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THE SSI EFFECTS ON SEISMIC RESPONSE ASSESSMENT OF MASONRY BUILDINGS

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ABSTRACT

Masonry buildings are one of the most common building types in rural areas especcially for developing countries. Investigation of their behavior during the earthquakes is very important. For understanding their accurate behavior, boundary conditions should be defined accurately. It is valid especally for their support mechanisms. Therefore, soil-structure interaction is one of the important issue. It is also an important concern for earthquake engineers to define earthquake behavior exactly of the masonry buildings. Buildings designed without considering soil-structure interaction effect, may behave different then predicted. Hence, Soil-structure interraction should be considered for an accurate structural definition. In the present study, soil-structure interaction for masonry buildings was investigated. A masonry building with several structural damages from March 8th 2010 in Elazig Kovacilar earthquake was selected and investigated as an representative building. In the study, 3 different soil profiles and linear springs for each soil profile with different stiffness coefficient were defined. Time history analysis was carried out through Elazig Kovacilar earthquake by considering soil-structure interaction system. In the time history analysis, data from March 8th, 2010 Elazig Kovacilar earthquake were used. As a result of the study, importance of soil-structure interaction behavior in an accurate behavior was demonstrated through base shear forces and displacements. The results were evaluated comparatively for different soil profiles.

KEYWORDS: Masonry Buildings, Finite Element Method, Time History Analysis, Soil-Structure Interaction.

INTRODUCTİON

Mosonry buildings are built commonly in rural areas in generally in developing countries. Even in the economically established countries, similar structural types are seen in various urban units. During an earthquake, a chracteristical behavior is observed in masonry buildings due to its heavy and brittle characteristics. Masonry buildings have a complex behaviour depending on various parameters such as the presence of rigid or flexible slabs, on the presence of seismic devices, the general quality of the masonry. General structural behaviors of masonry buildings in various loads are demonstrated in Figure 1 (Cogurcu and Kamanli, 2007). Investigation of their behavior during the earthquakes is very important. For understanding their accurate behavior, boundary conditions should be defined accurately. It is valid especally for their support mechanisms. Therefore, soil-structure interaction (SSI) is one of the important issue.

Buildings are forced out of their loads under efect of earthquake, it causes damages on buildings. According to the caracteristics of the ground layers, damages at the buildings are varied. Thickness of the ground layers, consistency, flexibility and plasticity are parameters that changing the properties of earthquakes. While earthquake waves are passing through the ground layers, the properties of waves and the behavior of the buildig change due to the difference of ground layers. Buildings affects the ground as a result of ground affects the buildings. Records which are recieved with and without buildings in the same area during earthquake, are different from each other, observed differences were at the basis of the buildings and at the ground not far from the buildings basis points. These differences show that, the building affects the ground (Karabork, 2009). When buildings are desined, it is considered that the shape of ground does not change, buildings basis connected to the ground as fixed and earthquake load does not effect the building. But this situation is used only where there is no significant soil-structure interraction (Elmas, 2005).

There are many studies crried out in this era. Karabork (2009), to investigate the affect of ground properties on buildings under an earthquake, created threedifferent building models with same plan and rigidity for two different ground types. Analyses were performed using SAP2000 program with time history analysis. Caglar vd. (2005), investigated the affect of ground properties under an earthquake on buildings. Dynamic analyses were applied to soil-structure model in time history domain by using finite element method. Dynamic analysis of the model was created by using 1999 Marmara earthquake data with SAP2000 software

(Caglar et al., 2005). Karabork et al. (2010) studied dynamic behavior of soil-structure interaction under the influence of multi storey buildings on soft ground. As dynamic load, Marmara earthquake's North-South acceleration records were used which were taken from Yarımca-Petkim station. As a result of analysis which were made by SAP2000 software, soil-structure interaction were compared with the values of period, fold acceleration values, relative displacements of building, base shear forces and axial force, shear force, bending moment for an element (Karabork et al. 2010). Elmas et al. (2005), examined the effect of seismic behavior of the reinforced concrete buildings which has same plan and ground rigidity with different carrying capacities. The analysis models were made with different spring factors. SAP2000 software and data which were taken from Yarimca -Petkim in Kocaeli was used (Elmas vd., 2005).

