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Wedge Foundation in Expansive Soils

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Abstract

The object of this study is to find a construction solution to the problem of expansive soils by suggesting of a new shape of the conventional footing which has a sharp edge, this footing is named a "wedge footing" which is considered as an alternative shape to the strip footing to dissipate the swelling pressure produced in the soil when inserting the footing in it. These soils have a tendency to absorb water and expand causing high damage to the lightly loaded buildings and structures. The analysis carried out using finite element method to assess the behaviour of displacement of the wedge footing compared with strip footing which is considered as a basic problem. An equation is obtained from the results of the computer package of "STATISTICA" based on the results of finite element analysis related to the displacement of wedge shaped footing as a function of soil properties and footing with coefficient of regression of
(R^2= 98.9%).

Keywords: Wedge, Expansive soil, Finite element, STATISTICA.

الاساس الاسفيني في التربة الانتفاخية

الخلاصة

الهدف من هذا البحث دراسة امكانية استخدام اساس اسفيني مقترح كبديل للاساس الاعتيادي لحل مشكلة التربة الانتفاخية عن طريق تقليل الضغط الانتفاخي المتولد فيها, هذه الترب عند تعرضها الى الماء تقوم جزيئاتها بامتصاصه مسببة زيادة في حجم التربة وبذلك تسبب ضرر كبير للمنشات المقامة عليها وخصوصا المنشات ذات الاحمال الخفيفة. تم استخدام طريقة العناصر المحددة لغرض التحليل واستخراج النتائج ومقارنتها مع تلك الناتجة من تقييم سلوك ازاحة الاساس الاعتيادي الذي يعتبر المسألة الاساسية, ولقد اثبتت النتائج درجة تحسين عالية في تقليل مقدار ازاحة الاساس الاسفيني وبمقدار (٩٥٪) عند استخدامه كحل انشائي لهذه التربة. تتضمن الدراسة ايضا استنباط معادلة تربط خواص التربة بمقدار الازاحة باستخدام البرنامج الاحصائي (STATSTICA) ولقد اعطت معامل انتظام عالي بمقدار (٩٨.٩٪).

Introduction

Soil is an essential component in the construction and stability of houses, commercial buildings and other structures. Since structures are built on soil, structural damage to a structure can occur if the soil expands or slides and the annual losses are estimated between $2 billion and $9 billion which include severe structural damage, cracked driveways, sidewalks and basement floors, heaving of roads and highway structures. ***(Jone and Jones, 1987).***

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Expansive soil is a soil that under some conditions is capable of increasing its volume when wetted. Normally, the soil which contains expansive clay minerals such as the montmorillonite. As they get wet, the clay minerals absorb water molecules and expand. Conversely, as they dry they shrink, leaving large voids in the soil. *(Rogres et al., 1987).*

Considering different clays minerals, it can be said that montmorillonite clays are the mostly swelling ones, while kaolinite are of negligible swelling properties. Illite clays can be classified as moderately expansive. *(Coduto, 2003).* There are many criteria available to identify and characterize expansive soils according to their behaviour due to water content alteration, such as Atterberg Limits as shown in Figure (1.1). *(Lucian, 2006).*

Tables (2.1) and (2.2) identify soil swelling ability according to their Atterberg limits, shrinkage index, free swell index (FSI), activity and percent free swell. *(Sridharan and Prakash, 2000).*

Expansive Soils in Iraq:

Expansive soils in Iraq found in large areas in the north, middle and south, especially in Akashat area in Al-Anbar Governorate, so many researches had reported and studied the behaviour and distribution of these problematic soils such as *(Rashed, 1985)* has investigated the swelling characteristics of local clay of Mosul Governorate. *(Sabaa, 1987)* investigated the expansive soils in several locations in Iraq.

Including eight Governorates. *(Hattab and Kachachi, 1990)* studied the distribution of the expansive soils in Baghdad governorate, the expansive soil causes many damages to low buildings that exist with moderate to high swelling ability.

Scope of the Research:

The main purpose of present work is:

1. To asses the validity of using the uncommonly footing, named a wedge shaped footing to avoid the problem of expansive soils using the finite element analysis.
2. To reduce the harmful effect of the swelling pressures induced in expansive soil underlie the foundations of the light weight constructions.
3. To make a comparison between the results which obtained from using the finite element method to analyze the behaviour of suggested wedge footing and the strip footing.
4. To give a relationship between the properties of expansive soils in the form of statistical model by using the “STATISTICA” computer package.

