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Numerical Simulation of a Building on Shaking Table

Hudhaifa Mohammed A., Serkan Bekiroğlu
[1]*Department of Civil Engineering, Yildiz Technical University, İstanbul, Turkey*

Abstract

The shaking table test of a structure has a very important role in the understanding of the dynamic behavior of the structure. In conjunction with the shaking table, a seismic simulation of the building, bridge, and underground structures can be conducted up to the collapse stage. Traditionally, engineers have used laboratory test to investigate the structural behavior of building products and systems subject to the expected wind and earthquake loads and to develop appropriate design rules. Laboratory testing was also used to develop new building products and systems. However, laboratory testing has time- consuming and expensive effects so that numerical analysis can be included to optimize or minimize these effects. In this study, a three-dimensional finite element analysis of a shaking table (substructure) model and model of a one-story and one-bay building (superstructure) was conducted together using the ANSYS program. A linear dynamic analysis was carried out under displacement-controlled cyclic loading to find the overall strength of the substructures and superstructures and to get imagine about the collapse styles and failure mechanism.

Keywords: finite element analysis, ANSYS workbench software, shaking table model.

1. INTRODUCTION

It is well-known that the shaking table model test is one of the most effective ways to study the dynamic performance of complex structures, and it is an important and useful method to help structural engineers get better knowledge about the dynamic behavior and seismic response of the buildings [1,2]. Not only can engineers study the damage mechanism, the failure pattern and the dynamic response of the structure, but also weak points in the structure can be exposed [3]. The building such as special and complex structure system which are far beyond the limitation of interrelated codes should be firstly studied through the experiment on seismic behavior to investigate the structural response, the weak points and crake pattern under loads of different levels and to help the designers improve the scheme [4]. The seismic response of a building structure depends on its dynamic properties and characteristics of input ground motions. Nowadays, after calibration with experiment is carried out the static and dynamic properties of structures can be approximately calculated using computer softwares [5]. Advance analysis method based on Finite Element is the best suited to analyze complex structures in three dimensions [6]. In this study, a shaking table model with prototype of building are modeling and simulated using ANSYS workbench software, including the structural system characteristics, model material selection, similitude relationship and simplification of the model design [7]. By using numerical analyses (modal and dynamic analyses) the dynamic property, mode shapes, acceleration and displacement responses of the model structure are investigated and make comparative of the results in different cases of analyses with different loads and boundary conditions.

2. FINIT ELEMENT MODELING

By using a finite element method, a shaking table model (substructure) and model of a one-story building (superstructure) were modeling using ANSYS Workbench. In the finite element analysis, the solid elements were used with hexahedral mesh (regular mesh) including total 98934 elements, 481328 nodes, and approximately 1.9 million degrees of freedom. The surface-to-surface contact element was taken into consideration by using two types of contact such as bonded, and no separation [8]. The geometry modeling is shown in Fig.1 and modeling details are described as below.

