Estimation of Some Mechanical Soil Properties from Static and Dynamic Plate Load Tests

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ABSTRACT

When the depth of stressed soil is rather small, Plate Load Test (PLT) becomes the most efficient test to estimate the soil properties for design purposes. Among these properties, modulus of subgrade reaction is the most important one that usually employed in roads and concrete pavement design. Two methods are available to perform PLT: static and dynamic methods. Static PLT is usually adopted due to its simplicity and time saving to be performs in comparison with cyclic (dynamic) method. The two methods are described in ASTM standard.

In this paper the effect of the test method used in PLT in estimation of some mechanical soil properties was distinguished via a series of both test methods applied in a same site. The comparison of the test results between both methods showed that the dynamic (cyclic) method gives lower values of soil properties than the static one does.

Key words: Plate load test, modulus of subgrade reaction, dynamic, static.

تخمين بعض خصائص التربة الميكانيكية من فحصي تحميل الصفيحة الأستاتيكي والديناميكي

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الخلاصة

عندما يكون عمق التربة المجهدة قليل نسبيا يصبح فحص تحميل الصفيحة اكثر الفحوص فعالية لتخمين خصائص التربة للأغراض التصميمية. ومن بين هذه الخصائص يعتبر معامل رد الفعل الأرضي الأهم والذي عادة ما يستعمل في تصاميم الطرق والبلاطات الخرسانية. وتتوفر طريقتان لأنجاز فحص تحميل الصفيحة: الطريقة الإستاتيكية والطريقة الديناميكية. وغالبا مايتم تبني الطريقة الإستاتيكية في فحص تحميل الصفيحة لسهولتها ولغرض التوفير بالوقت إذا ما قورنت بالطريقة الدورية (الديناميكية)، علماً أن الطريقتان موصوفتان في مواصفات الجمعية الأمريكية للفحص والمواد (ASTM).

في هذا البحث تم التعرف على تأثير الطريقة المستعملة في انجاز فحص تحميل الصفيحة على القيم المخمنة لبعض خصائص التربة الميكانيكية من خلال اجراء سلسلة من فحوص تحميل الصفيحة باستعمال كلا الطريقتين في نفس الموقع. من خلال مقارنة نتائج الفحوص بكلا الطريقتين تبين أن طريقة الفحص الديناميكي (الدوري) تعطي قيم أقل لخصائص التربة من تلك المستخلصة من طريقة الفحص الإستاتيكي.

الكلمات الرئيسية: فحص تحميل الصفيحة، معامل رد الفعل الأرضي، ديناميكي، إستاتيكي.

1. INTRODUCTION

Plate Load Test (PLT) is one of the tests that usually performed in situ to estimate some of the soil properties within shallow depths. The influenced depth (depth of stressed soil) in this test depends directly on the size of the plate used. This finding comes from the fact of bulb of stress beneath any loaded footing. Generally, the test can give an accurate estimation of mechanical properties of underneath soil in a range of about twice of plate diameter, **ASTM D1194, 2012**. However, the following empirical relation that given by, Bowels, 1988 may be used to explorate load-test results to full size footings in cohesionless (sandy) soils:

$$q_{ult.} = q_{plate}\left(\frac{B_{footing}}{B_{plate}}\right) \qquad (1)$$

Where,

$q_{ult.}$ = ultimate bearing capacity of the soil under footing.

$q_{plate.}$ = ultimate bearing capacity from PLT.

$B_{footing}$ = footing width.

B_{plate} = plate diameter.

On the other hand, for clay soils, since it is common to note that the BN_γ term is zero, so that it is concluded that $q_{ult.}$ Is independent of footing size, i.e.:

$$q_{ult.} = q_{plate} \qquad (2)$$

Several soil properties can be predicted from PLT such as modulus of subgrade reaction, modulus of deformation, rebound (elastic) and residual (plastic) settlement as well as allowable bearing capacity.

PLT may have static and dynamic features. Static PLT is the conventional test and used widely through the world. **ASTM D1194, 2012**, standard test method may be used to perform this test sufficiently. Dynamic PLT may be subdivided into two categories: impact and cyclic PLT. The former can be executed according to the test method specified in, **ASTM D1195, 2012**. This test is conducted using the same apparatus used in static test. The only difference is in applying incremental pressure as will be detailed hereafter. Impact PLT can be performed according to German specification TP BF-StB part B 8.3, Technical Test Provisions of Soil and Rock in Road Construction, 2003 using the Light Falling Weight Device (LFWD). The apparatus of this technique is shown in **Fig.1**.

