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Research Article

STUDY OF INTERACTION OF SOIL AND STRUCTURE IN MASONARY STRUCTURE

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ABSTRACT

In structure analyze, generally will be assumed that the soil below the footing is solid and have rigid connection in between. In this assumption not only the soil Flexibility will be omitted but the possibility of footing uplifting also won't be considered. Whereas, if the interaction of soil and structure will be considered in analyze, response of structure in connections will be flexible which is different from the previous assumption. After implementing these impacts on structure, the effect of soil and structure interaction on structure behavior will be reduced or increased depending on soil and structure characters and omitting these effects as an connection conditions in strengthening methods and designs of new structures , will reduce the reliability of structure designs. In some Seismic analyze Regulations which are being used for designing the normal structures, a certain reduction in Equivalent static load will be allowed to apply the interaction effect when the rigid footings will be considered. In this research, the interaction of soil and masonry wall with different lateral and compression loads and various soil characters will be studied and the effect of soil on masonry wall will be observed.

***Keywords**: Interaction of Soil and Masonry Wall, Flexible Soil, Lateral Load, Behavior of Masonry Wall*

INTRODUCTION

Masonry buildings are one of the oldest structures which are common from long ago till date. About 70% of buildings in Iran and all over the world are masonry buildings. The experiences from past earthquakes, epically Bam's earthquake, show the Vulnerability of these buildings. Incomprehension of failure and behavior of masonry structures and their members in inelastic limits can create major issues in seismic behaviors. Hence one of the most important engineering issues is seismic evaluation and Improvement of these buildings against the earthquakes. Dynamic response of structure is a result of movement of soli layers beneath the building and on the other hand, response or stress behavior of soil layer changes is an affect of structure movement. Generally, settlement of footing due to seismic load is different in static mode. But in lose sand these effects are so important since they result the changes in internal forces of structural members (for or against the safety factors), which is different from the mode that the soil-structure interaction considered. Interaction between structure and its adjacent soil, changes the real behavior of structure drastically in comparison of structure behavior with rigid support. So an efficient and exact model of soil-structure interaction system is required for this study. Previous experiences shows that the soil beneath the foundation has affect on dynamic behavior of structure. Dynamic response of structure during applied seismic loads is a variance of soil type. So without considering this effect it is not possible to have a real estimate of seismic load applied to the structure (Ghanad 2000). In addition the local characters of soli like type of soil, layers soil and changes along the depth of layer are the factors which affect the seismic response of structure and need to be studied and applied in structure analyze (Bargi, 2001). Therefore it seems studying the seismic behavior without counting the soil effect will result unreal analyze. A major research has been done in recent to study more precisely about the soil effect. Since there are many factors which most of them are nonlinear (Kramer, 1996), evaluation of interaction of soil and structure has to be done with non linear models. One of the most important issues in analyzing the soil and structure interaction is having a suitable model. There are different precise and complicated methods to create a model for evaluation of soil and structure interaction during the earthquake. If the layered soil to be considered in the modeling, below methods can be used (Bargi, 2001).

A) Considering the soil as a mass, spring and Shock absorber (damping), average in structure foundation.
B) Considering the soil as a shear beam with continuous or focused mass and vast stiffness.
In cases that the soil layers are in vertical and horizontal directions and evaluating the nonlinear behavior of soil is required, the finite element model can be used to implement the soil layers in analyze. So, the error due to considering the linear behavior (resilient) of soil -which is considered in modeling methods like shear beam- will be omitted (Clough, Gulkan, 1997). In this method in addition to foundation sinking, soil layers in vertical and horizontal directions can be entered in analyze. In layered soil finite element modeling it is assumed that the soil is lengthy with having less width to assure the exact result.

Effective Factors on Shear Masonry Walls

From previous studies it is clear that the load-displacement response and the failure pattern in shear walls are resulted from various factors. Reinforcement, vertical pressure, dimensional ratio and the material characters are some of the main parameters which are mainly affecting the shear walls behavior. This chapter will explain these parameters (19)

1- Reinforcement. 2- Vertical pressure. 3- Dimensional ratio. 4-Material characters.

Main specifications of masonry walls can be summarized as below :

- Brick acts as a elastic- fragile material.
- Mortar’s nonlinear stress- Strain relation, allows an important inelastic deformation .
- Masonry materials transfer the compressive loads effectively, while due to low adherence capacity they have low tensile strength.
- Behavior of masonry material in torsional stress strongly is a result of direction of mortar joints.

Modeling By Finite Element Method

Considering that in previous projects (Belmouden, Lestuzzi, 2007) for modeling the masonry wall, the finite element software ABAQUS was being used, in present study also the same method has been used. Important note in using this software is selection of element, behavior of element and also the network modeling. Element’s dimensions and their numbers in some cases will change the results strongly. So according to finite element knowledge, past experiences and correct scientific decisions a reasonable relation between number of elements and analyze cost (time) can be created, because with increasing the number of elements and followed by that the increasing of freedom degrees, the analyze time will increase.

In present study for modeling the brick and soil, C3D8R element has been used. This element is a SOLID Lagrangian and in each node has three degree freedom. C3D8R element has eight nodes and its shape Function is primarily function. Figure1: shows this element.

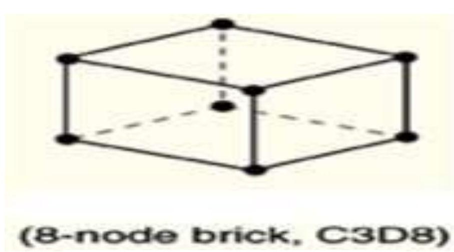

Figure1: shows this element.

