Investigation of Equal Stress of Reinforced Slopes Using Soil Nail under Dynamic Loading

Ali Abdollahi, Sina Shaffiee Haghshenas, Pooria Jalilvand, and Sami Shaffiee Haghshenas

Abstract--- Soil nail of slopes is a method that is under the attention of geo technique engineers in different cases including reinforcement of slopes and gable roofs. In this regard, the issue which has been neglected is the effects of dynamic forces on soil nailed slopes. Thus, it is needed to investigate the effect of earthquake on the behavior and performance of soil nailed slopes. The maximum tangential stress between nail and soil has been conducted under accelerometers of Manjil and Bam by help of ABAQUS software. Parametric study on factors affecting seismic stability of soil nailed slopes showed that increasing Cohesion parameters and internal friction angle of the soil will decrease the maximum equal stress between nail and the soil. Increasing elasticity module will increase the maximum equal stress between nail and soil. The effect of slope height and the distance of nails on maximum equal stress between nail and soil have been investigated; so that they increase with increase of slope height as well as increase of nails distance.

Keywords--- Slope Stability, Soil Nail, Dynamic Loads, Finite Element, Abaqus

I. Introduction

SOIL nail operation is to stabilize acute slopes by planting steel bars close to the each other, called nail, in a slope or a hole created during excavation from top to bottom. Nowadays, soil nailing slopes is considered as an appropriate solution in many parts of the world in order to increase the stability of the slopes. The stability of the slopes is changed during the earthquake. In many cases, human and financial losses result from slope instability during the earthquake is more than damages induced by other factors of earthquake.

In this regard, the issue which has been neglected is the effects of dynamic forces on soil nailed slopes. These structures show desired seismic behaviors; so that they will not be disjointed even during strong earthquake. For instance, in Lomaprita earthquake, even bulkheads we not transformed under high acceleration of the earthquake. Therefore, it is needed to investigate the effect of earthquake on the behavior and performance of soil nailed slopes. Most of analytical methods to investigate dynamic behaviors of the soil nailed slopes only control general stability of the structure. Several empirical studies and numerical analyses have been performed until now in order to better understand the behavior of soil nailed slopes. In addition to the slope geometry and soil properties, other factors such as distance of rebar, affect the stability of soil nailed slopes. Assessment and generalization of trustable methods for seismic design of soil nailed walls and armed soil need better understand the factors affecting the interaction of soil and nail, surface response of the ground, facing displacement, and disjoint mechanism under earthquake. In this article, we investigate the maximum equal stress between soil and nail.

The first model which is identified as basic model and is defined by geometry and known properties is slope with 80 degree angle, height of 30m, and slope height of 9.5m. In this model, 6 rebar with diameter of 30mm and length of 7.7m and angle of 15degree to the horizon with distance of 1.5m have been used. And a Shotcrete with thickness of 10cm have been drawn on the slope. Due to the 2D analyses of this article, it is assumed that all of the nails are placed by the same distance and along each other in horizontal and vertical directions. And the properties of the rebar have been measured according to their distances. Various models have been created by changing the parameters of the soil and changing geometry and arrangement of the rebar. In these models, the effect of soil parameters, slope height, and nail distances on dynamic responses have been considered. These models with basic model investigate the effect of each mentioned factors. Indeed, there is 3 models to investigate the effect of each variables. The software used in this analysis is ABAQUS. This software has more capabilities than other software by several functions including interaction of soil and structure, large transformations, different behavioral models of the soil.

II. Material Properties and Modeling

Mohr-columb elasto-plastic model have been used in this article. For more accuracy in the problem, meshing with 6-nodes triangle model has been used. The properties of elastic and plastic parameters of the soil are in the Table(I). Linear elastic behavior has been considered for structural element shotcrete of the bar. The properties of the soil nail and its shotcrete have shown in Table(II).

