NUMERICAL ANALYSIS OF PLATE LOADING TEST BASED ON FIELD WORKS

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Abstract

In this work, the bearing capacity of soil is evaluated for a substation of residential compound in Amarah city by plate loading test. The study consists of two parts, the first part is the field work which includes soil tests in the field for the locations of two rectangular foundations of transformers with dimensions (for each foundation) of (3.5 m x 2.5 m), called (Point 1 and Point 2). Results showed that the settlements in the locations of points 1 and 2 are within the permitted settlement, and the allowable bearing capacity of soil in these locations is (9.1) T/m^2.

In the second part of the study, the tested soils by plate loading test are analyzed using nonlinear three dimensional finite element models. ANSYS (11.0) program is used to analyze the three dimensional model. The adopted finite element models are found to give results in an excellent agreement with the field results. For the same applied load, it is found that the ratio of theoretical to field values of settlement is 0.99 for the both points (1) and (2).

The effect of size of plate of loading has been carried out to investigate its effect on the predicted finite element results. It is found that the settlement is increased with increasing the size of the loading surface.

التحليل العددي لفحص تحميل الصفيحة بالاعتماد على الاعمال الميدانية

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الخلاصة

في هذا العمل، قيّمت سعة تحمل التربة لمحطة كهرباء ثانوية في مجمع سكني في مدينة العمارة بواسطة فحص تحميل الصفيحة. تتكون الدراسة من جزأين، الجزء الاول هو العمل الميداني والذي يتضمن فحوصات التربة موقعيا لاثنين من اساسات المحولات المستطيلة، أبعاد كل اساس (٣,٥ م * ٢,٥ م) سميت (نقطة ١ و نقطة ٢). أظهرت النتائج بأن الهبوط في مواقع النقطتين ١ و ٢ هو ضمن المسموح به، و 1 حمل المسموحة لهذه المواقع هو ٩.١ طن/م٢. وفي الجزء الثاني من الدراسة، تم تحليل الترب المفحوصة بواسطة فحص تحميل الصفيحة بالاعتماد على طريقة العناصر المحددة ثلاثية الابعاد اللاخطية. وجد بأن التمثيل (ANSYS11.0) لتحليل النموذج الثلاثي البعد. وتم اعتماد برنامج المستخدم للاساسات بطريقة العناصر المحددة يعطي قيم ذات اتفاق جيد مع النتائج الميدانية. وقد وجد إن نسب الهبوط للدراسة النظرية إلى قيم النتائج الميدانية هو ٩٩% لكلا النقطتين ١ و ٢. تم دراسة تأثير حجم صفيحة التحميل بأستخدام طريقة العناصر المحددة لمعرفة تأثيرها. وقد وُجد ان الهبوط يزداد بزيادة حجم سطح التحميل.

Introduction

Bearing capacity is the ability of soil to safely carry the pressure from any engineered structure without undergoing, a shear failure nor large settlements. Applying a bearing pressure which is safe with respect to failure does not ensure that settlement of the foundation will be within acceptable limits. Therefore, settlement analysis should generally be performed since most structures are sensitive to excessive settlement.

One of the methods for calculating the bearing capacity is the plate bearing test. This test method is a semi-direct method to estimate the bearing capacity of a soil in the field [1]. The test allows the determination of the relationship between the applied pressure and the displacements (pressure-displacement curve) [2]. The test has been used to avoid comprehensive geotechnical investigations which take more time and cost in small jobs with light load structures, and also to give quick results and data concerning bearing capacity of soil. The technique adopted in this study for carrying out the plate loading test has been described by ASTM D1194-94 [3] and BS 1377 part 9 [4].

According to the test procedure, a hydraulic device transfers pressure in stepwise through a circular rigid plate onto the surface of foundation, until the displacement or pressure criterion is satisfied.

Soil settlements are difficult to estimate. Settlement is stress induced, but is a statistical, time dependent accumulation of particle rolling and slipping which results in a permanent soil skeleton change. Elastic deformation (which is recoverable on removal of stress) is only a very small contribution to the total settlement of a foundation. It is a computational convenience to use elastic theory to predict soil settlement; however, reasonable estimates can be made if "elastic" parameters which describe the stress model over the range of actual stresses from the foundation can be obtained [1].