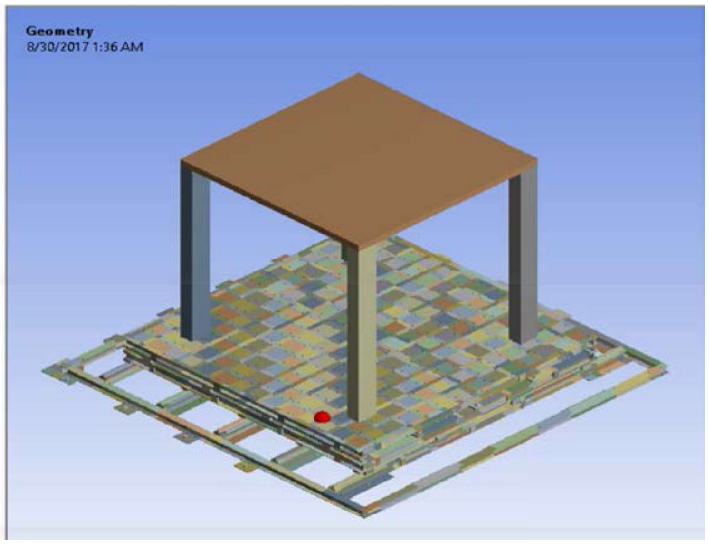


Fig. 1 Geometry model

2.1. Geometry Modeling

In this study three dimensional-modeling approach was chosen for analyzing the specimen. The geometry of model created by using design modeler with ANSYS Workbench, it consists of a shaking table (Substructure) model and model of one story concrete building (Superstructure). A shaking table model which have dimension of 4m x 4m and bearing capacity of 50 tons, acceleration up to 4.5g and speed up to 1m/sec. The geometry of shaking table divided into three steel frame layers' bottom, middle, top layers and top cover plate as show in Fig.1. The main section of steel frames is made of (I-section profile). these frames layers which contact together by pace plats, side plats and cars. The superstructure consists of one bay concrete frame and dimension of column is 0.3x0.2x3 m and for slab is 3x3x0.1 m.

2.2. Defining Materials properties

The materials properties of the model were defining in engineering data with ANSYS program, Table. 1 lists the material properties of steel structure for shaking table and concrete properties for up structure building.

Table .1 Materials properties

Member	Material	Density (kN/m^3)	Young's Modulus (MPa)	Poisson's Ratio	Yield Strength (MPa)	Compressive Strength (MPa)	Tensile Strength (MPa)
Shaking Table	Steel	76.98	2E+05	0.3	250	250	460
Building	Concrete	22.55	30000	0.18	4	41	5

2.3. Meshing of Model

After simplifying the geometry of model the mesh is created by using mesh control/sizing, multizon, mapping face mesh [9]. and in order to get more accuracy results a hexahedral mesh are used in this model as show in the Fig. 2.

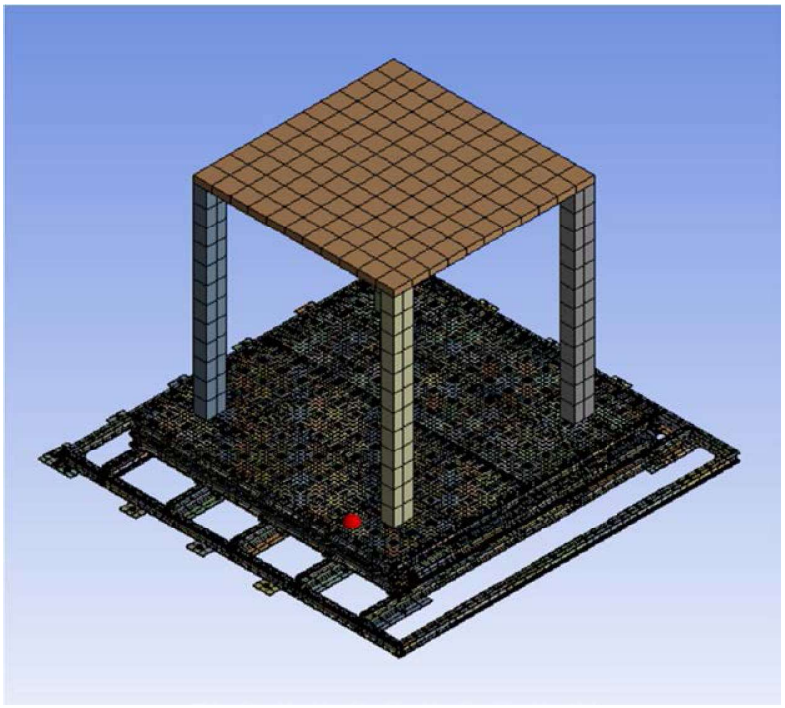


Fig. 2 Mesh of model

2.4. Contact

One important thing when dealing with multipart geometries is contacts between parts. In ANSYS the surface-surface contact is generated for parts of model [10]. In this model surface to surface contact are created by using some types of contact such as:

- **Bounded**: No penetration, no separation and no sliding between contact faces and this type of contact created for all most parts of model.
- **No separation**: Similar to bounded, except frictionless sliding can occur along contact faces and this type apply between cars and sliding line faces.

2.5. Loading and Boundary Conditions

In order to understand the dynamic behaver of shaking table model and building, in this model there are three type of boundary conditions are used:

Fixed support: between bottom surface of a shaking table and sub ground which work to fix the model from motion in any directions as show in Fig. 3(b).