Yield Criteria Used For Material

Corrected Drucker-Prager‘s Plasticity model (warhead model), has a vast usage in finite element analyze software for different Uses in Geotechnical engineering. This model has high ability in soil behavior modeling and different cases like stress history, stress path and Dilation will be considered in this model. This model can be used for adhesive materials which act the same as soil and stone in slippage condition under the pressure. This model is based on a adding a slippage surface to the plasticity model which

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creates a hardening inelastic mechanism for considering the compression paste mode to control the expansion of volume when the material will slip under the shear.

Drucker-Prager's Yield Criterion

This criterion has been used by Drucker-Prager (1952) as a correction to Van misuz's criteria, an approximate Coloumb's law in effect of hydrostatic stress in yield.

***Verifying the Reference According to** (Belmouden, Lestuzzi, 2007)*

To verify the modeling, a numerical study in ABAQUS software done. For this purpose the behavior of masonry wall test which was done in Genoa, Italy College by Gambarota & Legoma resinous (1997) was modeled in ABAQUS software. The diagram of laboratory tests and the diagram derived from simulation model have been shown in below figure. It is clear that the results are reasonably matching to each other.

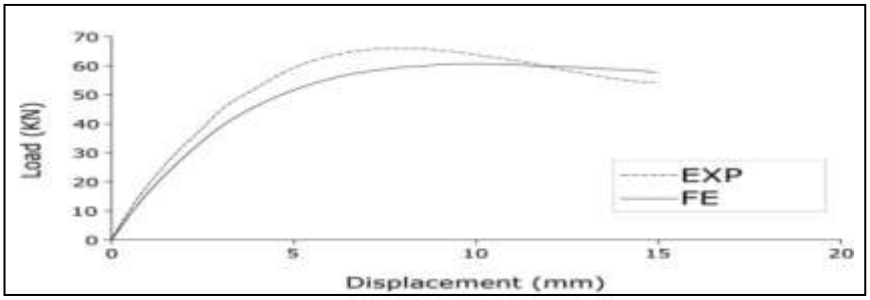

Figure 2: The diagram of laboratory tests and the diagram derived from simulation model have been shown in below

PARAMETRIC STUDY TO EVALUATE THE SOIL- STRUCTURE INTERACTION

Behavior of Wall within the Wall and the Masonry Material at the Bottom Connection

According to the masonry building's Seismic improvement instructions (issue number 376) features of unreinforced masonry buildings, while going under lateral force along the wall plate, will be evaluated. Normally the failure modes in the wall behavior with unreinforced masonry material will be categorized in four groups:

Failure mode due to slippage of mortar
Failure mode due to rocking motion
Failure mode due to diagonal tensile
Failure mode due to compression pan

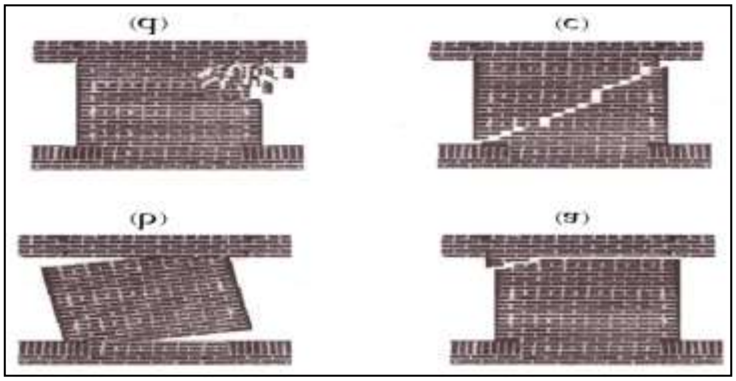

Figure 3: failure mode's of masonry walls behavior

a) Failure mode due to slippage of mortar
b) Failure mode due to rocking motion
c) Failure mode due to diagonal tensile
d) Failure mode due to compression at the bottom connection

Procedures of Parametric Studies

For applying the soil behavior two types of corrected Drucker-Prager‘s warhead model and also Drucker-Prager‘s model have been used. Also two different lateral and compressive loads applied and rate of these variances on the samples have been evaluated.

Specifications of Analyzed Samples

To evaluate the behavior of masonry wall one of the testes done in Genoa, Italy College by Gambarota & Legoma resinous (1997) and modeled in ABAQUS software. In below figure the dimensional specifications shown.

