorded.

(c) The test is carried out to a total penetration of 2 to 3 in. (50 to 75 mm).

The main advantages of this method are that it is fast (2 to 3 h) and is economical. This method is of particular value for friction piles but may not be practical for end-bearing piles because of the high force requirements to cause penetration through hard-bearing stratum.

4. Swedish Cyclic Test Method (SC Test) This method as recommended by Swedish Pile Commission consists of the following main steps:

(a) Load the pile to one-third of the design load.

(b) Unload to one-sixth the design load. Repeat the loading and unloading cycles 20 times.

(c) Increase the load by 50 percent higher than the item (a) and then repeat as item (b).

(d) Continue until failure is reached.

This test method is time consuming, and cycling changes the pile behavior so the pile is different than the original pile. It is only recommended on special projects where cyclic loading may be of main importance.

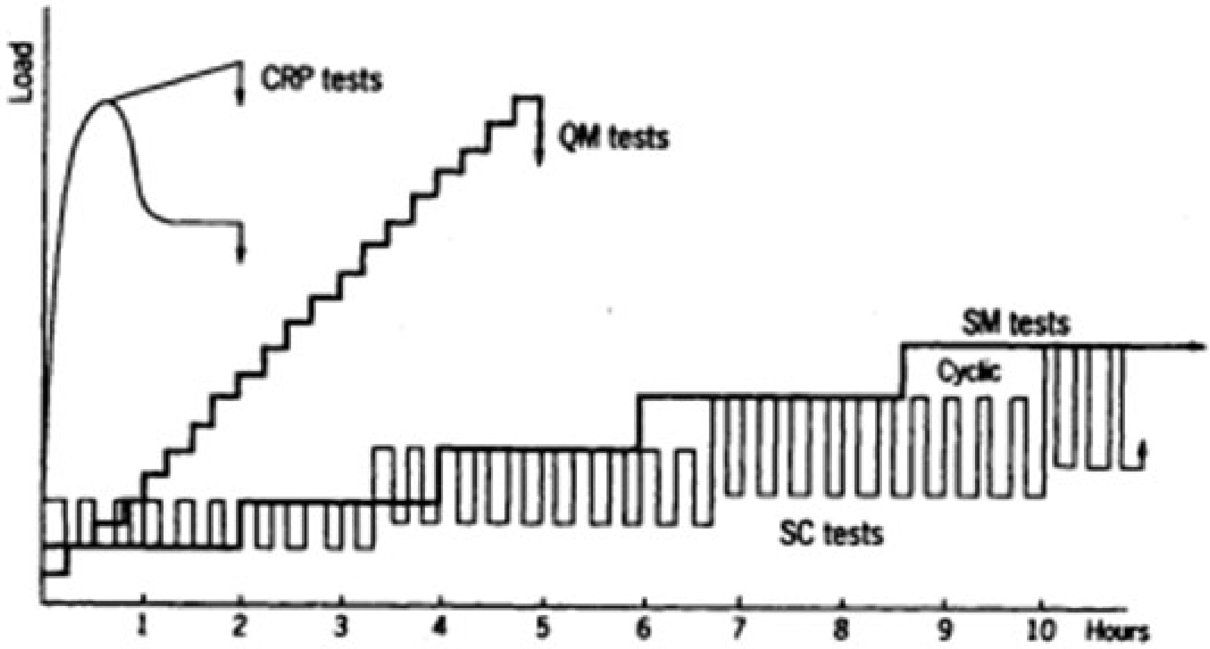


Figure 9.6 Comparison of required time for various test methods (Fellenius, 1975).

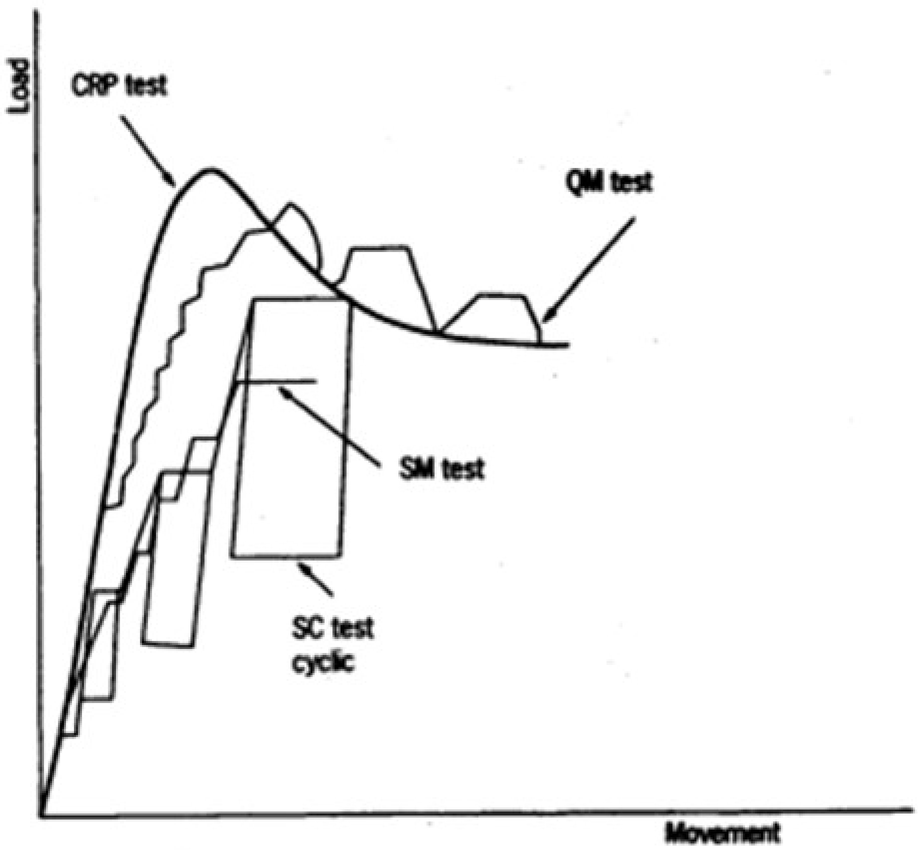


Figure 9.7 Comparison of load–movement behaviour for test methods (Fellenius, 1975)

As shown in Figure 9.6, the SM tests and SC tests are the slowest tests and the CRP test is the fastest. Figure 9.7 compares typical load-movement behavior for the four test types discussed. This figure shows that the shape of load–movement curve by the CRP test method is well defined and agrees well with the QM-test load-movement curve before the failure is reached. The SM test method is commonly used in North America because it is simple, most engineers are familiar with it, its interpretation based on gross and net settlements can be made easily, and it can furnish a rough estimate of the expected pile settlement under working load. Interpretation of the failure load from load-movement curves obtained from load tests will be discussed in the following section.