Finite Element Program Used:

The finite element program used in this study is a program modified by ***(Shlash, 1979),*** it has been coded in FORTRAN language based on program coded for University of California**.** The last developed version which was considered named “***KAIS 2006”***.

The results which have been obtained by using this program are the deformations of the nodal points at the surface of footing and adjacent surface of soil at both sides of the footing. The stresses of elements and their directions are taken at the centriod of the elements. The swelling pressure was applied to the soil and footing of the structure as a concentrated force at the nodal point.

The Problem Considered:

A footing carrying a light loading of brick wall or a fence, having 3m in height and 0.25m in width is considered with the geometry and is exerting a total load of 28.5 kN/m^2 on the strip footing, as shown in figure (2).

The finite element program is used to calculate the displacement of footing producing under a variety of swelling pressures imposed by various expansive soils. This problem is considered as the basic problem. So, to clarify the effect of replacing footing type in the expansive soils, wedge shaped footing is considered to replace the strip shaped footing and the finite element analysis is used to estimate the expected settlement for such type of footing and a comparison is made between the results.

Various angles for the apex of wedge footing (θ) are considered and they are 25, 30, 35, 40, 60 and 80 degrees. Each one of these footings is exposed to the same external surcharge applied to the rectangular shaped footing and to the various swelling pressures which are 20, 40, 80, 125, 250, 300 and 800 kPa. As illustrates in the Figure (1.3) which shows the geometry of the wedge shaped footing.

Mesh Discretization:

Three types of elements are considered in mesh preparation to perform the finite element analysis. The first is the two dimensional quadrilateral element (4 node), and the second is the triangular one, while the last is the interface element. The different problems are simulated in a mesh form as illustrated in the figures (4 and 5).

80^o Wedge Shaped Footing:

The results obtained for this wedge apex angle are presented in Figure (1.6), and indicate the ability of reducing or controlling the effect of expansive soil pressure on a footing. When using this type of footing the upwards movement has either vanished or minimized to minimum values, even at the highest swelling pressure considered which equals 800 kPa, the reduction is about (95.75%) and as can be observed in Figure (7) later.

Effect of Surcharge Load on the Displacement of Footing:

The highest degree of improvement is achieved at 80^o wedge footing. Therefore, this model is used under the same circumstances to explore the effect of the surcharge on this suggested shaped footing under two different swelling pressures which are 250 and 800 kPa and compare the results with the strip footing. So, to find the effect of the variation in the applied load on the behaviour of displacement of this footing, a brick wall is replaced with a concrete wall with different heights of 3, 4, and 5m inducing a load of 18, 24 and 30 kN/m respectively. A series of finite element analysis was carried out on both wedge and strip footings.

Figure (8) represents the relation between the increments in the load and the displacement of the footing

The results obtained from figure show that, the external load has very slight effect on the displacement of footing for both wedge and strip footings and this effect can be negligible. These results agree with the results obtained by ***(Chen, 1975)***.

Summary of Results of Wedge Shaped Footings:

The results obtained for the wedge shaped footings are summarized in Figure (9). The advantage of using or considering an apex angle for the footing is found to be very effective in controlling the expected developed upwards movement of the footing under different applied swelling pressures. The important point in this work is that the change in apex angles almost leads to the same amount of enhancement, and the variety of displacement results of these apex angles are very close in difference. So, taking into account the simplicity of the construction considerations, it can be seen from Figure (10) that the 80° wedge shaped footing is a suitable measure to dissipate the swelling pressure in the case of a continuous footing to support light loadings because it has the highest degree of improvement.

