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Research Article

Providing a Model for Assessment of Horizontal and Vertical Earthquake Effects on the Double-layer Barrel Vaults in Space Structures

Taleb Sadeghian
Department of Civil Engineering, Ilam Branch, Islamic Azad University, Ilam, Iran

Abstract: In this study, the effect of place soil and seismic vulnerability has not been considered in determining the earthquake force, although all results have been based on scale accelerographs. Moreover, the importance of structures has not been rated based on small or large spans, decorative or structural structure and the effect of these cases is not considered. In this regard, double-layer barrel vaults have been studied and effect of horizontal and vertical seismic force on it reviewed and equations are presented in order to evaluate the equivalent static force of horizontal and vertical earthquake. Presented equations facilitate determining the equivalent static force due to earthquake for space structures, but they also have deficiencies which solving them can be useful for researchers who want to continue the way.

Keywords: Double-layer barrel vaults, horizontal earthquake, space structures, vertical earthquake

INTRODUCTION

The space structure is the one which has three-dimensional behavior, so that, its general behavior can never be approximate by using one or more independent double-dimensional sets (Ishikawa and Kato, 1993). With this definition, a wide range of structures and even some of the previous brick arches and domes are considered as the space structures, but the purpose in this study is the specific three-dimensional structures which usually have direct components with rigid or joint connections (Kato *et al*., 1997). A space structures can be considered as a structural system, which composes of linear components and these are placed in a way that are transferred three-dimensionally for many times (Kawaguchi, 1997). A space structures often has a form of flat or curved surface. Applying the least material, the space structures create the most rigid structures and they have ability to cover large spans without using the middle columns. In today world, the use of space structures for covering the large spans has been also developed (Maalek and Mohyeddin Kermani, 2002). Types of space structures are very various in terms of geometrical structures, type of material and behavior. Barrel vaults are one of the types of latticed space structures which are implemented as one layer or two. Due to the ability to cover the areas with large spans and making beautiful architecture, these structures have wide applications and are considered by architects and designers (Nooshin, 1998). Space barrel vaults are divided into one or multi-layer space barrel vaults (Ogawa *et al*., 2002). One-layer barrel vaults have rigid joints and the components work as three-dimensional bending beam; the multilayer barrel vaults are jointed and the function of components is in the form of three-dimensional truss. In this study modeling of earthquake force exerted on the barrel vault and different types of space structures were surveyed.

Latticed space structures are tantamount to double-layer barrel vaults based on the shape and position. In this study, the effect of earthquake on space structures has been evaluated.

DIFFERENT TYPES OF SPACE STRUCTURES

Flat lattices: It means the combination of a tetrahedral or polyhedral system with unit layers of lattice. Flat lattice composed of a planar unit which is connected with unit beams. Flat lattices can have one, two, three or even multiple layers, but they are widely used in the form of two layers (Saka and Taniguchi, 1997). Double-layer lattices consist of two parallel plates which are jointed together by elements. When the components in a double-layer lattice are elongated, three-layer lattices are used in order to prevent the risk of buckling and given that half of space structures costs is related to the joints, these type of structures are often non-economical. Another point, which should be considered in designing double-layer lattices and most of space structures, is that it is better for better distribution of force and making it tensile to design the columns inside the lattice and the column be connected to multiple nodes and located around the console for achieving the regular distribution (Sokol and Sumec, 2002).

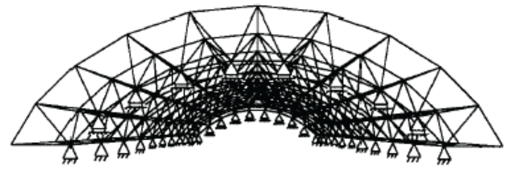
Barrel vaults: The barrel vault is a lattice which has curvature in a direction. This structure is used widely for covering the rectangular corridor surfaces and sometimes is without columns and is placed on the ledge of barrel vault which is attached to the fulcrum. Barrel vaults have the axis (Saka and Taniguchi, 1997). If the barrel vault has a layer, the joints are rigid. Barrel vault are often used in a combined form and the back beams play the role of combining the barrel vaults to each other. The point which should be considered in designing this type of structures is that the end of barrel vaults should be strong and this is reinforcement can be achieved by the beam, beam and column and sun-like shape.

