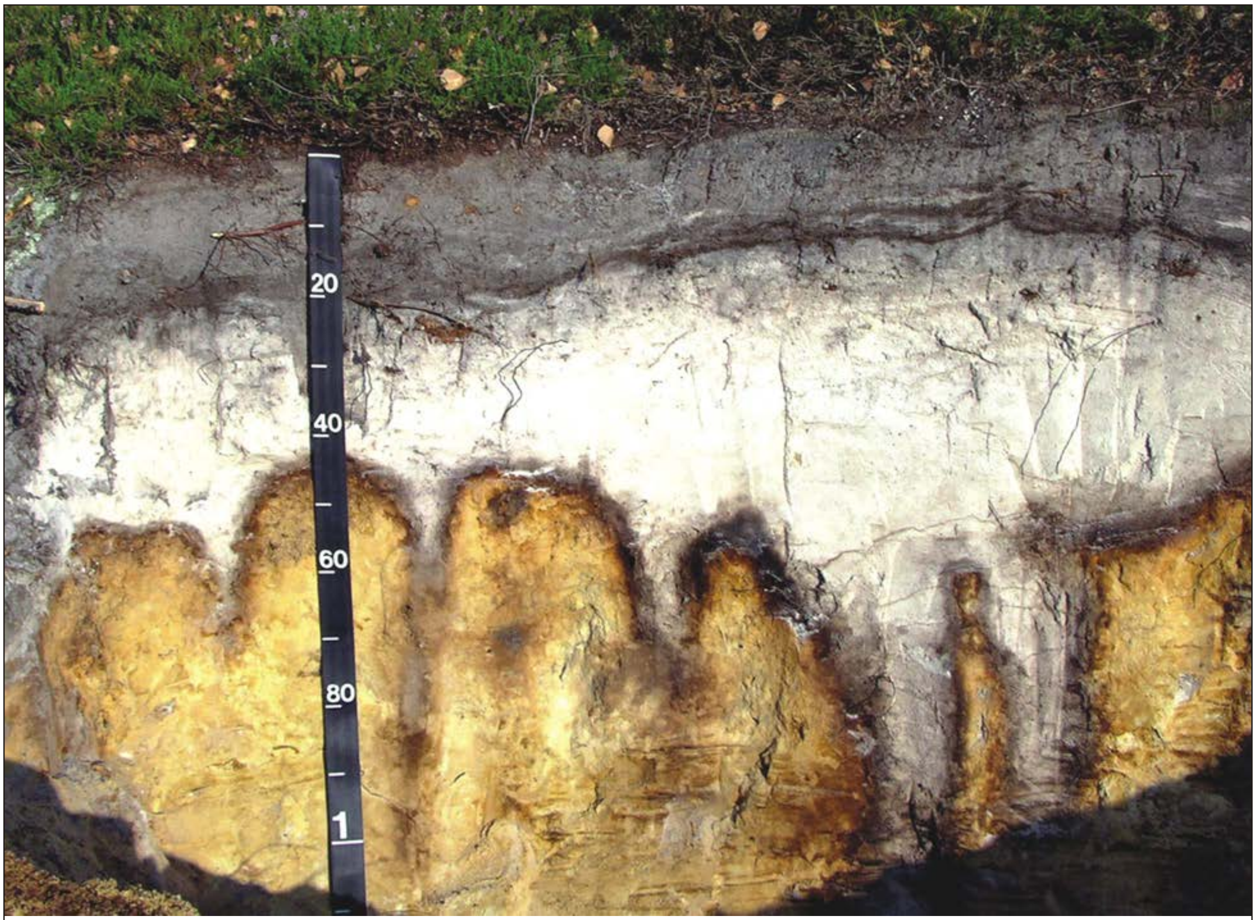

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Assessing the Load Size Effect in the Soil (Under Single Foundation) Using Finite Element Method

