INFELUENCE OF SOIL IMPROVEMENT ON SEISMIC BEARING CAPACITY OF SHALLOW FOUNDATION

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ABSTRACT:

This paper presents a rigid footing model with specified properties and dimensions on a sandy-clay soil with Mohr-coulomb material. This elasto-plastic soil foundation model is analyzed dynamically with finite difference 2D FLAC software under vertical component of ground excitations. Then the soil is improved with cement grouting and analyzed again. Consequently, the vertical stress under a strip footing, due to vertical component of ground accelerations through the underlying soil is plotted. Also the stress distribution and dynamic bearing capacity of natural and soil cemented foundation is presented and discussed.

KEYWORDS: Dynamic bearing capacity, Grouting, Soil improvement, FLAC-2D

1. INTRODUCTION

In one of the first researches about dynamic bearing capacity which consists of pseudo-statically method, an inclined force is applied on the footing (the horizontal component considers as earthquake load). Meyerhof (1953) [1], Sokolovski (1960) [2] and Shinohara et al. (1960) [2] used this method to determine dynamic bearing capacity. Parakash & Chumar (1967) [3] and Shikiev & Jakovlev (1977), using this view, presented some articles too. Okamoto (1973) [4] introduced that decrease of dynamic bearing capacity is corresponding to decrease of friction angle to $i = \tan^{-1} k_h$ in simulation. The next developments in precise analysis of this case are some which consider the effect of horizontal component of earthquake on various parts of soil under footing and overburden layer.

Sarma and Isossifelis (1990) [5], were first researchers that did some analysis in this field (in their researches, horizontal component of earthquake were considered in different layer of soil). After that, Budhu and Al-kerni (1993) [6] were considered vertical component of earthquake. Other researchers such as Kumar and Mohan (2002) were completed these comments in analyses [7]. In another method which presented by Richards et al. (1993, 2003) [8]. Inertia forces in the soil mass, decrease the bearing capacity of the soil and as a result bearing capacity of foundation is decreased. This method is shown that the shear transfer in soil-structure interface is decreased. During recent years, other researchers such as Askari & Farzaneh (2003) [9], Knappcu et al. (2006) [10] and Merlos & Romo (2006) [11] were completion of previous analysis. The noticeable point of recent two articles is that writers have been used laboratory results specially centrifuge status results which represent actual behavior of soil.

Considering presented analytical methods since 1950, all of calculation can be divided to three categories. First group of calculation consider the earthquake as a horizontal component that apply on foundation and ignore the inertia forces of soil resulted from earthquake (Such as Meyerhof and Parakash). In fact these kinds of calculations are the result of inclined loads. In second group of calculations horizontal component of earthquake affects on foundation structure, its overburden and deference layer of soil under foundation and also consider inertia forces (such as Sarma and Isossifelis method). Third group of calculations, consider vertical component of the earthquake too (such as Kumar and Rao method).

Considering earthquake vertical acceleration in dynamic analysis and experimental observations has been taking into account intensely. For instant experimental observations conducted by Varadi & Saxena (1980) pointed out this trend. In these experiments, a rectangular foundation located on a sandy soil was used and transferring of vertical load under foundation was studied. In addition, vertical soil stresses in relation with depth in static and dynamic states with and without foundation was studied and compared which results is shown in Figure 1 [12].

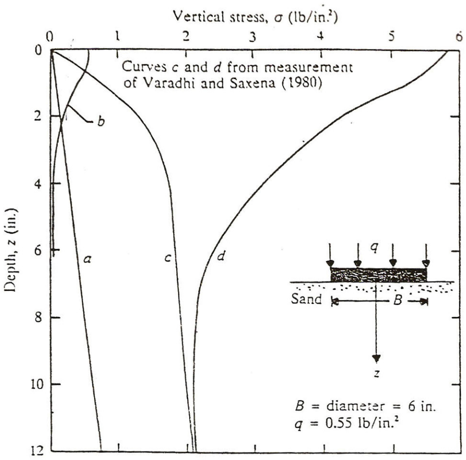

Figure 1 Normal stress under circular footing on sandy subsoil caused vertical component of earthquake

In accordance with mentioned explanations and in order to study and develop this subject, a numerical model of foundation has been modeled in FLAC software and distribution of normal stress in depth and vertical displacement has been studied.