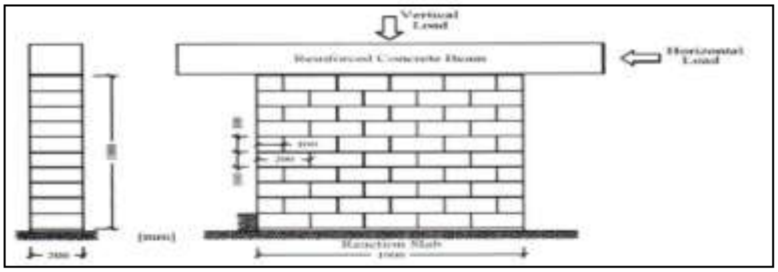

Figure 4: Dimensional Specifications

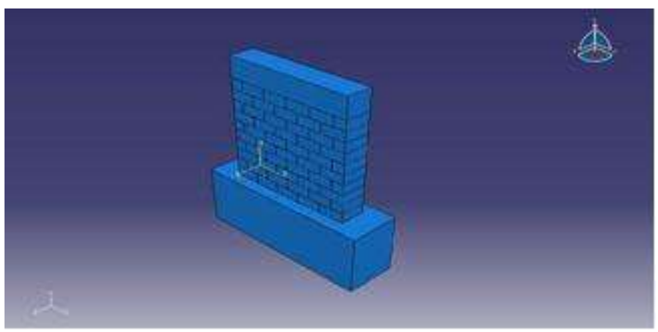

Figure 5: Sample dimensions

Modeled sample in finite element software ABAQUS

From the 11 soil samples, seven soil samples with corrected Drucker-Prager‘s warhead model and other four models with Drucker-Prager‘s model have been modeled in finite element software ABAQUS. Soil specifications with corrected Drucker-Prager‘s warhead model and soil specifications with Drucker-Prager‘s model is as below. It should be noted that F used for naming the samples in corrected Drucker-Prager‘s warhead model and also S used for naming the samples in Drucker-Prager‘s model.

Loading Method

Loading simultaneously applied with gravity and lateral loads on the samples.

Results of Analyzed Models

A) Results from the Analyzed Study of F1 to F7 Models According to Load 1

Firstly sample F1 with Modulus of elasticity equal to 328 mega Pascal analyzed and it can be seen that at the time of 11.24 loading, diagonal break will start in wall and slowly the lateral displacement of wall will increase. Finally the lateral displacement at the location of applied load will reach to 148 centimeter. Below figures show the break mechanism of F1.

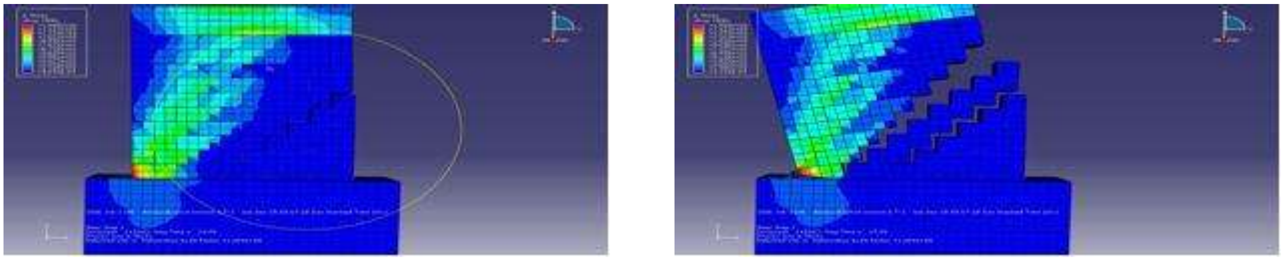

Figure 6: Break Mechanism

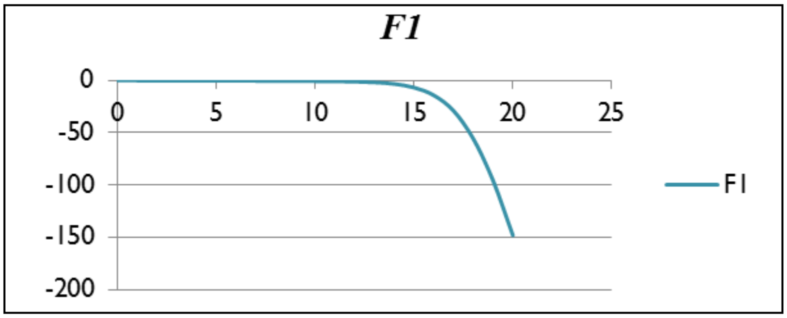

Figure 8: Diagrams of displacement of location of compressive applied load and the sample energy for F1

Displacement diagram of location of compressive load
Also from energy Diagram it can be said that at 11.21 of loading, in which graph goes up, is the failure of the sample. Later on the samples F2 to F7 will be discussed.