Previous studies have shown the necessity of the SSI effect. Chaallal and Ghlamallah (1996) searched the seismic performance of 20-story models that have regard to SSI effect. Spyrakos and Chaojin (1996) analyzed systems that had been modeled for one degree of freedom under the influence of different factors such as soil hardness and type of foundation. Han (2002) studied the seismic behavior of a 20-story frame building by considering the soil-pile interaction. Jahromi (2009) has shown the impact of soil–structure interaction on the design of buildings. Farghaly and Ahmed (2013) performed a 3D timehistory analysis of structure-foundation-soil system models under strong earthquake ground motion. Jiang et al. (2013) took the Shanghai Tower and discussed the influence of the SSI on the dynamic properties and seismic displacement responses. Baragani and Dyavanal (2014) have quantified the effect of interaction behavior on 4 and 7-story buildings. Karapetrou et al. (2015) investigated influence of soil depth under nonlinear soil behavior of a 9-story RC building designed with low ductility for the fixed base and SSI models.

In this study, a masonry building which is located on different layers of ground was modelled and defined with springs, for different surfaces different spring factors are used. Masonry building as a shell and different ground layers were modelled at 12 different profile with SAP2000 finite element software. Masonry buildings were compared with displacements and base shear force values with time history analysis. For the time-history analysis, acceleration records of earthquake in Elazig-Kovacilar on March 18th 2010 was used.

Masonry Buildings in Turkey

History of masonry buildings in Turkey goes years back. There have been so many masonry buildings in Istanbul from Ottoman period. From the history to now, construction technology of masonry structures has not changed significantly. In some rural areas in Turkey, masonry building technology has still been applied in same way, which is mainly composed of units and mortar. Bricks, blocks, adobes, ashlars, irregular stones and others are typical masonry units (Altin et al., 2005). Wood and steel were also used for different purposes in historical masonry structures.

In the recent earthquakes, most of the existing buildings including masonry buildings got damage. Therefore, earthquake behavior and vulnerability of existing masonry buildings are very important. Assessment of the masonry buildings considering seismic capacity is one of the essential steps in earthquake assessment point of view (Celep, 2001).

In the literature, there are various research studies for masonry buildings. However, it is difficult to find studies for Turkish type of historical masonry buildings. Some researches worked on real mechanical specifications of masonry buildings via application of numerical methods. They also set up an experimental design for masonry buildings (Kanit and Isik, 2007; Kanit 2007).

In Turkey, typical old masonry building sample could be seen in rural areas. Most of them are single- or double-story buildings. They generally don't have any project or application profile. They have been built by owners of the buildings. In Figure 2, some of the examples of old masonry buildings are demonstrated. In the recent Turkish earthquakes, most of them get damaged. The main reason of the damage is the poor construction. In Figure 3, some examples of failure from Elazig earthquake (Mach 8th, 2010) are demonstrated. Some of the recent research works focus on the damage reasons of masonry buildings.

Structural Analysis of Masonry Buildings

Finite element method is one of the major accounting method which is developed in recent years. Finite element metod is based on Ritz and Galerkin at the beginning of 1900s', later on has reached todays level as a result of using of computers and Courant's studies about solution of partial differential equations in 1943. The essence of the method is establishing and solving of a structural or complex problem with various of equation which defines the system (Vatan, 2005).

In the finite element method, structure, area or object is divided into many small finite elements as seen in Figure 4 (Mutlu, 2005). It is getting much more closer to the geometry of material When the number of finite elements are increase. Thus the solution of the problem can be done for small and selected points, not for the whole system. Then the solution of the whole system can be reached by bringing all the parts together. For example, finite element method can be used and can be obtained realistic results when objects that do not have a smooth geometry or non linear material behavior (Mutlu, 2005).

For complex-shaped structures such as masonry buildings, the elements are expressed with finite-sized elements in finite element method and considered that these elements are connected to each other from the nodes of their corners (Vatan, 2005). Any geometry and material properties for a required element can be created easily with finite element method. Becasue of these reasons finite element method can be available for complex loading conditions, boundary conditions and multi-layer ground problems.