Adam and Adam, 2003, suggested a simple and efficient mechanical model of the dynamic load plate test with the LFWD to allow the numerical simulations of the test. The motion of the device is characterized by a mass-spring-dashpot system as shown in **Fig. 2**. The mechanical properties of the spring-damper element were modeled as a Kelvin-Voigt body, i.e. a linear spring with stiffness k, and a viscous damper with damping coefficient**, Adam and Adam, 2003**.

A series of PLTs on a loam fill were carried out by **Matsuzawa et. al., 2006** via employing three loading methods: static, cyclic and rapid (dynamic) PLTs to estimate a static load-settlement relation from the rapid PLT results. They aimed to minimize the time consumed for assessment of mechanical properties of the tested ground. The rapid (dynamic) tests were conducted using the spring-hammer (SH) load test method shown in **Fig.3** which is essentially a dynamic test method.

In this work, static and cyclic PLT methods according to, **ASTM D1194, 2012** and, ASTM D1195, 2012 were adopted. A typical assembly for conducting both static and cyclic load test is illustrated in **Fig.4**.

2. EXPERIMENTAL WORKS

Four PLTs were carried out on 0.5 m compacted subbase layer in the location of storage tank and turbines at 2.0 below ground level in Al-Haydaria Gas Power Plant. Two of these tests were static tests and others were conducted near the locations of the static tests adopting the cyclic (repetitive) PLT method. The procedure of both above methods can be seen in the following brief:

<u>Static PLT method</u>

As mentioned in the previous section, **ASTM D1194, 2012** is adopted to perform the conventional static PLT. The test procedure can be summarized as follows:

1. A load is applied on the plate of 305mm in diameter and settlements are recorded from a dial gage accurate to 0.01mm. The load increment was taken approximately one fifth of the estimated bearing capacity of the soil. Time intervals of loading were taken one hour for all the load increments.
2. The test was continued until one of the following is achieved:
   (a) A total settlement of 25mm is obtained.
   (b) The maximum soil bearing capacity is reached.
   (c) The capacity of the testing apparatus is reached.

Cyclic (Repetitive) PLT method

On the other hand**, ASTM D1195, 2012** is taken a guide to execute cyclic (repetitive static) PLT:

1. After the equipment has been properly arranged, the total assembly (plate, jack and loading column) is seated by quick application and release of a load sufficient to produce a deflection of not less than 0.25mm or more than 0.50mm. After This release, the plate is reseated by applying one half of the recorded load that produced (0.25-0.50) mm. When the dial needle has again some to rest it is set accurately to its zero mark.
2. A load giving a deflection of about 1.0 mm is applied and maintained approximately constant until the rate of deflection is 0.03 mm/min. or less for three successive minutes. Then the load is completely released and the rebound is observed until the rate of recovery is 0.03 mm/min. or less for three successive minutes.
3. The load application and release is repeated in the same manner six times. The reading of dial gage resting on the bearing plate just before the application and release of load for each repetition is recorded.
4. The load is increased to give a deflection of about 5.0 mm and the procedure given in (2) and (3) above is repeated. Similarly, the method of load application and release is conducted for load increment giving more deflection or until the load capacity of testing apparatus or the maximum bearing capacity of the soil is reached. Keeping in mind that the standard end point of each loading or release in each repetition for each load increment is 0.03 mm/min. or less for three successive minutes.

3. RESULTS AND DISCUSSION

The plots of applied load against the corresponding plate settlement are given in **Figs. 5 - 8.**

For the nonrepetitive plate load test, the following procedure is followed to predict coefficient of subgrade reaction and the modulus of deformation (Young modulus):

(a) The yield point, see **Fig.9**, is obtained at intersection of the straight lines tangent to load-settlement curve from which the ultimate applied load (P_{ult}) in kN is assessed.

(b) Calculate the allowable applied load (P_{all}) in kN from:

$$P_{all} = \frac{P_{ult}}{F.S.} \quad (3)$$

Where, F.S = Factor of safety usually taken 2.5.

(c) Read δ which is the corrected settlement corresponding to applied load.

δ = observed settlement - δ_c (4)

Where, δ_c = to be estimated by backward projection of arithmetic load-settlement curve to zero load.