Domes: If a lattice has curvature in two directions, it is called the Dome (Specifications for the Design and Construction of Space Trusses, 2001). The covering of a dome is probably part of a sphere or a cone or combined of several coverings. Domes are structures with high rigidity and are used for very large spans up to approximately 250 m. Dome height should be greater than 15% of base diameter of dome.

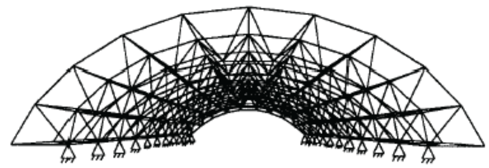
Appropriate design of each structure requires the correct prediction of forces which are imposed to the structure (Sadeghi, 2003). The force of earthquake is among these forces. Many regulations provide several approximate equations which estimate the equivalent earthquake force for building structures (Shear frames). Using these equations is on the basis of simple hypotheses which are not beneficial for such these structures in terms of geometric structure and structural behavior of space structures. The main objective of this study is to provide a model for evaluating the effects of horizontal and vertical earthquake on double-layer barrel vaults in space structures.

MODELING OF EARTHQUAKE FORCE EXERTED ON THE BARREL VAULT

Equivalent static earthquake forces on double-layer barrel vaults can be calculated horizontally and vertically. For instance, the horizontal effect of earthquake in this method is measured for barrel vault according to Eq. (1) by determining the basic shear for the barrel vault:



(a) support conditions A



(b) support conditions B

Fig. 1: Context and fulcrum conditions of barrel vaults

$$Vb = CH_0 \times W_t \tag{1}$$

In which,
CH_0: The coefficient of earthquake horizontal force
W_t : The effective weight of whole barrel vault

The coefficient of earthquake horizontal force can be calculated by Eq. (2):

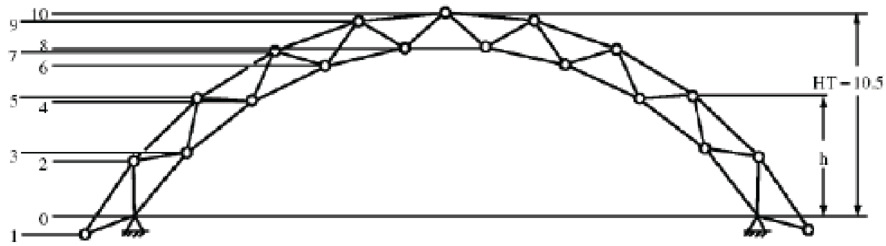
$$CH_0 = \alpha \times [SA\ (T_1)\ /g] \tag{2}$$

In which, α is the constant factor and depends on the type of barrel vault fulcrum and SA (T_1) is the response acceleration of design range for the first mode of barrel vault vibration. In this method, distribution of horizontal seismic forces in height of barrel vaults is also according to triple Eq. (6).

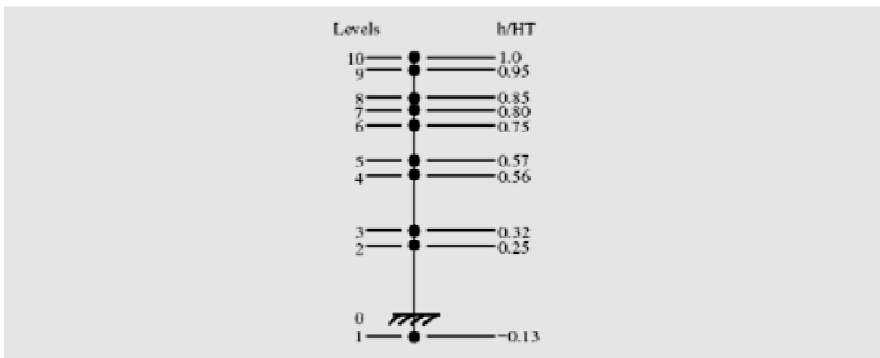
In Research Part I, Part II by Sadeghi (2004a, b), various double-layer barrel vaults (with square context on a square) are considered with ratio of rise to span 0.15, 0.30 and 0.45 in order to obtain the base shear force. Two types of fulcrum conditions are considered for each of the barrel vault that is shown in Fig. 1. In this figure mode A and B are presented. Mode A: In this mode, the barrel vaults have the joint fulcrum only on two edges. Mode B: In addition to fulcrums of mode A, this mode has roller fulcrum in sub-nodes of arch in the beginning and at the end. In order extract the equivalent static force of earthquake, 12 accelero graphs with high PGA (Table 1) are exerted in base of