The scope of the research is to evaluate the allowable bearing capacity of soil for a substation of residential compound in Amarah city by plate loading test in the field, and then the plate loading tests will be analyzed using three dimensional finite element models to check the validity of the adopted finite element models in predicting the overall behavior of the field plate bearing test, and to get more information about the size effect of plate loading test on the soil. The zones which should be tested were rectangular foundations of transformers with dimensions (for each foundation) of (3.5 m x 2.5 m) called (Point 1 and Point 2).

Load-Settlement Criteria

The load is applied to the plate in increments of the design load. The increments are applied until shear failure, the loading is 2 to 3 times the design load [5], or until a total settlement of 25 mm is obtained [1]. After the load is released, the elastic rebound of the soil should be recorded for a period of time at least equal to the duration of a load increment.

Field Plate Loading Test

The plate was placed on the soil to be tested. The load was applied to the plate in successive increments and a settlement was measured. Load increments are applied until the load intensity on the plate reach to (274 kPa) for all zones in the Amarah site as shown in the plates (1) to (2).

The load was applied to the plate via a factory calibrated hydraulic load cell and a hydraulic jack. Large plate with a diameter of 0.61m and thickness of 30mm was used.

Settlement is measured using dial gauges. In order to measure any tilt that may occur, two gauges on the perimeter of the plate were used. These gauges supported on rigid uprights fixed firmly into the ground at a distance of more than twice the plate width from the plate center. At each pressure increment, a note was made of the load on the plate and dial gauge readings were made on a (0.25, 0.5, 1, 3.5, 7.5, 10, 15) minutes after load application. This would ensure sufficient readings in the early stages of each load application when movement occurs most rapidly.

After completion of observations for the last load increment, release this applied load in three decrements. Continue recording rebound deflections until the deformation ceases.

The results of these measurements were plotted in two forms: a time-settlement curve and a load-settlement curve as shown in Figs. (1) to (4).

Field Results

The field results of plate bearing test for the soil at the location of Point (1) and Point (2) are shown in Table (1). The recorded settlement, plastic settlement and elastic settlement for zones (Point 1 and Point 2) are given. Table (2) shows the settlement corresponding to maximum applied stress and allowable bearing pressures for the same zones.

Table (1): Recorded settlement, plastic settlement and elastic settlements for all tested zones

Zone	**Recorded Settlement (mm)**	**Plastic Settlement (mm)**	**Elastic Settlement (mm)**
Point 1	7.48	4.35	3.13
Point 2	6.72	3.85	2.87

Table (2): Recorded settlement of the plate due to maximum applied stress

Zone	Recorded Settlement (mm)	Maximum Applied Stress (kPa)	Ultimate Bearing Pressure (kPa)*	Allowable Bearing Capacity (kPa)
Point 1	7.48	273.96	274	91
Point 2	6.72	273.96	274	91

* : Ultimate bearing pressure corresponding to recorded settlement of the plate.

Finite Element Model

The finite-element method is one of the mathematical methods in which continuous media is divided into finite elements with different geometries. It provides the advantage of idealizing the material behavior of the soil, which is non-linear with plastic deformations and is stress-path dependent, in a more rational manner. The finite-element method can also be particularly useful for identifying the patterns of deformations and stress distribution during deformation and at the ultimate state. Because of these capabilities of the finite element method, it is possible to model the construction method and investigate the behavior of shallow footings and the surrounding soil throughout the construction process, not just at the limit equilibrium conditions [6].

In the present section, the plate loading tests have been analyzed using three dimensional finite element models. The main objectives of the analysis are to check the validity of the adopted finite element models in predicting the overall behavior of the field plate bearing test, and to get more information about stresses and strains developed in the soil.

The analysis is made by using **ANSYS 11.0** computer program. The three dimensional 8-noded brick element (SOLID45) is selected to represent the soil and the loading plate. The contact between loading plate and soil is represented by TARGE 170 and CONTA 173 elements.