(d) Calculate Coefficient of subgrade reaction Ks as:

$$Ks = \frac{P_{all}}{A_p \delta} \text{ in kN/m}^3 \quad (5)$$

Where, A_p = area of plate used in the test in meters.

δ = the corrected settlement at the $P_{all.}$

(e) Calculate the modulus of deformation (Young modulus) E from, UFC, 2005:

$$E \approx 1.5 \times R_p \times K_s \quad (6)$$

Where R_p is the radius of the plate used.

The results of the nonrepetitive plate load tests can be seen in **Table 1**.

For the repetitive plate load test which has a different feature compared with the nonrepetitive

test, the final settlement and rebound of each load increment after six cycles of loading and unloading is recorded. The test includes inducing a settlement and keeping the load produced this settlement constant and recording the observed settlement. Then the load is vanished and the rebound settlement is recorded. This cycle of loading unloading is repeated six times. For each load increment an assessment of coefficient of subgrade reaction and modulus of deformation can be made adopting the final observed settlement.
The results of the repetitive plate load tests can be seen in **Table 2** and **Table 3**.

It is clear that repetitive PLT method gave lowest values of soil properties (modulus of subgrade reaction and modulus of deformation). This may be attributed the effect of cyclic (or hysteresis) stress loop that causes a continuous rearrangement of the skeleton of soil particles. In other words, the strain energy that expected to be stored in the soil skeleton was dissipated due to soil particle rearrangement. This finding may has an importance in practice of machine foundation problem in which cyclic (or repetitive) loading is expected.

4. CONCLUSIONS

The following conclusion can be drawn from this study:

1. A considerable decrease in values of soil properties (modulus of subgrade reaction and modulus of deformation) was found using the repetitive PLT in the same site where the static PLT have been used.
2. Repetitive PLT is recommended in prediction of soil properties when the practice involve a fluctuated or repetitive loading such as rotating machine foundation or tanks subjected to cyclic operations of filling and voiding.

5. REFERENCES:

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Table1. Nonrepetitive plate load tests results**.**

No.	Point location	Depth m	Modulus of sub-grade reaction, Ks (kN/m^3)	Modulus of deformation, E (MPa)
1	Storage Tanks	2	378462	86.6
2	Turbines	2	300000	68.6

Table2. Repetitive plate load tests results**.**

No.	Point location	Depth m		Incr.1 producing 1mm sett.	Incr.2 producing 5mm sett.	Incr.3 producing 10mm sett.
1	Storage tanks	2	Load, kN	20	92	125
			Final sett. mm	1.16	6.5	9.7
			Rebound mm	1.02	6.1	7.8
2	Turbines	2	Load, kN	10	30	40
			Final sett. mm	4.65	12.35	13.3
			Rebound mm	3.87	11.05	11.20

Table3. Summery of repetitive plate load tests results**.**

No.	Point location	Depth m	Modulus of sub-grade reaction, Ks (kN/m^3)	Modulus of deformation, E (MPa)
1	Storage tanks	2	43294	2.90
2	Turbines	2	2581	0.68

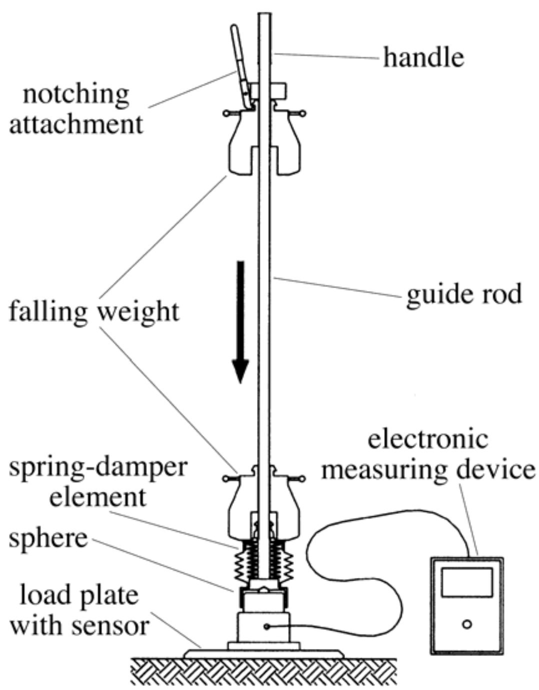

Figure 1. Components of the light falling weight device (LFWD).

