NUMERICAL STUDY OF STRIP FOOTINGS BEAVIOUR ON COMPACTED SAND

ABSTRACT

The aim of this research is to investigate numerically the effect of using compacted sand as soil replacement layer beneath a strip footing on its bearing capacity. Finite element computer software Plaxis 2D version 8.6 was used to predict the behavior of strip footing resting on loose sand and on compacted sand. Study was conducted for footing widths of 1 up to 2 meters and various depths ranging from 1m up to 2m, also the effect of replacement layer thickness was investigated. It was found that using replacement layer beneath strip footing increases its bearing capacity for different widths and depths of footing. This improvement is observed up to thickness of replacement layer equal to 3 times the footing width (H/B=3), where further increase in replacement layer thickness does not affect significantly bearing capacity of footings.

Keywords: Strip footing, compacted sand, bearing capacity, finite element, Plaxis

INTRODUCTION

Foundation design consists of two steps: first one is the estimation of ultimate bearing capacity of the soil under the foundation, and the second is predicting allowable settlement that the foundations can undergo without affecting the superstructure. The ultimate bearing capacity aims at determining the load that the soil under the foundation can sustain before shear failure occur; while, the calculation of the settlement caused by the superstructure should not exceed the limits of the allowed settlement through the expected service life of superstructure.

Research on the ultimate bearing capacity problems can be carried out using analytical solutions, experimental investigations and numerical model using finite element analysis. A satisfactory solution is found only when theoretical results agree with those obtained experimentally and numerically.

For layered soil profile as the case in this research (compacted sand underlined by loose sand),the ultimate load failure surface in the soil depends on the shear strength parameters of the soil layers such as; the thickness of the upper layer; the shape, size and embedment of footing; and the ratio of the thickness of the upper layer to the width of the footing.

over the last few decades, many research deals with the problem of foundations resting on layered soils. At first, researchers based their studies on the results of prototype laboratory model testing in order to develop empirical formulae to predict the ultimate bearing capacity of these footings. Recently, theories based on finite element analyses were presented and gave more accurate solutions as compared to the previous ones. Previous research includes work done by **Hanna (1981), Georgiadis and Michalopoulos (1985), Burd and Frydman (1997) and Carlos Abou Farah (2004).**

MATERIALS AND METHODS

Materials used

The material used in this study is fine to medium sand. Sand is classified as SP according to Unified Classification System. The properties of sand sample are given in table (1

Table (1) Summary of Sand properties

Parameter	Value
Specific gravity Gs	2.67
Maximum dry density (kN/m^3)	17
Effective diameter D_{10} (mm)	0.08
Uniformity Coefficient (Cu)	3.4
Coefficient of curvature (Cc)	1.2
Modulus of elasticity Es (Mpa)	15
Poisson's ratio υ	0.30
Angle of internal friction (ϕ)	30°

Numerical analysis

Numerical analysis using the finite element method (FEM) was carried out using finite element method computer software (PLAXIS ver. 8.6) to study the behavior of strip footing resting on loose sand and on compacted sand. The PLAXIS Version 8.6 is used for the two-dimensional analysis of deformation and stability in geotechnical engineering. Full modelling of soil, footing and loading are performed.

Numerical Model Setup

The soil was modeled using an elasto - plastic type of hyperbolic model, called the hardening soil model. The hardening soil model implemented in PLAXIS combines of plasticity theory with the logic of the Duncan-Chang model. It involves ten input parameters, including cohesion (effective) C, angle of internal friction (effective) ϕ, angle of dilatancy ψ, primary loading stiffness E_{50}^{ref}, primary oedometer loading stiffness E_{oed}^{ref}, unloading-reloading Poisson's ratio υ_{ur}, unloading- reloading stiffness Eur^{ref}, power m in stiffness laws and failure ratio R_f. The soil parameters used in plaxis software are shown in table (2). The footing was modeled as a rigid plate element having properties as shown in table (3).