It is generally accepted that pressure grouting was first used in 1802 by a French engineer, Charles Brigny, who injected clay and lime suspension under pressure into Masonry walls to repair deteriorated sections [13]. The introduction of cement grout represented a major step in the evaluation of grouting technology. Portland cement grout was used in England by M. Brunel, W. Kinipple, and T. Hawksley in the mid 19th century [13]. In France and Belgium similar cement grout was developed between 1880 and 1905 and used for control of seepage into shafts in coal mines. The French and Belgian experience resulted in a significant progress in the development of grouting equipment and methodology the confidence in the technology led to its expensive [14].

Application of cement and clay/cement grout in the United States started at the turn of century by federal agencies for the purpose of foundation improvement and creation of cut-off walls. Application of grouting expanded rapidly in the construction industry and appropriate specifications were developed to improve the effectiveness of this new technology [14].

2. CHARACTERISTICS OF NUMERICAL MODEL

Geometrical characteristics of numerical model have been selected as if boundary conditions haven't had any effect on analysis results. Subsoil horizontal distances between soil boundaries and centre of foundation have been assumed 15m from each side and vertical boundary extended to the bed rock. The bed rock depth has been assumed to be 30m and earthquake acceleration applied to the bed rock.

Subsoil dimensions have been postulated 30x30 meters with 0.5x0.5 meters rectangular mesh grids near the footing as well as 0.5x1.0 and 1.0x1.0 meters far from footing so as to study accuracy of model functioning.

Footing lay in the middle of upper boundary of clayey sand soil with 2 meters width and 50cm depth (Figure 2). In addition, soil model with Mohr-coulomb failure criterion has been exploited in order to model soil stress-strain behavior because of simplicity of the criterion. Furthermore, main soil parameters like C and φ could have been obtained via ordinary soil mechanic laboratory tests.

In FLAC software, soil parameters like ρ (Soil density), K (Bulk module), G (Shear module), C (Cohesion), φ (Soil friction angle) and ψ (Soil dilation angle) have to be introduced for soil model. Bulk and Shear module which are essential inputs for software was extracted from following equations [15]:

$$K = \frac{E}{3(1-2\nu)} \tag{2.1}$$

$$G = \frac{E}{2(1+\nu)} \tag{2.2}$$

In above mentioned equations, E and υ are Elastic module and Poisson's ratio.

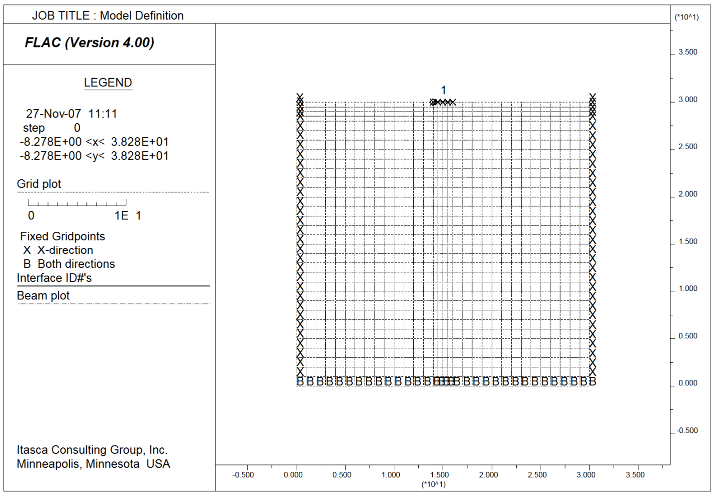

Figure 2 Schematic of analyzed model

Foundation has been modeled as a bending elastic element (beam element) which elastic module, density, area and inertial moment assigned to it. For modeling discontinues boundaries between soil and foundation, boundary elements or interface with zero depth has been used which connected to beam element from one side and rectangular mesh grids of soil from another side (Figure 3). Normal and shear stiffness of this element is about 10 times greater than equal stiffness of smallest appressed mesh of soil which could be calculated with following equation [15]:

$$k_n = k_s = 10\max\left[\frac{K+\frac{4}{3}G}{\Delta z_{\min}}\right] \tag{2.3}$$

Specified model for Interface, postulated as prefect Elasto-plastic Mohr-Coulomb model which this model has been included Cohesion, soil friction angle, Soil dilation angle, tensional strength, normal and shear stiffness.