Lecture – 6
Interpretation of Pile Load Test Data

9.1.3 Interpretation of Test Data

Generally, load and settlement test data are plotted with load along the abscissa and settlement along ordinate. However, these coordinates can be interchanged depending on the engineer's preference. The plotted settlement could either be gross (the total movement of pile butt under full test load) or the net (the distance the pile has permanently moved after it has rebounded upon removal of the test load). These plotted data are then used to estimate the failure load so that allowable pile capacity can be calculated.

The ultimate failure load for a pile is defined as the load when the pile plunges or the settlements occur rapidly under sustained load. Plunging, however, may require large movements that may exceed the acceptable range of the soil–pile system. Other failure definitions consider arbitrary settlement limits such as the pile is considered to have failed when the pile head has moved 10 percent of the pile end diameter or the gross settlement of 1.5 in. (38 mm) and net settlement of 0.75 in. (19 mm) occurs under two times the design load. Many engineers define the failure load at the point of intersection of the initial tangent to the load–movement curve and the tangent to or the extension of the final portion of the curve. All these definitions for defining failure are judgemental. Ideally, a failure definition should be based on some mathematical rule and should result in repeatable values. Also, the value should be independent of scale effects and individual's personal opinion. The following interpretation methods have been used in the past for various load tests. First, these methods are reviewed and their applicability for different pile types discussed.

1. Davisson's method (1972)
2. Chin's method (1970, 1971)
3. De Beer's method (1967)
   or De Beer and Wallays' method (1972)
4. Brinch Hansen's 90 percent criterion (1963)
5. Brinch Hansen's 80 percent criterion (1963)
6. Mazurkiewicz's method (1972)
7. Fuller and Hoy's method (1970)
8. Butler and Hoy's method (1977)
9. Vander Veen's method (1953)

1. Davisson's Method The procedure for obtaining failure load by this method consists of the following steps:

(a) Draw the load-movement curve as shown in Figure 9.8a.

(b) Obtain elastic movement, $\Delta = (Q_{va})L/AE$ of the pile where Q_{va} is the applied load, L is pile length, A is pile cross-sectional area, and E is modulus of elasticity of the pile material.

(c) Draw a line OA based on equation for elastic movement, Δ, as identified in item (b) .

Draw a line BC parallel to OA at a distance of x where $x = 0.15 + D/120$ in., (D = diameter of pile in in.).

(e) The failure load is then at the intersection of BC with load–movement curve (i.e., point C).

This method was originally recommended for driven piles, and its use is preferred for the QM test method. The main advantage of this method is that the limit line BC can be drawn before starting the test. Therefore, it can be used as one of the acceptance criteria for proof-tested contract pile.