Table (2) Soil parameters

Parameter	Loose Sand (Dr=25%)	Compacted Sand (Dr=70%)
Unit Weight (kN/m^3)	18	19.5
E_{50}^{ref} (Mpa)	15	35
E_{oed}^{ref} (Mpa)	15	35
E_{ur}^{ref} (Mpa)	45	105
Poisson's ratio for unloading- reloading υ_{ur}	0.2	0.2
Angle of internal friction (ϕ)	30°	38°
Cohesion C in (kPa)	1	1
Dilatancy angle (Ψ)	0°	8°
R_f	0.9	0.9
M	0.5	0.5

Table (3) Material properties of Footing

Parameter	Value
Axial Stiffness (EA) in kN/m	$1.05 * 10^7$
Flexural Rigidity (EI) in KN/m^2.m	$2.18 * 10^5$
Equivalent thickness of plate (d) in m	0.5
Poisson's ratio υ	0.15

Weight of Footing (w) in KN/m/m	**4.5**

A strip footing of widths ranging from 1m up to 2 m was placed at depths ranges from 1 m up to 2 m below soil surface at the center of the soil model as shown in Fig.1. The finite element model used the 6-noded triangular elements. Medium mesh size was used with refinement cluster beneath the footing. The boundaries are laterally fixed on both sides, and fixed horizontally and vertically at the bottom boundary as shown in fig. (1). To verify the improvement of bearing capacity a single layer of loose sand beneath the footing was considered first, then a compacted sand layer beneath the footing was used with varied thicknesses from 0.5 m up to 3.5 m to verify the effect of compacted layer on bearing capacity of footing. The effect of footing width and depth on bearing capacity was investigated also in case of loose sand layer and for compacted layer.

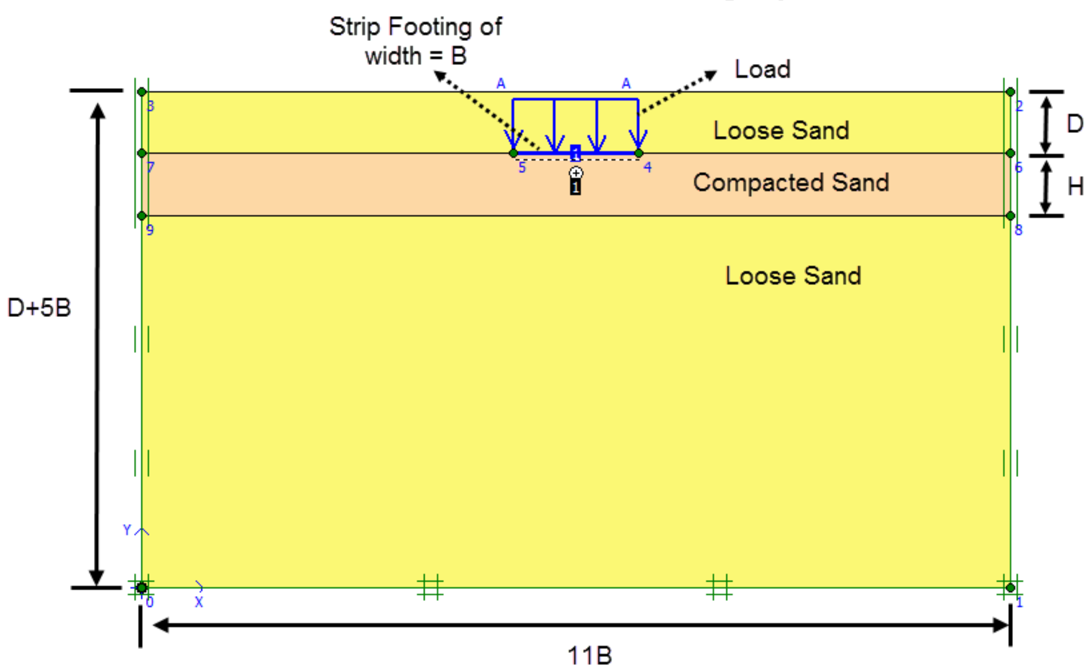
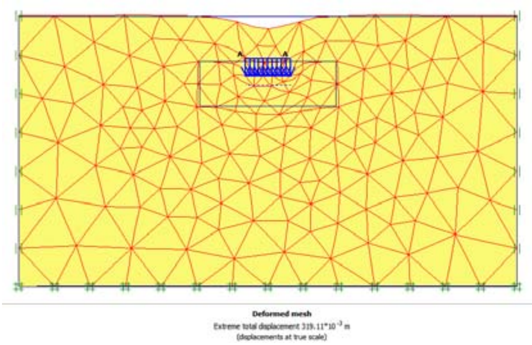


Fig.(1) Geometry of finite element model

Figs. (2-5) show the deformed mesh of the model and total displacement contours after application of footing load in case of Strip footing of width = 1m and at depth equal to 1m resting on loose sand and compacted sand layer of thickness equal to 1 m.