Frictionless support: which apply on side face of cover plat and side face of top flange with X-direction and work to fix the top part of model from move with X-direction as show in Fig. 3(b).

Harmonic displacement load: displacement 20 cm is applied in X and Z-direction with middle frame layer and top part of shaking table in two cases as show in Fig.3 The harmonic displacement load step is shown in Table 2.

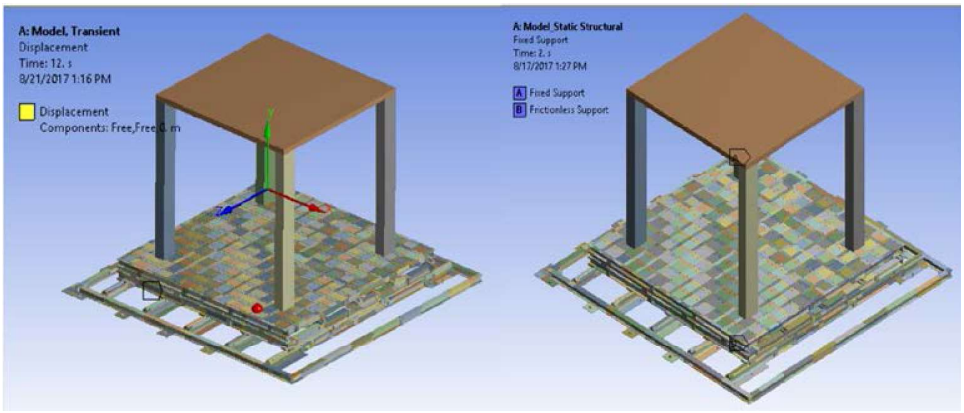
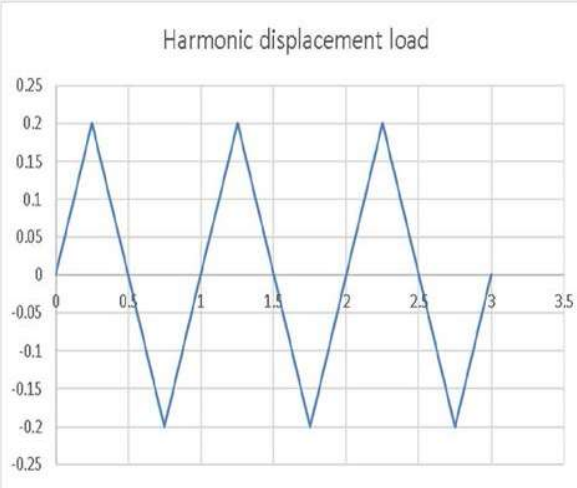


Fig. 3. (a) Harmonic displacement load (b) Boundary conditions (Fixed and Frictionless Supports)

Table 2. Harmonic displacement load step



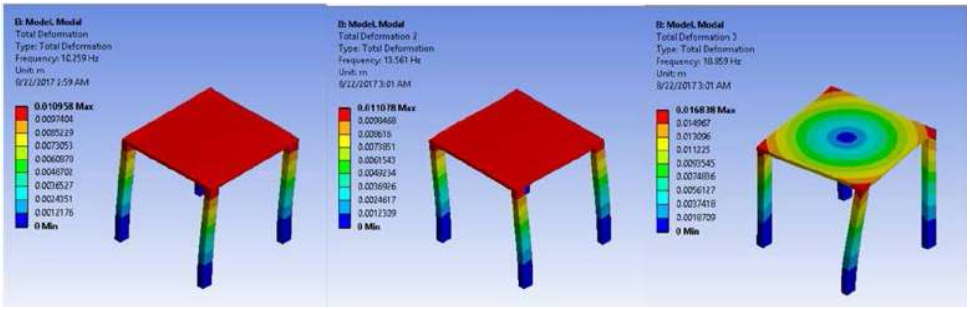
Step	Time	Disp.
1	0	0
2	0.25	0.2
3	0.5	0
4	0.75	-0.2
5	1	0
6	1.25	0.2
7	1.5	0
8	1.75	-0.2
9	2	0
10	2.25	0.2
11	2.5	0
12	2.75	-0.2
13	3	0

3. ANALYSIS PROCEDURES

The main idea of the analysis is to understand the behaviour of the structure under dynamic load. and to obtain a valid and adequate model that can used in simulation the of specimen. For this reason, two model were generated. In the first model, the effect of shaking table was ignored and the base of the superstructure was considered as fixed. In the second model the shaking table was included in the model in order to check adequacy of the model and the performance of shaking table and structure. Two type of analysis such as model analysis and dynamic analysis were run using ANSYS Workbench. The results of frequency, displacement, stress, acceleration and strain are carried out and compared in different cases.