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TABLE I

ELASTIC AND PLASTIC PARAMETERS OF THE SOIL

Cohesion (N/m^2)	Friction angle (deg)	Modulus of elasticity (N/m^2)	Density (Kg/m^3)	Dilation angle (deg)	Possion Ration
20×10^3	34	70×10^6	1800	4	0.3

TABLE II

PROPERTIES OF STRUCTURAL ELEMENTS

Element Type	Density (Kg/m^3)	Modulus of elasticity (N/m^2)	Possion Ration
Soil Nail	7850	2.1×10^{11}	0.25
Shotcrete Facing	2400	2.5×10^{10}	0.25

For modeling the interaction, mediator element have been considered for this article, which has the properties of soil element with difference that resistance percent of this element is 0.67 of base soil.

Meshing basic model and arrangement of soil nail in slope have been considered as Figure(1) regarding to the fact that model width is 10 times larger than modeled structure width

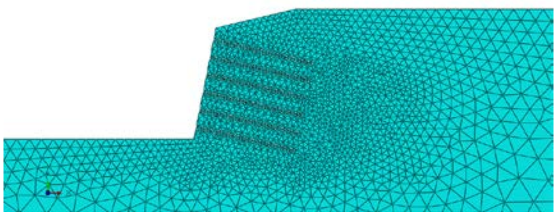

Fig. 1. Meshing Basic Model and Arrangement of soil Nail

III. BOUNDARY CONDITIONS AND DAMPING

In dynamic problems for the waves propagated to the interior of the model, certain conditions are usually applied in artificial boundaries after classification of limited space of the model, in order to prevent from irregular dissipation of energy. Considering base conditions consistent with the reality can prevent from rigid movement of the model. In this article, damping considered for the model in dynamic analysis is 5%. Appropriate damping percent is considered according to the type of material between boundary surfaces and interfaces.

IV. DYNAMIC LOAD

For loading the earthquake, accelerometers of Manjil and Bam have been used whose properties are in Table(II) and shown in Figures(2),(3).

TABLE III

THE PROPERTIES OF ACCELEROMETERS OF MANJIL AND BAM

Records	Station	Frequency Content (Hz)	PGA (g)	PGV (cm/s)	PGD (cm)
Manjil (1990)	Abbar	0.1-20	0.56	59.1	25.9
Bam (2003)	DSA-1	0.15-21	0.79	124.0	34.3

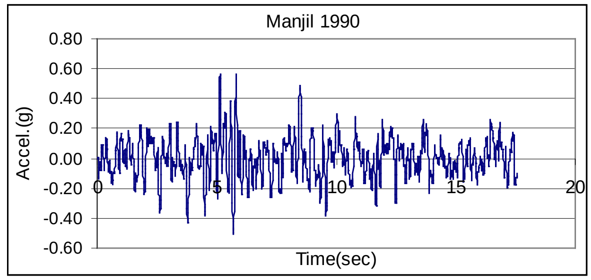

Fig. 2. Accelerometers of Manjil Earthquake Applied on The Model

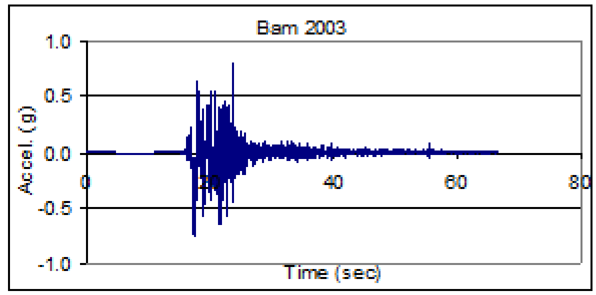

Fig. 3. Accelerometers of Bam Earthquake Applied on The Model

V. THE RESULTS OF FINITE ELEMENT ANALYSIS

In this stage, analysis of dynamic response of the slope is performed by considering maximum equal stress between nail and soil in Manjil and Bam earthquakes. The results of these analyses are observable for given parameters.

A. Cohesion Effect

Figures(4),(5) shows the results of investigating the Cohesion effect of soil on dynamic response of soil slope toward maximum equal stress.