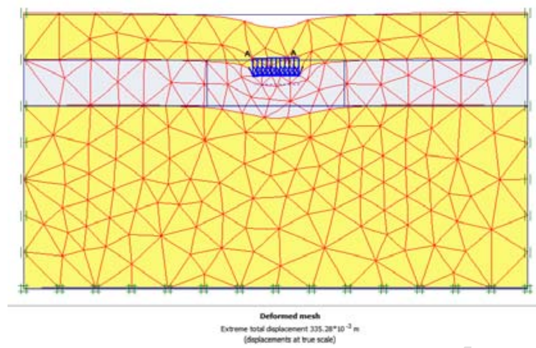


Fig. (2) Deformed mesh for loose sand **Fig. (3) Deformed mesh for compacted sand layer**

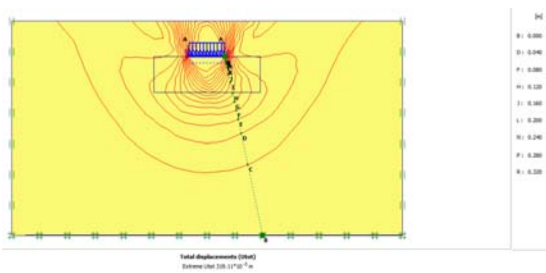


Fig. (4) Total Displacement contours for loose sand

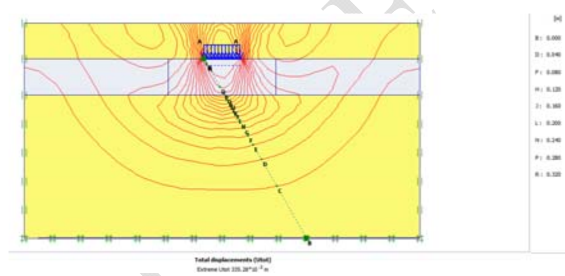


Fig. (5) Total Displacement contours for compacted sand layer

Figs. (6-7) show the mean stress distribution in case of Strip footing at depth equal to 1m resting on loose and compacted sand layer of thickness equal to 1 m.

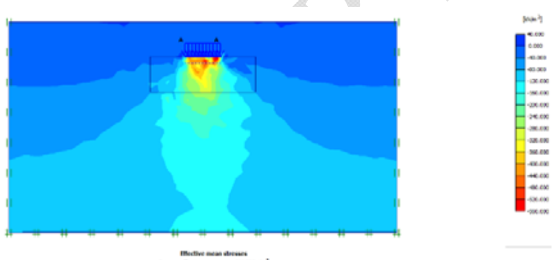


Fig. (6) Mean effective stress distribution under the footing for loose

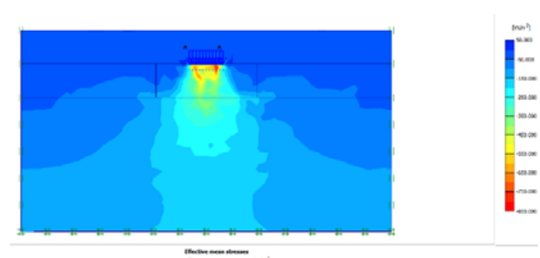


Fig. (7) Mean effective stress distribution under the footing for compacted sand

RESULTS AND DISCUSSION

The behavior of strip footing resting on loose sand and compacted sand layer is shown as the relationship between applied stress versus settlement. Table (4) illustrate the parametric study results of ultimate bearing capacity values obtained by FEM in case of footing resting on loose sand for different depths and widths. The values of ultimate bearing capacity are obtained using tangent intersection method **(Trautmann and Kulhawy 1988)** as shown in Fig. (8).