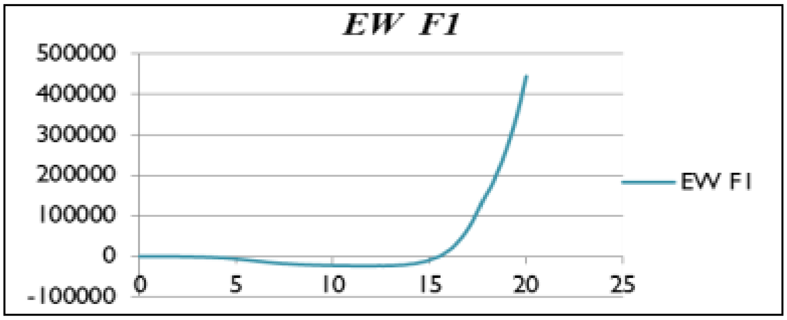

Figure 9: Displacement diagram of location of compressive load

Energy Diagram for F1 sample

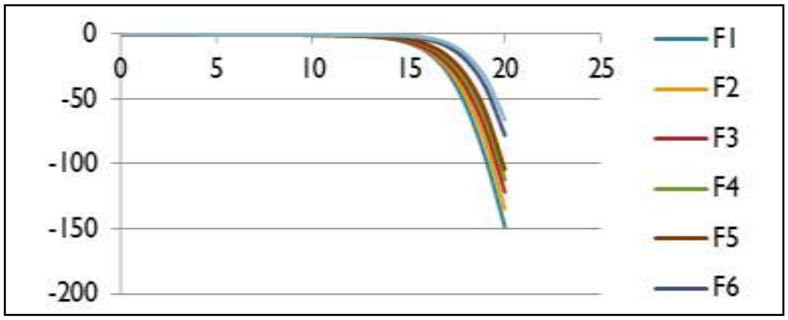

Figure 10: Energy Diagram for F1 sample

Diagram for displacement of models F1 to F7

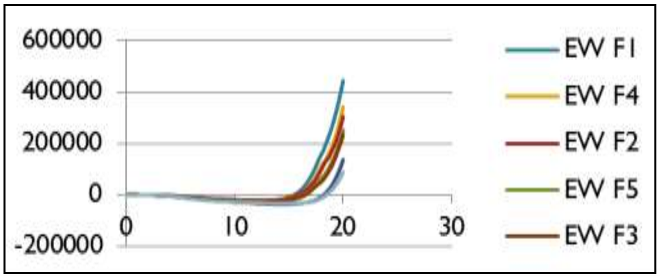

Figure 11: Diagram for displacement of models F1 to F7

Figure Energy diagram for models F1 to F7
It is obvious that by increasing the soil's Modulus of elasticity the structure's displacement will decrease in a way that the least displacement for F7 sample with the elasticity's module of 1121mega Pascal the displacement was 65 Centimeter which is the highest Modulus of elasticity comparing to other samples. In Figure 4-9 as below the failure mechanism for F7 has been shown.

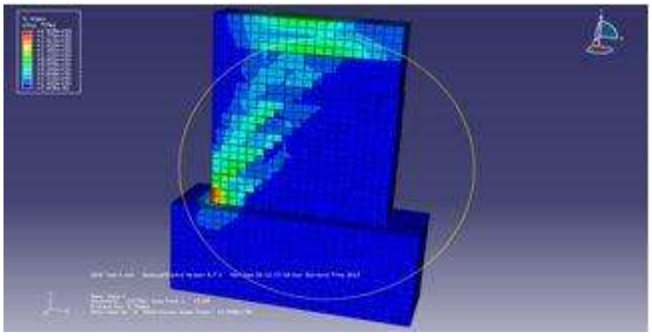

Figure 12: Figure Energy diagram for models F1 to F7

With comparing the energy diagram the same result will be seen, which means in samples with higher Modulus of elasticity the failure time was longer.

Comparing the Results from Analyzed Study of F1 to F7 with Model F1 in Loading Pattern Load1

As mentioned before, among the models, F7 with highest Modulus of elasticity, gone under the lowest displacement whereas sample F1 with lowest Modulus of elasticity had the highest displacement. In below figure the vertical axel is final displacement of other samples relative to the F1 and horizontal axel is the relation of Modulus of elasticity of other samples with F1. For example in F5 in which the Modulus of elasticity is 1.5 times higher than F1, the final displacement is less than 37 percentage of F1 final displacement.

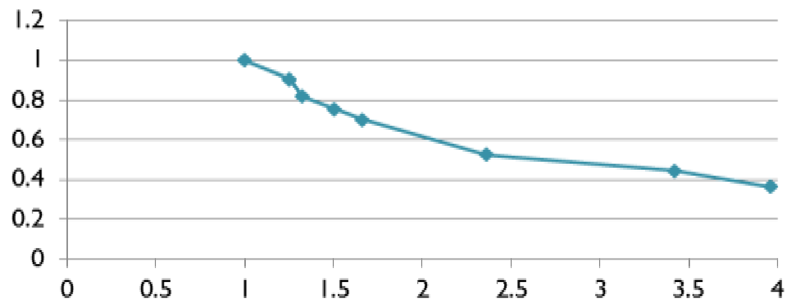

Figure 13: Final displacement relation of other samples compared to F1

Results of Analyzed Study of FR1 to FR7 Models According to LOAD2

For evaluation of compressive and lateral loading on samples behavior, 2 times of compressive load and 1.5 times of lateral load added. In sample FR1 observed that the wall's diagonal failure starts on 14.9 of loading and slowly the lateral displacement adds up till the lateral displacement on place of applied load will reach to 64 centimeter. In below figure the failure mechanism of FR1 has been shown.