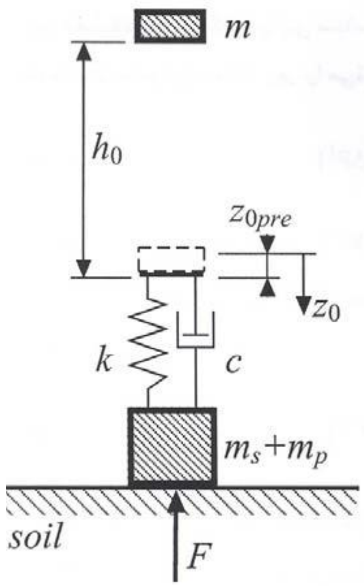

Figure 2. Mechanical model of the LFWD**.**

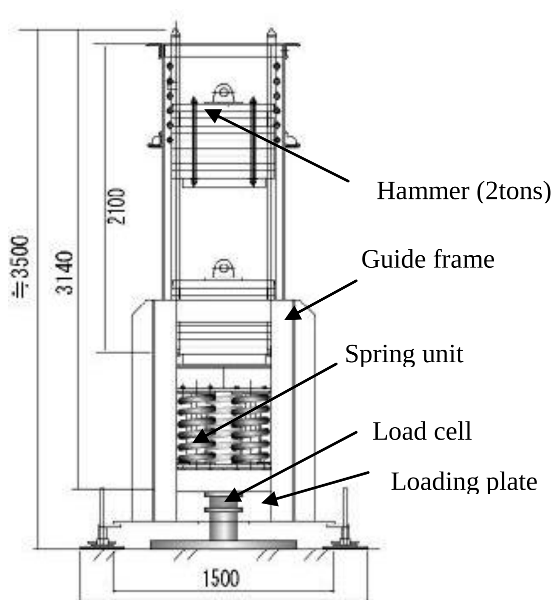

Figure 3. Spring hammer (SH) loading device.

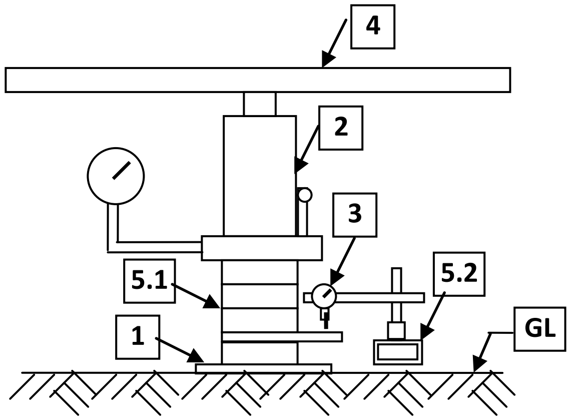

Plate loading apparatus

The loading apparatus is consisted of the following parts:

1. Bearing plate:

Circular steel bearing plate 30 mm thickness and 305 mm diameter is used.

2. Hydraulic jack:

Hydraulic jack capacity is 35 ton (350kN).

3. Settlement recording devices:

Dial gauge, capable of measuring settlement of the loaded plate to an accuracy of 0.01 mm.

4. Reaction beam (chessiet of a full loaded truck).

5. Miscellaneous apparatus Includes.

5.1. Comprssion post

5.2. Reference beam steel stands

Figure 4. Typical assembly of PLT apparatus**.**

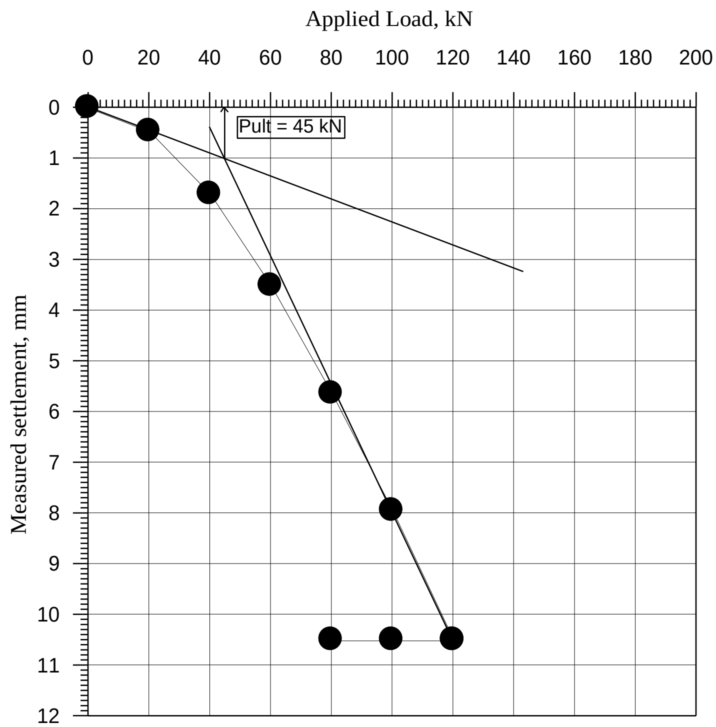

Figure 5. Static plate load test results for a point in storage tanks area.