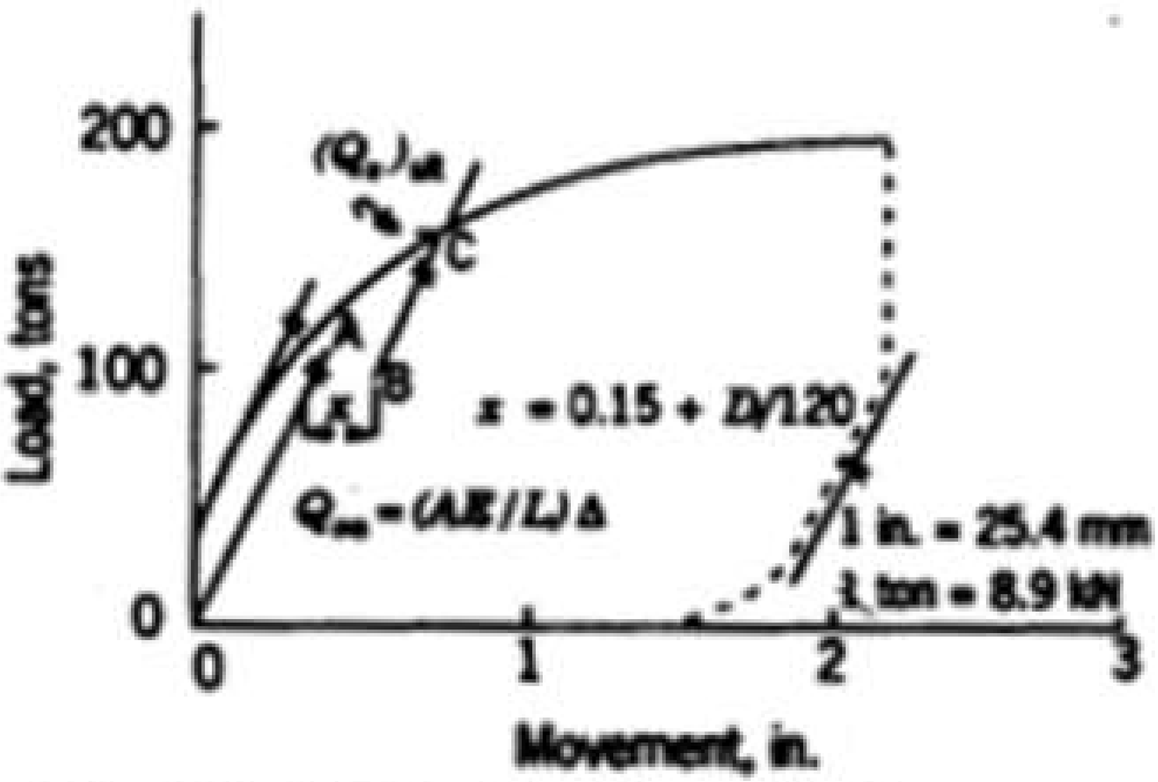
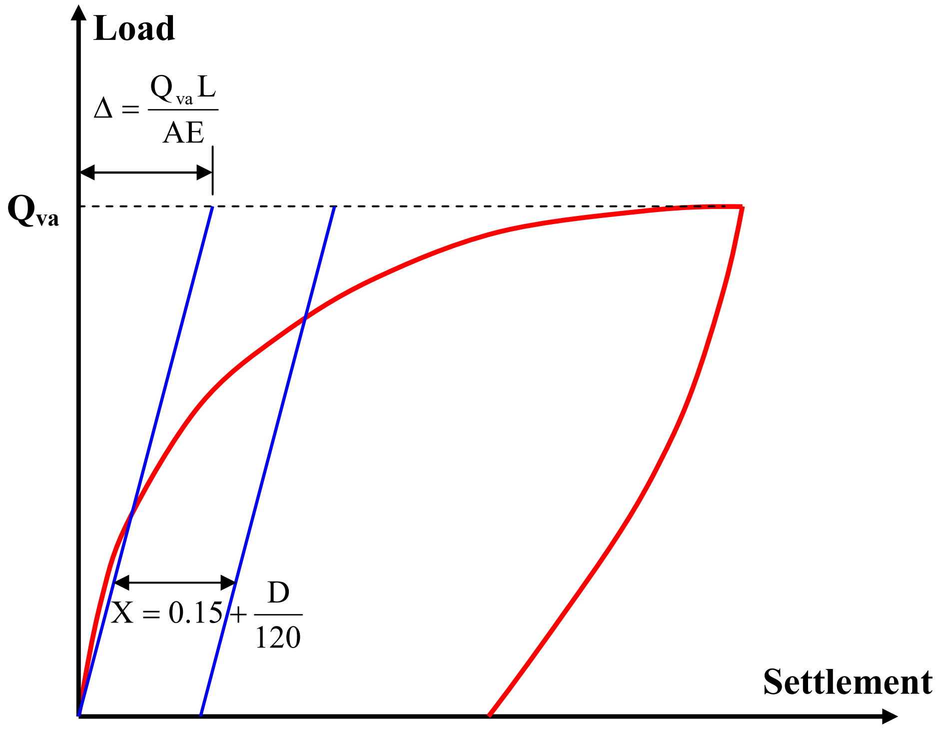


Figure 9.8 (a) Davisson's method,



Load
$\Delta = \frac{Q_{va}L}{AE}$
Q_{va}
$X = 0.15 + \frac{D}{120}$
Settlement

2. Chin's Method This method is shown in Figure 9.8b and consists of the following steps:

(a) Draw the Δ/Q_{va} versus Δ plot, where Δ is the movement and Q_{va} is the corresponding applied load.

(b) The ultimate load $(Q_v)_{ult}$ is then equal to $1/C_1$. Figure 9.8b explains all the terms. The relationships given in this figure assume that the load–movement curve is approximately hyperbolic.

This method of ultimate load interpretation is applicable for both the QM and SM tests, provided constant time increments are used during the test. In selecting the straight line from the points, it should be understood that the data points do not appear to fall on the straight line until the test load has passed Davisson's limit value. This method may not provide realistic failure value for tests carried out as per ASTM Standard Method because it may not have constant time load increments.

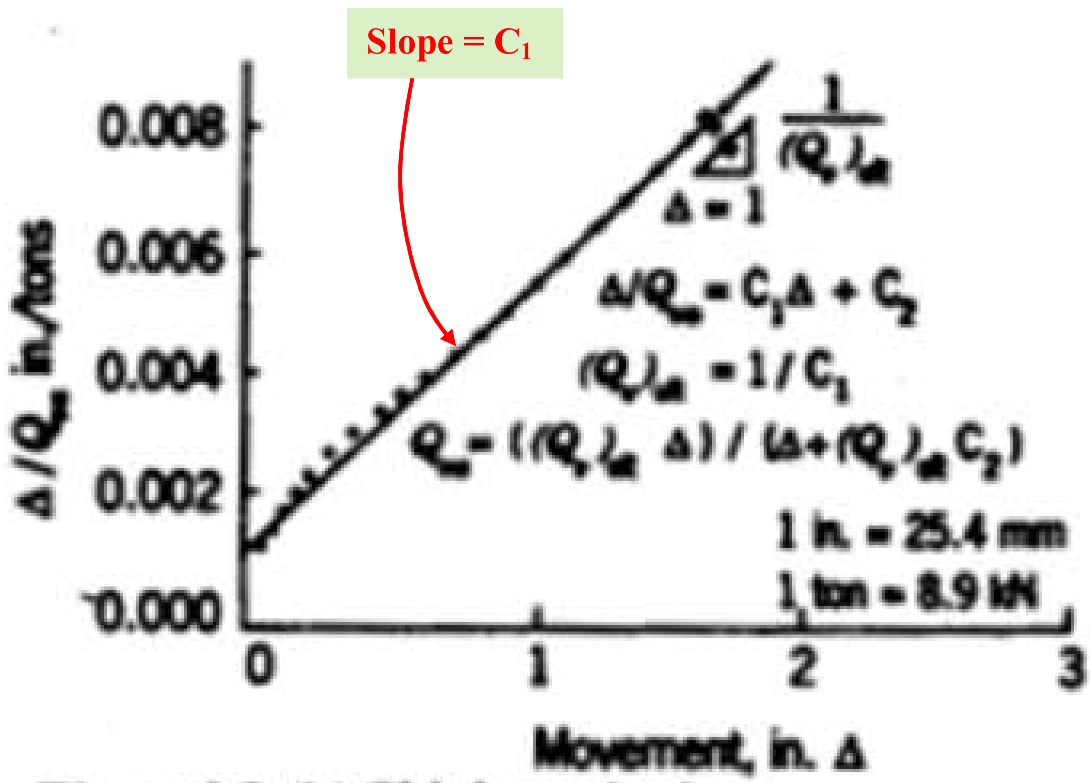


Figure 9.8 (b) Chin's method.