Statistical Modelling:

The field of statistics deals with the collection, presentation, analysis and use of data to make decisions, solve problems and design products and process. Because many aspects of engineering practice involve working with data, obviously some knowledge of statistics is important, especially statistical techniques can be a powerful aid in designing new products and systems. As cited in ***(Montgomery and Ranger, 2004).***

The computer package (STATISTICA) was implemented to determine the relationships between the values of displacement and unit weight of expansive soils, swelling pressure, apex angle of the wedge footing, undrained shear strength and the width of the footing. Three-dimensional contour area for the variation in displacement with the apex angle and swelling pressure is shown in Figure (11), the assumption used to represent this relationship is nonlinear. It can be observed that, the displacement of footing decreases with an increase in the apex angle of wedge shaped footing. Accordingly, the mathematical model for the displacement is as follows:

$$Disp. = E_s^{-0.94} + 0.003(Ps + Cu) - 50.3\left(\frac{x}{g}\right) + \frac{q}{2231.5}$$

where:

$Disp.$= displacement of footing. (mm).

E_s = modulus of elasticity. (MPa).

P_s = swelling pressure. (kN/m^2).

Cu = undrained shear strength. (kN/m^2).

x = width of footing. (m).

g = unit weight. (kN/m^3).

q = apex angle. (degree).

The coefficient of determination (R^2) is (98.9%).

Verification of Mathematical Model:

The comparison between the predicated and measured displacement of wedge shaped footing suggested is plotted in Figure (12). It is clear from this figure, the ability of mathematical model to predict the displacement of wedge shaped footing at any point for any data set within the data range used in determining the mathematical model.

Conclusions:

From the analysis carried out in this work the following results and conclusions are drawn:

1. The results of the finite element analysis show the efficiency of using the uncommon footing (wedge shaped footing) to solve the problem of the expansive soils. It gives the smaller values of displacements than the strip footing. Therefore, the suggested wedge shaped footing can be considered as a good construction solution with a low cost to support the light load of buildings.
2. The results of analysis shows that at 20 kPa swelling pressure, the footing settles and untill reaching 300 kPa swelling pressure, then the settlement vanishes and the footing begins to swell with the increase of swelling pressure. This process is observed for all apex angles of the wedge shaped footing.
3. As swelling pressure increases, the values of displacement of footing is increased and the soil surface heaves due to swelling pressure in a hyperbolic shape, in the zone adjacent to foundation on both sides.
4. The wedge shaped footing with different apex angles leads to almost similar reduction, which is about 95% in the swelling displacements compared with the strip footing.
5. The results show that, the effect of external load is limited to the displacement of wedge footing. Increasing the unit weight of soil results slight decrease in the displacement of footing and the increase in value of modulus of elasticity will cause decrease in displacement of footing.
6. The verification with ***(Al-Wakeel, 2004)*** work has proved the efficiency of using the suggested wedge shaped footing as a solution.
7. The mathematical or statistical methods are useful to describe and give understandingof variability and give a useful way to incorporate this variability into the decision making processes.
8. It can be observed the displacement of the footing can gain from the three dimensional contour area diagrams of the statistical method that used within the rang of data used.

Recommendations

The following recommendations and suggestions for future studies can be put forward:

1. Carrying out a field study to investigate the performance of using the uncommonly used wedge footing when it is constructed in an expansive soil.
2. Carrying out a laboratory model to assist in the validity of the use of wedge shape footing and making a comparison with the results of this study.
3. Using the general equation was gained from the "STATISTICA" computer package to evaluate the expected displacement of the wedge footing within the range of data instead of using the complex finite element method.
4. Considering the simplicity of the construction and higher degree of improvement, the higher apex angle (80º), is to be recommended for practical applications.
5. Making a comparison between the results of the wedge footing in this study with another work used "Waffle Slab" as a solution to the expansive soil problems.

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Table (1) Soil expansivity prediction by liquid limit.
(Sridharan and Prakash, 2000).

Degree of expansion	Liquid limit (LL) (%)	
	Chen (1975)	IS 1498*
Low	< 30	20-35
Medium	30-40	35-50
High	40-60	50-70
Very high	>60	70-90

* Indian standard classification and identification of soil for general engineering purpose (1987).

Table (2) Soil expansivity predicted by plasticity index.
(Sridharan and Prakash, 2000).