Masonry consists of mainly unit element and mortar. Most common unit elements are brick and stone. Mortar is used for connecting the units each other. Compressive strength, tensile strength, durability, shear strength, water absorption coefficient and thermal expansion affect the load bearing capacity of masonry (Ozcebe, 2002). Numerical modeling of masonry structures through the FEM is very complex. Masonry structures include blocks connected by mortar joints that is geometrical complexity, and reflected in the computational effort needed. Modelling of joints is specificly important, since the sliding at joint level often starts up the crack propagation. The mortar joints in the masonry buildings cause the masonry to be anisotropic. Two different approaches have been adopted to model such anisotropy: the ‘micro-model’, or ‘two-material approach’ and the macro-model. In both models, the discretization follows the actual geometry of both the blocks and mortar joints, adopting different constitutive models for the two components. In FEM applications, the system is meshed in finite members instead of driving equations. The meshed members are solved considering the whole system. The boundary conditions members are superposed to form the equations in the matrices for the whole system.

In the present study, to understand the structural behavior of the masonry buildings with various soil-structure interactions, a masonry building was modelled. Modelled building was selected from one of the masonry buildings with damage from earthquake in Elazig-

Kovacilar on March 18th 2010. The representative building is shown in Figure 5. The Building was modelled with different soil-structure interactions.

Nonlinear dynamic time history analyses have been employed to the representative masonry buildings. An extraordinarily important step for application of time history analysis is the selection of a representative earthquake. Here, in the analyses, March 18th, 2010 Elazig-Kovacilar earthquake data was selected for the analysis as detailed in Table 1.
The results of nonlinear time history analysis for representative masonry buildings are presented for comparison.

Time-history analysis is a method used for determining time-dependent behavior of buildings under dynamic loads. In this analysis method, analysis is carried out by appliying earthquakes data directly to the building. In the present study, it was considered that building remains elastic. Real period of building is designed by number of modes and therefore these analysis are desciribed as the most accurate analysis affected by the behavior of building (Karaduman and Donduren, 2004).

Step by step numeric integration of motion equation in time domain is a common system solution method under the influence of ground motion. It is needed to be written the equation of motion system to determine the dynamic behavior of a system. Generally, use of time history analysis is; recording acceleration or ground forces of earthquakes in a specific direction and time frame.

X-Y directional base shear values, X-Y directional maximum displacements, X-Y directional maximum stress and first period values of the models which were created in dynamic analysis in time-history analysis were obtained by using Elazig earthquake accelerations with SAP2000 software.

Structural Properties of Masonry Buildings

The masonry structure has higher compressive strength and lower tensile stress. This property of the masonry structure is very important that the structural form of masonry constructions is based on compressive forces. The masonry material is brittle. Sudden failure occurs in tension loading. Fracture energy is the absorbed energy until the failure time. It can be determined calculating the area under stress-strain diagram (Figure 6) (Mendes et al., 2010). Strength of stone masonry depends on the material properties and bond type of units. The stone is massive and stiff. Type and thickness of mortar is more effective on the compressive strength of stone masonry than stone units. The strength of stone does not much effect to stone masonry. The joint behavior of unit and mortar determines the strength of stone masonry. If the mortar strength is weaker than units, masonry strength primarily depends on the strength of mortar. The shear strength of the stone masonry is approximately 25% of the compressive strength. Different types of stone masonry are shown in Figure 7 (Mendes et al., 2010).

Soil-Structure Interaction

Over the last decades, nonlinear procedures have been widely used in engineering practice to predict seismic demands in masonry buildings in seismically active regions. However, due to the lack of considering soil-structure interaction (SSI), analysis results may be unrealistic. SSI can be significant for stiff buildings such as masonry buildings founded on soft soils. Unconsidered soil effects may lead to the unreliable decisions in the design these buildings. Therefore, variable soil properties which can significantly affect the building behavior should be taken into account. Seismic assessment is the first step within adopting retrofit strategies to reduce the seismic risk. For better understanding the behavior of the buildings, all the pertinent sources affecting the motion should be modelled appropriately. For instance, the flexibility of soil leads to a reduction of stiffness. Hence the deformation capacity of buildings increase. This phenomenon is not taken into account in many seismic codes. When fixed base approaches are adopted, non-uniform soil profiles, embedded foundations, foundation flexibility and shapes cannot be considered in the analyses.