3. De Beer's Method As seen in Figure 9.8c, this method consists of the following steps:

(a) Plot load and movement on logarithmic scales.

(b) These values then fall on two straight lines.

(c) The failure load is then defined as the load that falls at the intersection of these two straight lines.

This method was originally proposed for a slow test, such as SM tests.

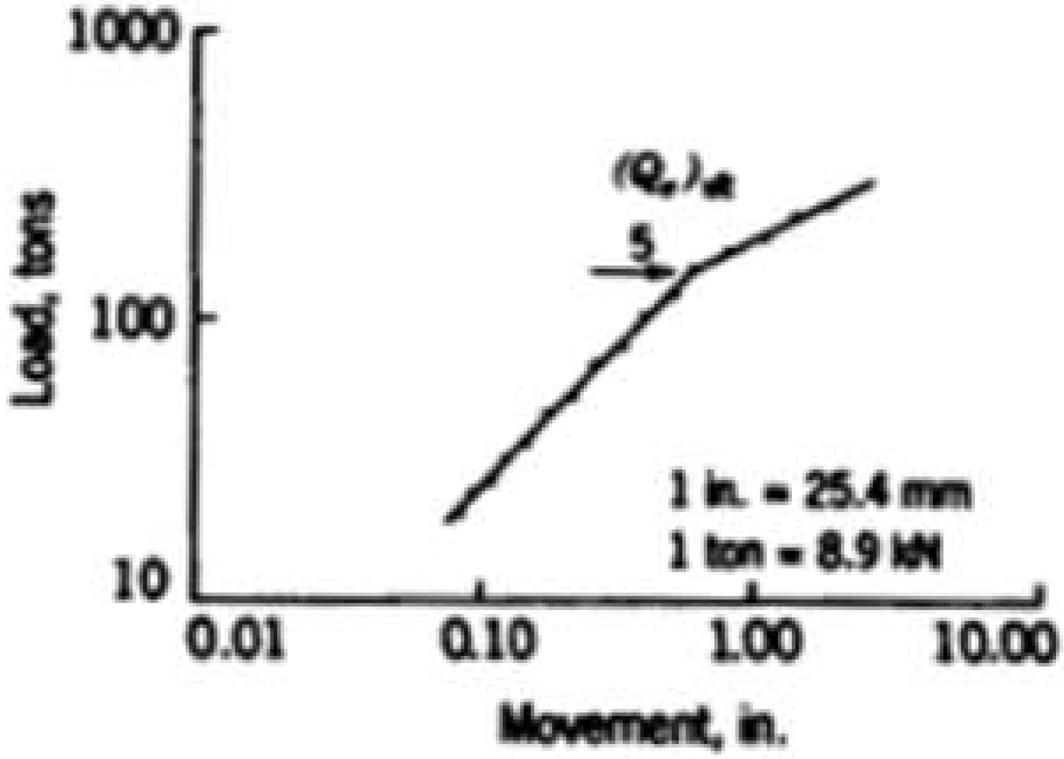


Figure 9.8 (c) De Beer's method,

4. **Brinch Hansen's 90 percent Criterion** This is a trial and error method and the method of interpretation is shown on Figure 9.8d and consists of the following steps:

(a) Plot the load–movement curve.

(b) Find the load $(Q_a)_{ult}$ and Δ_u that gives twice the movement of the pile head as obtained for 90 percent of the load $(Q_a)_{ult}$, where $(Q_a)_{ult}$ is the failure load.

This method is applicable to the CRP test method regardless of the soil type.

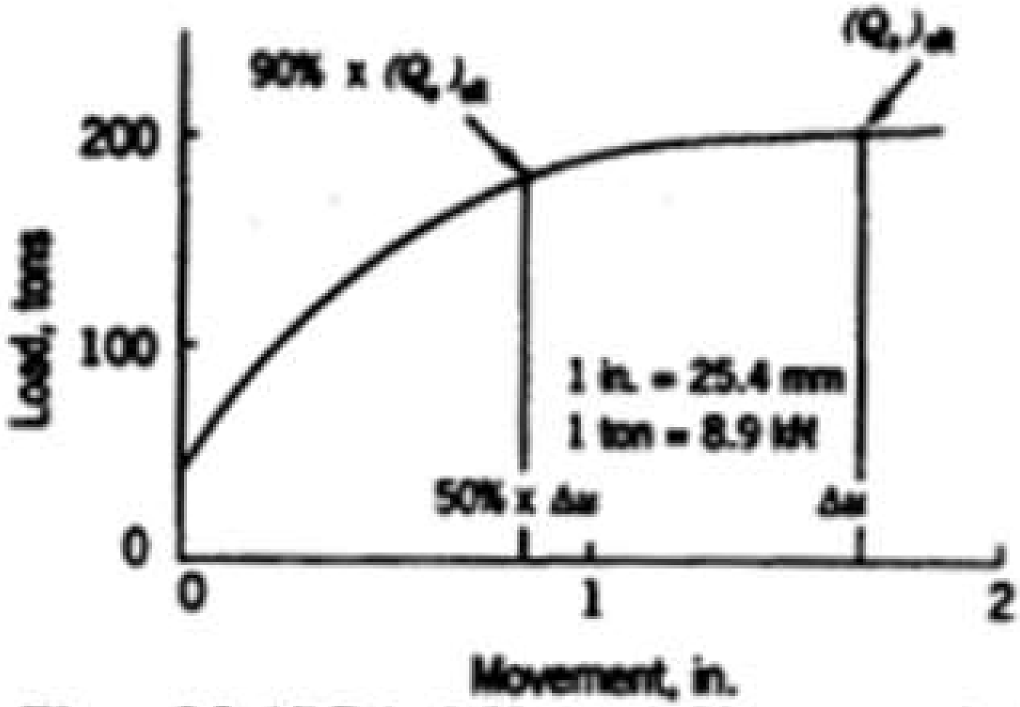


Figure 9.8 (d) Brinch Hansen's 90 percent criterion.

