Scientific Research and Essays Vol. 6(2), pp. 283-292, 18 January, 2011
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE10.659
ISSN 1992-2248 ©2011 Academic Journals

Full Length Research Paper

Seismic response of multi-drum classical columns of Apollo Temple at Claros

Bengi Arisoy*, Ayhan Nuhoglu and Emre Ercan

Civil Engineering Department, Engineering Faculty, Ege University, 35050 İzmir, Türkiye.

Accepted 6 December, 2010

This paper presents a small scale experiment investigation on the seismic response of multi drum classical columns. The model of a 1:10 scale replica of a multi drum column of the Temple of Apollo at Claros in Türkiye was analyzed with MSC Marc Mentat software and tested by shaking table applying several earthquake motions and harmonic excitation. In the experimental study, the base motions were applied only in horizontal direction. Experimental results indicated that small scale multi drum models were capable to make large deformations without collapse due to lead poles between drums. The responses of the test model were also compared with the computer-simulation results. This comparison and the overall evaluation of the results obtained throughout the study showed that the results were compatible, effect of the poles between drums was considerably high and any application that increased the frictional force between drums increased the rigidity and linearity of the columns. Observations and the results may indicate a safe way to rebuild the ancient classical structures and to protect afterwards.

Key words: Classical columns, multi-drum, dynamic analysis.

INTRODUCTION

Ancient monuments are great importance because they represent the common cultural heritage of humanity. The Mediterranean region, especially Türkiye, Greece and Italy, has many monumental structures that require strengthening or rehabilitation. Since the most ancient buildings were basically made up of several classical columns or colonnade system, the investigation of the dynamic behaviors of multi-drum columns has gained a special attention in order to generate an effective procedure for restoration of ancient buildings. The general trend in this area of research is to study the seismic vulnerability of multi-drum classical columns, and by this way to determine the earthquake resistance of ancient buildings systematically.

Multi-drum classical columns are built by fitted marble drums that are placed on top of each other, mostly using a metallic shear links between drums, by this way; district-drum column system becomes a continuum column. However, during an earthquake, metallic links (metallic poles) are pulled out or fractured completely; after the shear links are failed, drums slide or rock independently or in group causing column to fail. Therefore, most of the studies on this issue were done with the assumption of ignoring the resistance effect of the metallic shear links; since the columns behave like a rocking blocks. The behavior of the column after links have failed is non linear, and performing an analytical investigation is almost impossible. The rocking behavior of the classical columns is investigated in many papers. Detailed algorithmic information may be found in Psycharis et al. (2000); Tanigucki (2001), Mouzakis et al. (2002), Papantonopoulos et al. (2002) and Konstantinidis and Makris, 2005.

In this study, an experimental setup for investigating results of the earthquake response of a 1:10 scale marble model of a classical column that is a reproduction of the Apollo Temple in Claros, Türkiye (Figure 1). Claros was a prophecy center of Colophon, one of the twelve Ionic cities in Asia Minor, located at Ahmetbeylli-Izmir at west cost of present Türkiye. The region is considered highly seismic and seismic activity of the region is rated at first degree. The Temple of Apollo was built on a marble

*Corresponding author. E-mail: bengi.arisoy@ege.edu.tr.

Figure 1. One of the multi-drum column.

Figure 2. Marble drumof Apollo Temple.

platform measuring 26 by 46 m. The original columns were approximately 9 to 11 m high and each column

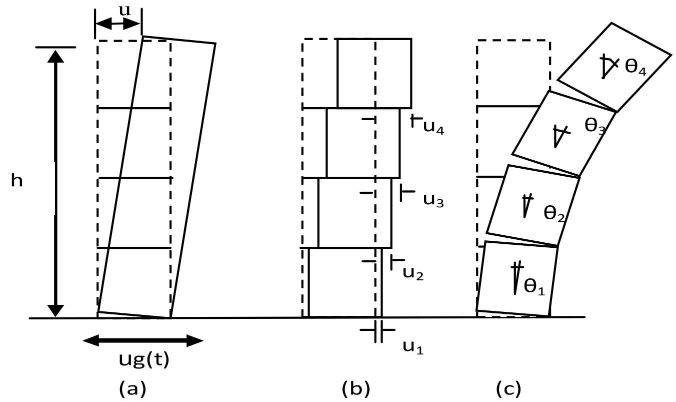


Figure 3. a) Linear behavior, b) sliding behavior after collapse of the connections pins, c) rocking behavior after collapse of the connection pins under seismic excitation.

contained nine to eleven individual drums with different height (Figure 2). 1:10 scale marble model was subjected Düzce 1999; El Centro 1940 (afterwards, they are mentioned as Düzce and El Centro in the text) earthquake motions and 2 and 10Hz harmonic excitations in plane. The model was also analyzed using MSC Marc Mentat computer program (MSC Marc Mentat, 2004). Mentioned analysis programming uses Discrete Element Method to analyze the systems. Detailed information about mentioned method may be found in reference (Munjiza, 2004).

Experimental and analytical results were compared. It is seen that results are compatible. On the other hand, response of a rocking system is size-dependent therefore the experimental results cannot be generalized to the original column.