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ABSTRACT

In this research the analysis of foundation is efficiently accomplished by using the pure displacement-based finite element method; it should be noted that the effect of the concrete column dimension in the connection place of column to foundation is examined with the aid of finite element method. It is possible to interpret the finite element method as a method of substitute loadings or load cases in the same boundary situation. To meet this objective, single foundations with square shape are analyzed for more than 50 different point loads at the center of the slab. The structural layer is used to define slab geometry, load and boundary conditions which are related to analysis only. At the time of analysis, the object-based model created by the authors converts into a finite element model, called the analysis model. The finite element mesh used in the analysis is a rectangular mesh, based on a maximum acceptable element size. The stress and displacements in a soil mass due to applied loading are considered in this paper. The authors found that the single footing settlement and stress of soil depend not only on physical and mechanical properties of base soils but also on applied load intensities and the size of the column connected to single foundation, as well as on footing and column rigidity, shape and dimensions. Based on the obtained results, it can be stated that by increasing in the load size (column size) the value of maximum stress and deformation in the soil of under foundation will increase.

Key words: Single foundation, finite element method, stress,displacement, load, column size

INTRODUCTION

The design of foundations involves the use of many different combinations of structural elements and foundation types which in turn vary to perform a wide variety of functions (Trivedi and Sud, 2005). Strip footings and pad bases are used to deliver and spread superstructure loads over a suitable area at foundation (formation) level. The foundation is required to be stiff enough to distribute the loadings onto the sub-strata in a uniform manner (Reznik, 1998).

The selection of the appropriate foundation solution is the most important part of the design process and most difficult to define. Calculation usually involves analyzing from certain parameters, the forces and stresses involved in a particular structural element (Atkinson and Han, 2001). Structural design is the process of exploiting engineering knowledge in an attempt to select the most suitable and economic structure. Foundation design should therefore be carried out using a careful blend of geology, soil mechanics, theory of structures, design of materials, experience, engineering judgment, logic and down-to-earth engineering.

Foundation design like other structural design requires a good sound basic approach in order to achieve a truly successful result (Zolfaghari and Hajabbasi, 2008).

Recently, extensive studies have been done on the behavior of footing and the new graphs and several geotechnical researchers have examined formulas. Zhao and Wang (2008) utilized a finite difference code FLAC to study bearing capacity factor N_γ for ring footings in cohesionless, frictional and ponderable soil. The present soil model employs Mohr-Coulomb yield criterion and associative flow rule. Kumar and Bhattacharya (2010) have been studied about the bearing capacity of interfering multiple strip footings by using lower bound finite elements limit analysis. The ultimate bearing capacity of a number of multiple strip footings, identically spaced and equally loaded to failure at the same time is computed by using the lower bound limit analysis in combination with finite elements. They mentioned that the failure load for a footing in the group becomes always greater than that of a single isolated footing. Lee *et al.* (2005) assessed the bearing capacity of circular footings under surcharge using state-dependent finite element analysis. In their study, estimation of the bearing capacity of footings resting on a soil mass acted upon by a surcharge is investigated and related to the cone resistance qc. Non-linear finite element analyses based on a state-dependent stress-strain model were performed to obtain the load-settlement responses of axially loaded circular footings. Various values of relative density, lateral earth pressure ratio, depth of embedment and footing diameter were considered in the analyses. Based on the finite element results, load-settlement curves were obtained and used to determine the unit limit bearing capacity of the footings in terms of the cone resistance qc. Values of the unit bearing capacity for different values of surcharge were in a narrow range while considerable variation in unit bearing capacity was observed with relative density D_R. Algin (2007) researched on practical formula for dimensioning a rectangular footing. The relationship among the flexural formulae and the vertical and rotational equilibrium of forces is correlated analytically to develop a simple and unique expression to determine the required minimum footing area under full compression. The practice of estimating the size of footing in structural design usually employs the conventional iterative process initiated with the educated guess of designers.