5. Brinch Hansen's 80 percent Criterion This method of interpretation is shown in Figure 9.9a and consists of the following steps:

(a) Plot $\frac{\sqrt{\Delta}}{Q_{va}}$ and Δ curve, where Δ is the movement and Q_{va} is the load.

(b) Failure load $(Q_v)_{ult}$ and failure movement Δ_u are then given as follows:

$$(Q_v)_{ult} = \frac{1}{2\sqrt{C_1 C_2}} \tag{9.3a}$$

$$\Delta_u = \frac{C_2}{C_1} \tag{9.3b}$$

All the terms are defined in Figure 9.9a. This method assumes that the load–movement curve is approximately parabolic. The method is applicable for both the quick and slow tests (e.g., QM and SM tests). The failure criteria agrees well with the plunging failure. However, the plot and calculations can not be performed in advance of the test loading. This method of interpretation is not suitable for test methods that include unloading cycles or where plunging failure is not achieved.

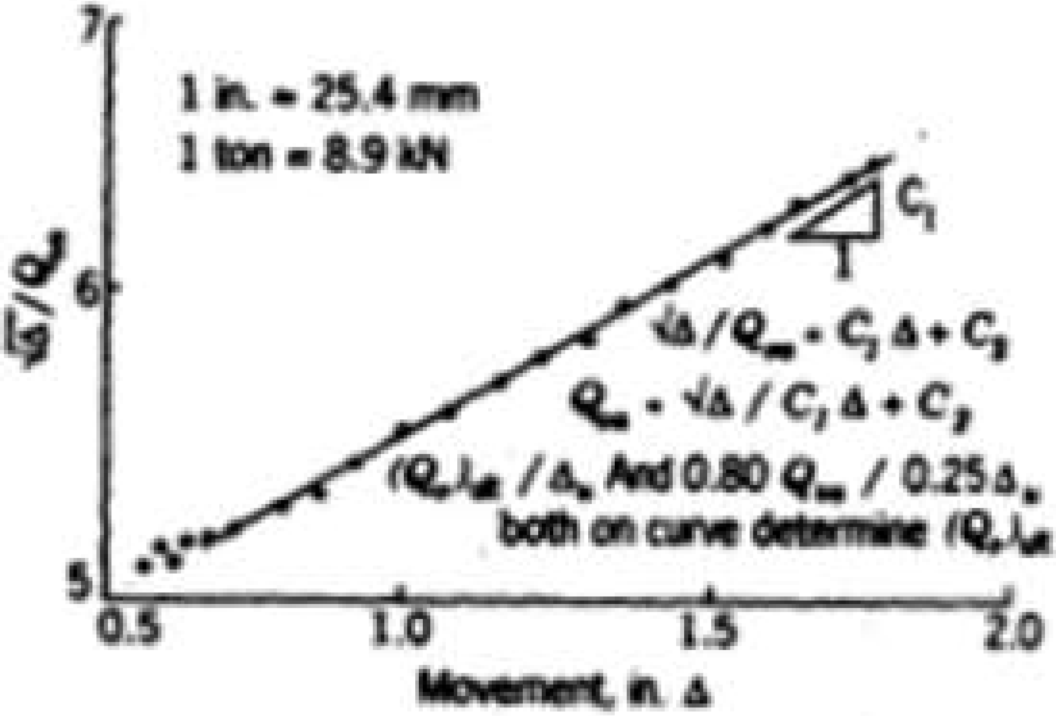


Figure 9.9 (a) Brinch Hansena's 80 percent criterion method.

6. Mazurkiewicz's Method As shown in Figure 9.9b, this method consists of the following steps:

(a) Plot the load–movement curve.

(b) Choose a series of equal pile head movements and draw vertical lines that intersect on the curve. Then draw horizontal lines from these intersection points on curve to intersect the load axis.

(c) From the intersection of each load, draw 45° line to intersect with the next load line.

(d) These intersections fall approximately on a straight line. The point which is obtained by the intersection of the extension of this line on the vertical (load) axis is the failure load.

This method assumes that load–movement curve is approximately parabolic. The failure load values obtained by this method should, therefore, be close to the 80 percent criterion. Furthermore, all the intersections of these lines do not always fall on a straight line. Therefore, some judgment may be required in drawing the straight line.