MATERIALS AND METHODS

Materials

The column under investigation, presented in Figure 1, is one of the columns in Apollo Temple in Claros, Türkiye. The column is composed of multiple marble drums with a pair of lead connectors between drums. The height of drums in each column is not constant depending availability of the ancient marble quarry. On the other hand, in modeling, same size drums were used. The specimen tested was a model 1:10 scale of the original column mentioned above. The marble blocs used in specimen were approximately the same material from which the Apollon Temple was constructed. The model column was composed of 10 marble drums with 150 mm in diameter and 90 mm in height as shown in Figure 4. Drums were connected with two lead shear links (or poles) to each other from each surface shown in Figure 4. Detailed dimensions of the model are given in Table 1.

Methodology

Behavior of the multi-drum marble columns under seismic excitation is presented in Figure 3. The column exhibits linear behavior

Figure 4. Marble drums and shear links.

Table 1. The physical properties of the sample.

Element	Material	Cross section	Original element		Samples	
			Diameter/ Section length (mm)	Length (mm)	Diameter/ Section length (mm)	Length (mm)
Drums	Marble	Circular	1500	900	150	90
Links	Lead	Circular	150	400	0,5	40
Column	Marble	Circular	15000	9000	150	900

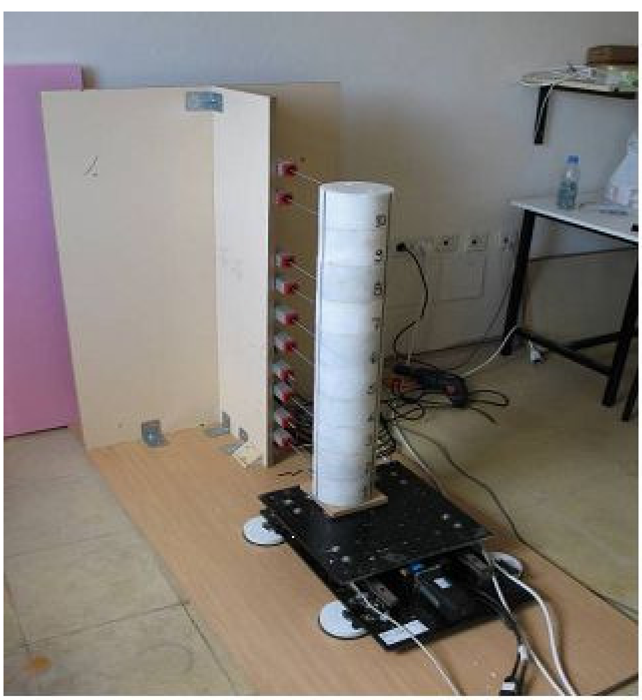


Figure 5. Experimental set up.

(Figure 3a) until the connection pins between the drums fails, afterwards, whichever level that connection pin fails, the drum above mentioned level would either slide or rock (Figures 3 b and c). The shear links between drums are usually made from lead materials. Lead has capability to recover its original shape in ambient temperature after any deformations. These characteristics of lead make the multi-drum column behave continuum linear. Although other materials such as wood and iron were used as connection pins in ancient marble columns, lead was used more widely.

Experimental design

All the experiments were carried out on the shaking table. The table has dimensions 40 × 40 cm and it can move in one direction. The maximum mass carried by the table is about 40 kg. The electricity engine has 400 watt capacity and can produce 1.274 N-m rotations on an infinite shaft. The force produced by the engine can move an 80 kg mass with 2 g acceleration in one direction. The sample column was tested by Düzce, El Centro earthquake motions and 2 and 10 Hz harmonic excitations. Displacements were measured using 8 potentiometers. Potentiometers were placed on table, 2^{nd}, 4^{th}, 5^{th}, 6^{th} 7^{th}, 9^{th} and 10^{th} drums as shown in Figure 5. Potentiometers have measuring capacity of ±100 mm.

Düzce, El Centro earthquake motions and 2 and 10 Hz harmonic excitation with amplitudes 28 and 2.8 mm, respectively, were given to the shaking table as displacements and responses