During the recent earthquakes experienced in various parts of the world, such as the 1985 Mexico City, the 1995 Kobe and the 1999 Kocaeli earthquakes, soil structure interaction has played an important role for the response of seismic activity in existing buildings (Chu, 2002). With the technological development, considering SSI in the analyses is possible however, it is still a demanding procedure for daily routine analyses. Existing research work demonstrated that soil structure interaction is critical for many cases.

Soil-structure interaction is defined as the effects of changing the shape of building to ground deformation and building internal forces (Caglar, 2005). Recent earthquakes such as 1985 Mexico City, 1989 LomaPrieta, 1992 Erzincan, 1995 Dinar, 1999 Marmara and Düzce has clearly shown that building deformations and dynamic performances of buildings are effective on Soil-structure interaction. Earthquake motion is transmitted to building through its basis. Dynamic loadings such as earthquakes, building and ground motions are conjuncted with each other, because of that their behaviors are affected from each other and at these loadings, basis could be in different locations on the ground. Evidences shows us first frequencies of the damaged buildings is approximately equal to frequency of the ground layer where building is located. This event shows us the impact of ground to earthquake behavior more than soil-building interaction (Elmas, 2005).

In the structural analysis, there is no rotation and displacement at the basis of building but even at the design of the building systems under static load has rotations and deflections (Caglar, 2005). However, buildings are usually assumed as fixed to the ground which is not accurate unless a rock is very close to the surface of ground and ground motions created by earthquake is not affected from the building on it. This assumption is getting far from reality when the flexibility of the ground increases, its strength takes low values or lack of sufficient rigidity of the basis system (Livaoglu et al., 2005).

Usually, soil-structure interaction increases when structure ground variability and structure rigidity is increased (Gursoy, 2006). Generally soil-structure interaction consider with, the geological structure of the ground and the distance parameter from focus of the earth. Distance from the focus of earthquake, is classified as "map of earthquake zones" and defined as maximum effective ground accelerations given by equivalent acceleration curves occured in hard rock (Elmas, 2005).

During an earthquake, ground generates important significiant changes in dynamic properties of the buiding such as periods, damping ratios and mode shapes. For instance, reactions of the building located on soft surface and hard surface are different from each other. Predicted behavior of the building during an earthquake is related with ground properties. When elasticity decreases in the ground, rigidity of the building increases and the frequency of structure–ground decreases. Also the impact of the earthquake on buildings is felt more (Korkmaz ve Carhoglu, 2009).

SSI should be considered for a better accuracy in detailed analyses as touched in many designed codes. Early SSI development was motivated by the seismic design of nuclear power plants. In the analyses in which soil structure interaction is taken into consideration, the natural periods of the structures and axial forces are changing with soil properties. To investigate the effects of soil properties, nonlinear spring models are used and the models were compared. Figure 8 demonstrates the supoort with fixed and springs. In the analyses, structural dynamic interaction between superstructure and substructure are mainly considered with two interactions as inertial and kinematic. Kinematic interaction is referred to the deviation of ground motion due to presence of a stiff foundation with/without mass and inertial interaction is a consequent deformation of foundation soil due to induced base shear and moments from the superstructure (Mylonakis et al., 2000a, b, Panagiotakos and Fardis, 1996; Shing, and Mehrabi, 2002). The relative importance of these two components depends on the foundation characteristics and nature of incoming wave field (Arefi, 2008).