The stability of a structure depends upon the stability of the supporting soil (Leucci, 2006). Two important factors that are to be considered are: (1)-the foundation must be stable against shear failure of supporting soil. (2)-the foundation must not settle beyond a tolerable limit to avoid damage to the structure.

The finite element method is a technique for solution of mathematical problems governed by systems of partial differential equations (Bathe and Zhang, 2004). It can produce close approximate solutions to problems with highly complex geometries, material behaviors and boundaries which would result in highly complex field variations in the solution variables (Mukherjee *et al.*, 2000). The method accomplishes this by subdividing the solution space into many pieces (the finite elements) sufficiently small that the variations in the solution variables can be well approximated within each by very simple functions (Liu *et al.*, 2001). Implementation of the method numerically on modern digital computers enables highly accurate solutions with extremely large numbers of small elements. All of the governing equations are then solved on all of the elements and the elemental solutions are assembled into the solution for the whole subject to compatibility and continuity requirements (Narra, 2009).

The finite element method is a numerical procedure for obtaining solution to many of the problems encountered in engineering analysis . In this research the authors used Finite element method for utilizing discrete elements to obtain the joint displacement and under foundation soil pressure for different load size. In order to assess the effect of column dimension in the connection place to single foundation, different columns and single foundations are modeled.

MATERIALS AND METHODS

This research, carrying out in Babol University of Technology (Iran) from Dec 2009 to Sep 2010, models are object-based and consist of point, line and area objects to which assignments are made to define structural members, such as slabs, columns and supports, as well as to define loads (Curley *et al.*, 2011). In this project Area objects are used to model slabs, soil supports and surface loads. Point objects are used for column supports and concentrated loads.

Properties are assigned to each object to define the structural behavior of that object in the model (Handayani and Prawito, 2008). Some properties, such as slab properties that contain both material and section definitions, are named entities that must be specified before assigning them to objects (Choobbasti *et al.*, 2009).

Supports may be assigned to point, line and area objects and similar to properties. The most difficult part of a settlement analysis is the evaluation of the modulus of elasticity E_S that would conform to the soil condition in the field. There are two methods by which E_S can be evaluated (Kouzer and Kumar, 2010). They are laboratory method (triaxial tests) and field method (plate load tests, standard penetration test, static cone penetration test,...). Slab property data and subgrade modulus are shown in Table 1.

There are several reasons for the popularity of finite element methods. Large code segments can be implemented for a wide class of problems (Demkowicz, 2000). The software can handle complex geometry. Little or no software changes are needed when boundary conditions change, domain shapes change, or coefficients vary (Hiller and Bathe, 2003). A typical finite element software framework contains a preprocessing module to define the problem geometry and data; a processing module to assemble and solve the finite element system (Brenner and Scott, 2002); and a post processing module to output the solution and calculate additional quantities of interests. A finite element analysis of any physical problem requires that a mesh of finite elements be generated. Because the generation of finite element meshes is a fundamental step and can require significant human and computational effort (Mushari Al-Naeem, 2008). Figure 1 shows typical finite element meshes (or finite element assemblages) modeling of the foundation. In mentioned case the finite elements are used to represent the volume of the system. The finite elements are connected at the nodal points located at the corners and along the sides and in the faces of the elements (Hughes and Wells 2005). However, nodal points can also be located within the volume of an element (Liu, 2002b). An important feature is that the finite elements do not overlap geometrically but together fill the complete volume of the solid. In finite element based model, a two-way slab of arbitrary shape is meshed into isotropic thin plate bending elements, using the area objects. Those elements are three- to four-node elements with one vertical and two rotational degrees of freedom at each node which capture out-of-plane bending behavior (Liu, 2002a).