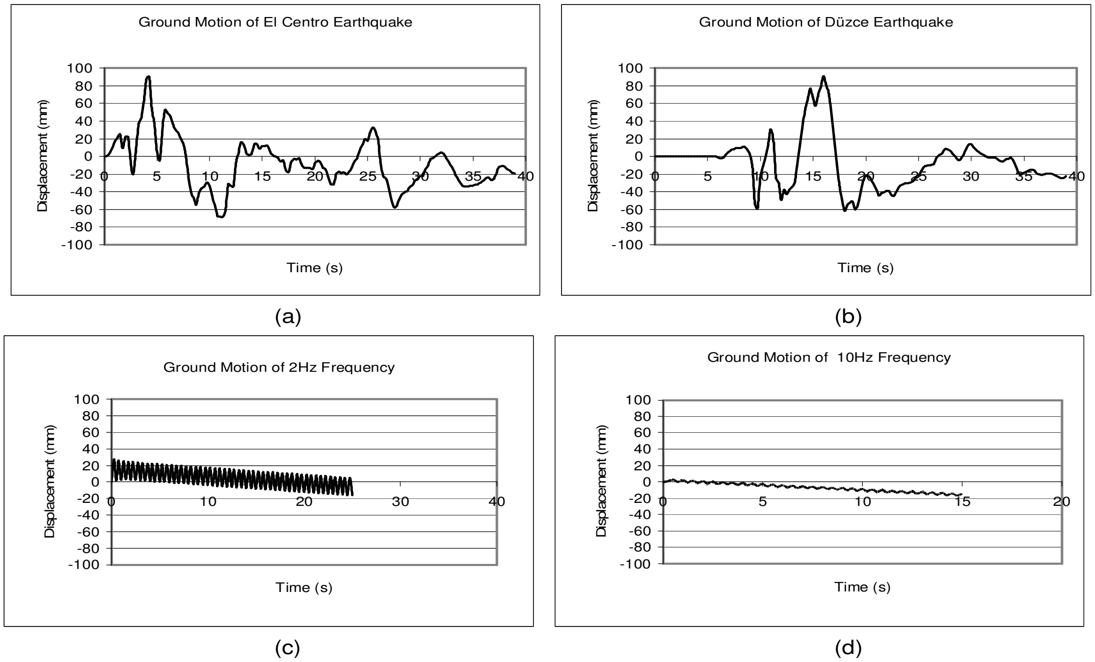


Figure 6. Applied excitation in experiments a) Düzce earthquake motion, b) El Centro earthquake motion, c) 2Hz harmonic excitation and d) 10Hz harmonic excitation

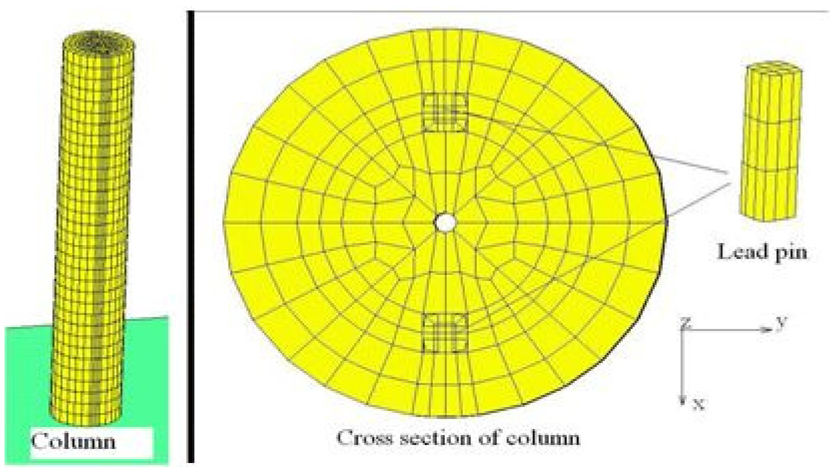


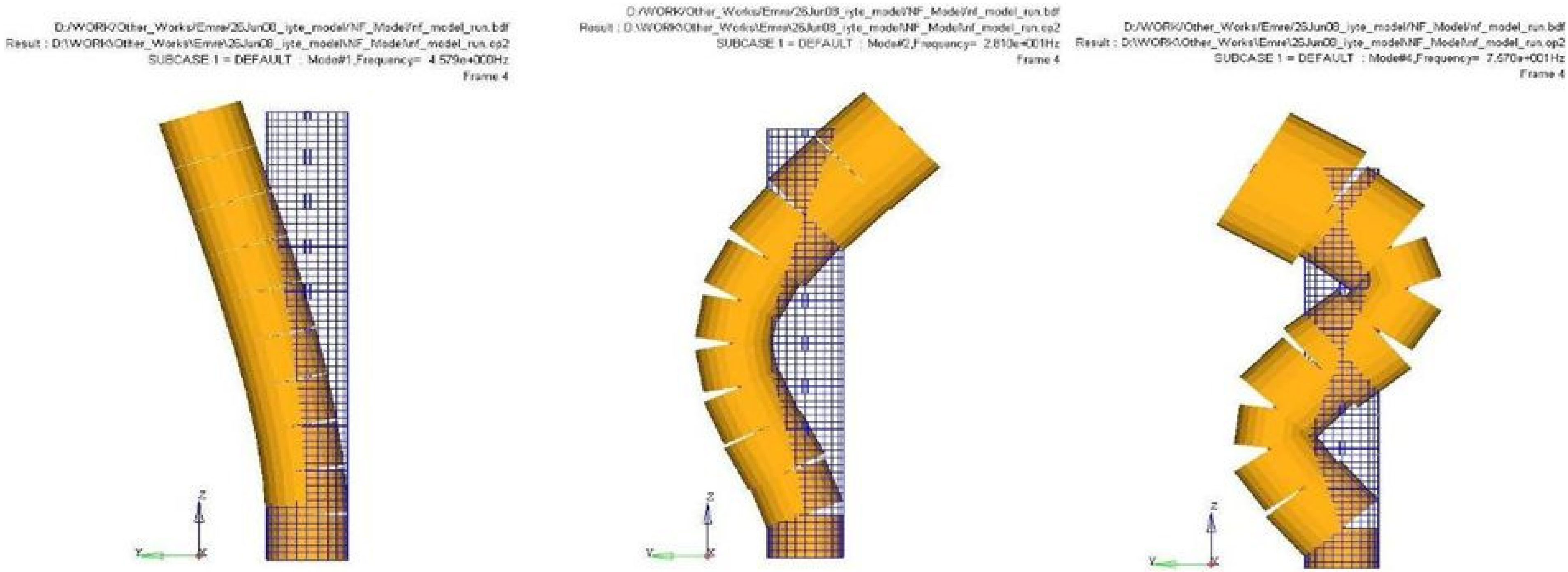
Figure 7. Finite Element Modeling of the column and lead pin.

were measured as displacements. Excitations applied are given in Figure 6 as displacements. Each test was repeated 5 times. After each testing, metallic links between drums were checked whether any failure exists or not.