In the study, soil-structure interaction is defined with springs. The rigidity values are calculated with spring coefficients. Spring coefficients method is one of the oldest method which considers the ground and elastic basis deformations (Keleşcioğlu and Çinicioğlu, 2000). Spring coefficient concept has been proposed first time by Winkler. This teory is based on; the ground is elastic and springs are independent, close, adjacent from each other. As a result, ground is regarded as a completely discontinuous enviroment. (Karaca vd., 2007). The ideal ground enviroment model proposed by Winkler, he is considered that the effect of ground (p) is proposional to beam collapses (y) and the forces which act to the ground changes their shapes only at their acting point. Winkler hypothesis is defined as p = ks * y, where, "ks" coefficient is defined as the load that should be installed per unit area to obtain downfall. "ks" is called as spring coefficient and coefficient could be constant or variable for the ground (Mutlu, 2005).

In this study, a damaged masonry building in Elazıg Kovacilar eathquake was modeled with SAP2000 software as shown and spring connections are used in the models developed for various soilconditions as given in Figure 9. Building material is defined as fair and mudbrick. Modules of elasticity, poisson ratio and unit weight of the material used in brick masonry building is given in Table 2. Approximate spring coefficients for used ground types are shown in Table 3.

Spring coefficient is a function of loading conditions, stratification, physical properties of ground, basis rigidity and rigidity of the upper structure. Spring coefficient cannot be defined as physical constants. Spring coefficient, varies according to the soil-structure interaction. In fact, this parameter is an indicator of stress-deformation relationship for any ground-basis. There are many different empirical proposals for determining the value of "ks" but there is no generally accepted method for displacement calculation in literature.

In the research, spring rigidity was defined with soil spring coefficient. As given in Table 4, selected ground types as sand, hard clay and rock are considered in 12 different combination with springs which have different rigidity values. Table 5 shows the used gorund profiles in modelling of the masonry building. Total ground height was taken 6m. The masonry building height which is used in the model is 3m. Displacements and base shear forces were found by using time-history analysis.

Table 1: Ground Motion Data Used in the analyses.

Earthquake	Date	Time	Magnitude
Elazig-Kovancilar	08.03.2010	02:32:29.96(GMT)	5.8

Table 2: Material properties of masonry building used in analysis.

Material	Elasticity module (KN/m^2)	Unit Weight (kN/m^3)	Poisson Ratio
Masonry	1,400,000	1.7	0.3

Table 3. Spring Coefficient for Soil Types.

Soil Type	K_0 (kN/m^3)
Full, organic	5000-10000
Sand	15000-20000
Hard Clay	20000-50000
Rock	200000-600000

Table 4: Soil Properties used in analysis

Material	Elasticity module (KN/m^2)	Unit Weight (KN/m^3)	Poisson Ratio
Sand	60,000	20	0.3
Middle Hard Clay	47,000	15.70	0.4
Rock	50,000,000	26	0.28

Table 5: Profiles used in SSI.

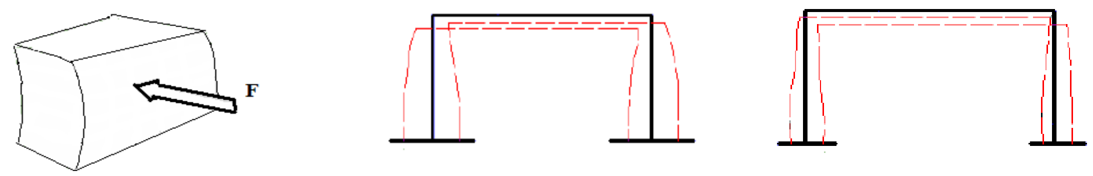
Models	Ground Condition
1	Sand 2m, Hard Clay 2m, Rock 2m
2	Hard Clay 2m, Sand 2m, Rock 2m
3	Sand 4m, Rock 2m
4	Hard Clay 4m, Rock 2m
5	Hard Clay 3m, Sand 3m
6	Sand 3m, Hard Clay 3m
7	Rock 6m
8	Hard Clay 6m
9	Sand 6m
10	Hard Clay 2m, Sand 3m, Rock 1m
11	Sand 2m, Hard Clay 3m, Rock 1m
12	Sand 3m, Hard Clay 2m, Rock 1m

Table 6: Period values obtained from analysis.