One of the most common methods for seismic analysis in FLAC software is Time history Analysis which has been exploited in this research so as to evaluate and analysis the model under vertical acceleration of earthquake. In this regard three distinct earthquake accelerogram included Kojour vertical earthquake records (M = 6.1 Richter and a = 0.289g), Bam vertical earthquake records (M= 6.5 Richter and a = 0.231g) and Ardebil vertical earthquake records (M = 6.1 Richter and a = 0.400g), recorded on the bedrock, has been applied to the models which related accelerograms and Fourier amplitude spectrum is shown in Figures 4 to 6.

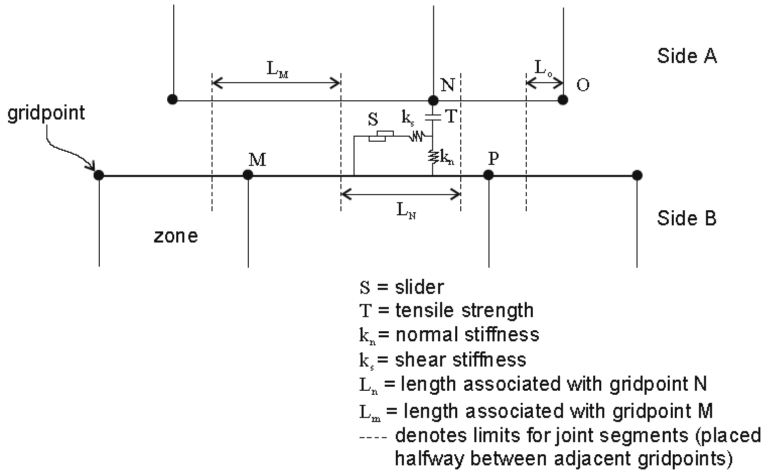

Figure 3 Interface of soil-structure system connected with shear and normal spring

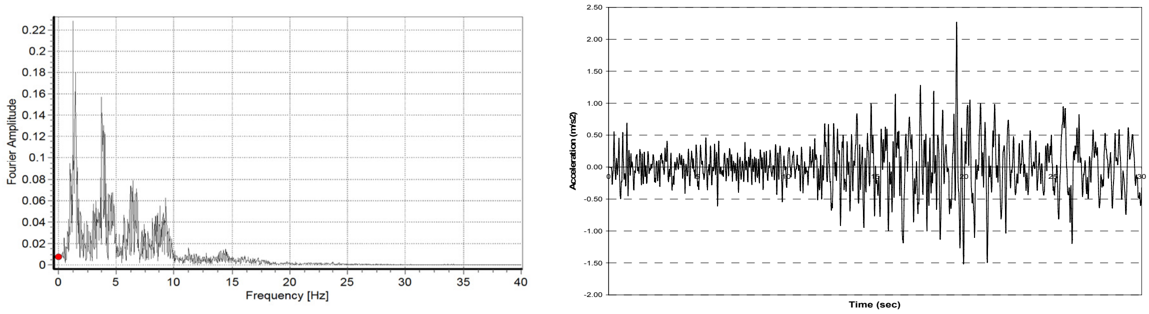

Figure 4 Time history of acceleration (Vertical component) and Fourier Spectrum for Kojour earthquake

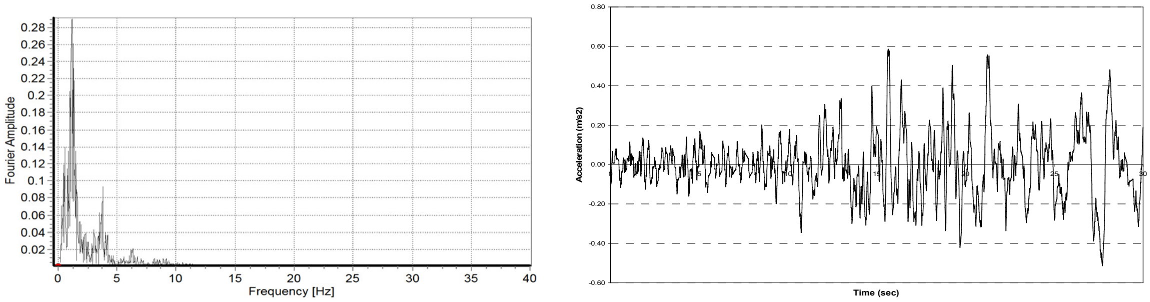

Figure 5 Time history of acceleration (Vertical component) and Fourier Spectrum for Bam earthquake