Stresses in a Soil Mass due to Footing Pressure

Results from elastic theory indicate that the increase in vertical stress in the soil below the center of a strip footing of width B is approximately 20% of the foundation pressure at a depth 2.5B. In the case of a square footing the corresponding depth is 1.2B. For practical purposes these depths can normally be accepted as the limits of the zone of influence of the respective foundations and are called ***the significant depth***. It is essential that the soil conditions are known within the significant depth of any foundation [7].

To study the behavior of the plate loading test on soil using finite element analysis, it is necessary to simulate the conditions as close as possible to those occur in the field. As mentioned above, the stresses applied on the soil decrease with the depth inside the soil. Sing [8] mentioned that these stresses vanish at a depth equal to width of footing. Therefore the the depth should be equal or greater than (610mm to 1.2 B, whichever is greater), to ensure the stress be within the depth of the model. In this research was taken equal to 1.5 m. The plan dimensions of soil were decided depending on the Boussinesq and Westergaard theories. The Boussinesq and Westergaard theories are more mathematically oriented methods for estimating soil pressures at various points in a soil stratum. Both these are based on elastic methods. Figures (5) and (6) show the pressure bulb for square footing. It can be seen that the stresses expand horizontally up-to a maximum distance of 1.25 B approximately from centerline of footing. So, the width and length in this research are taken equal to 1.5 m.

In order to prevent any rigid motions of the whole problem domain, it is assumed that both the displacements in the horizontal and vertical directions are zero for all nodes along the bottom boundary of the mesh. On the vertical side boundaries, the horizontal displacements have been assumed to be zero too [9].

The load, in the present study, is distributed on the nodes under the loading plate in such a manner that each node takes a load equal to the uniform applied pressure times the related area to the node, and for the circular loading plate, an equivalent square loading area is assumed to calculate the loads on nodes [10].

The yield criteria depend on the behavior of the soil. The Drucker - Prager ***(DP)*** criterion is used for soil as yield criteria which is applicable to granular (frictional) material such as soil, and uses the cone approximation to the Mohr-Coulomb law.

The soil behavior is described by the Mohr-Coulomb model, having Young's modulus, E_s= 140 MPa, Poisson's ratio, ν= 0.3, c = 1 kPa and angle of shearing resistance, ϕ = 30^o.

Load-Settlement Relationship

Figures (7) to (10) illustrate the pressure-settlement relationships and the contours for vertical displacement of the tested soils in the points (1 and 2). These figures show that the predicted behavior concerning the load-settlement curve is almost similar to the field results. The relationships start linear to fourth of the ultimate load and then become nonlinear. Good agreement between the field and theoretical results is achieved. The ratio of theoretical to field value of settlement is 0.99 for the both points (1) and (2).

The Size Effect in Plate Loading Test on Soil

To investigate the effect of size of plate loading test on the nonlinear finite element analysis of soil, Point (1) has been chosen to carry out this study. In each numerical test, plate diameter has been considered to vary while the other parameters being held constants in order to isolate the effect of the size. In order to study the effect of size of plate loading test on the soil (D), different values of (D) have been considered. The selected values for this parameter are

0.2, 0.4, 0.6, 0.8 and 1.0 m. Figure (11) show the settlement versus plate diameter relationship obtained from the finite element model for the selected values of (D). It can be seen, the settlement increases proportional with the size of the loading surface.

Conclusions

In this study, the main concluding remarks that have been achieved from the test results may be summarized as follows:-

1- The settlement faster increased in the first few seconds after each new load increment and contributed to obtain a plastic settlement.

2- The average elastic settlement for points 1 and 2 forms 42.27 % of total settlement, this represent high percentage and is contrasted with that mentioned by reference (1).

3- Nonlinear finite element solution by ANSYS package program using three dimensional elements for modeling the plate loading test on soil gives excellent agreement with the field results for the load-settlement relationships.

4- The finite element analysis shows the increase in the size of plate loading test of the soil (D) causes an increase in the settlement.