Model	T1	T2	T3	T4
1	0,032876	0,32396	0,32390	0,032254
2	0,032876	0,32396	0,32390	0,032254
3	0,091451	0,088426	0,088426	0,085720
4	0,091451	0,088426	0,88426	0,85720
5	0,117207	0,114456	0,114391	0,108534
6	0,121285	0,117207	0,114456	0,109662
7	0,091451	0,088426	0,088426	0,085720
8	0,121285	0,117207	0,114456	0,109662
9	0,116427	0,114456	0,114391	0,108534
10	0,121285	0,117207	0,114456	0,109662
11	0,1212285	0,117207	0,114456	0,109662
12	0,121285	0,117207	0,114456	0,109662

Table 7: Displacement Values, Shear Values and Stress Values.

Displacement Values			Shear Values		Stress Values	
Models	**X (m)**	**Y (m)**	**X (kN)**	**Y(kN)**	**X (kN/ m)**	**Y (kN/m)**
1	-0,001481	-0,001405	- 901,332	-1153,82	-796,97	-1749,83
2	-0,001481	-0,001405	-901,332	-1153,821	-901,332	-1153,821
3	-0,083252	-0,079859	-4931,889	-8901,544	-11703,44	-44194,81
4	-0,012087	-0,010798	-702,839	-1313,71	-702,839	-1313,71
5	-0,019868	-0,016929	-2240,852	-1567,909	-5249,16	-6486,93
6	-0,019882	-0,027439	-2240,882	-2505,199	-5254,78	-8991,83
7	-0,012087	-0,010798	-702,839	-1313,71	-1661,94	-6562,61
8	-0,019882	-0,027439	-2240,822	-2505,199	-5254,78	-8991,83
9	-0,018134	-0,016929	-904,837	-1567,912	-2966,37	-6484,94
10	-0,019882	-0,027439	-2240,822	-2505,199	-5254,78	-8991,83
11	-0,019882	-0,027439	-2240,822	-2505,199	-5254,78	-8991,83
12	-0,019882	-0,027439	-22,885	-42,929	-5254,79	-8991,87



(a) Resultant inertia force (b) Logitudinal Behavior (c) Transversal Behavior

Figure 1: The General Behavior of Masonry Buildings Under the Earthquake Effect (Cogurcu and Kamanli, 2007).

Figure 2: Some examples for Turkish old masonry buildings.

Figure 3: Some examples of masonry failures.

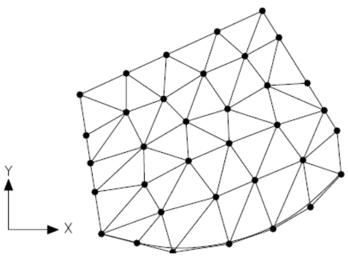


Figure 4: Seperation of Irregular Shaped Plate to Triangular Finite Elements (Mutlu, 2005).

Figure 5: Damaged masonry bulding in Elazig – Kovacilar used in the study.

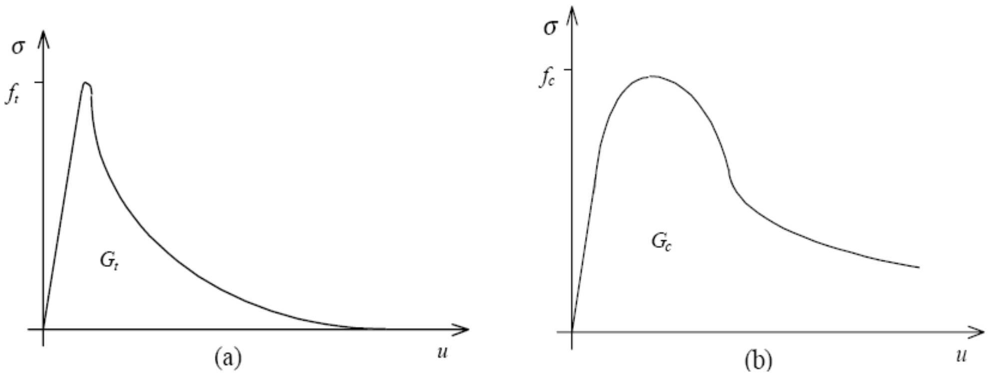


Figure 6: Typical behavior of quasi-fragile materials under uniaxial loading and definition of the fracture energy a) tension loading b) compression loading (Mendes et al., 2010).