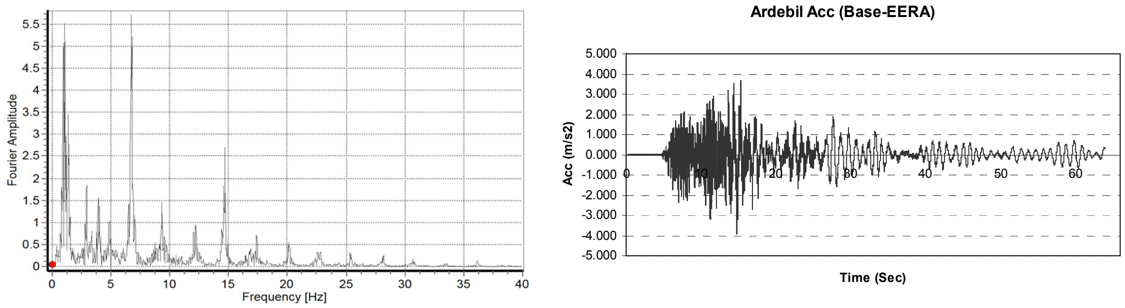

Figure 6 Time history of acceleration (Vertical component) and Fourier Spectrum for Zarand earthquake

Footing Elastic parameters:

$A = 1m^2$, $\rho = 2500kg/m^3$, $E = 2.5e10pa$, $I = 0.0208m^4$

A: Area, ρ: Density, E: Elastic modulus, I: Inertial moment

Plastic parameters of subsoil:

$K = 1.36e8pa$, $\rho = 1715kg/m^3$, $G = 6.3e7pa$,

$\varphi = 30$, $C = 2000pa$, $T \& di = 0$

C: Cohesion, φ: Soil friction angle, di: Soil dilation angle, T: Tensional strength

In order to dynamic modeling of soil, Rayleigh damping factor assumed D=0.05 and central frequency assumed f=1.6 Hz in addition Beam elements has been used for foundation modeling which its Nodes has been connected to the subsoil mesh.

3. ANALYSIS RESULTS

3.1. Study on Normal Stress in Static and Dynamic States in Untreated Soil

Depicting of normal stresses diagram in conjunction with depth in dynamic state has pointed out; existing of the footing would increase normal stresses in subsoil foundation up to 8 times more than static state in accordance with Bousinesque equation (Figures 7 to 9). For evaluating of this trend in this research a 450kPa static load has been used and applied to the 2 meters width strip footing which average vertical stress of subsoil in dynamic state has been obtained 5.4e+5Pa under the influence of three mentioned earthquakes. In deeper depths of subsoil media, existence of footing has had fewer effects on the normal stresses in so far as, in the depth of 4B (B = width of foundation), existence of footing hasn't had any effect on this specific factor whatsoever.

3.2. Comparing of Normal Stress in Dynamic States in Untreated and Treated Soil

Grouting is changed static and dynamic behaviors of treated soil, based on percent of cement and water/cement ratio. In this research, to apply changes in static and dynamic parameters have used numerical studies. Experimental studies have exhibited charts based on some assumption [16 & 17]. In this paper static and dynamic parameters are changed based on Table 3.1.

For grouting is used penetration method and it is assumed that grout do not change the soil structure and soil particles are not moved related each other. Average of confined pressure is σ_3=115kPa, water/cement ratio is 2 and injection pressure is 50kPa. The maximum of axial strain is 3×10^{-4}% and volume decrement of treated soil related to untreated soil is zero. Because of low strain, the cohesion has more effects on shear strength than friction angle [18].

The Poisson's ratio of untreated soil is 0.29 and because this ratio is in the range of 0.15 to 0.3, it is no changed in treated soil [19]. The dilation angle is zero in treated and untreated soil [19]. In penetration injection method Changing of density is negligible [16]. Based on percent of cement and water/cement ratio which is 2, The changes in cohesion is according to Table 3.1 [17].