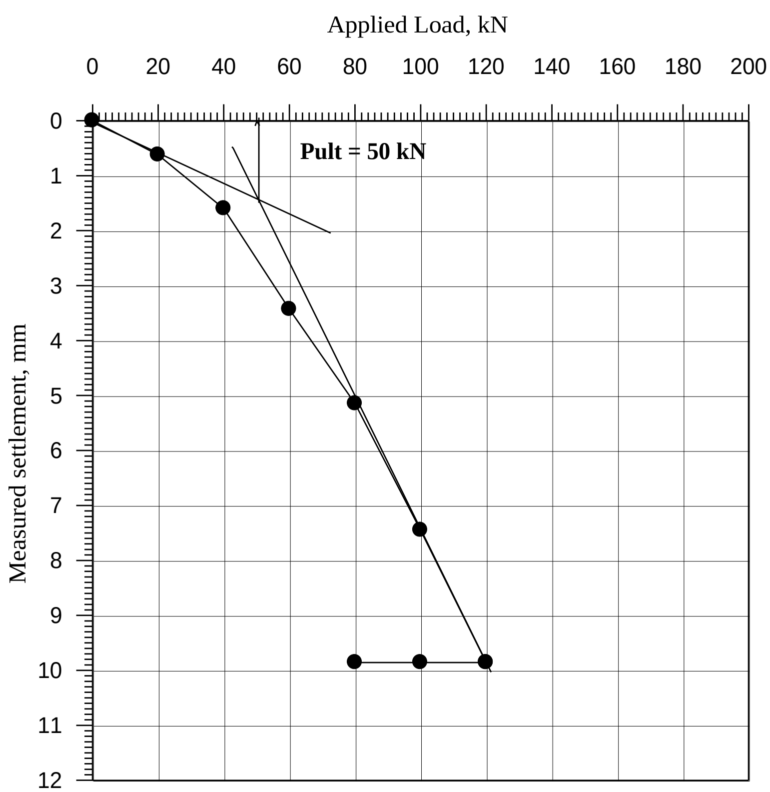

Figure6. Static plate load test results for a point in turbine area**.**

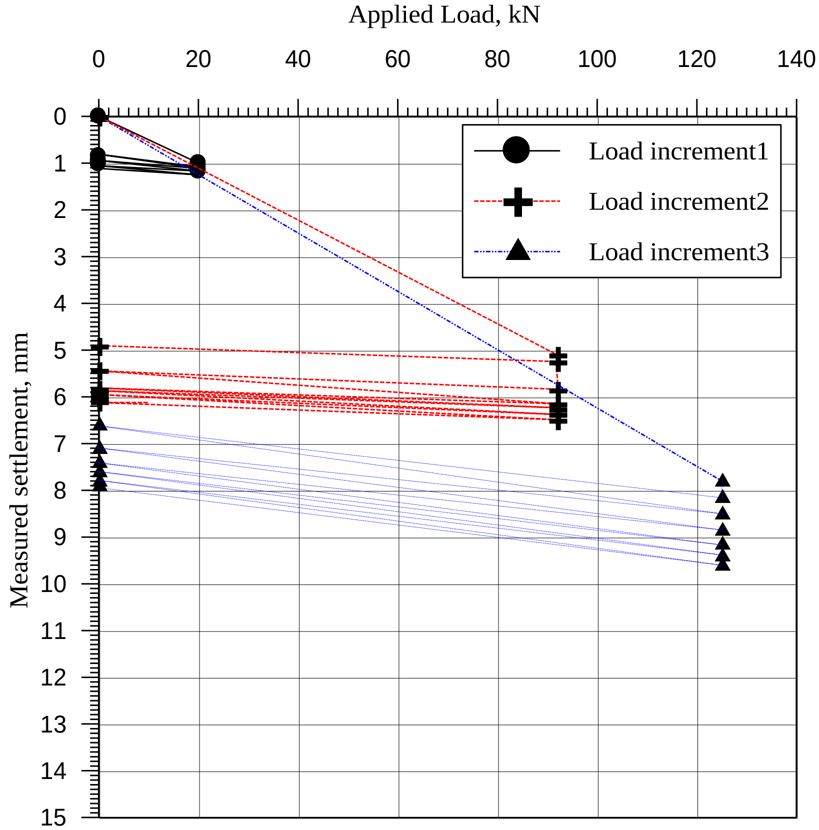

Figure7. Repetitive (dynamic) plate load test results for a point in storage tanks area**.**