Table (4) Ultimate bearing capacity values for different cases

Footing Width (m)	Footing Depth (m)	Ultimate Bearing Capacity (kN/m^2)
1	1	518
	1.25	662
	1.5	764
	1.75	876
	2	930
1.5	1	628
	1.25	700
	1.5	906
	1.75	1140
	2	1270
2	1	683
	1.25	794
	1.5	1090
	1.75	1150
	2	1330

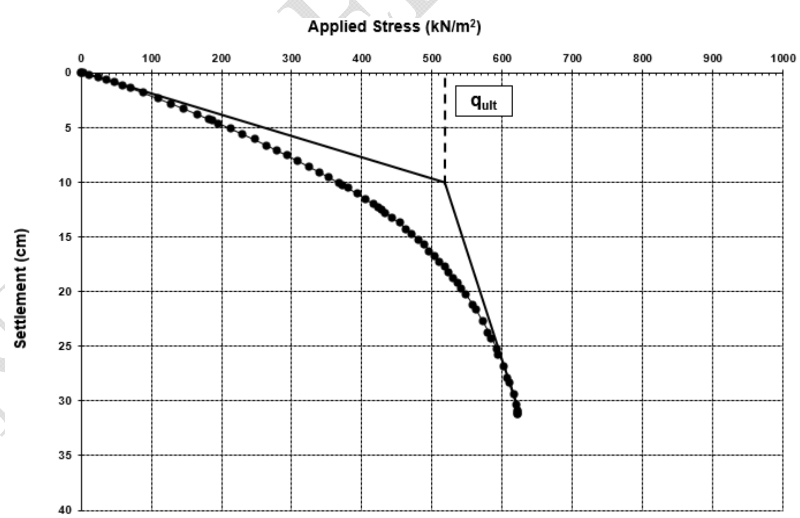


Fig. (8) Tangent intersection method

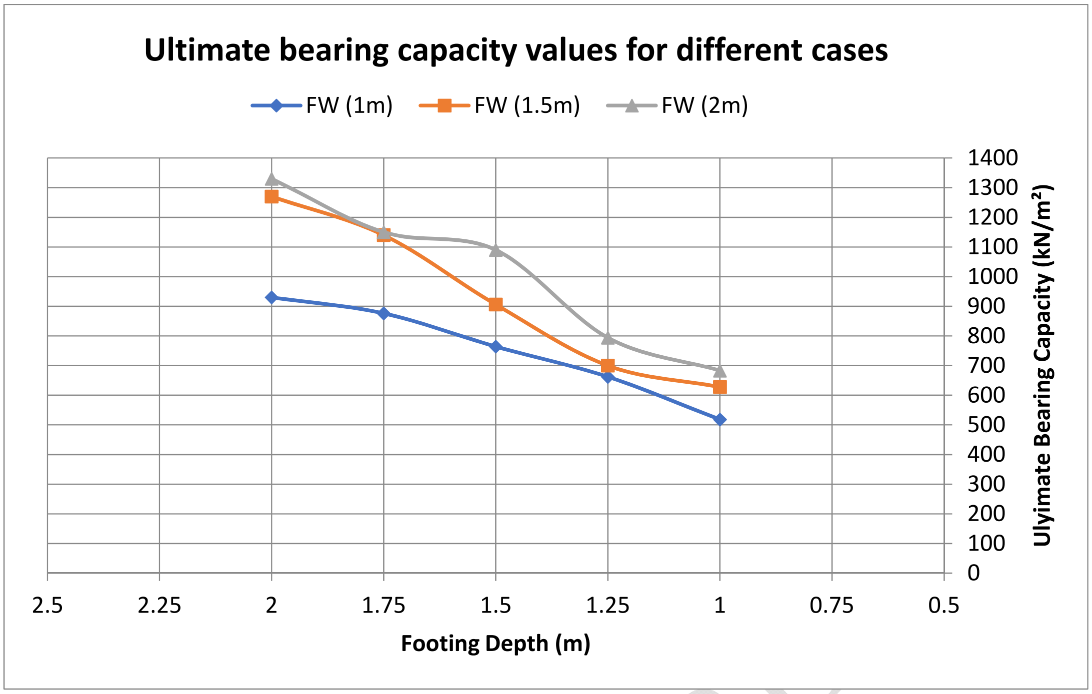


Fig. (9) Ultimate bearing capacity vs Footing Depth for different cases (optional)