RESULTS AND FINDINGS

Computer analysis

The finite element models of the drum and lead pin are created by using eight-node quadratic solid elements, shown in Figure 7. One drum is defined by 512 elements and 792 nodes; one lead pin is defined by 27 elements and 56 nodes. Modal analysis of the column reveals the frequencies of first, second and third modes are 4.58 Hz, 28.1 Hz, and 75.7 Hz, respectively (Figure 8). Computer analysis of 1:10 scale column under Düzce, El Centro earthquake motions, 2 and 10 Hz harmonic excitations were completed. The results are given in Figure 9, 10 and 11, respectively. The reason to select 2 and 10 Hz harmonic excitation is that 2 Hz is smaller; 10 Hz is larger than the frequency of first mode of the column in modal analysis.



(a) (b) (c)

Figure 8. Modal Analysis of 1:10 Scale Column a) 1st mode b) 2nd mode c) 3rd mode.

The results for 2 Hz harmonic excitation could not be collected, because the 1:10 scale multi-drum column collapsed immediately after analysis started. In Figure 9, Düzce earthquake respond is shown. The nodes given under the graphic indicate the locations where the potentiometers are placed. It is seen that the column behaved as continuum column until the metallic links between the 6th and 7th drums is broken. After themetallic links are failed, the behavior of the column becomes nonlinear and computer analysis is stopped. In Figure 10, behavior of the column under El Centro excitation is shown. It is seen that there is not any link failure until the excitation is completed and the column exhibits a linear behavior.

In Figure 11, the behavior of column under 10 Hz harmonic excitation is exhibited. It is seen that at 12th second of the analysis, the link between 6th and 7th drum is failed. In Figure 9, 10 and 11, the nods given under graphics represent the location where potentiometers were placed. Besides displacements graphics, computer analysis program also computes the maximum base shear forces. The base shear force of the column is determined as 23.24 N under Düzce excitation, 16 N under El Centro excitation, and 7 N under 10 Hz harmonic excitation.

Evaluation of computer analysis

Evaluation of the results is given in Table 2. In Table 2, the maximum displacements, the base shear forces and fracture occurrence are given according to the applied excitation acceleration. Results in Table 2 indicates that fracture occurrence in the metallic links between drums is related with the acceleration of the excitation

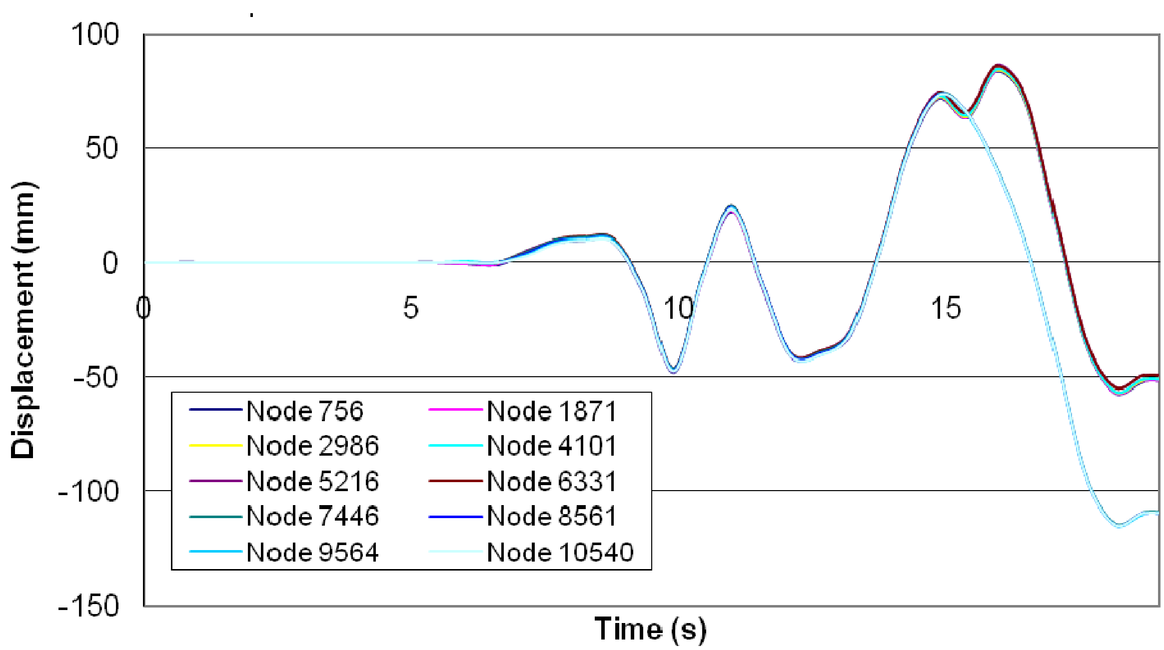


Figure 9. Computer Analysis Response of 1:10 Scale Columns under Düzce Excitation.