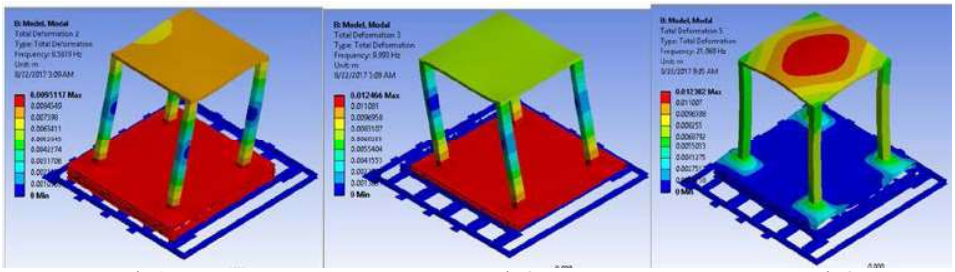
3.1. Model analyses

Model analyses were performed to obtain frequencies from the two models developed. The first three mode shapes are given in Figs. 4.1 and 4.2 for the case of fixed base and shaking table, respectively. The frequencies and periods obtained from modal analyses are compared in Tables 3.1. and 3.2. respectively. As can be seen from the results the fixed based model is more stiff and so yields larger frequency values as compared with other model results. Considering the high stiffness of the shaking table, the finite element representing the shaking table were assumed to remain elastic and almost infinitely rigid. The total mass of the shaking table was uniformly distributed to these finite elements. It appears that the modal properties obtained from the model with shaking table are much acceptable compared with other ones.



Mode 1 Mode 2 Mode 3

Fig. 4.1. First three modes of the structure calculated with fixed base model



Mode 1 Mode 2 Mode 3

Fig. 4.2. First three modes of the structure calculated with fixed shaking table model.

Table 3.1. Comparisons of frequencies from numerical models results

Mode	Frequency (Hz)	
	Model with fixed base	Model with shaking table
Mode 1	10.259	8.5619
Mode 2	13.561	9.993
Mode 3	18.859	21.969

Table 3.2. Comparisons of periods from numerical models results

Mode	Periods -T (second)	
	Model with fixed base	Model with shaking table
Mode 1	0.0974	0.116
Mode 2	0.0737	0.1
Mode 3	0.053	0.0455

3.2. Dynamic analysis

In the next step a liner dynamic analysis with harmonic displacement was done and the results are carried out using ANSYS Workbench software. The goal of the analysis is to obtain the performances of shaking table and superstructure in dynamic state and to determine the dynamic response of a structure under the action of any general time-dependent loads.

In this analysis the model of superstructure with shaking table was used and the harmonic displacement load was applied as shown in Table 2, the time step of the load was 0.25 second with 3 cycles and the boundary conditions were applied using fixed support in the bottom face of shaking table which work to fix the model with sub ground, and frictionless support which applied on the top part of table and work to fix the model with X-direction as shown in Fig.3(a), (b).

The important dynamic results such as displacement, stress, strain, drift, and acceleration were taken on the shaking table and top floor of superstructure and compared with others in different cases. Table 4 shows the comparison of dynamic results.

Table 4. Comparison of dynamic results

Measured points	Direction	Displacement(m)	Drift %	Acceleration m/sec^2
Top floor of superstructure	X	2.15E-06	0.000001	0.000398
	Z	1.14E-03	0.00037	1.101
shaking Table	X	-9.65E-07		0.00011
	Z	2.22E-05		1.133

As seen in Table 4, it is observed that maximum displacement value is 1.14E-03m at top floor with Z-direction because the load applied on Z-direction while the model fixed with X-direction. That leads to maximum drift 0.00037% on the top floor with Z-direction. The second observation is that the maximum

acceleration value of numerical model is 1.133 m/sec^2 occurs on shaking table in Z-direction.