References

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Plate (1): Plate Bearing Test for Location of Point (1)

Plate (2): Plate Bearing Test for Location of Point (2)

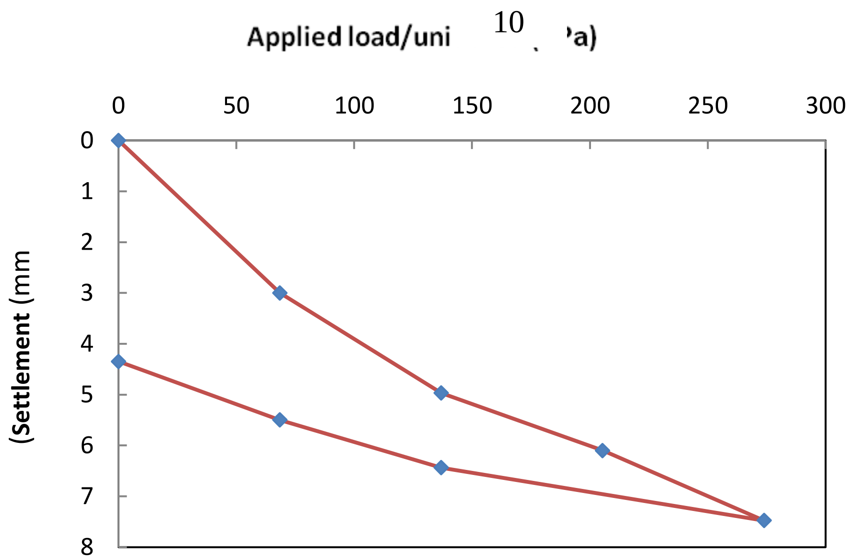

Figure (1): Load-Settlement Curve for Point (1)

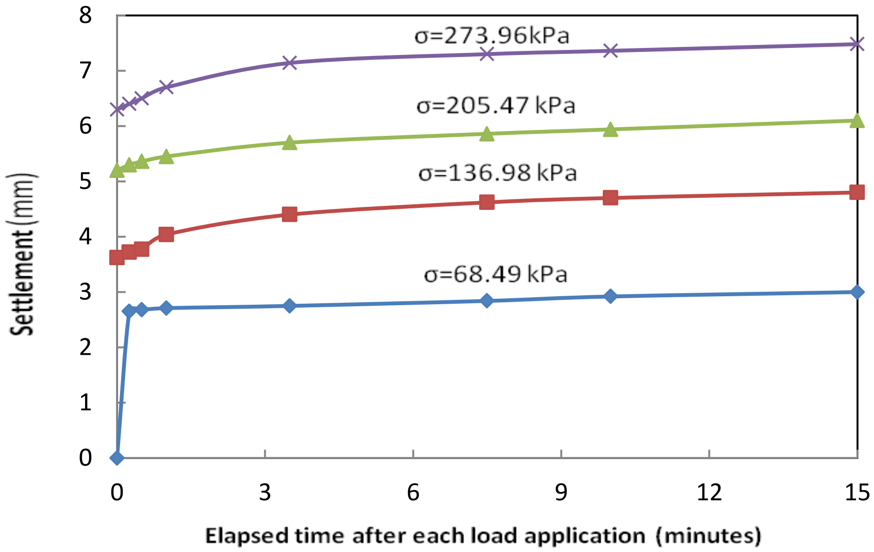

Figure (2): Time-Settlement Curves for Point (1)