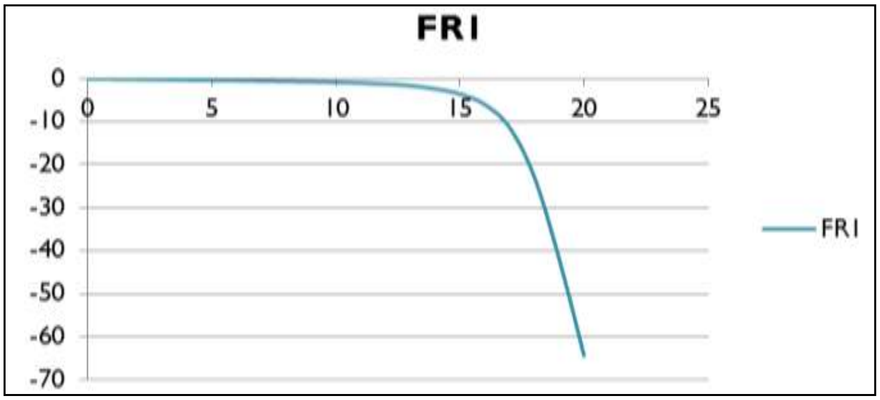

Figure 14: failure mechanism of FR1

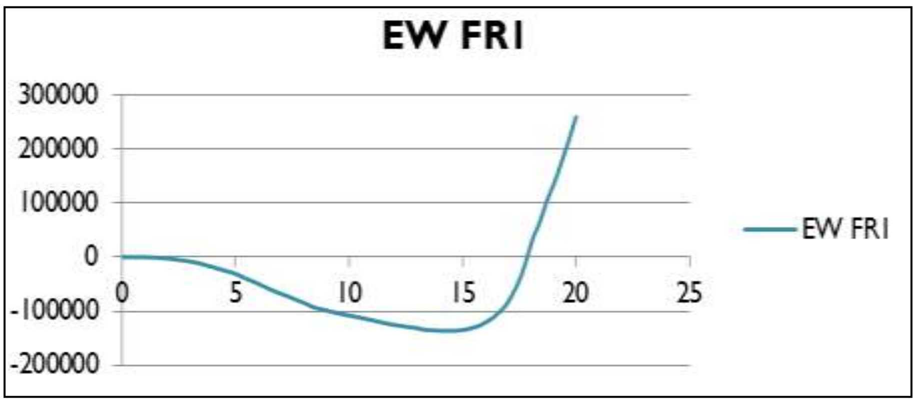

Figure 15: Energy Diagram for F1 sample

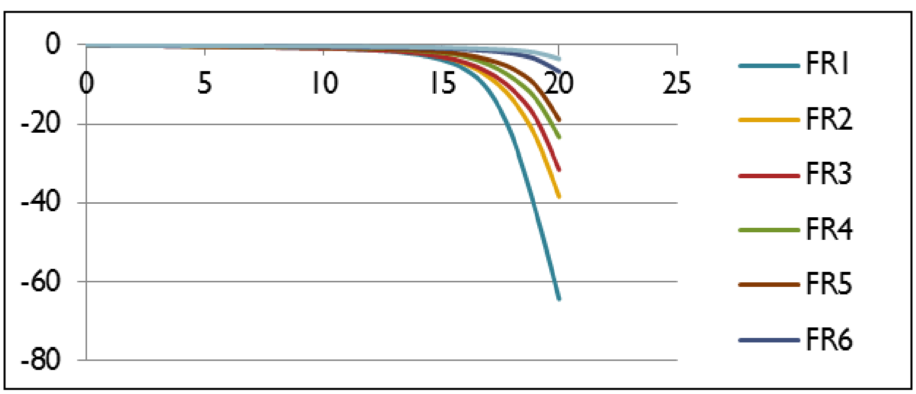

Figure 16: Energy Diagram for F1 sample

Displacement diagrams for FR1 to Fr7

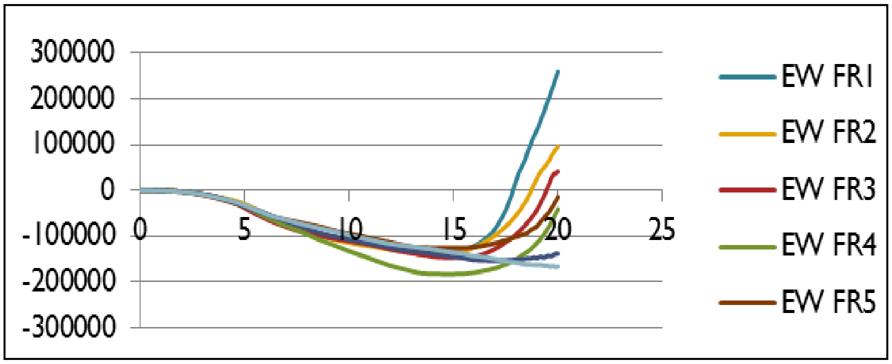

Figure 17: Energy Diagram for F1 sample

Energy diagrams for FR1 to FR7 models

It can be seen that in this condition also with increasing of soil's Modulus of elasticity the structure's displacement will decrease in a way that the lowest displacement for FR7 with Modulus of elasticity equal to 1121 Mega Pascal is less than 4 centimeter. In below figure the failure mechanism for FR7 has been shown. It is to be noted that under this loading pattern, no failure happened in this sample.

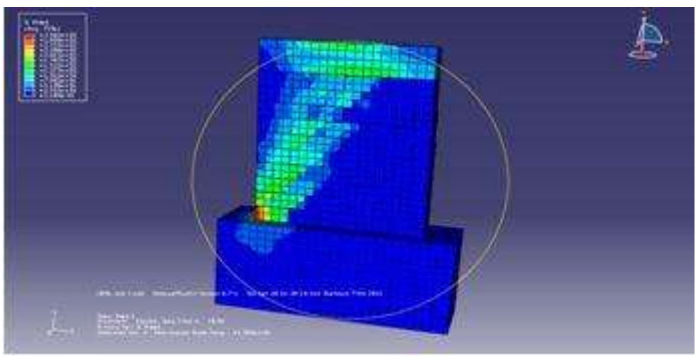

Figure 18: Energy diagrams for FR1 to FR7 models

Comparing the results from analyzed study of FR1 to FR7 with FR1 model in Load 2 pattern, shows that FR7 sample with highest modulus of elasticity has least displacement whereas for FR1 sample reverse conditions which means goes under highest displacement. In below diagram the vertical axel shows the displacement of samples relative to FR1 and horizontal axel shows the modules of elasticity of samples relative to FR1.