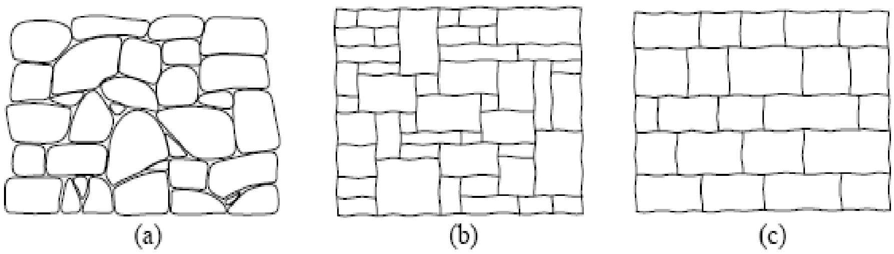


Figure 7: Different kinds of stone masonry: (a) rubble masonry, (b) ashlar masonry; c) coursed ashlar masonry (Mendes et al., 2010).

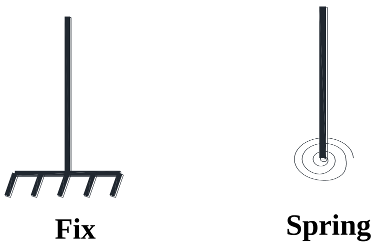


Figure 8: Demonstration of the supoort with fixed and springs.

Figure 9: Ground profiles layers which is used in analysis.

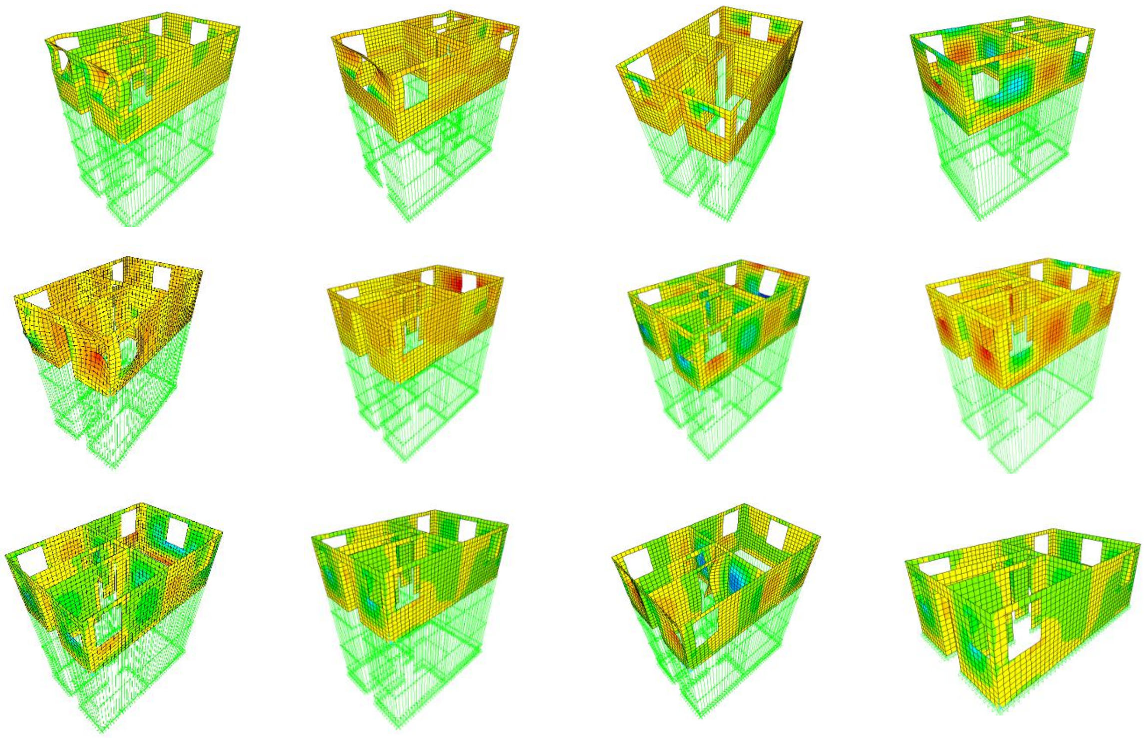


Figure 10: Stress distribution obtained from analysis in X-direction.