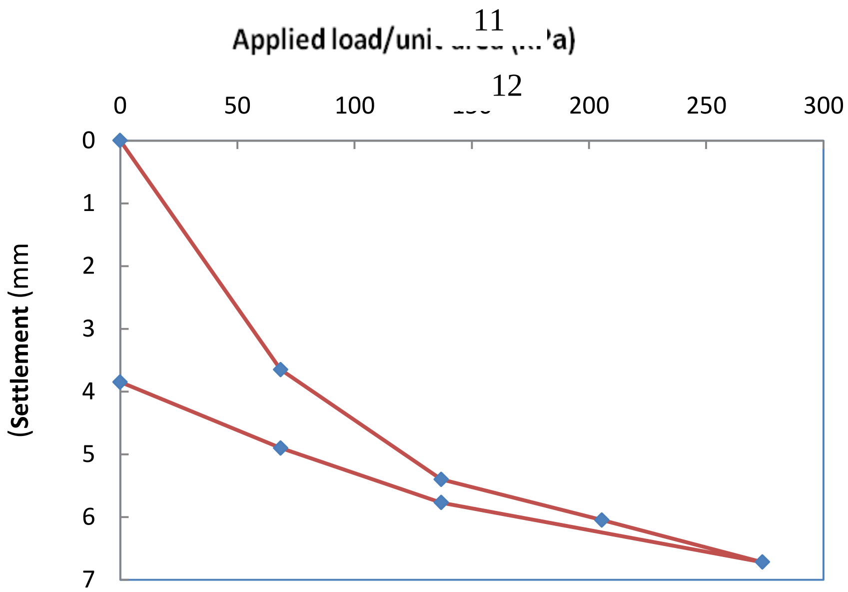

Figure (3): Load-Settlement Curve for Point (2)

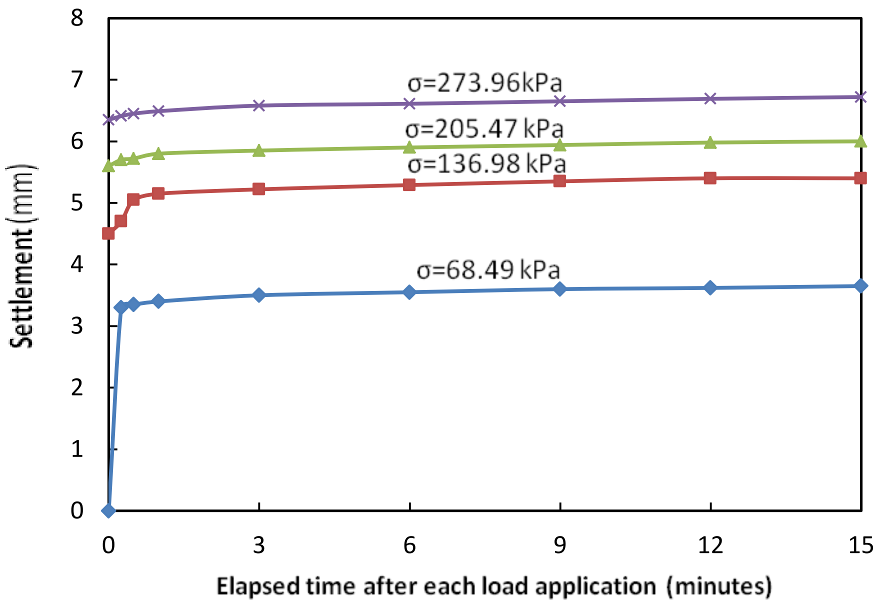

Figure (4): Time-Settlement Curves for Point (2)

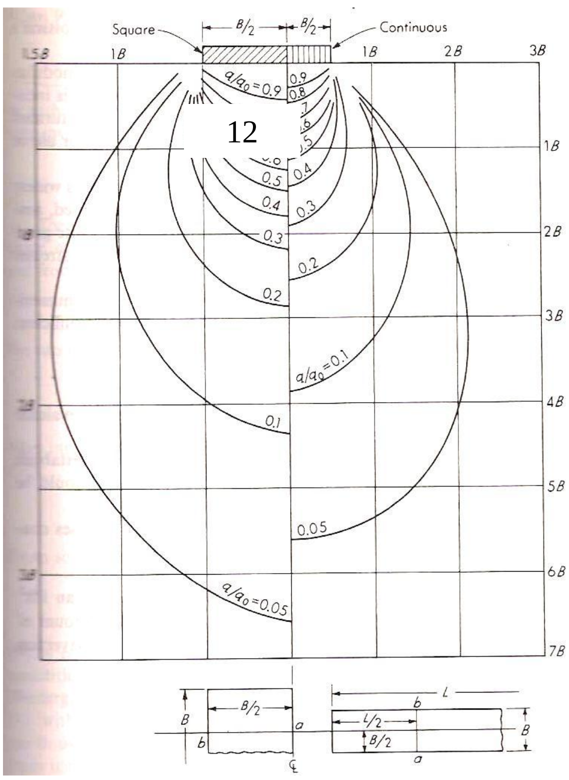

Figure (5): Pressure Isobars Based on the Boussinesq Equation for Square and Continuous Footings. Applicable Only Along Line *ab* (Ref.1)

