Evaluating the effect of earthquake components on the space roofs

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Abstract: Space structures are widely used in covering the large spans. Similar space structures are largely used in the lattice space structures. Space roof is one of the most common types of space structures. Moreover, evaluating the effect of earthquake on the behavior of space structures has always been a significant and notable issue for the researchers. In this paper, the effect of horizontal, vertical and both horizontal and vertical components of three famous earthquakes, TABAS, KOBE and DUZCE, on a space roof is studied and the rates of buckling and vertical and horizontal displacement are investigated in four areas. The results of research have indicated that the displacement of the whole structure and the number of buckling items are higher in 62 percent of models, undergoing both horizontal and vertical earthquakes, than the models, undergoing just the horizontal earthquake, and these values have been reduced in 21 percent of models and 17% of models have had no buckling.

[***Farzad Hatami and Neda Esmaeili***. **Evaluating the effect of earthquake components on the space roofs** . *Life Sci J* 2012;9(3):1860-1864] (ISSN:1097-8135). http://www.lifesciencesite.com. 270

Keywords: Space structures, roof structures, horizontal earthquake, vertical earthquake

1) Introduction

Space structure means the structure which has the three-dimensional behavior so that its general behavior cannot be estimated by one or more two-dimensional independent sets (Ishikawa, 1993). Nowadays, new needs and demands in the field of structural engineering have been occurred by the advancement of science and technology. Time factor in building the structures has been so important, thus the tendency towards the prefabricated structures has been increased. Moreover, the tendency to large areas with no intermediate columns has been enhanced due to the increased population of societies. In this regard, since the early current century a number of experts have been fascinated by the unique capabilities of space structures and have sought the response of many new requirements in these structures, thus they have achieved very positive results. There are several examples of space structures, which have been built in the world and Iran including: the sport stadiums, cultural centers, community halls, shopping malls, train stations, hangars, recreational centers, radio towers, and… (Chiwiacowsky, 2008) Space structures are classified into three major groups as follows.

A - Flat networks

It is the combination of tetrahedral or polyhedral system with the layers of network unit. Flat network is composed of a dual-layer system which is connected to the unit beams. Flat networks can have one, two, three or even multiple layers, but are widely used as a dual-layer unit (Saka, 1997). Dual-layer networks are composed of two parallel networks plates which are connected to each other by several elements. When the items in a two-layer network are elongated, the three-layer networks are used in order to prevent the risk of buckling, and since a half of space structures costs belongs to the jointers (Chen, 2005), this type of structures is often non-economic. Another point, which should be considered in designing the two-layer networks and most of the space structures, is to provide a better distribution of force and making it tensile by building the columns within the network and connecting the column to multiple nodes, and it is better to build it around the console for creating a regular force distribution (Sokol, 2002).

B: Barrel Vault

Barrel Vault is a network which has the curvature in one direction. These structures have been used for covering the rectangular corridor surfaces and are sometimes without the columns and are placed on the edges attached to the support. Barrel Vaults have the axis (Saka, 1997). If the Barrel Vault has just a layer, the connections are rigid. Barrel Vaults are often connected to each other and the horizontal beam has a role to attach the Barrel Vaults to each other. The point, which should be considered in designing this type of structure, is that the end of Barrel Vault should be reinforced and this reinforcement can be achieved by the beam, beam and column, and the sun-shaped form.

C: Domes

If a network has the curvature in two directions, it is called the Dome (Specifications for the Design and Construction of Space Trusses, 2001). Probably, the covering of a dome is a part of a sphere or a cone or the connection of several coverings. Domes are structures with high rigidity and are used for very large spans until approximately 250 meters. Dome height should be higher than 15% of dome base diameter.

Appropriate design of each structure requires the accurate prediction of forces which will be imposed the structure (Sadeghi, 2003). The force of earthquake is among these forces. Numerous regulations have provided several approximate correlations which estimate the equivalent earthquake force for building structures (Shear Frames). Using these correlations are based on simplifying assumptions, which according to the geometric structure and structural behavior of space structures are not useful for these structures. Given the widespread application of space structures it seems that the prediction of dynamic behavior of structure is so important due to the high volume of data needed for structure analysis, wide volume of calculations in the structure analysis, evaluating the behavior of structure before building it, making the physical models for investigating the structures behavior, and creating the appropriate view for the designers (Khabbazan, 1989, Anekwe, 1984).