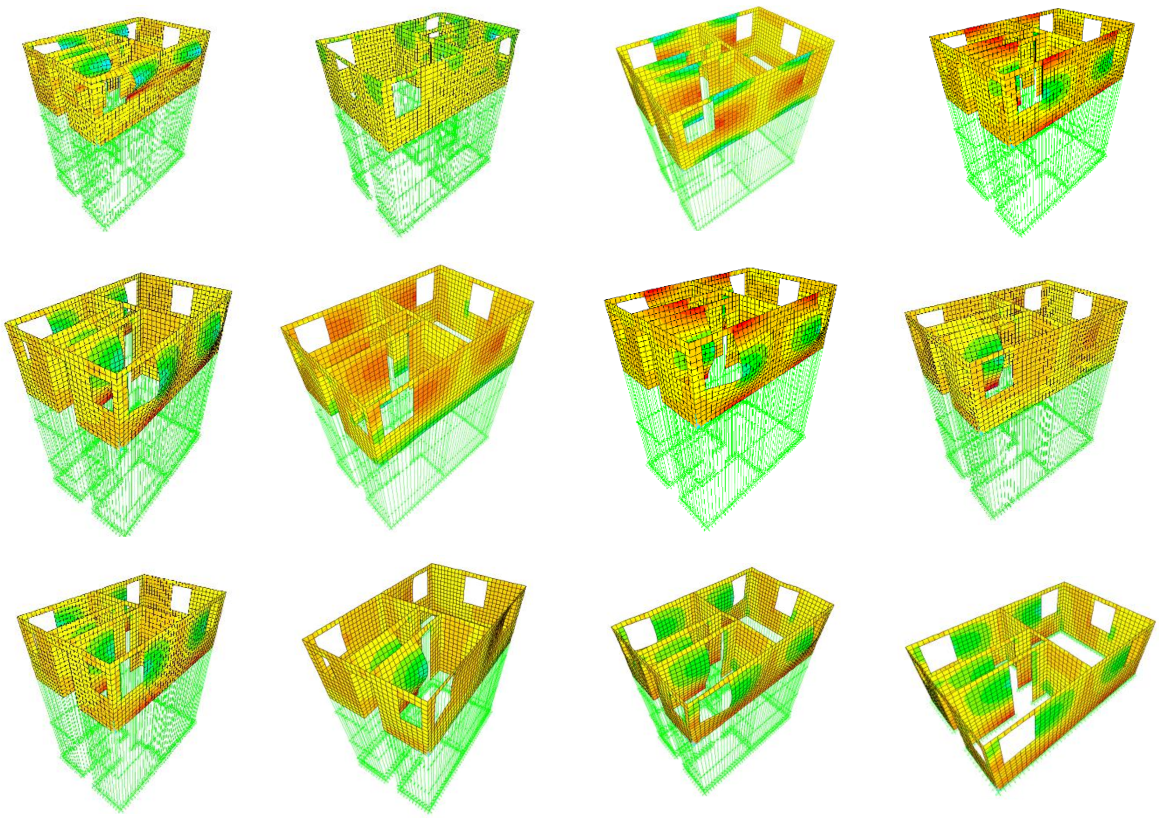


Figure 11: Stress distribution obtained from analysis in Y direction.

CONCLUSİON

As a result of the analysis, values of maximum displacement, maximum ground shear and maximum stress values were obtained for each structure-ground model. Period values which were obtained from the result of analysis and X-Y directional stress values are shown Table 6. Values of maximum displacement, maximum ground shear and maximum stress were given in Table 7. In Figures 10 and 11, stress distributions are given fo X and Y direction respectively.

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