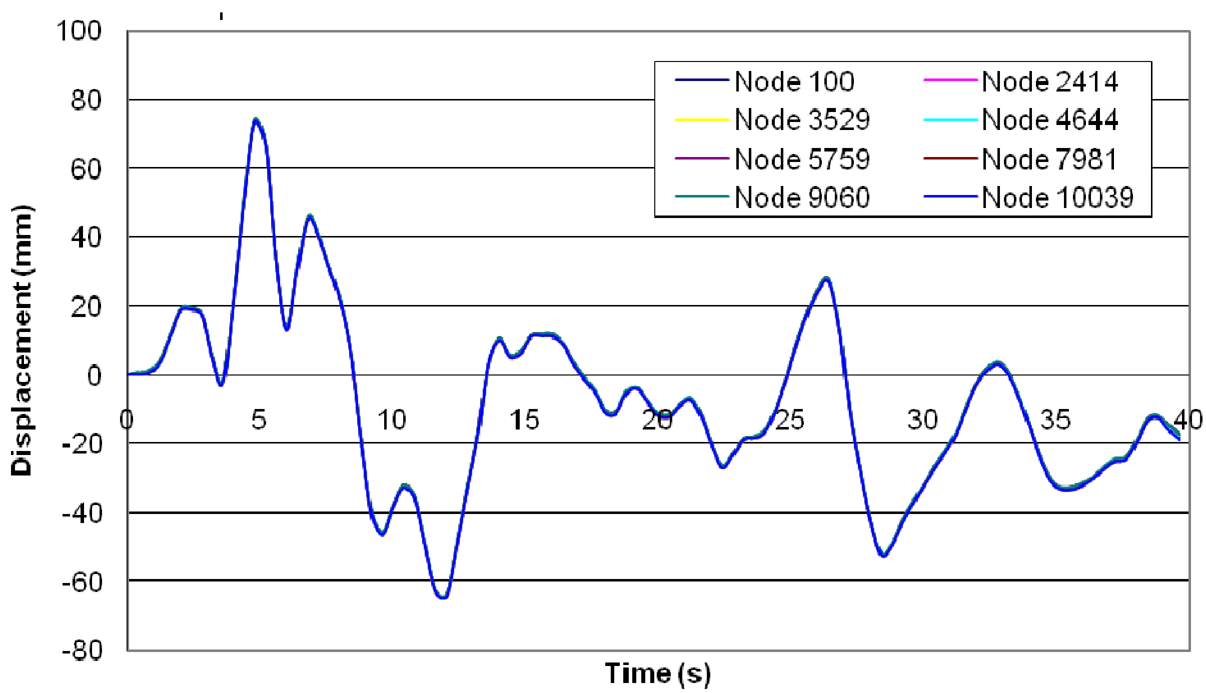


Figure 10. Computer analysis response of 1:10 scale columns under El Centro excitation.

applied.

Experimental study

The same excitations used in computer analysis were applied in experimental study, as well. Experimental result for Düzce, El Centro, 10 Hz and 2 Hz harmonic excitation are given in Figure 12, 13, 14, and 15, respectively. In the experimental study, multi-drum column exhibits much stronger behavior than compatible computer analysis. Especially, under Düzce excitation, in

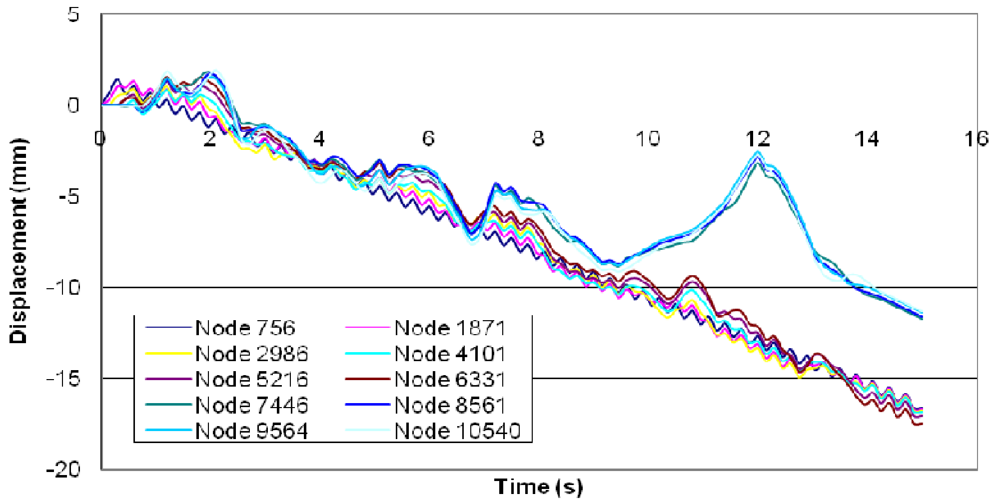


Figure 11. Computer analysis response of 1:10 scale columns under 10Hz excitation.

Table 2. Evaluation of computer analysis.

Excitations	Application time (s)	Maximum acceleration applied (m/s^2)	Maximum displacement applied (mm)	Maximum base shear force (N)	Link breakage
Düzce	20	3.37	86.3	23.24	Exist
El Centro	40	2.31	73.4	16	Non
10Hz Frequency	15	0.63	2	7	Exist
2Hz Frequency	Due to immediate collapse, analysis were not completed				