Because of soil improving by cement injection, the dynamic parameters of soil such as damping ratio (D %), shear modulus (G), shear wave velocity (Vs) and bulk modulus (K), are change according to Table 3.1 [20].

Table 3.1 comparing of parameters in treated and untreated soil based on percent of cement

No	Percent of cement (C%)	Water/cement ratio	Shear modulus (kPa)	Bulk modulus (kPa)	Damping ratio	Predominant frequency (Hz)	Cohesion (kPa)	Shear wave velocity (m/s)
1	0	0	6.3e7	1.36e8	5.0	1.6	2.00	192.0
2	2	2	1.26e8	2.94e8	5.6	2.26	50.25	271.1
3	4	2	1.79e8	3.86e8	6.4	2.69	84.91	323.1
4	6	2	3.45e8	7.45e8	12.1	3.74	144.1	448.5

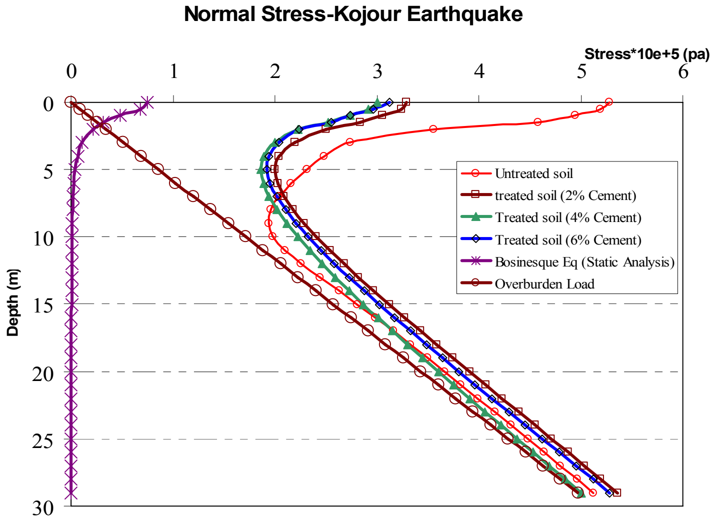

Figure 7 Comparing of Normal stress under footing versus Depth in static and dynamic states

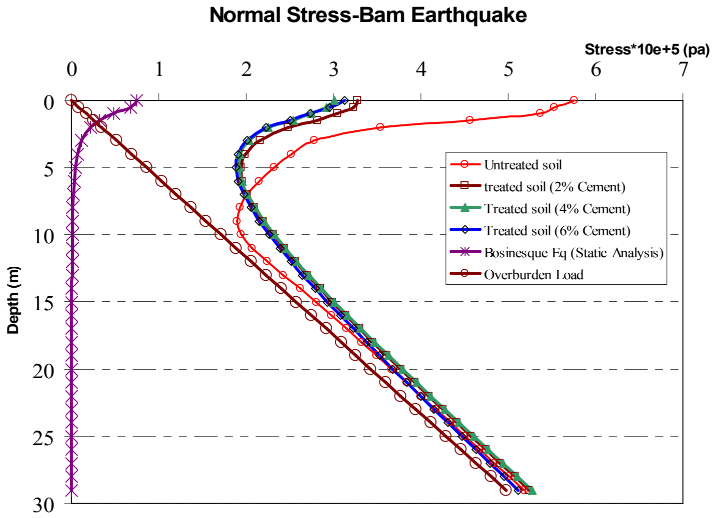

Figure 8 Comparing of Normal stress under footing versus Depth in static and dynamic states