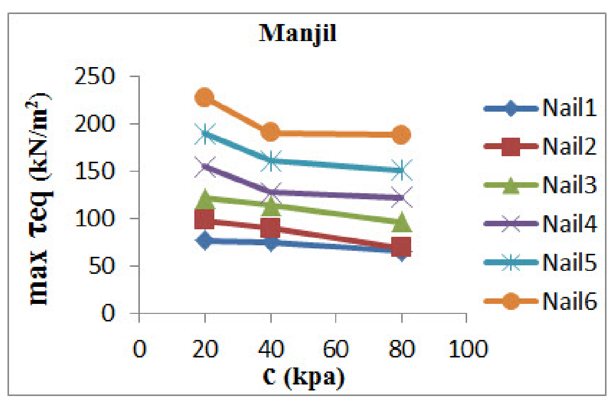

Fig. 4. Maximum Equal Stress Between Soil and Nail Induced by Cohesion changes in Manjil Earthquakes

As it can be expected, improvement of resistant parameter of the soil (C) can increase shear resistance of the soil in dynamic state. In analysis of soil nailed wall, it is assumed that shear resistance of the soil is staffed completely along disjointed surface. Therefore, by increasing these parameters, the soil can bear more of moving forces. Thus, increased shear resistance of the soil can decrease equal stress between soil and nail. The values of maximum equal stress between soil and nail have been used when Cohesions are 20 (kpa),

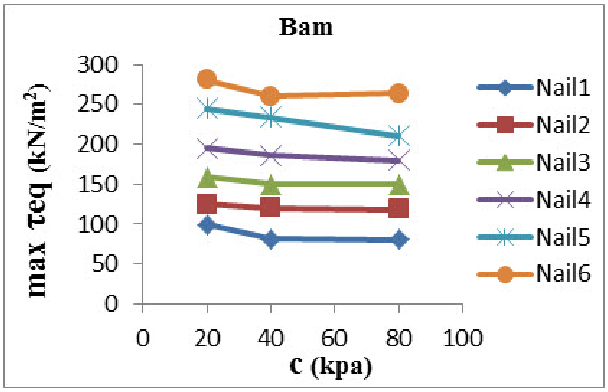

Fig. 5 Maximum Equal Stress Between Soil and Nail Induced by Cohesion changes in Bam Earthquakes

B. *Internal Friction Angle Effect*

Figures(6),(7) shows the results of investigating the effect of internal friction angle on dynamic response of soil slope toward maximum equal stress.

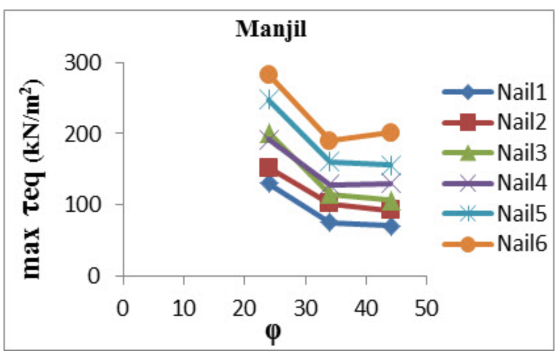

Fig. 6. Maximum Equal Stress Between Soil and Nail Induced by Changing Internal Friction Angle in Manjil Earthquakes

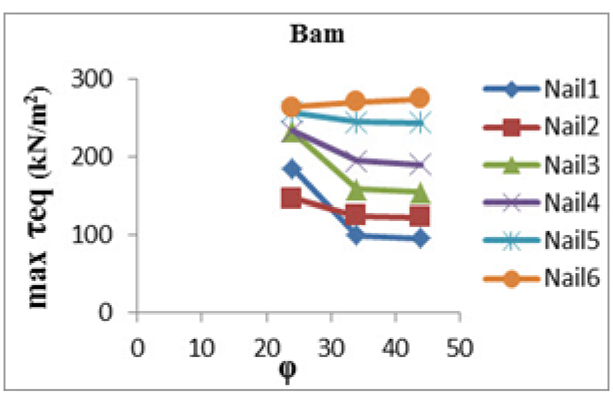

Fig. 7 a. Maximum Equal Stress Between Soil and Nail Induced by Changing Internal Friction Angle in Bam Earthquakes

As it can be expected, improvement of resistant parameter of the soil (φ) can increase shear resistance of the soil in dynamic state. In analysis of soil nailed wall, it is assumed that shear resistance of the soil is staffed completely along disjointed surface. Therefore, by increasing these parameters, the soil can bear more of moving forces. Thus, increased shear resistance of the soil can decrease equal stress between soil and nail. The values of maximum equal stress between soil and nail have been used when friction angles are 24, 34 and 44. It can be seen that increase of internal friction angle can decrease equal stress between soil and nail.