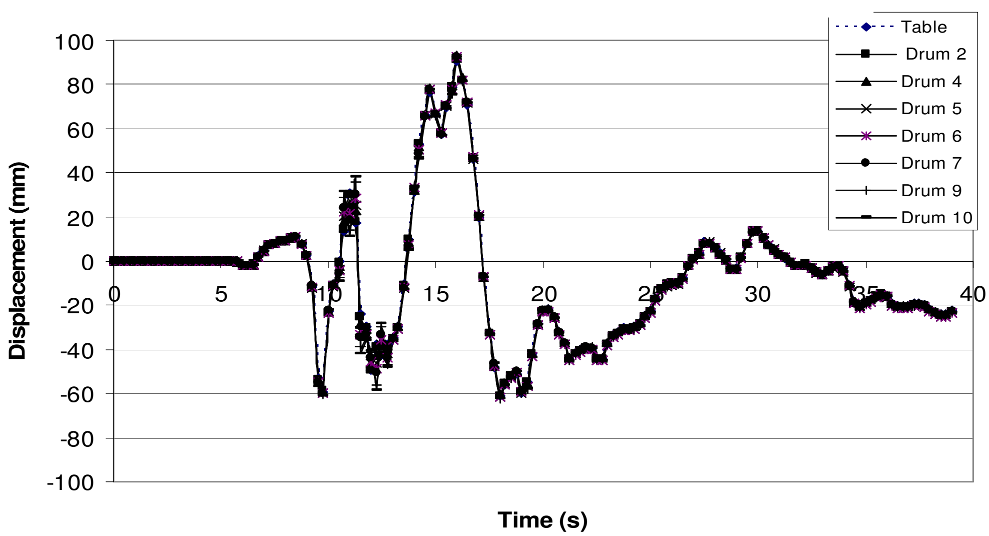


Figure 12. Experiment results of 1:10 Scale Multi-Drum Column under Düzce excitation.

most cases, fracture in the metallic links did not occur. Although fracture in the metallic links is seen in few testing, location of fractured metallic links differs in every time indicating improper connections. This result indicates that application of the metallic links has considerable effect on the behavior. Given example in Figure 12, for instance, bond between the metallic links and the marble drum are much stronger in test specimen than the parameter inserted for bond strength in computer analysis.

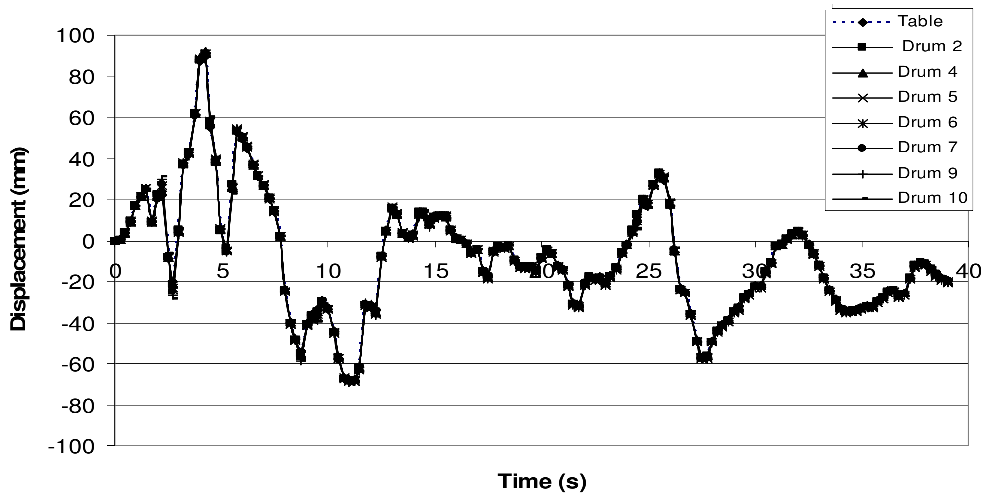


Figure 13. Experiment results of 1:10 scale Multi-Drum Column under El Centro excitation.

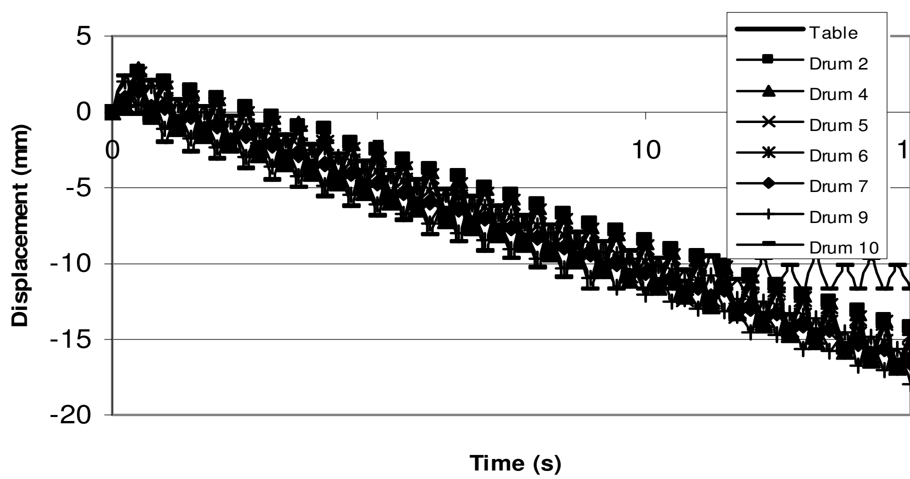


Figure 14. Experiment results of 1:10 Scale Multi-Drum column Under 10 Hz excitation.