Effect of footing embedment depth

To study the effect of footing embedment depth on ultimate bearing capacity the relationship between applied stress versus settlement at various depths for footing resting on loose sand for various widths are studied. Fig. It was (10) shows the relationship between applied stress versus settlement for footing width = 1m. it was observed that the ultimate bearing capacity improved significantly with the increase of footing embedment depth associated with a corresponding reduction in settlement for the same stress values.

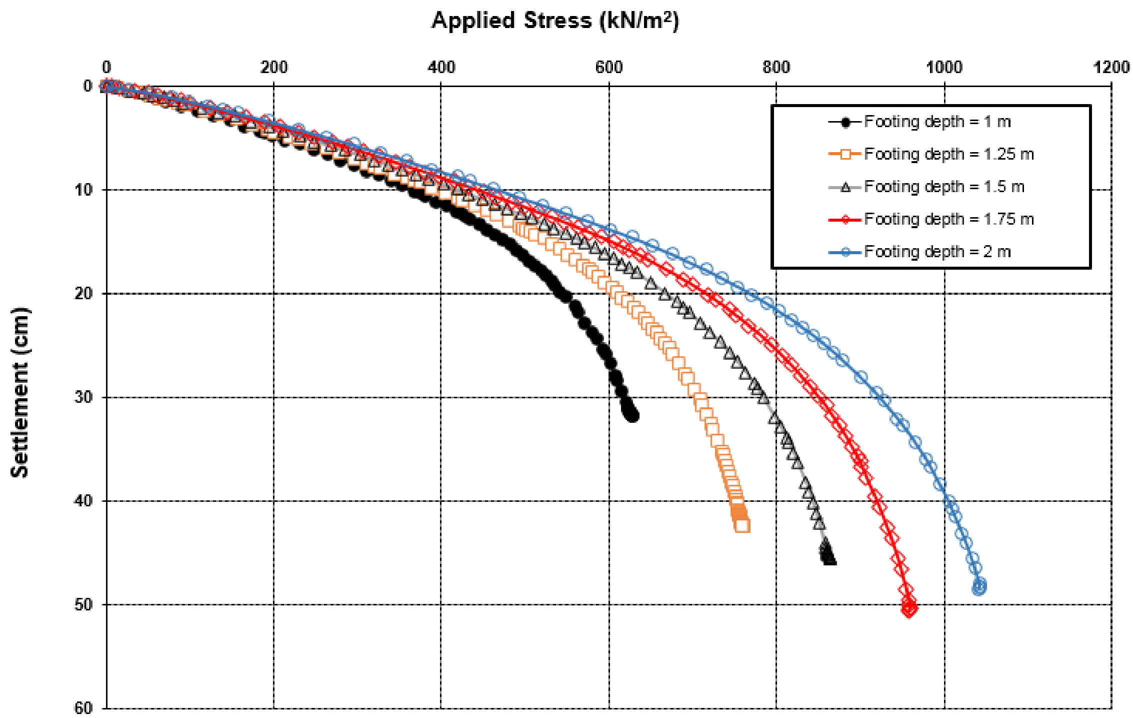


Fig. (10) Applied stress vs settlement for footing width = 1m

Effect of Footing width

To study the effect of footing width on ultimate bearing capacity the relationship between ultimate bearing capacity and footing width at various depths was plotted as shown in fig. (11).

From fig (11) it was observed that the ultimate bearing capacity increases with increase of footing width. The maximum percentage improvement of ultimate bearing capacity obtained was 43% for footing depth equal to 2m, therefore, it was concluded that the effect of footing width is more pronounced for footings with bigger embedment depth.