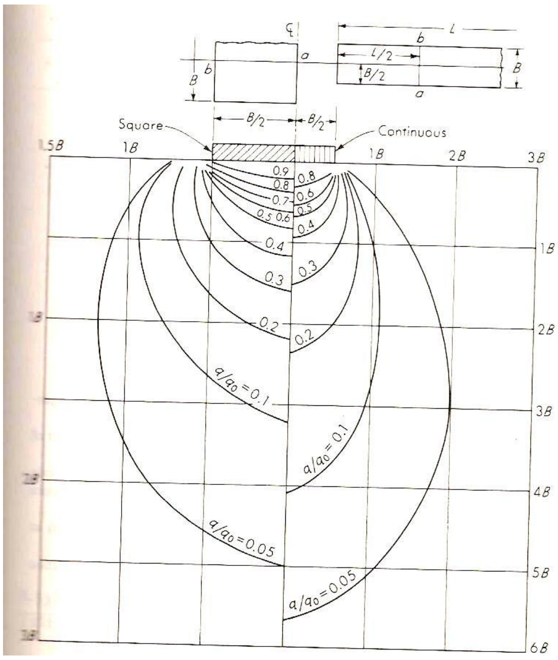

Figure (6): Pressure Isobars Based on the Westergaard Equation for Square and Continuous Footings. Values for the Continuous Footings are at the Point *L/2* from the End (Ref.1).

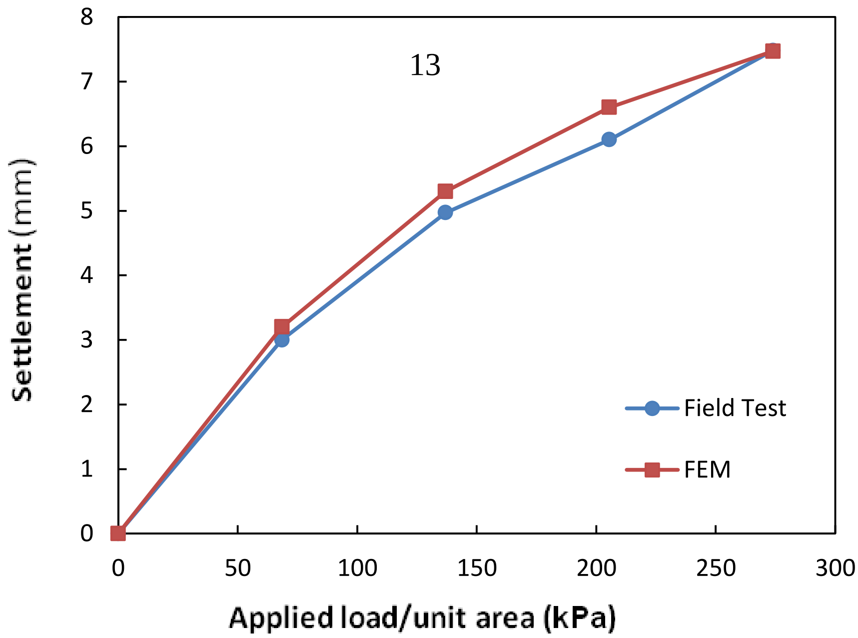

Figure (7) Variation of Settlement with Load for Point (1)