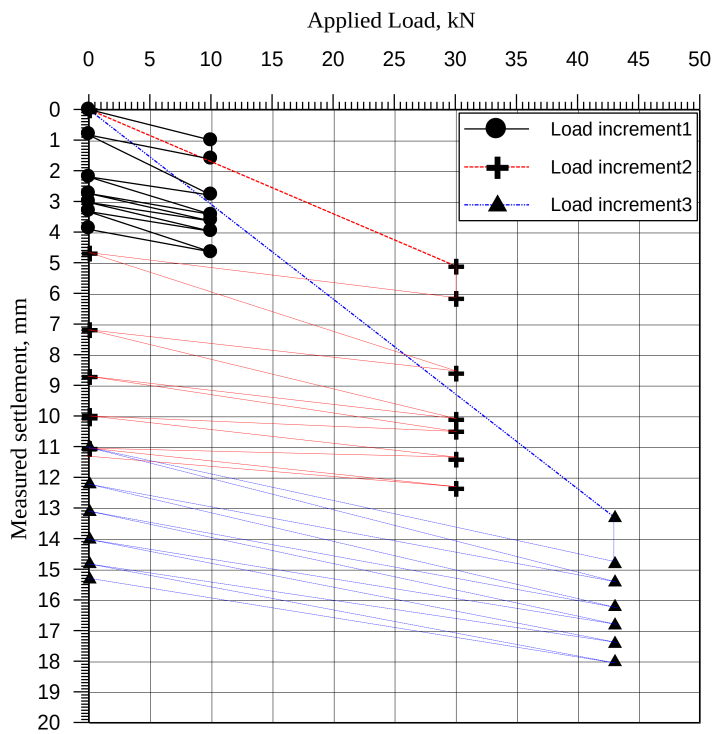

Figure8. Repetitive (dynamic) plate load test results for a point in turbine area**.**

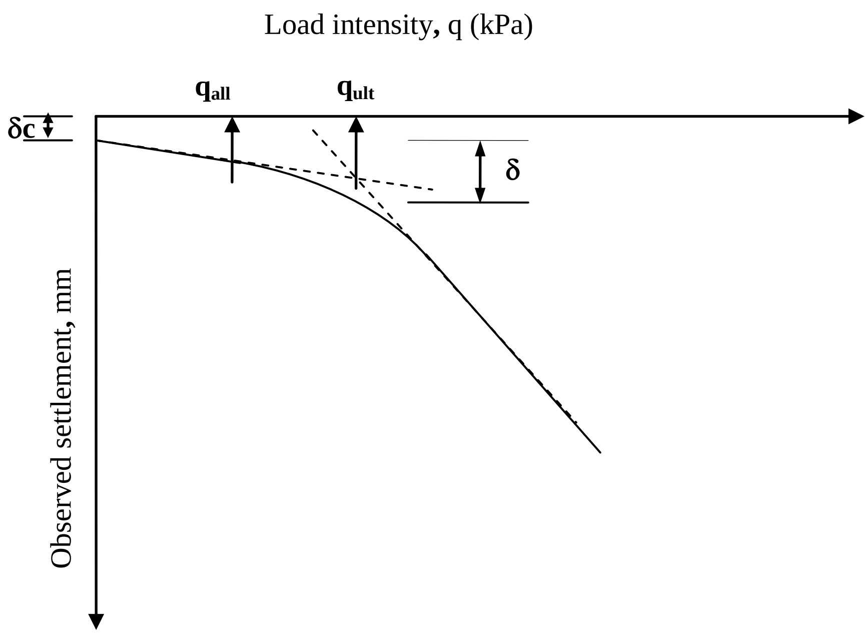

Figure 9. Method of calculation**.**