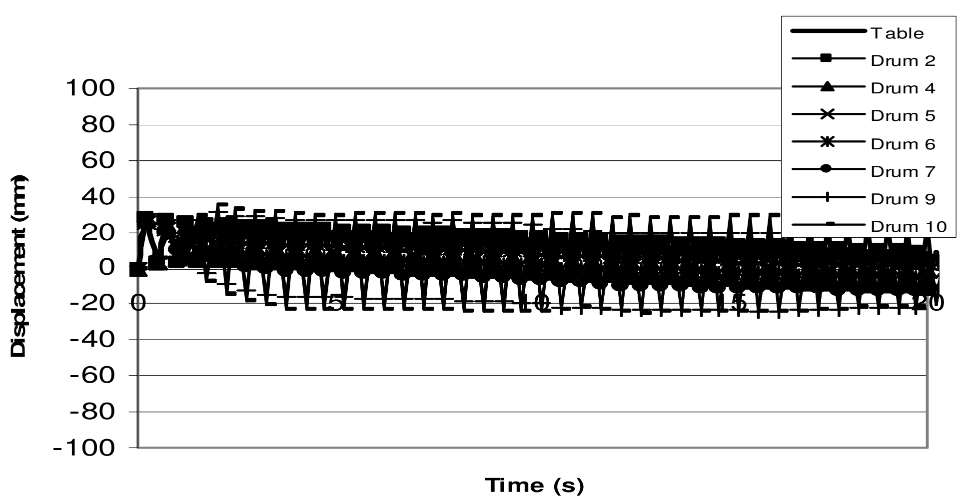


Figure 15. Experiment results of 1:10 Scale Multi-Drum Column under 2 Hz excitation.

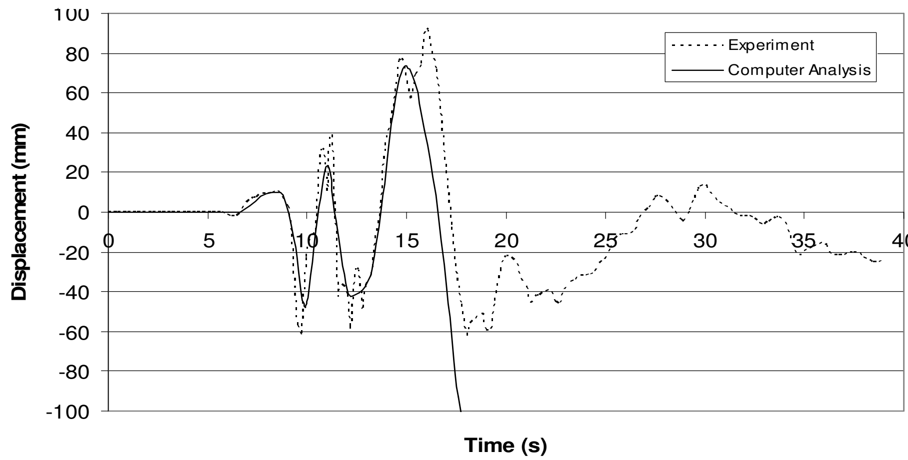


Figure 16. Computer analysis and experimental results of Drum 10 under Düzce excitation.

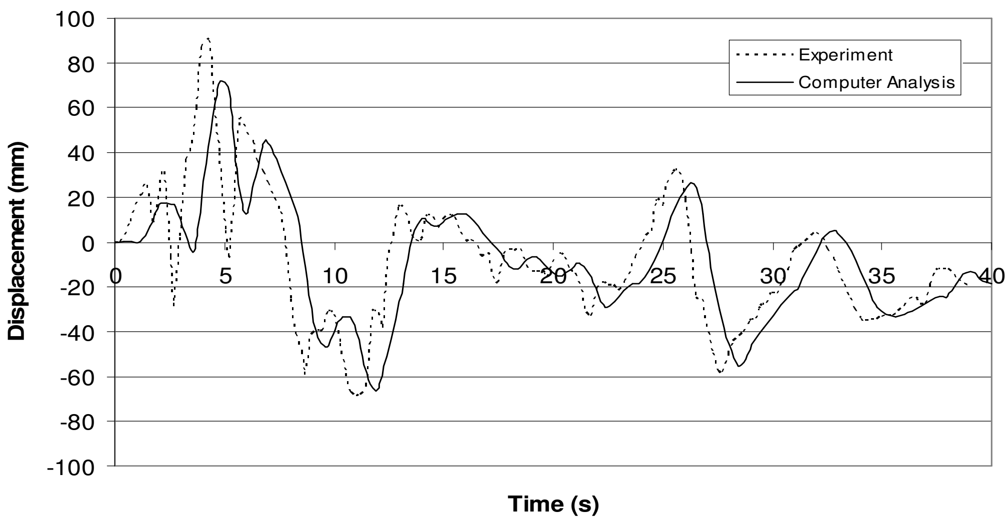


Figure 17. Computer analysis and experimental results of Drum 10 under El Centro excitation.

For El Centro excitation, the column exhibited approximately the same behavior in all testing. Fracture in the metallic links was not observed in any testing. Experimental test results are pretty much compatible with numerical analysis. On the other hand, in the experimental testing given in Figure 13, the displacement at the top of the column is 91.8 mm, while it is 73.5 mm in the numerical analysis. This indicates that in numerical analysis, the column is considered more rigid than it is suppose to be. In both, 10 and 2 Hz harmonic excitations, the columns behaved as linear column without any metallic link fracture (Figures 14 and 15, respectively). For 10 Hz harmonic excitation, both analytical and experimental test results are compatible with each other. On the other hand, for 2 Hz harmonic excitation, numerical analysis can not be performed due to immediate collapse. This also indicates that, the actual column has better performance than the theoretical one.