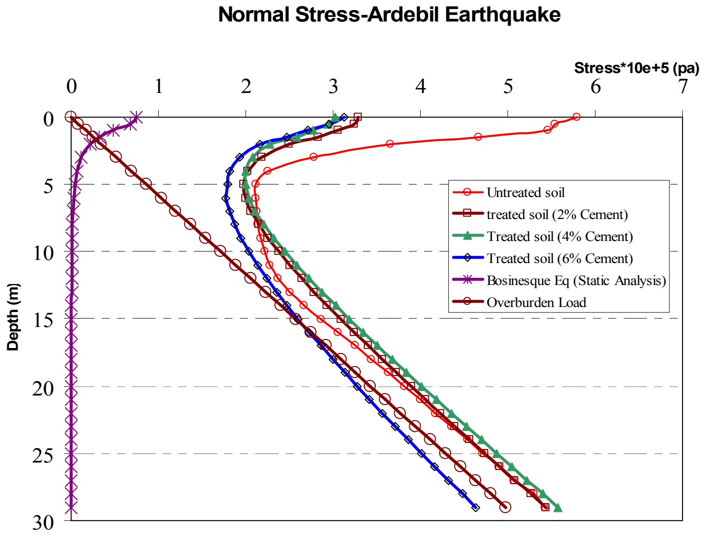

Figure 9 Comparing of Normal stress under footing versus Depth in static and dynamic states

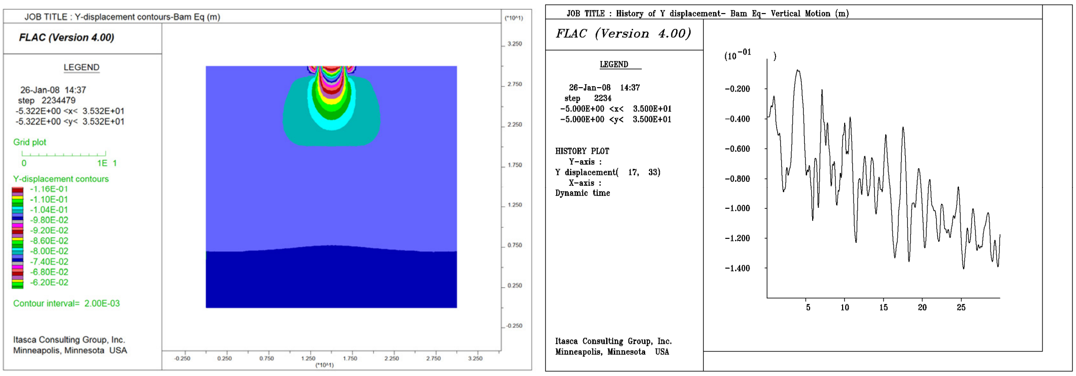

Figure 10 Y-displacement contour and Time history of Y-displacement in untreated soil for Bam earthquake (q=450kPa)

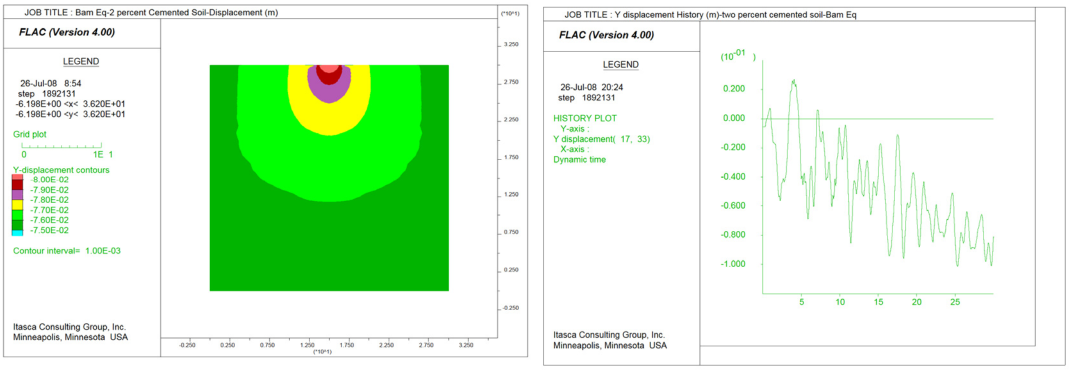

Figure 11 Y-displacement contour and Time history of Y-displacement in 2% cemented soil for Bam earthquake (q=450kPa)