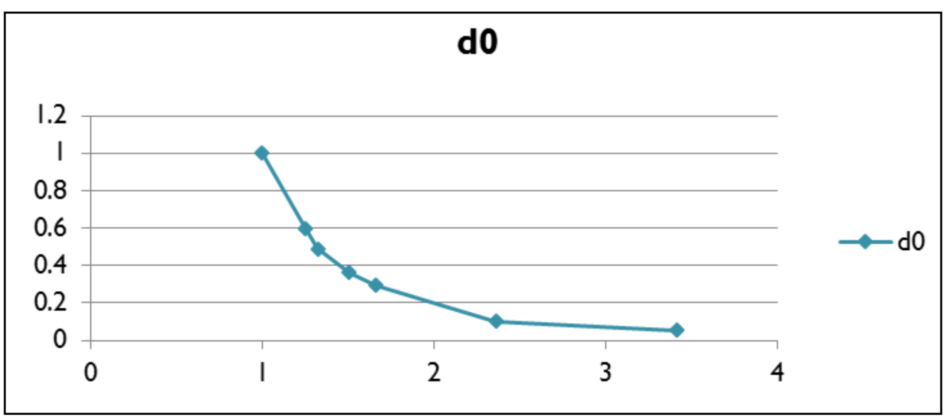

Figure 19: diagram the vertical axel shows the displacement of samples relative to FR1 and horizontal axel shows the modules of elasticity of samples relative to FR1.

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Relation of final displacement of samples compared with FR1

Comparing the Results of Analytical Study of F and FR Samples in Load1 and Load 2 Pattern

To compare the effect of compressive and lateral loading on masonry wall's behavior and also type of soil beneath the wall the percentage of displacement in load1 pattern compared with Load 2 pattern will be discussed. According to figure 4-18 the ratio of variance in first sample is 43%. This ratio for second to forth sample will decrease to 20 to 30%. With increasing of modulus of elasticity this ratio will decreased until reaches to 5% for sample F7.

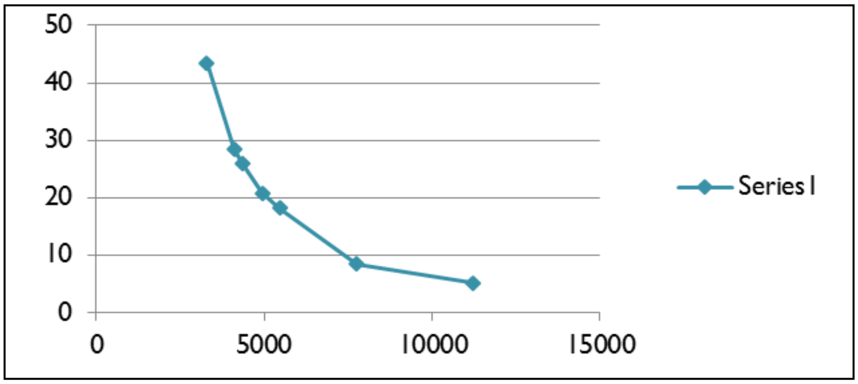

Figure 20: modulus of elasticity this ratio will decreased until reaches to 5% for sample F7.

Figure Percentage ratio of sample's displacement in Load 2 compared to Load1 pattern

Results Derived From Analytical Study of S1 to S4 Sample According to Load1pascal

For samples S1 to S4, the modulus of elasticity of soil considered between 124 to 2482 mega Pascal and the models analyzed. Values of SE,PD,EW,ASE,E of samples also shown. First S1 sample with modulus of elasticity of 124 mega Pascal has been analyzed and it can be observed that at loading equal to 5 the mortar failure in wall will start and the wall's lateral displacement will increase till the final lateral displacement at the place of applied lateral load will reach to 165 centimeter. In figures 20 and 21 the failure mechanism and energy diagram for S1 sample has been shown. In this sample soil goes under high elasticity displacement and at the initial stage of wall loading due to compressive and lateral load the wall was settling inside the soil.

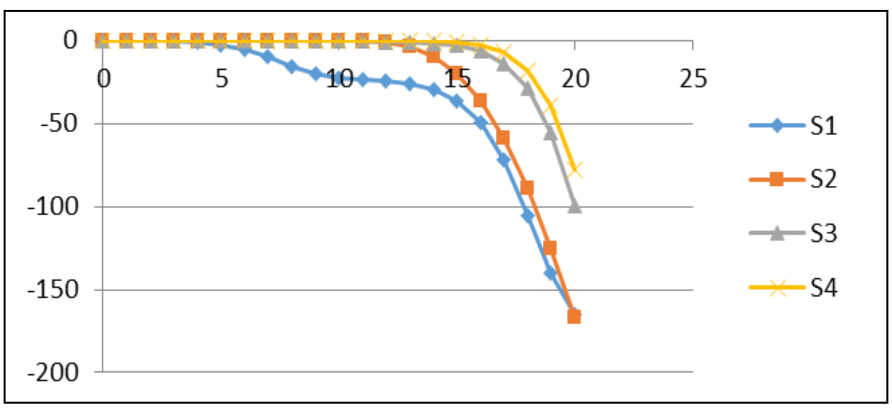

Figure 21: failure mechanism and energy diagram for S1 sample

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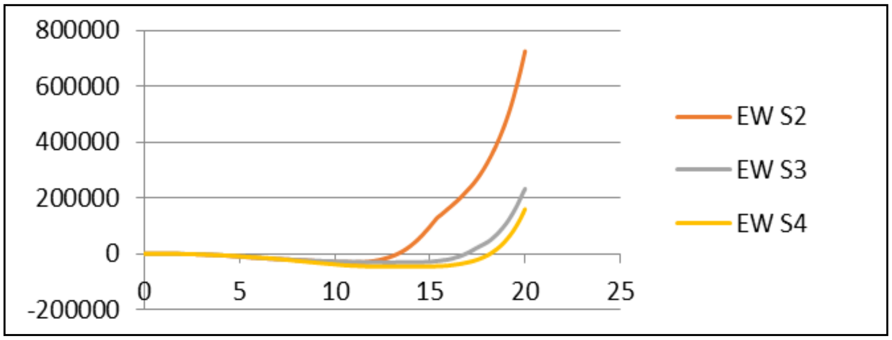