Degree of expansion	Plasticity index (PI) (%)		
	Holtz&Gibbs (1956)	Chen (1975)	IS1498
Low	< 20	0-15	<12
Medium	12-34	10-35	12-23
High	23-45	20-55	23-32
Very high	>32	>35	>32

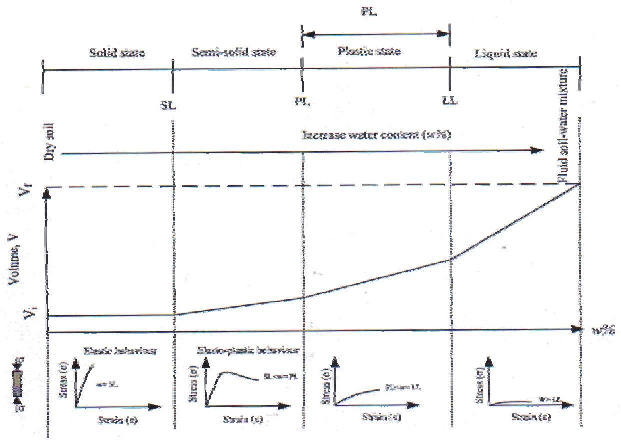


Figure (1) Atterberg limits description, volume change and generalized stress-strain response of expansive soils. (Lucian, 2006).

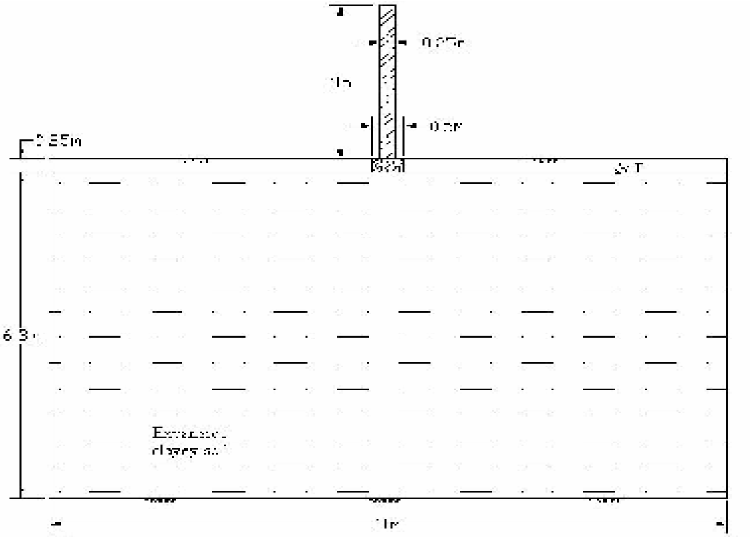


Figure (2) Ordinary strip footing scheme.

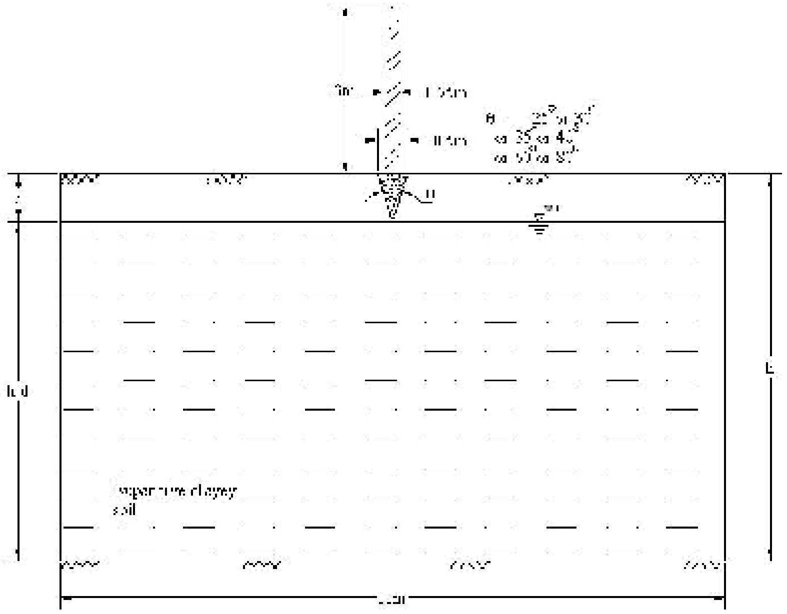


Figure (3) Wedge-shaped footing scheme.