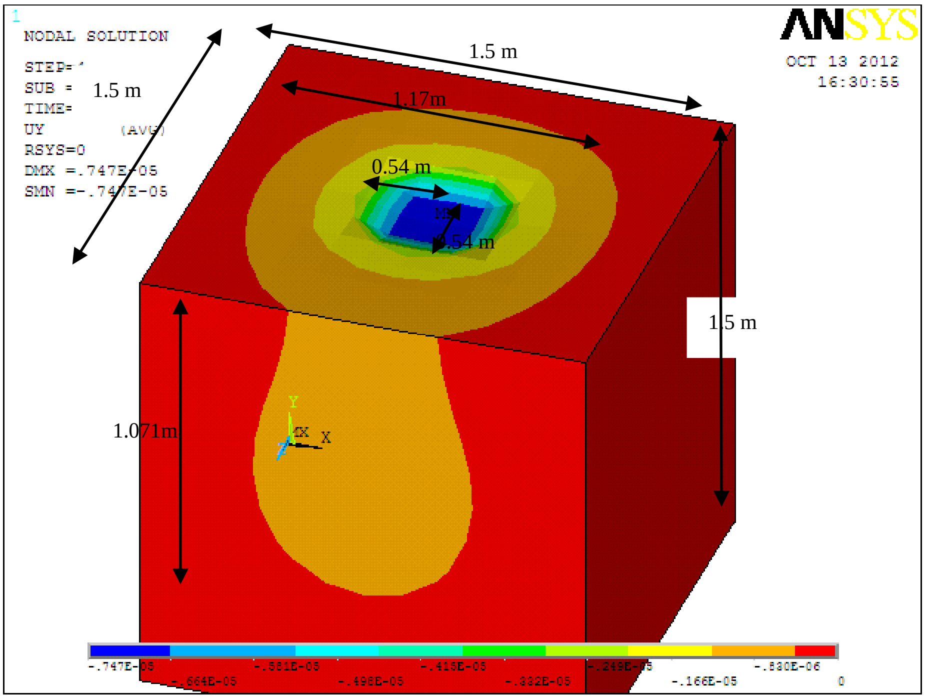

Figure (8) Contour Plot for Vertical Displacement (y) for Point (1)

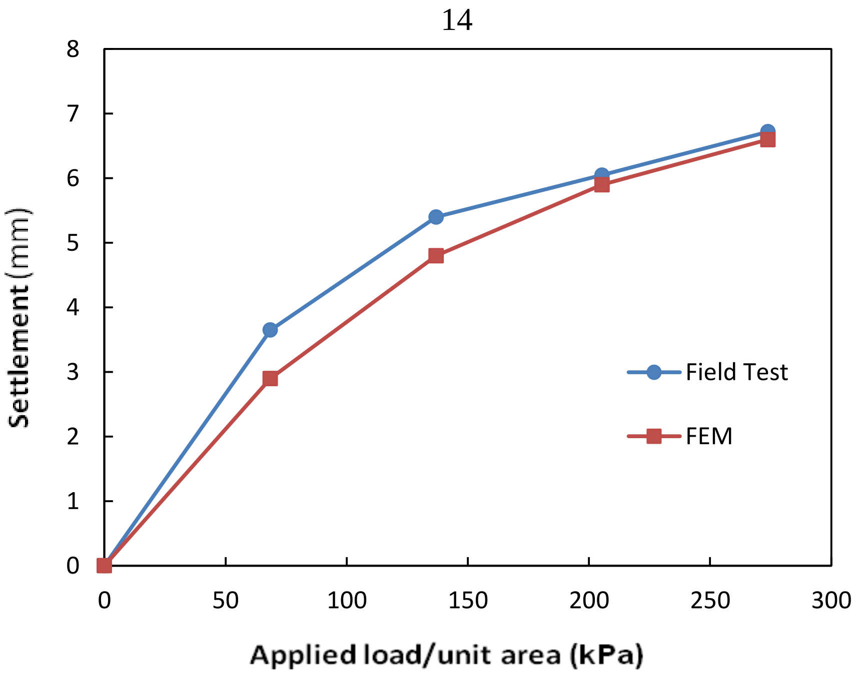

Figure (9) Variation of Settlement with Load for Point (2)