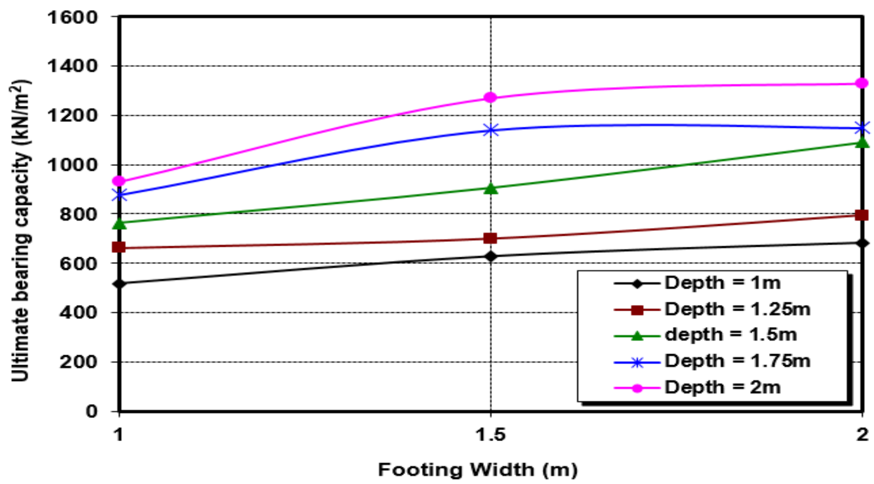


Fig. (11) The relationship between the ultimate bearing capacity versus footing width for various depths

Effect of compacted layer thickness

To study the effect of using compacted sand layer beneath the footing on ultimate bearing capacity the relationship between applied stress and footing settlement was plotted as shown in fig. (12).

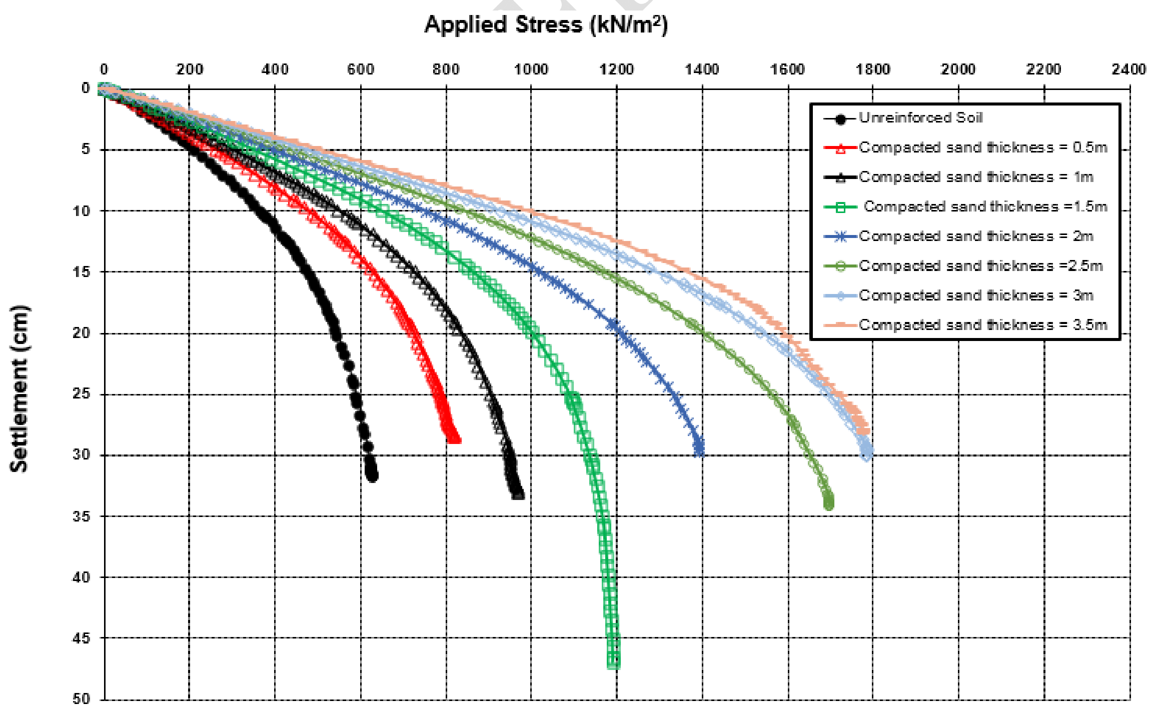


Fig. (12) The relationship between the applied stress versus settlement in case of Compacted Sand layer of various thicknesses for footing width = 1m