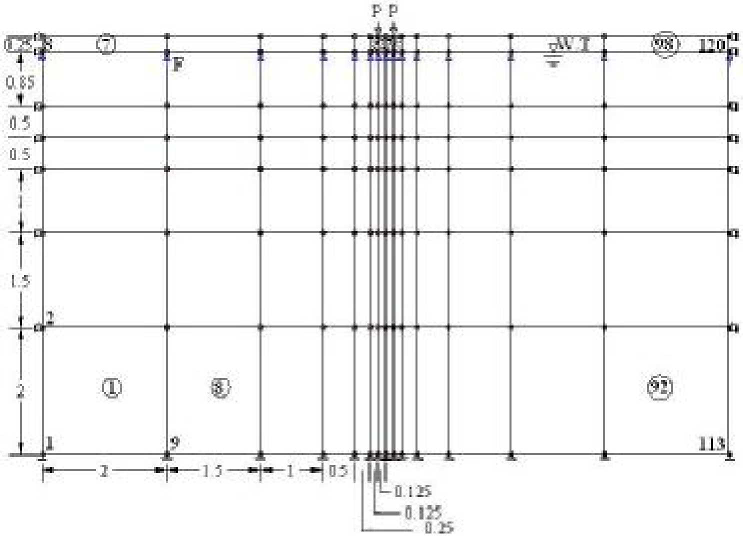


Figure (4) Finite element mesh of strip footing.

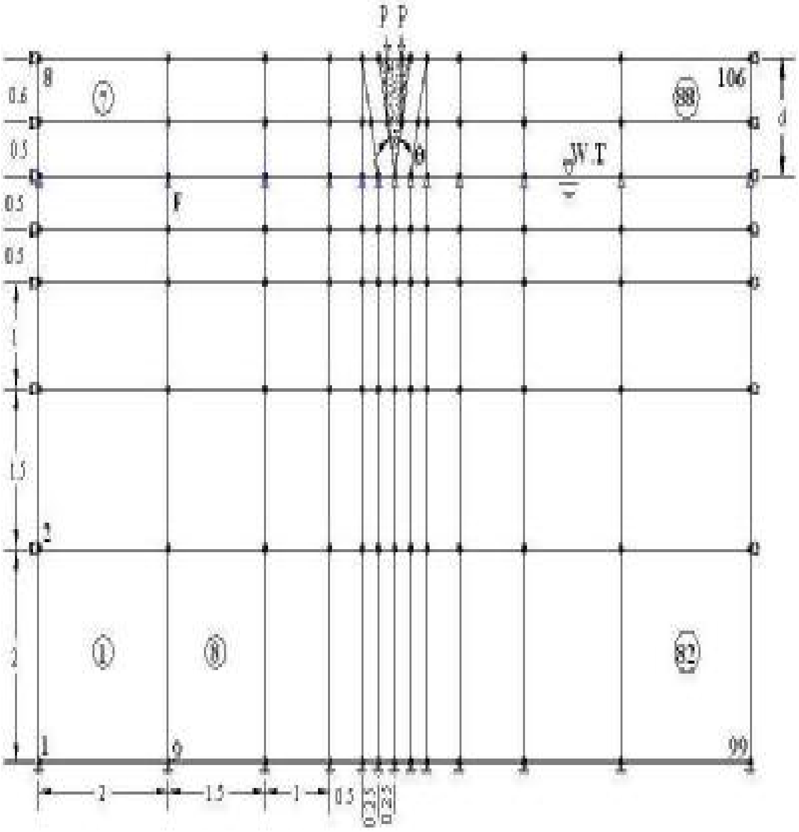


Figure (5) Finite element mesh of wedge footing.