Table 1: Slab property data and subgrade modulus

Modulus of elasticity (ton m^{-2})	Poisson's ratio	Unit weight (ton m^{-3})	Thickness of footing (m)	Subgrade modulus (ton m^{-3})
2500000	0.2	2.4	0.6	2000

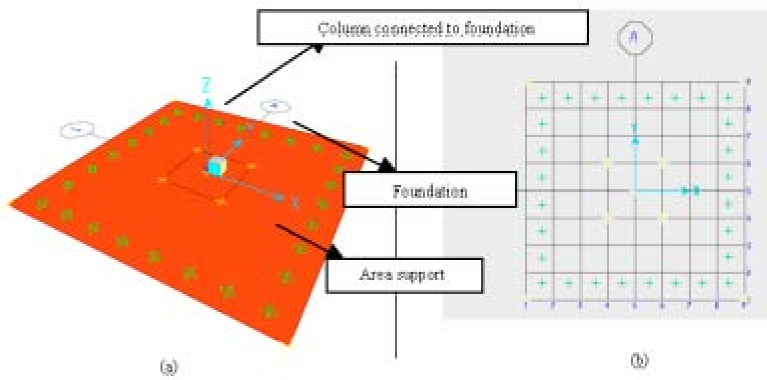

Fig. 1: (a) 3D view of structural layer in detail and (b) the bilinear rectangular elements of the finite element

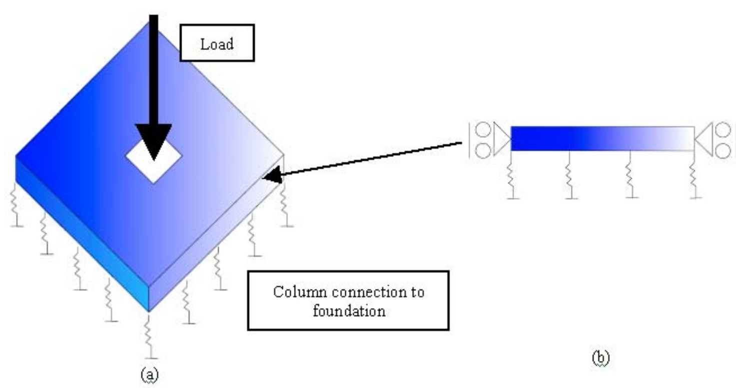

Fig. 2: (a) 3D view of foundation and spring which simulate the sub-soil and (b) boundary condition

The finite element mesh used in this analysis is a rectangular mesh based on a maximum acceptable element size. However, extra mesh lines are introduced at all locations of objects and object boundaries. Additional mesh lines can be introduced at specified locations by adding gridlines. Natural coordinate systems can be defined for 2D elements. They are more convenient system for both analytical and numerical integration. Elements produced by the quad tree techniques have good geometric shapes near boundaries in this research (Farrokhzad *et al*., 2010).

After the mesh has been generated, subdividing all the area objects that have been assigned slab properties creates slab elements. Support properties are lumped into discrete springs and are assigned to finite element mesh points (Fig. 2).

Support properties of all point objects are assigned directly to the corresponding finite element mesh point. Similarly, support properties of all area objects are applied to all the mesh points that exist within the area and on the boundaries of the area, based on the tributary area associated with the mesh point. Point loads of all point objects are assigned directly to the corresponding finite element mesh point. Similarly, surface loads of all area objects are applied to all the mesh points that exist within the area and on the boundaries of the area based on the tributary area associated with the mesh point. All of the internal meshing and assigning performed by the program does not alter the number or size of the objects which allows revisions and modifications to be executed at the object level.

RESULTS AND DISCUSSION

The accuracy of the finite element analysis results, measured on the exact solution of the mathematical model, highly depends on the use of an appropriate mesh and this holds true in particular when coarse meshes need be used to reduce the computer time employed for complex analyses. Hence, effective mesh generation procedures are most important (Braess, 2002).