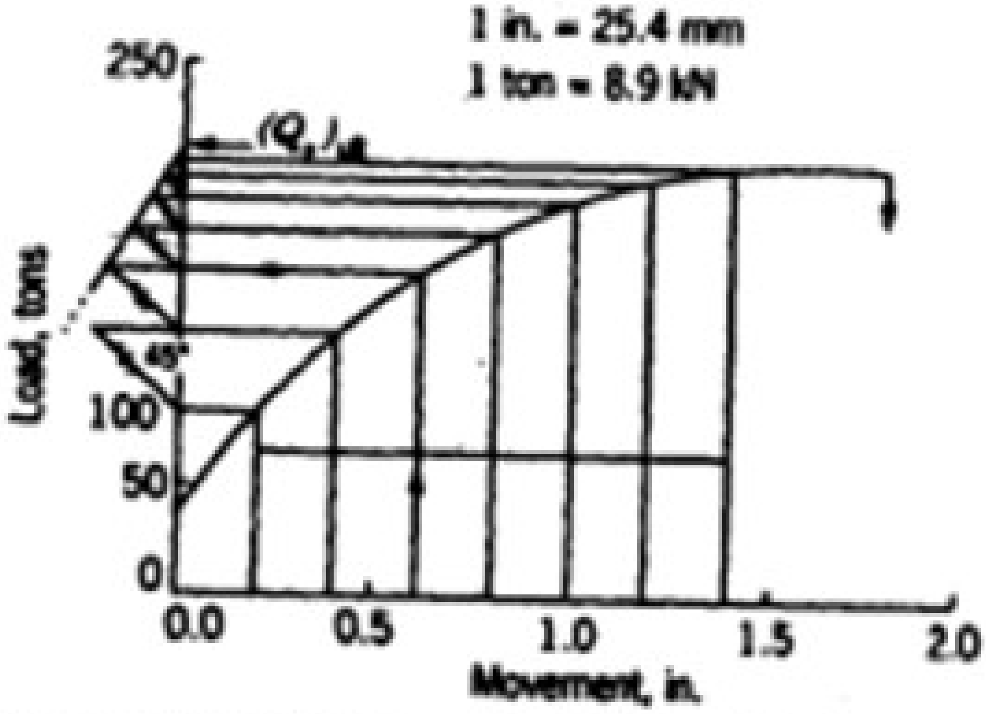


Figure 9.9 (b) Mazurkiewicz's method.

7. Fuller and Hoy's Method This consists of the following steps:

(a) Plot a load–movement curve as shown in Figure 9.9c.

(b) Find the failure load $(Q_u)_{ult}$ on the curve where the tangent on the load–movement curve is sloping at 0.05 in./ton.

This method is applicable for QM test. The main disadvantage with this method may be that it penalizes the long piles because they will have larger elastic movements and therefore 0.05 inch/ton slope will occur sooner.

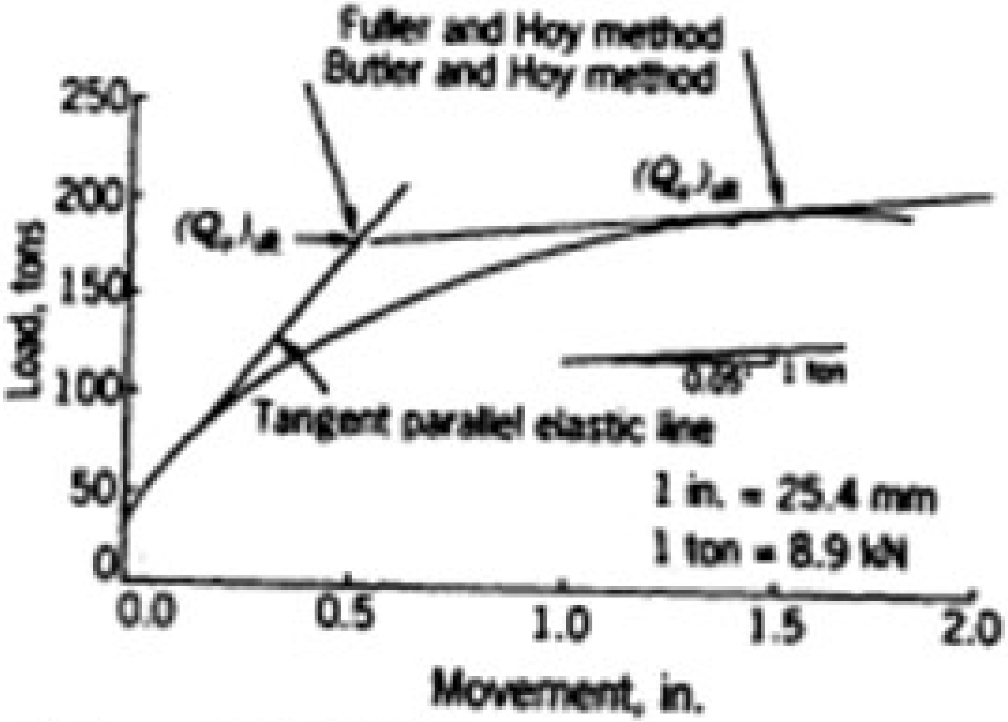


Figure 9.9 (c) Fuller and Hoy's and Butler and Hoy's methods.

8. Butler and Hoy's Method As shown on Figure 9.9c, this method consists of the following steps:

(a) Plot the load–movement curve.

(b) The failure load is then the intersection of the 0.05-in./ton slope line with either the initial straight portion of the curve (Figure 9.9c) or the line parallel to the rebound curve or the elastic line starting from the origin (not shown).

This method is applicable for the QM test.