It was observed that the improvement in ultimate bearing capacity of footing increased by increasing the thickness of compacted sand layer. The steady increase in bearing capacity can be attributed to the increase in the bearing resistance offered by the compacted sand layer which distributed the footing load acting on the loose sand layer over a wider area. With stronger layer of compacted sand of larger thickness, the improvement is further increased. It was observed also, that the bearing capacity of the footing increases with the increase in thickness of compacted sand layer up to a certain value of (H/B=3). Beyond this value, there is no substantial improvement in the ultimate bearing capacity.

Comparison between finite element and analytical results

An analytical study was performed to verify the accuracy of Numerical study carried out using plaxis software. A good agreement was obtained by comparing the fem results with results obtained by analytical methods (Terzahi and Vesic analysis) for determining ultimate bearing capacity of strip footings as shown in fig. (13).

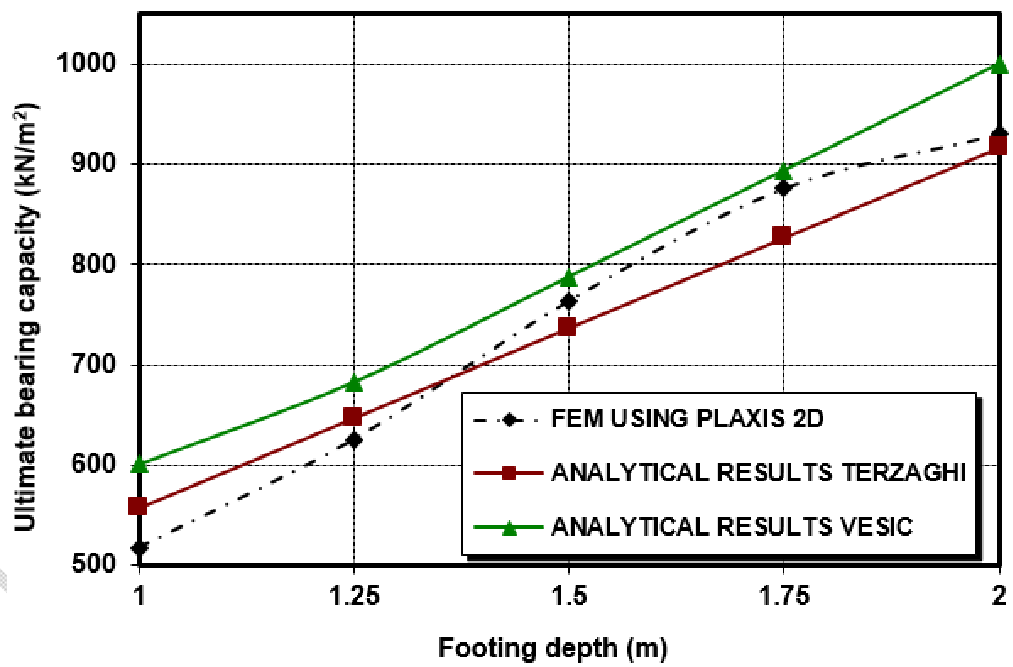


Fig. (13) Comparison between analytical vs finite element method results in case of 1 m width strip footing resting on loose sand

CONCLUSIONS

Based on the results obtained, the following conclusions obtained:

- For footings rested on layer of loose sand the effect of footing width on ultimate bearing capacity is more pronounced with footings of bigger width, where the maximum increase in bearing capacity reaches a maximum percentage of 43% when footing width increases from 1 up to 2 m.
- In case of using a layer of compacted sand under the footing it was it was found that the improvement in ultimate bearing capacity of footing increased by increasing the thickness of compacted sand layer. The maximum percentage increase reaches 240%.
- For case of using compacted sand layer, the optimum layer thickness obtained is three times the width of footing (H/B=3), when further increasing the thickness of compacted sand layer, it has no effect on the bearing capacity of footings.

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