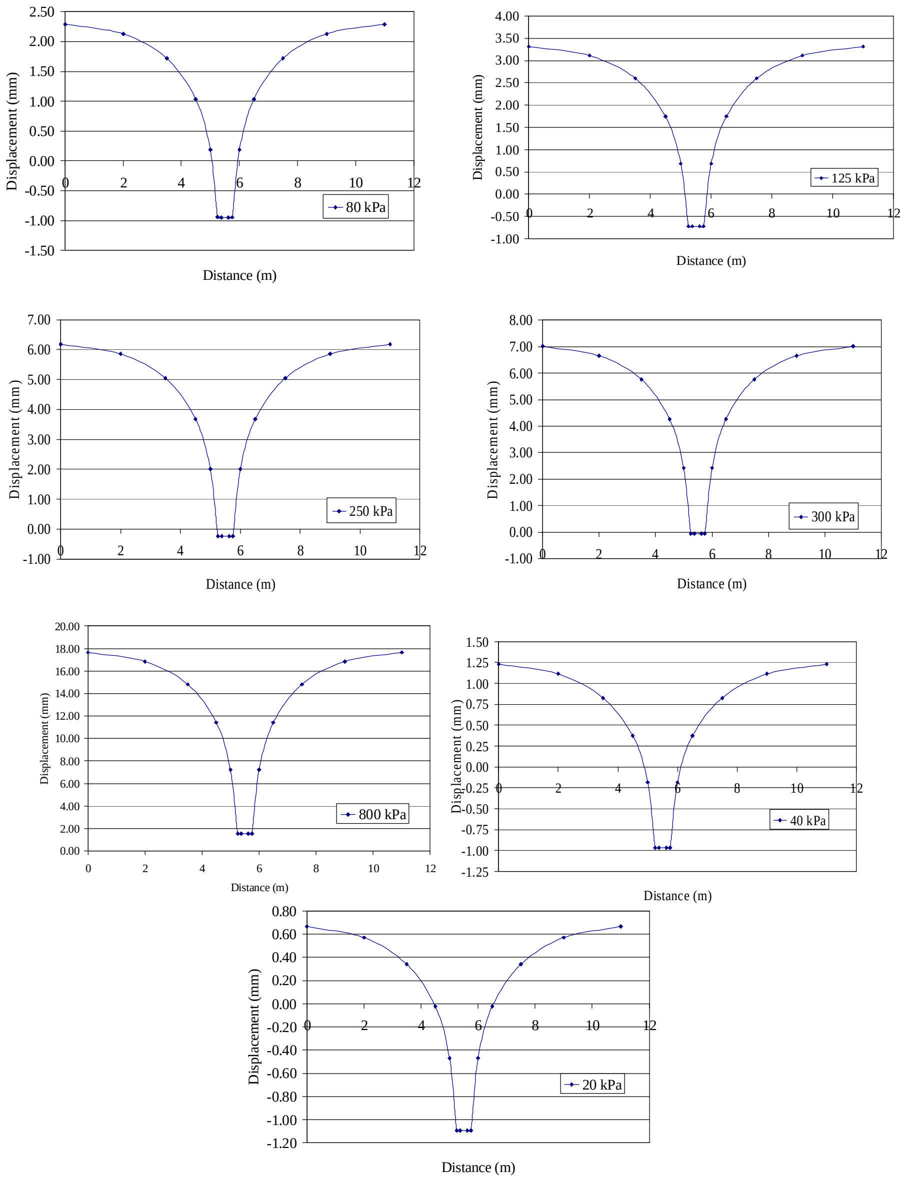


Figure (6) Displacement of footing for 80º wedge footing and adjacent soil at the ground surface under different swelling pressure.

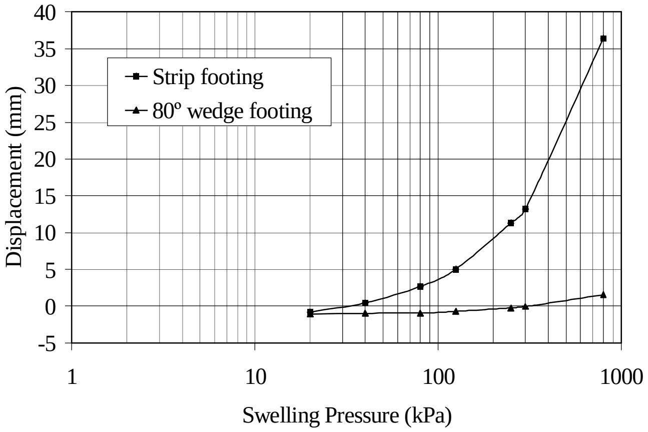


Figure (7) Swelling pressure versus displacement for 80º wedge footing and strip footing.

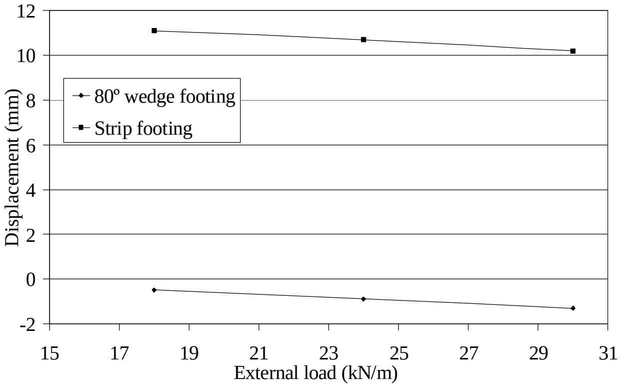


Figure (8) Effect of external load on the displacement of footings at 250 kPa swelling pressure.