Figure 22: Samples displacement in loading stages

Energy diagram of samples S2, S3, S4 during the loading stages

Results from the Analytical Study of SR1 to SR4 According to Load2

As it was mentioned in part 3-4, for evaluating the effect of compressive and lateral loading on sample's behavior, 2 times of compressive load and 1.5 times of lateral load have been applied to samples and the analyze according to section 4-4 done for samples. In table 4-10 the values of SE,PD,EW,ASE,E have been shown. The SR1 sample with modulus of elasticity equal to 124 mega Pascal analyzed and at the loading equal to 10 the mortar failure happened and the lateral displacement of wall increased. In this sample the soil gone under more deformation compared to the previous test and the initial stage of wall loading the wall had settled inside the soil due to lateral and compressive loading.

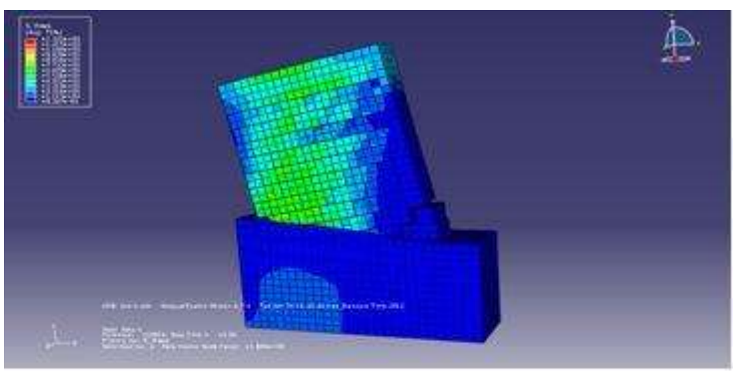

Figure 23: samples and the analyze according to section 4-4 done for samples

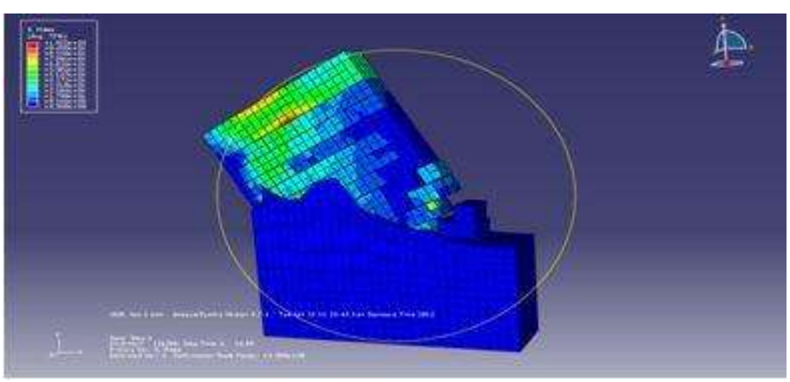

Figure 24: Failure mechanism of SR1 sample

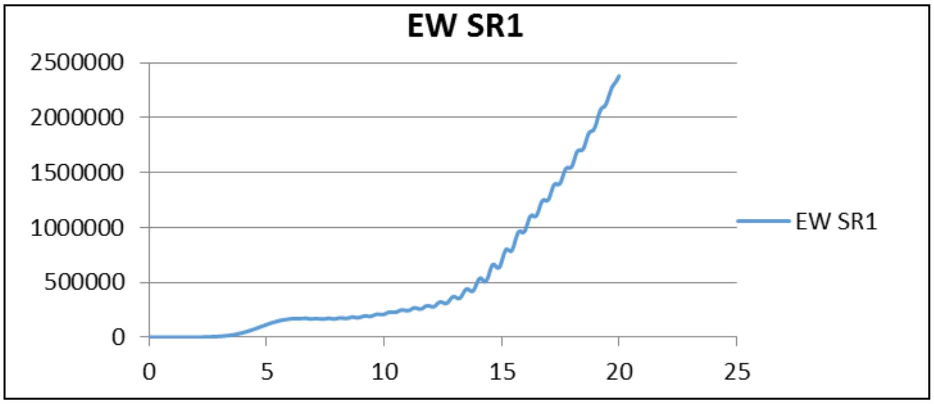

Figure 25: Energy diagram for SR1 sample

SR2 samples had settled in the soil unlike the pervious test and resulted diagonal tensile in the sample. In this sample the lateral displacement reaches to 36 centimeter.