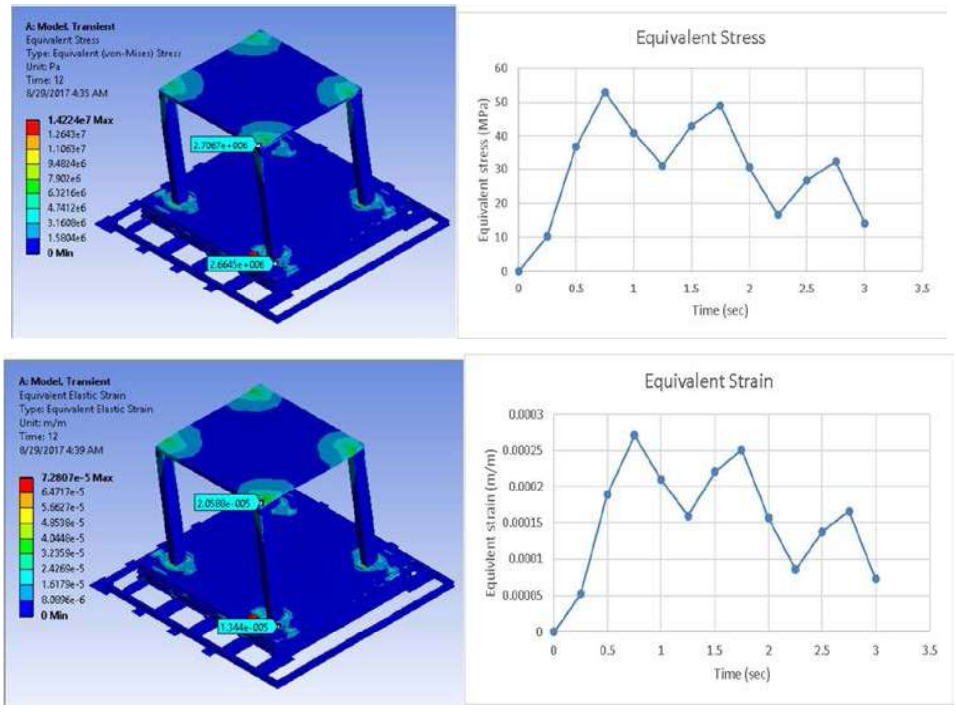


Fig.5. Equivalent values of stress and strain of model analysis

As can be seen from the result in the Fig. 5, the maximum value of equivalent stress and strain of numerical model occurred approximately at 0.75 sec. of the dynamic analysis under the harmonic load, and it can be made a comparison of stress and strain between the superstructure and shaking table with as shown in Table 5. As observed from Table 5, the maximum equivalent stress and strain occurred on the top floor of superstructure.

Table 5. Comparison of Maximum stress and strain

Model	Equivalent stress (MPa)	Equivalent strain (m/m)
Top floor of superstructure	2.71	2.05E-05
Shaking table	2.66	1.34E-05

4.CONCLUSION

In the present study, the numerical simulation of shaking table model and one story building was done and the geometry of structures were modelled and analysed in ANSYS workbench software. The two type of analysis were used such as model analysis and linear dynamic analysis. The results were carried out and compared with each other. The model analyses were performed to obtain the frequencies from two models developed. The first three mode shapes are obtained for the case of fixed base model and shaking table model. The frequencies and periods obtained from analyses are compared with each other. In the dynamic analysis a harmonic displacement load was applied with Z-direction. Displacements, accelerations, stress and strain calculated at different locations and different directions using ANSYS, and the results were compared with each other in different states. The following conclusions of this study can be drawn:

1- From model analysis results we can be seen the fixed based model is more rigid thus yields larger frequency values as compared with other model.

2- The model including the shaking table appeared more flexible than other.

3- From dynamic analysis the maximum value of accelerations of numerical model occurs in shaking table face with Z-direction.

4- The maximum displacement and drift value occurs on top floor of building in Z-direction.

5- The maximum value of equivalent stress and strain occurs in z-direction on the top floor of building.

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