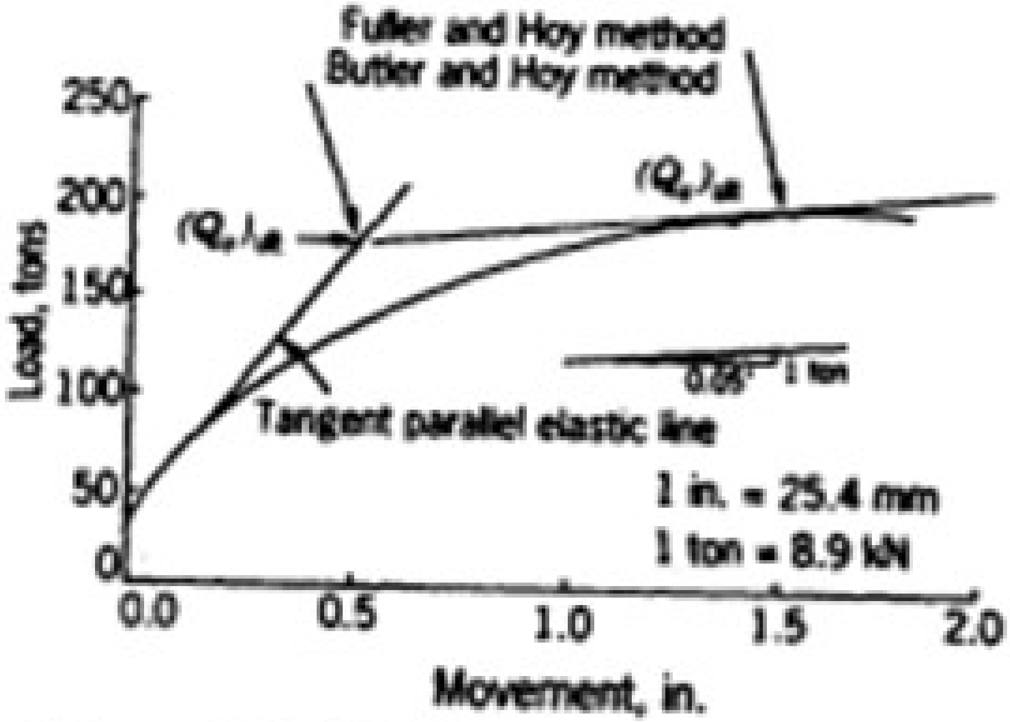


Figure 9.9 (c) Fuller and Hoy's and Butler and Hoy's methods.

9. Vander Veen's Method This method consists of the following steps:

(a) Choose a value of failure load, say $(Q_v)_{ult}$.

(b) Plot $l_n(1 - Q_{ov}/(Q_v)_{ult})$ for different values of Q_{ov} against the movement for various load, Q_{ov}.

(c) When the plot becomes a straight line, then the corresponding $(Q_v)_{ult}$ represents the correct failure load as shown by Q_{vu} in Figure 9.9d.

The main disadvantage of this method is that time-consuming calculations are required to obtain the failure load.

Joshi and Sharma (1987) carried out failure load interpretations on five different load–movement curves obtained by using the SM test method. The length to diameter ratio for these piles varied between 12 to 32. Load–movement curves for all these piles indicated plunging failure. All nine failure load interpretations methods discussed above were used. Results obtained from this study provided the following conclusions:

(a) For bored and belled concrete piles, the Fuller and Hoy method provided a reasonable estimate for the failure load.

(b) For expanded-base-compacted (Franki) piles, the Davisson, Butler and Hoy; and Fuller and Hoy methods provide reasonable estimates for failure loads.

(c) For driven H piles, Brinch Hansen's 90 percent criterion and Fuller and Hoy's method predicted the failure load similar to the failure test load.

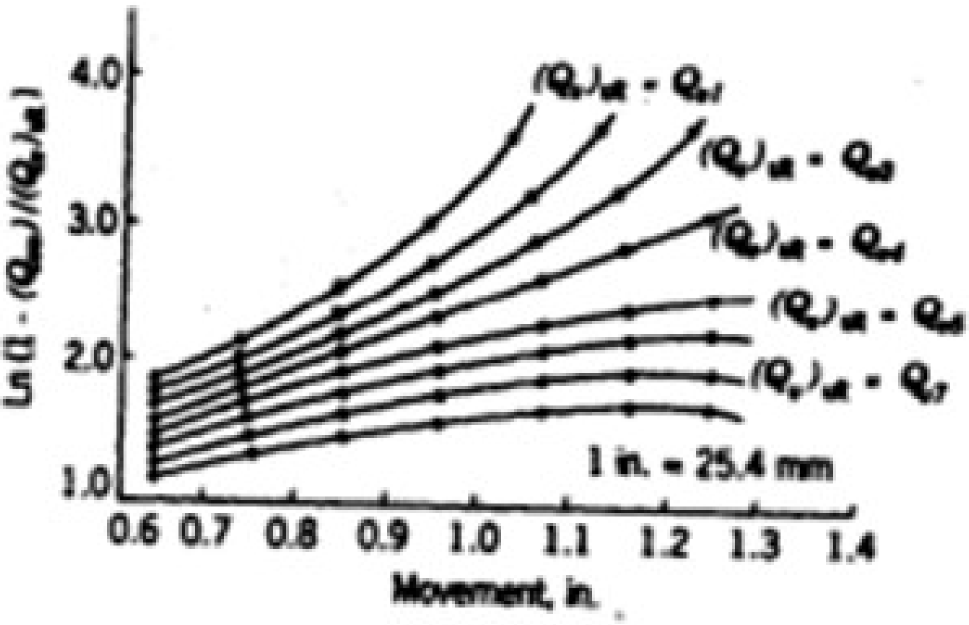


Figure 9.9 (d) Vander Veen's method

Fellenius (1980) carried out similar interpretations on a 12-in. (305mm) diameter concrete-driven pile that was tested by the CRP method. Interpretations indicated that Fuller and Hoy's, Brinch Hansen's 90 percent criterion, and Vander Veen's methods provided reasonable estimates of failure loads. The foregoing indicated that in call cases, Davisson's method predicted conservative values for failure loads, and Chin's method invariably yielded failure loads higher than the actual test failure loads. The Fuller and Hoy method appeared to yield failure loads that were reasonable approximations of the actual failure loads.

The total elastic recovery or settlement, S_e, is due to

1. The total elastic recovery of pile material,
2. Elastic recovery of soil at the tip of pile, $\bar{S}_e$.

The total settlement S due to any load can be separated out into elastic and plastic settlements by carrying out cylic load tests as shown in Fig. 9.15*a*.

A pile loaded upto Q_1 gives a total settlement S_1. When this load is released to zero, there is an elastic recovery which is equal to S_{e1}. This elastic recovery is due to the elastic compression of the pile material and the soil. The net settlement or plastic compression is S_{p1}. The pile is loaded again from zero to the next higher load Q_2 and released to zero thereafter. The corresponding settlements may be found out as before. The method of loading and unloading may be repeated as before.