C. *Elasticity Module Effect*

Figures (7),(8) shows the results of investigating the effect of internal friction angle on dynamic response of soil slope toward maximum equal stress.

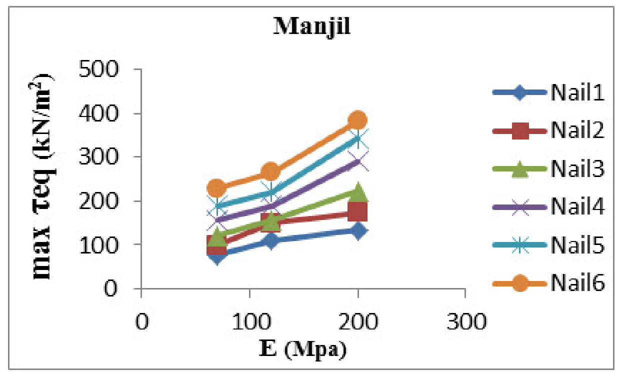

Fig. 7 b. Maximum Equal Stress Between Soil and Nail Induced by Changing Elasticity Module in Manjil Earthquakes

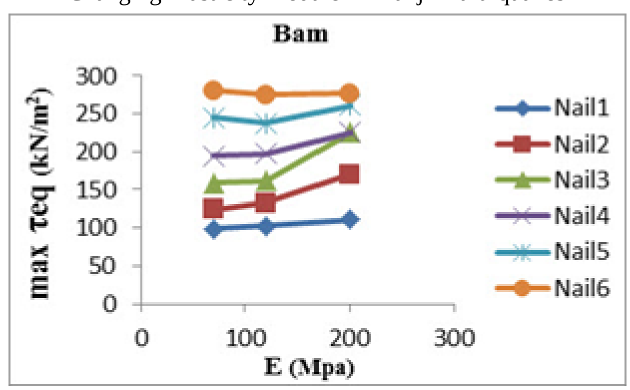

Fig. 8. Maximum Equal Stress Between Soil and Nail Induced by Changing Elasticity Module in Bam Earthquakes

As it can be expected, improvement of resistant parameter of the soil (E) can increase shear resistance of the soil in dynamic state. In analysis of soil nailed wall, it is assumed that shear resistance of the soil is staffed completely along disjointed surface. Therefore, by increasing these parameters, the soil can bear more of moving forces. Thus, increased shear resistance of the soil can increase equal stress between soil and nail. The values of maximum equal stress between soil and nail have been used when elasticity modules are 70(Mpa), 120(Mpa) and 200(Mpa). It can be seen that increase of elasticity module can increase equal stress between soil and nail.

D. Slope Height Effect

To investigate the effect of slope height in modeling by freezing other properties, 3 models will be created with respectively slope height of 6.5(m), 9.5(m), and 12.5(m). The number of rebar is increased due to the increased slope length and increased height. Equal stress between soil and nail increase with increase of slope height, which can be observed in Figures(9),(10)

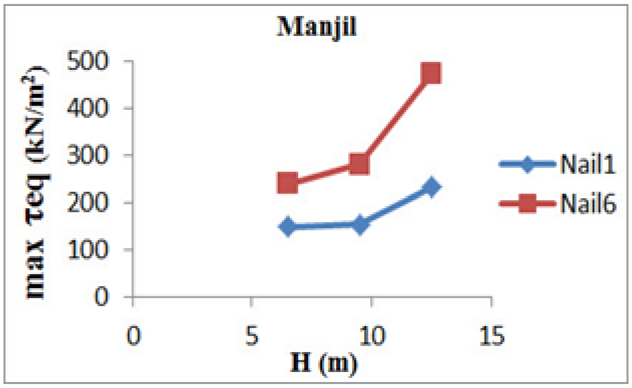

Fig. 9. The Effect of Changing Height on Maximum Equal Stress Between Soil in Manjil Earthquakes