The analysis model consists of joints, frame elements, plate elements and springs in contrast to the point, line and area objects in the user-defined object-based model. In addition, object meshing is performed with control over the maximum mesh dimension. It should be noted that maximum mesh dimension was selected 25 cm. Each slab element is an isotropic, thick plate-bending element. This research applies an iterative procedure using the original stiffness and corrective load vectors to obtain the no-tension results.

The concept of stress is closely associated with the concept of a continuum. Thus, when we speak of the stress acting at a point, we envision the forces against the sides of an infinitesimally small cube, which is composed of some homogeneous material.

Results from the theory of elasticity are often used to compute the stresses induced within soil masses by externally applied loads (Li, 2004). The assumption of this theory is that stress is proportional to strain. Most of the useful solutions from this theory also assume that soil is homogeneous and isotropic. Soil seldom if ever exactly fulfills and often seriously violates, these assumptions. Yet the soil engineer has little choice but to use the results of this theory together with engineering judgment (Ghosh and Sharma, 2010).

The processing module would need more information when adaptivity is performed. It, for example, would need a link to the geometric information in order to refine elements along a curved boundary (Piedrahita and Montana, 2007). Even without adaptivity, the processing software may want access to geometric information when using elements with curved edges or faces. If the finite element basis were known at the preprocessing stage, space could be reserved for edge and interior nodes or for a symbolic factorization of the resulting algebraic system.

Figure 3 shows the results of different analysis in assessing the relation of load size and deformation of under foundation soil. It is obvious that increasing the dimension of column cause to increase in deformation or settlement of soil. The soil is modeled as springs under the foundation by increasing the dimension of the column more springs are affected and more deformation would occur. In this research load shape was assumed square and load dimension varied between 30 to 60 cm, 25 and 50 ton were selected as column loads and dimension of the single foundation was assumed 2 m by 2 m in surface and 0.6 m in depth.

Figure 4 shows the variation of stress in the soil against the load size. Based on above results and the direct relation of stress and deformation, as it is obvious in figure, the maximum stress will increase when the size of column become larger.

A critical review on idealization and modeling for interaction among soil-foundation-structure system has been done by Dutt and Roy (2002). The interaction among structures, their foundations

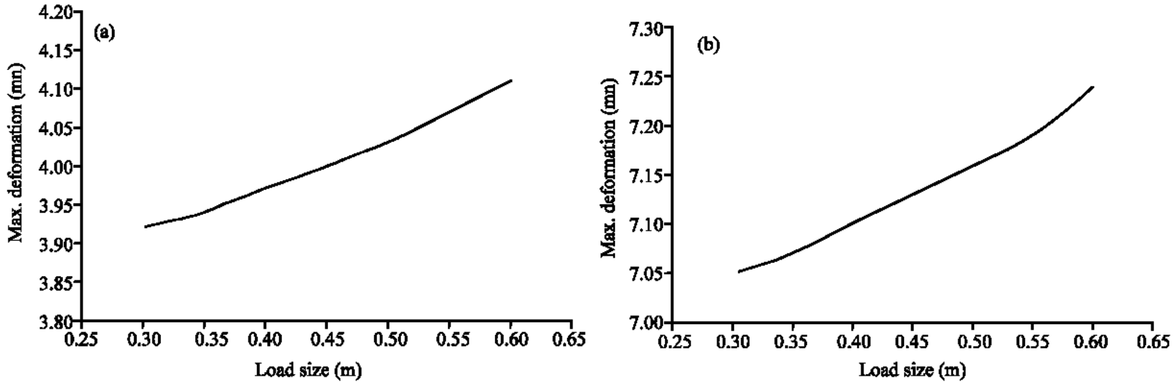

Fig. 3: The relation of load size and deformation (settlement of soil), (a) applied load: 25 ton and (b) applied load: 50 ton