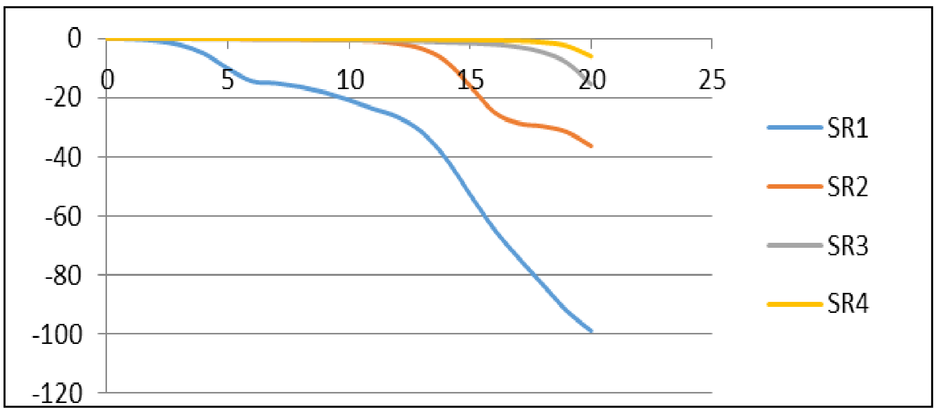

Figure 26: The displacement diagrams of SR1 to SR4 sample.

In figure 27 the energy diagram for samples SR2, SR3, SR4 during the loading have been shown. The reason of different behavior in SR2 compared to SR3 and SR4 from loading equal to 15 can be due to soil's deformation.

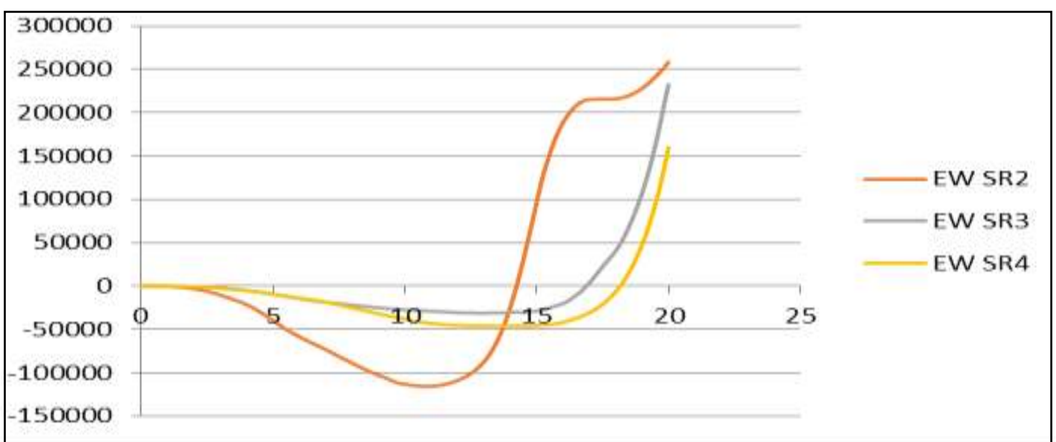

Figure 27 the energy diagram for samples SR2, SR3, SR4 during the loading

Comparing the Results of Analytical Study of S and SR Models According to Load1 and Load2 Pattern

It can be seen that the variance ratio at first sample with modulus of elasticity equal to 124 mega Pascal is 60%. This ratio fir second and third sample is less than 22 to 16 % and finally for sample S4 will reaches to less than 8%.

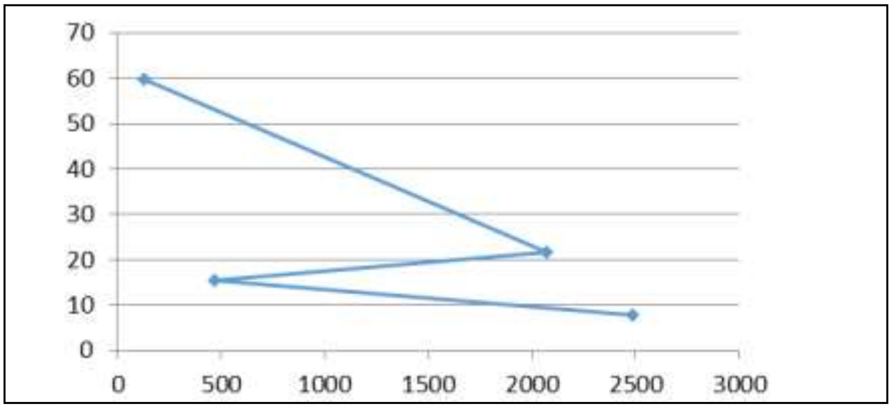

Figure 28: Percentage ratio of sample's displacement according to Load2 compared with Load1

CONCLUSION

As it was mentioned in section 1-3-4 among the 11 soil samples, seven of the soil samples analyzed with corrected Drucker-Prager's warhead model (the F samples) and other 4 samples with Drucker-Prager's model (the S samples) and the finite element ABAQUS software used for modeling and analyzed. Also to study the effect of compressive and lateral loading on soil-structure interaction two pattern of loading Load1 and Load2 have been considered. In Load2 pattern compared to Load1, two times of compressive load and 1.5 times of lateral load applied to the samples. The analyze results for F samples shows that the failure mechanism which rules in these samples is diagonal tensile failure whereas for S samples the mortar joints failure will rule. Also in F samples with increasing of soil's modulus of elasticity the lateral displacement will decreased. Whereas for S samples, this process will not happen all the time. In both F and S samples with changing of loading pattern from Load1 to Load 2 the lateral displacements were drastically decreased in a way that for F samples this decreasing ratio was from 43% to 5%. And for S samples this decreasing ratio of displacement is from 60% to 8%.

Recommendations for Future Studies

For future studies below studies will be recommended:
Dynamic evaluation of soil-structure interaction with recording different earthquakes.
Evaluations with alloys with inbuilt memory to control the failure mode of masonry buildings
Evaluation of soil-structure interaction in masonry structure's frequency
Evaluation of soil-structure interaction according to design and operation

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