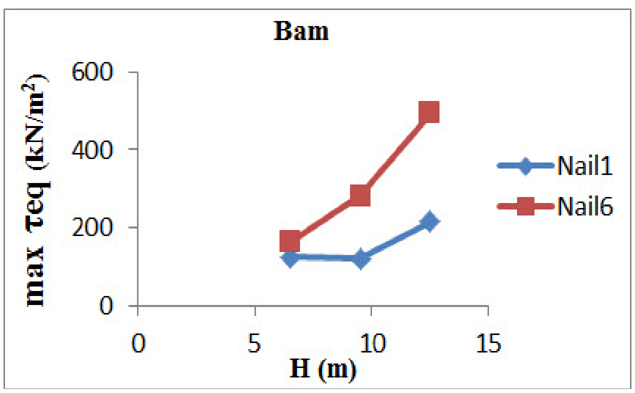

Fig. 10. The Effect of Changing Height on Maximum Equal Stress Between Soil in Bam Earthquakes

Slope heights of 6.5(m), 9.5(m) and 12.5(m) have been considered for maximum values of equal stress between nail and soil. By increasing slope height, equal stress between soil and nail will be increased.

E. Effect of Nails Spacing

3 models with rebar distances of 1.5(m), 2.5(m) and 3.5(m) have been considered to investigate the effect of changing the distance of armors on dynamic response of the slope toward maximum equal stress. The results have shown in Figures(11),(12).

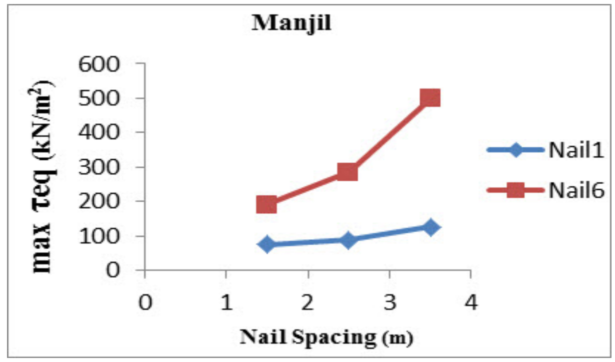

Fig. 11 The Effect of Changing Nails Spacing on Maximum Equal Stress Between Soil in Manjil Earthquakes

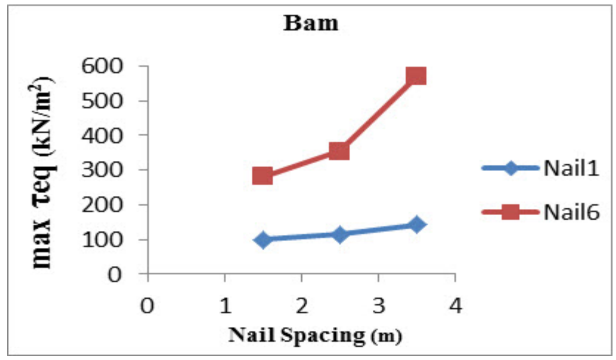

Fig. 12 The Effect of Changing Nails Spacing on Maximum Equal Stress Between Soil in Bam Earthquakes

According to the figure7, maximum values of equal stress between soil and nail, for distances of 1.5(m), 2.5(m), and 3.5(m) have been considered. By increasing nails distance, maximum equal stress between soil and nail will be increased.

VI. Conclusion

The results of dynamic analyses show that increased Cohesion of the soil decrease the equal stress between soil and nail, and this decrease is more in the Cohesions of 20(kpa) to 40 (kpa). Stresses from the first nail at the top of the slope to the sixth nail at the end of the slope have been increased. By increase of internal friction angle of the soil, equal stress between nail and soil was decreased. Stresses from the first nail at the top of the slope to the sixth nail at the end of the slope have been increased respectively. The effect of friction angle on decrease of stress between nail and soil is less than soil Cohesion. Increased elasticity module of the soil increase the equal stress between soil and nail, and this increase is more in the elasticity modules of 120(Mpa) to 200 (Mpa). Stresses from the first nail at the top of the slope to the sixth nail at the end of the slope have been increased respectively. Increased slope height increase the equal stress between soil and nail in Manjil and Bam earthquakes, and this increase is more in the heights of 9.5(m) to 12.5 (m). Increased nails distance increase the equal stress between soil and nail in Manjil and Bam earthquakes, but this increase is more in Manjil and Bam earthquakes between 2.5(m) to 3.5(m).

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