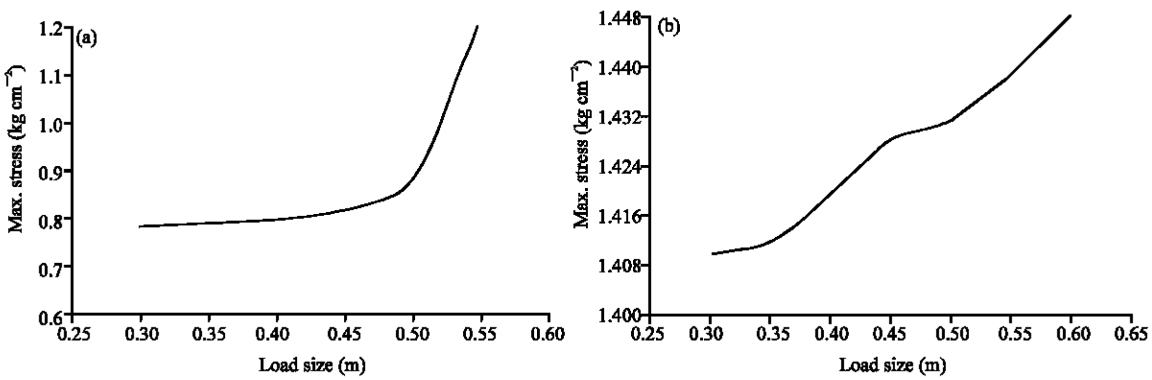

Fig. 4: The relation of load size and stress in soil, (a) applied load: 25 ton and (b) applied load: 50 ton

and the soil medium below the foundations alter the actual behavior of the structure considerably than what is obtained from the consideration of the structure alone. The mentioned study makes an attempt to gather the possible alternative models available in the literature for this purpose. Emphasis had been given on the physical modeling of the soil media, since it appears that the modeling of the structure is rather straightforward. In another research, by means of a semi-analytical finite element approach an embedded circular footing under monotonic horizontal and moment loading is studied (Bouzid and Vermeer, 2007). In a non-homogeneous soil whose shear modulus is characterized by a power law variation with depth, horizontal, rocking and coupled modes of displacement, expressed in terms of influence factors are thoroughly examined. The same effect of interface conditions on the soil normal stresses developed beneath the embedded footing for the case of loading applied at the footing top. By using small scale model tests, the interference effect on the vertical load-deformation behavior of a number of equally spaced strip footings, placed on the surface of dry sand was investigated by Kumar and Bhoi (2008). The interference effect becomes prominent with increase in soil friction angle. In contrast to an increase in the bearing capacity, with decrease in spacing of footings, an increase in the footing settlement associated with the ultimate state of shear failure was observed. The present experimental observations were similar to the result of this paper by the available theory based on finite element method.

In the study of Lee *et al.* (2005) estimation of the bearing capacity of footings resting on a soil mass acted upon by a surcharge is investigated. Non-linear finite element analyses based on a state-dependent stress-strain model were performed to obtain the load-settlement responses of axially loaded circular footings. It can be stated that the results of above study and the research which is done in Babol University of technology, show same thing in different way.

CONCLUSION

Foundation design is one of the most challenging aspects of engineering and no two-foundation conditions are the same. In this study, the authors have proposed analysis based on finite element method for a nonlinear elastic problem in order to asses the load size effect (column dimension) in connection place to foundation on behavior of sub-soil. The numerical results coincide with the analysis very well. The aim here was to link the behavior and modeling of foundations and soil to prior knowledge. The settlement of the footing is recorded against the size of the applied load or the dimension of column. The shape of the curve obtained by analysis depends generally on the size and shape of the footing, the column shape and the composition of the supporting soil. It can be noted that the applied load intensities and the size of the column connected to single foundation are the effective parameters on footing settlement and stress of soil. It can be concluded that increasing the dimension of column cause to increase in deformation or settlement of soil. The soil was modeled as springs under the foundation, by increasing the dimension of the column more springs are affected and more deformation would occur and finally it was obtained that the maximum stress will increase when the size of column become larger.

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