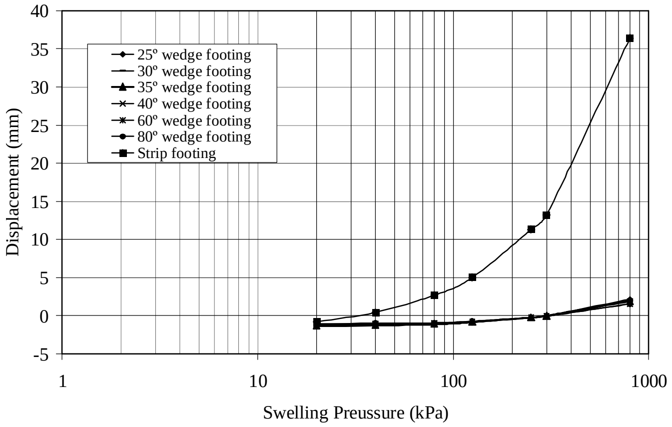
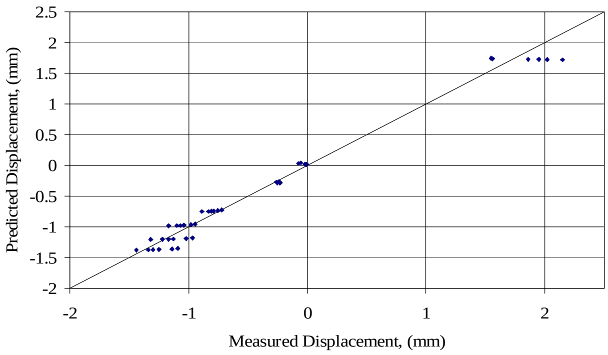


Figure (9) Swelling pressure versus displacement for the different wedge footing and strip footing.



25 30 35 40 60 80

Figure (10) Relation between apex angle of the wedge footing versus degree of improvement at 800 kPa swelling pressure.

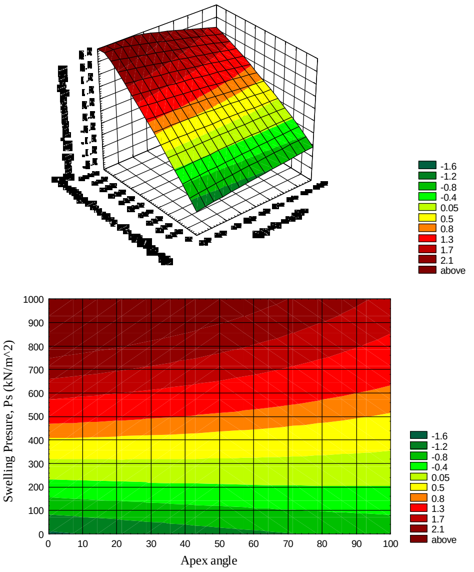


Figure (11) Three dimensional contour plot of variation in the displacement with apex angle and swelling pressure.

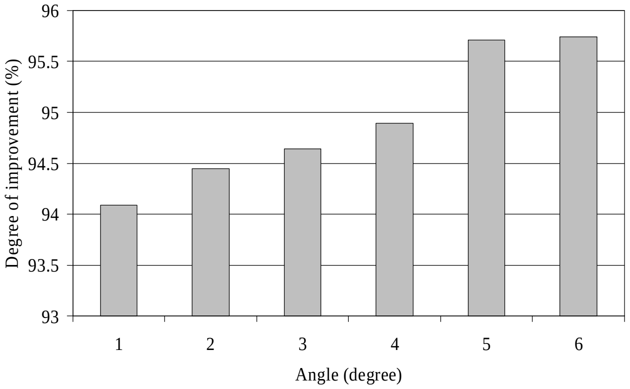


Figure (12) Comparison of predicted and measured displacement of the wedge shaped footing at different apex angles.