Several researchers have proposed the scientific contents in the field of evaluating the effect of earthquake components. For example

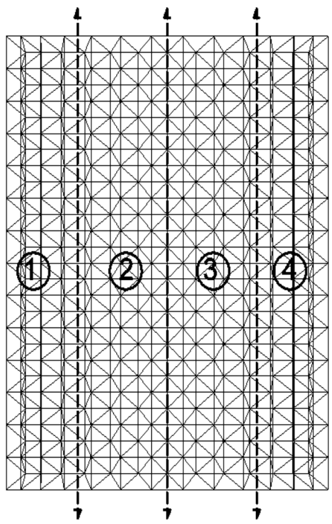
Shin,et.al (2012) studied on seismic behavior of double-layer barrel vault systems with different open angles and the models had maximum values at the 1/4 and 3/4 nodes, while having relatively smaller responses at the center node from horizontal earthquakes. It is believed that the barrel vault model with an open angle of 90 degrees has the most advantageous shape for model.

Khabbazan (1989) used Renecture Method for Analysis of Space Frame. This method usefuland simple to calculate space frame strength. Anekwe (1984) Reducation Method of Analysis for Dense Space Structure in his study.

Accordingly, the main objective of this paper is to evaluate the effects of horizontal and vertical earthquakes on the space roof. In this regard, three earthquakes of TABAS, KOBE and DUZCE are studied and the impact of these earthquakes on a space roof was investigated.

2) Research Methodology

In this study, the space roof was studied as shown in Figure (1). In this regard, as it is shown in Figure 1, the target barrel vaults were classified into four equal parts and each part was numbered and the impact of each studied earthquake on it was presented in order to determine the location of buckling items in the barrel vault.



Form 1: Schematic design of studied space structure

In this research, the following accelerographs have been used and selected from the available databases about the earthquake due to the high PGA. Table (1) represents the information about the selected earthquakes which have been used in the seismic analysis.

Table 1: Horizontal and vertical components of three studied earthquakes

Earthquake	Parameter	(H)	(V)
KOBE,Japan,1995	HP (Hz)	0.05	0.05
	LP (Hz)	Null	null
	PGA (g)	0.821	0.343
	PGV (cm/s)	81.3	38.3
	PGD (cm)	17.68	10.29
TABAS,Iran,1987	HP (Hz)	0.05	0.05
	LP (Hz)	null	null
	PGA (g)	0.852	0.688
	PGV (cm/s)	121.4	98.03
	PGD (cm)	94.58	76.37
DUZCE,Turkey,1999	HP (Hz)	0.15	0.06
	LP (Hz)	50	50
	PGA (g)	0.97	0.193
	PGV (cm/s)	36.5	9.5
	PGD (cm)	5.48	6.2

3) Research Results

The elements of COMBIN39 and MASS21 have been used in order to define the nonlinear geometric and material abilities for dynamic analysis in ANSYS. The items of target space structure models were investigated with the thinness coefficients 100 and then the post-buckling for desired thinness was calculated according to the formula (1) which was introduced by Mr. Kato and Ishikawa.

$$\left(\frac{\sigma}{\sigma y}\right)^2+3.476\left(\frac{\sigma}{\sigma y}\right)-11.62\left(\frac{\varepsilon}{\varepsilon y}\right)\left(\frac{\sigma}{\sigma y}\right)+2.10\left(\frac{\varepsilon}{\varepsilon y}\right)-.09241\left(\frac{\varepsilon}{\varepsilon y}\right)^2+1.189=0 \quad (1)$$

Because the structure enters the nonlinear field (item) at the time of earthquake, the geometric nonlinear and materials behavior have been applied for the structure. After defining the post- buckling diagrams with thinness 100 for the mentioned models, these models were faced with the earthquake TABAS (Iran) for 19.5 seconds, earthquake KOBE (Japan) for 18 seconds and earthquake Duzce (Turkey) for 18.5 seconds in horizontal, vertical and both directions and the seismic behavior of target barrel vaults was studied. The results can be observed in Tables (2) to (4).