Comparison between computer analysis and experimental study results

In comparison of the computer analysis and experimental study, displacements of the top drums are utilized. Comparisons for all the excitations are given in Figures 16, 17 and 18. In Figure 16, computer analysis indicates that the metallic links located at about two third of the column are the weakest link. On the other hand, in repeated tests, column shows mostly much stronger behavior. In few cases, the links are failed. But these failures occur every time at different locations; suggesting failures occur due to improper connection. These results also demonstrate that effect of metallic links between the drums is important to have durable column.

In Figure 17, comparison of the results of computer analysis and the experiments for El Centro excitation is given. As it is seen, the behavior of the column is

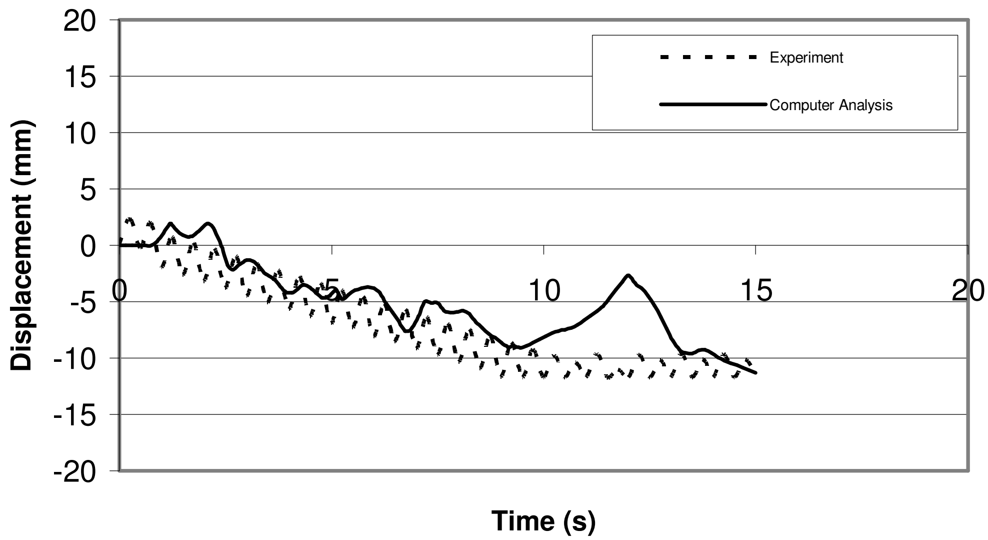


Figure 18. Computer analysis and experimental results of Drum 10 under 10 Hz excitation.

compatible in both experimental and computer analysis. In Figure 18, comparison of the result of computer analysis and the experiments for 10 Hz excitation is given. As it is seen, the column behavior is different in experimental and computer analysis. While the column behaves as linear without any fracture in the metallic links in experimental analysis, there is link fracture in computer analysis. This result also indicated that, the actual column exhibits better performance then the theoretical.

DISCUSSION AND CONCLUSION

The computational and experimental analysis of seismic response of a 1:10 scale multi drum classical column are performed and results are given. Four different excitations, Düzce earthquake motion, El Centro earthquake motion, 10 and 2 Hz harmonic motions are used. The model is analyzed using MSC Marc Mentat package programming and experiments are performed by using shake table. The response of test model and the response of computer modeling are compared and it is seen that the results are compatible. In both analysis methods; analytical and experimental, the models exhibits a rigid block behavior. In most cases, displacements of the column for the same excitations are larger in experiments than in analytical analysis. This result indicates that in experiments, the metallic links behave much elastic than it is assumed to be. In the case that building strong connection between drums has large impact on the behavior of the column.

The results may be summarized as follows:

1) In the case that ductile connections between drums are not failed, overall displacements of the column overlap with the displacements of excitations given.

2) After failure of the metallic links between the drums, response of the column to the excitation continues without collapse of the column, but prediction whether collapse would occur is impossible.

3) After failure of the metallic link at any level, rocking of drums dominated the sliding of the drums.

ACKNOWLEDGEMENTS

This study is funded by Scientific Research Found (project no: 05MUH50) of Ege University and TUBITAK (project no: 107M202). Experimental study is performed at IYTE Civil Engineering Department Laboratory.

REFERENCES

Konstantinidis D, Makris N (2005). Seismic response analysis of multidrum classical columns, Earthquake Eng. Struct. Dynamics, 34: 1243-1270.

Mouzakis HP, Psycharis IN, Papastamatiou DY, Carydis PG, Papantonopoulos C, Zambas C (2002). Experimental investigation of the earthquake response of a model of a marble classical column, Earthquake Eng. Struct. Dynamics, 31: 1681-1698.

MSC Marc Mentat (2004). MSC Software Corporation, Santa Ana, California, ABD.

Munjiza A (2004). The combined finite-discrete element method", Wliley Publishers.

Papantonopoulos C, Psycharis IN, Papastamatiou DY, Lemos JV, Mouzakis H (2002). "Numerical prediction of the earthquake response of classical columns using the distinct element method", Earthquake Engin. Struct. Dynamics, 31: 1699-1717.

Psycharis IN, Papastamatiou DY, Alexandris AP (2000). "Parametric investigation of the stability of classical columns under harmonic and earthquake excitations", Earthquake Eng.Struct. Dynamics, 29: 1093-1109.

Tanigucki T (2001). Non linear response of rectangular rigid bodies subjected to horizontal and vertical ground motion, Earthquake Eng. Struct. Dynamics, 31: 1481-1500.