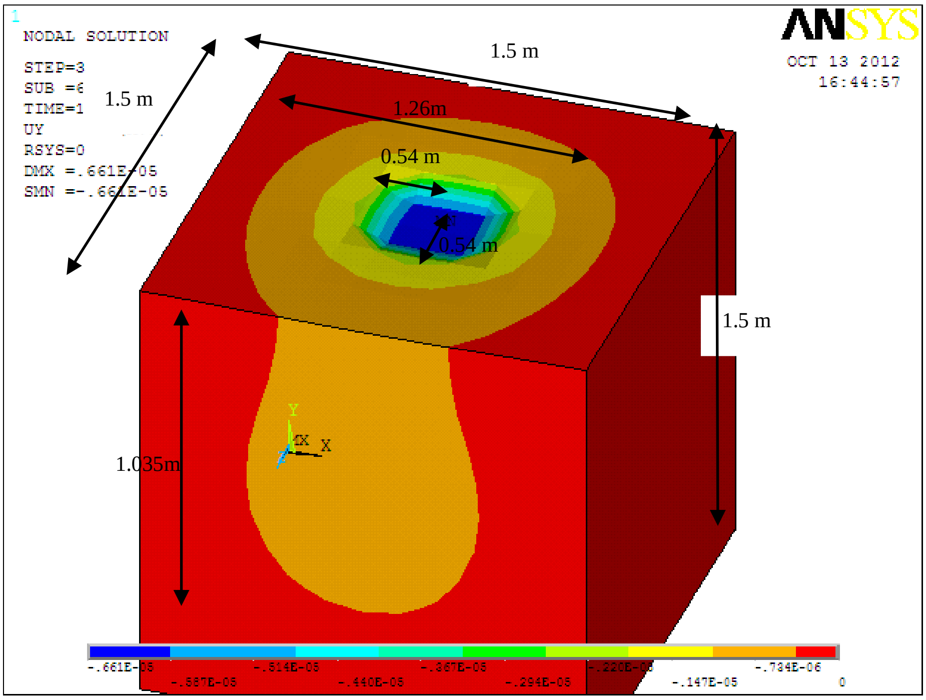

Figure (10) Contour Plot for Vertical Displacement (y) for Point (2)

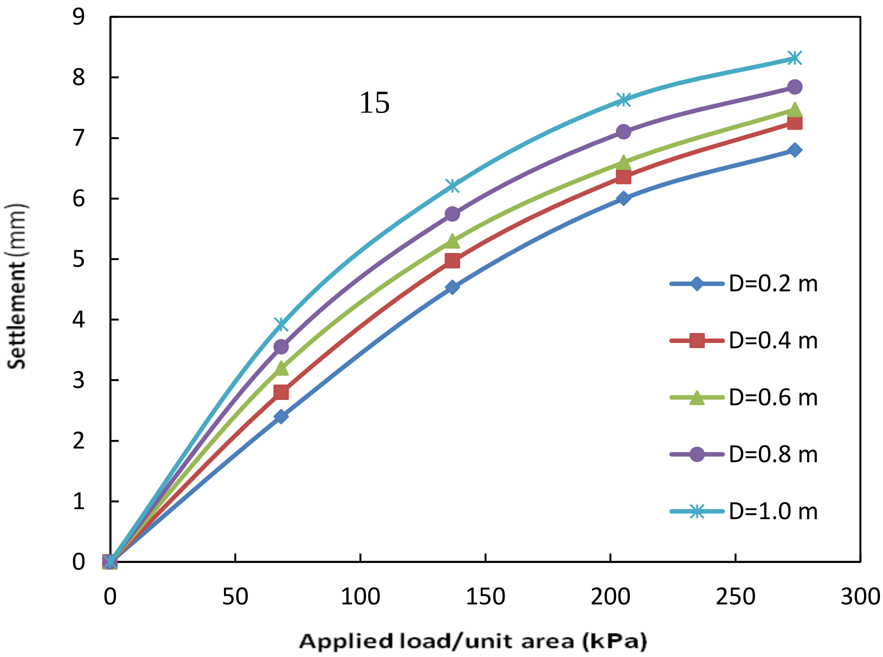

Figure (11) Numerical load vs. settlement curves