Table (2): Information of models after dynamic analysis under the earthquake TABAS

TABAS Earthquake					
Name of Model	Dx (m)	Dy (m)	t_0	x_0	N
BA15-H	0.02299	0.10088	4.23	2-3	25
BA15-V	0.00102	0.00102	---	---	---
BA15-HV	0.02183	0.18818	4.23	2-3	25
BA30-H	0.05859	0.04530	4.07	4	38
BA30-V	0.00039	0.01649	---	---	---

Table (3): Information of models after dynamic analysis under the earthquake KOBE

KOBE Earthquake					
Name of Model	Dx (m)	Dy (m)	t_0	x_0	N
BA15-H	0.00414	0.00762	---	---	---
BA15-V	0.00663	0.00798	---	---	---
BA15-HV	0.00465	0.00877	---	---	---
BA30-H	0.14841	0.12028	2.11	1	191
BA30-V	0.00000	0.00873	-		
BA30-HV	0.17654	0.14162	2.10	1	151
BA45-H	0.95642	0.49664	2.19	3	89
BA45-V	0.01106	0.01892	-		
BA45-HV	1.07670	0.57036	2.23	3	109
BB15-H	0.00456	0.00857	---	---	---
BB15-V	0.00093	0.00090	---	---	---
BB15-HV	0.00456	0.00456	---	---	---
BB30-H	0.06218	0.05093	2.95	1	62
BB30-V	0.00000	0.00960	---	---	---
BB30-HV	0.06392	0.05209	2.93	1	56
BB45-H	0.01765	0.04326	5.10	2-3	52
BB45-V	0.01310	0.02221	---	---	---
BB45-HV	0.01930	0.04753	5.08		66

Table (4): Information of models after dynamic analysis under the earthquake DUZCE

DUZCE Earthquake					
Name of Model	Dx (m)	Dy (m)	t_0	x_0	N
BA15-H	0.01135	0.02018	---	---	---
BA15-V	0.00081	0.00825	---	---	---
BA15-HV	0.01145	0.02018	---	---	---
BA30-H	0.35793	0.30264	2.0564	1	186
BA30-V	0.00000	0.00883	---	---	---
BA30-HV	2.74510	0.23183	2.0564	1	215
BA45-H	0.51701	0.01853	---	---	---
BA45-V	0.01077	0.01833	---	---	---
BA45-HV	0.05199	0.01727	---	---	---
BB15-H	0.00679	0.01232	---	---	---
BB15-V	0.00096	0.00094	---	---	---
BB15-HV	0.00673	0.01193	---	---	---
BB30-H	0.06916	0.05519	1.5132	4	106
BB30-V	0.00000	0.00977	---	---	---
BB30-HV	0.06829	0.05704	1.5132	4	97
BB45-H	0.03783	0.12222	1.6296	2-3	125
BB45-V	0.02609	0.02153	---	---	---
BB45-HV	0.01154	0.12222	1.6296	3	117

4) Conclusion and Discussion

In this paper, the horizontal, vertical components of three earthquakes, TABAS, KOBE and DUZCE, on a space roof are studied. The results of research have indicated that the displacement of the whole structure and the number of buckling items are higher in 62 percent of models, undergoing both horizontal and vertical earthquakes, than the models, undergoing just the horizontal earthquake, and these values have been reduced in 21 percent of models and 17% of models have had no buckling. The outbreak time of the first buckling is not different in the models with horizontal and both horizontal and vertical earthquakes. The mutation of barrel vaults node displacement has been intensified in the earthquakes which enter the structure both horizontally and vertically. By increasing the height of span, the outbreak time of the first buckling has been reduced according to the studied earthquakes and the number of buckling items has been severely reduced and no buckling have been occurred in most of the cases for the barrel vaults with height of span 0.15.

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10/22/2012