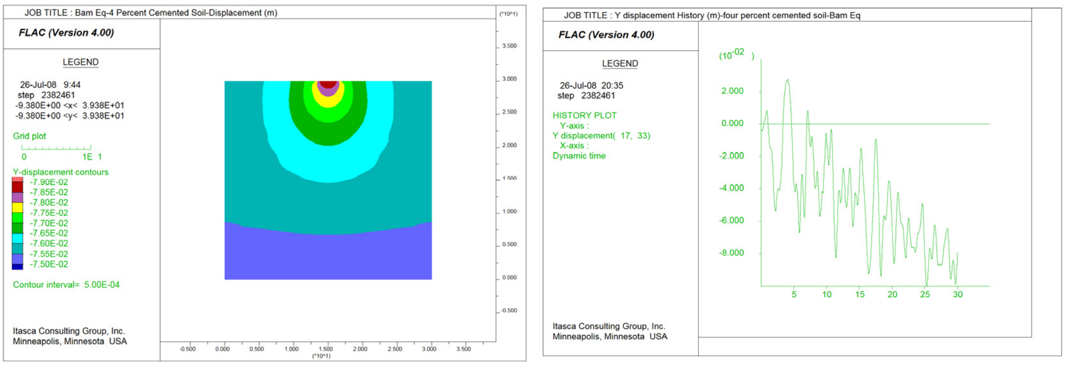

Figure 12 Y-displacement contour and Time history of Y-displacement in 4% cemented soil for Bam earthquake (q=450kPa)

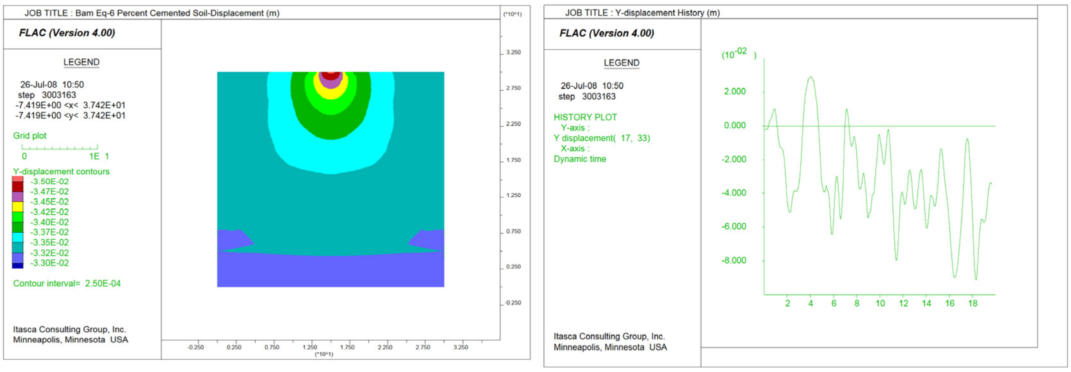

Figure 13 Y-displacement contour and Time history of Y-displacement in 6% cemented soil for Bam earthquake (q=450kPa)

Maximum settlement in dynamic settlements history has been recorded 65mm for Kojour earthquake, 136mm for Bam earthquake and 300mm for Ardebil earthquake. The Figures 7, 8 & 9 are shown that adding 2 percent of cement the maximum normal stress decrease 1.6 times. It is case adding more cement percent decrease maximum normal stress that its amount is 4.5% in six percent cemented soil compare to two percent cemented soil. Based on this, the study of vertical displacement contours (Figures 10, 11, 12 & 13) is shown maximum value of Y-displacement is 136mm for untreated soil, 105mm for two percent cemented soil, 89mm for four percent cemented soil and 75mm for six percent cemented soil. Consequently, failure of soil occurs in greater load with adding cement to it and the bearing capacity of soil is increased. Though the changes of normal stress are low, but the changes of vertical displacement are considerable.

4. CONCLUSIONS

The following conclusions may be drawn from the analytical investigation reported in this paper on theoretical evaluation of different soil parameters effects on dynamic settlement of shallow foundations:

1. Maximum normal stress under foundation in dynamic state has been about 8 times greater than static state.
2. In about 4B (B: width of foundation) depth, effect of foundation on the normal stress distribution has been negligence.
3. Difference of maximum normal stress and vertical displacement relative to percent of cement is exhibited in Table 4.1.

Table 4.1 Comparing of normal stress and vertical displacement in untreated and treated soil

Cement ratio	0%	2%	4%	6%
Normal stress×10e+5 (Pa)	5.76	3.278	3.123	3.014
Percent of difference from left		43.1%	4.7%	3.5%
Vertical displacement (mm)	136	105	89	75
Percent of difference from left		22.8%	15.2%	15.7%

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