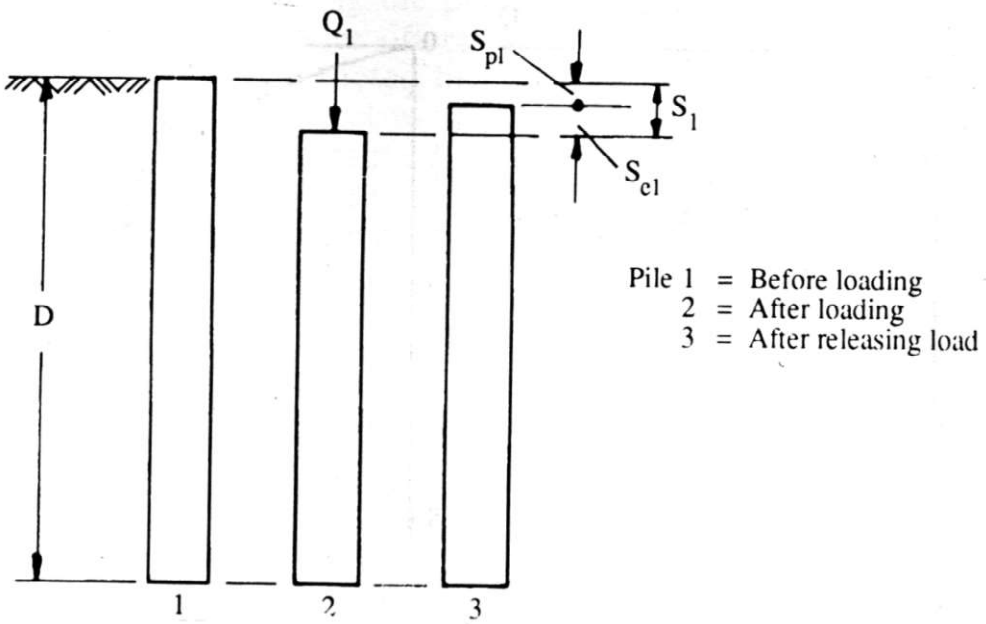


Fig. 9.15 (*b*) Elastic compression at the base of pile

9.12.4 Allowable Load from Single Pile Load Test Data

There are many methods by which allowable loads on a single pile may be determined by making use of load test data. If the ultimate load could be found out from load-settlement curves, allowable loads are found out by dividing the ultimate load by a suitable factor of safety which varies from 2 to 3. A factor of safety of 2·5 is normally recommended. A few of the methods that are useful for the determination of ultimate or allowable loads on a single pile are given below:

1. The ultimate load, Q_u, can be determined as the abscissa of

the point where the curved part of the load-settlement curve changes to a falling straight line Fig. (9.15*c*).

2. Q_u is the abscissa of the point of intersection of initial and final tangents of the load-settlement curve Fig. (9.15*d*).
3. The allowable load Q_a is 50 percent of the ultimate load at which the total settlement amounts to one-tenth of the diameter of the pile [Indian Standard Code of Practice IS: 2911 [(Part I)-1964], for uniform diameter piles.
4. The allowable load Q_a is sometimes taken as equal to two-thirds of the load which causes a total settlement of 12 mm (Indian Standard Code of Practice).
5. The allowable load Q_a is sometimes taken as equal to two-third of the load which causes a net (Plastic) settlement of 6 mm. (Indian Standard Code of Practice).

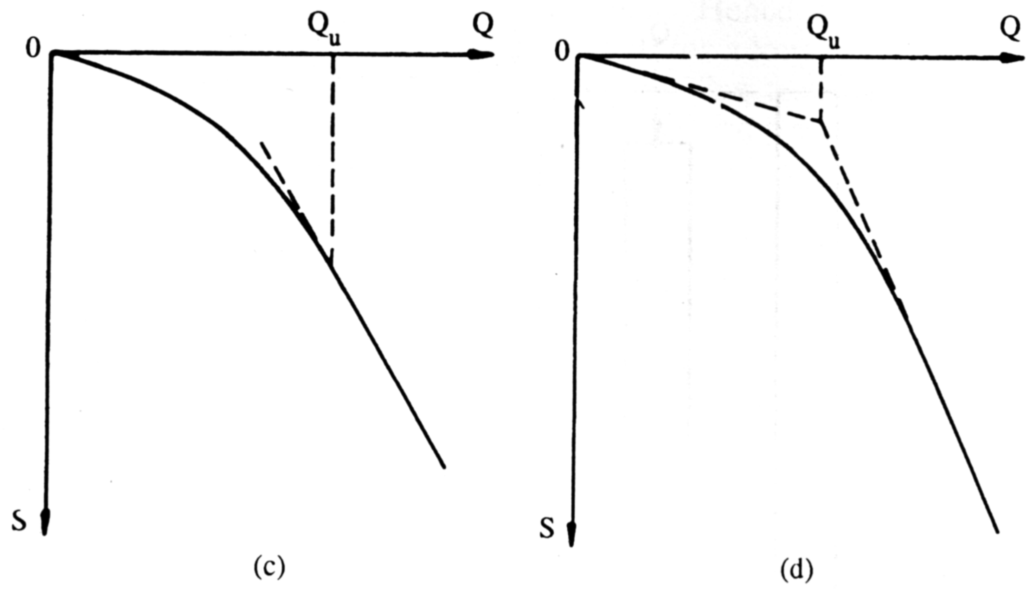


Fig. 9.15(*c*) and (*d*) determination of ultimate load from load-settlement curves.

If pile groups are loaded to failure, the ultimate load of the group, Q_{gu}, may be found out by any one of the first two methods mentioned above for single piles. However, if the groups are subjected to only one and a half-times the design load of the group, the allowable load on the group cannot be found out on the basis of 12 mm or 6 mm settlement criteria applicable to single piles. In the case of a group with piles spaced at less than 6 to 8 times the pile diameter, the stress interaction of the adjacent piles affect the settlement considerably. The settlement criteria applicable to pile groups should be the same as that applicable to shallow foundations at design loads.