Table 1: Selected earthquakes and their overall features

No	Earthquake	Component	PGA	PGV	PGD	A/V
1	Cape Mendocino, USA, 1992	U	0.754	63.0	109.48	1.20
2	Chi-Chi, Taiwan, 1999	U	0.724	49.0	27.82	1.48
3	Coaling, USA, 1983	U	0.568	12.5	1.20	5.44
4	Gazli, USSR, 1976	U	1.264	54.2	30.15	2.33
5	Imperial valley, USA, 1979	U	1.655	57.5	26.41	2.88
6	Kobe, Japan, 1995	U	0.433	34.8	12.38	1.24
7	Landers, USA, 1992	U	0.818	45.9	22.23	1.78
8	Loma Prieta, USA, 1989	U	0.890	54.9	17.56	1.62
9	Nahanni, Canada, 1985	U	2.086	40.5	12.12	5.15
10	Northridge, USA, 1994	U	1.048	75.4	20.05	1.39
11	San Fernando, USA, 1971	U	0.699	56.5	18.25	1.24
12	Tabas, Iran, 1978	U	0.688	45.6	17.04	1.51



(a) Nodes and levels of the barrel vault with rise to open ratios of 0.30



(b) Levels and corresponding relative heights for equivalent forces on the barrel vaults with rise to span tatio of 0.030 (not to scale)

Fig. 2: Level of different nodes and alternative mass model of barrel vaults

mentioned barrel vaults and the acceleration of various nodes response is obtained and the exerted inertia force is extracted by multiplying these accelerations by mass of related nodes. Then, the base shear is calculated by adding the forced of all the nodes. Furthermore, the coefficient of earthquake for different accelerographs is determined for all barrel vaults by dividing the base shear of each earthquake by the sum of nodes weights (Fig. 2) Eq. (3):

$$CH_0 = V_b/W_t \tag{3}$$

In order to calculate the coefficient of horizontal seismic force, CH_0 as the equivalent static force and without need for accelerographs, this coefficient has been linked to the response acceleration of barrel vaults Mode 1 which is obtained from the spectrum of different earthquakes Eq. (4):

$$CH_0 = \alpha \times [SA (T_1) /g] \tag{4}$$

In which, α is a coefficient, SA (T_1) is the acceleration of an earthquake response and the first mode of barrel vaults vibrations. Since, CH_0 is calculated before for different accelerographs and the response spectrum of different earthquakes is also available, the coefficient α can be calculated through the following equation:

$$A = CH_0/ [SA (T_1) /g] \tag{5}$$

Given the rise-to-span ratio (H/S) of barrel vaults, the values of this coefficientare shown in a curve for accelerographs and the following results are obtained:

- For barrel vaults with fulcrum conditions A: $\alpha = 7.5$
- For barrel vaults with fulcrum conditions B: $\alpha = 8.5$

For distribution of horizontal forces at different levels, the obtained forces at each level are calculated by adding the forces of mentioned node and then the comparison and equations 6 to 8 are measured for all barrel vaults and the earthquake and they are presented below according to the rise-to-span ratio (Fig. 3):

For $\frac{h_i}{H} \leq 0.3$ we will have:

$$F_i/V_b = 0.27 (h_i/H + 0.2) \tag{6}$$

For $0.3 \leq \frac{h_i}{H} < 0.96$ we will have:

$$F_i/V_b = 0.135 \tag{7}$$

And for $0.96 \leq \frac{h_i}{H} < 1.0$ we will have:

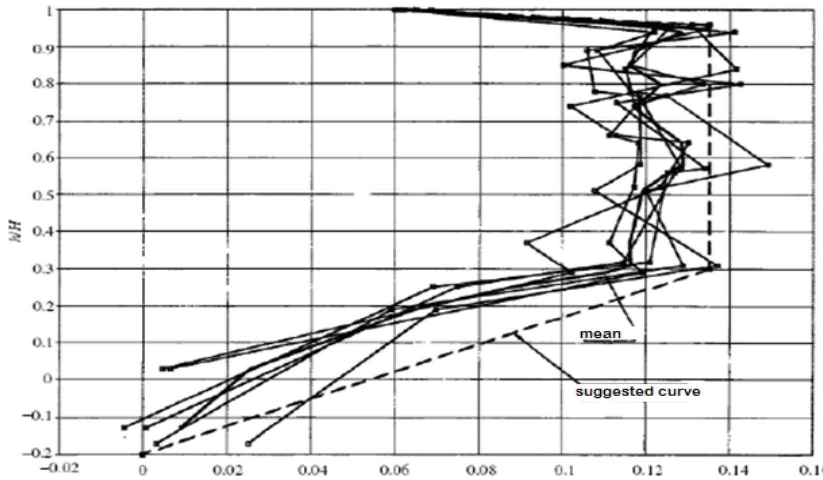


Fig. 3: Distribution of horizontal force caused by different earthquakes in the height of a barrel vault

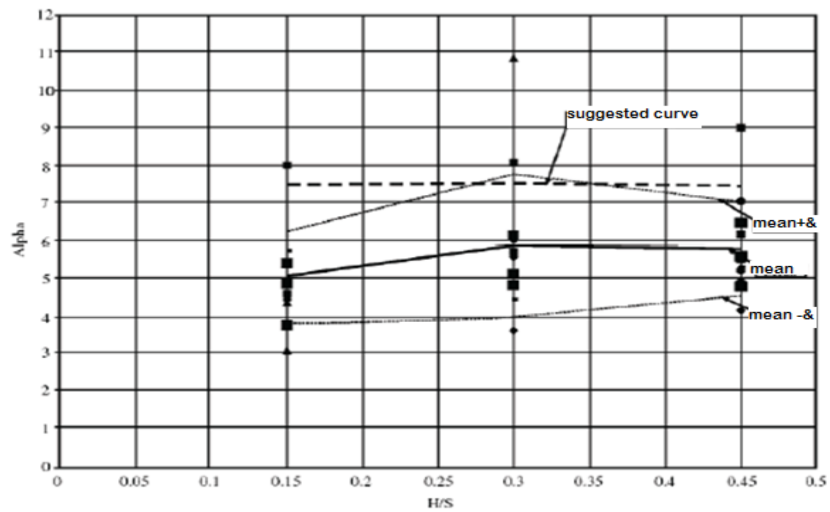


Fig. 4: α coefficient for different barrel vaults and accelerographs

$$F_i/V_b = 1.875\ (1.032 - h_i/H) \quad (8)$$

In which,

F_i = The lateral force of earthquake at level i
H_i = The height of level i from the ground
H = The height of barrel vault
V_b = The horizontal base shear

Also Fig. 4 determines α coefficient for different barrel vaults and accelerographs.

DISCUSSION AND CONCLUSION

Space structures are widely used in covering large spans. Latticed space structures are mainly from similar space structures. In addition, this family is equivalent to double-layer barrel vaults based on the shape and position. Study of dynamic and seismic behavior of these structures has been increased significantly in recent years. In this study, the effect of earthquake on space structures has been evaluated.

This study has used the similar modeling and the modeling by Sadeghi (2004b). Therefore, the results of this research are in line with the study by Sadeghi (2004b). Given the analyses carried out by Pushover method, Sadeghi (2003) has recommended that the coefficient of barrel vault behavior should be considered equal to the unit and based on the effect of earthquake load, the barrel vaults should be designed in the elastic forms.

REFERENCES

Ishikawa, K. and S. Kato, 1993. Dynamic Buckling Behavior of Single and Double Layer Latticed Domes due to Vertical Earthquake Motions. In: Park, G.A.R. (Ed.), Space Structures 4: Proceedings of the 4th International Conference of Space Structures, Thomas Telford, 1: 466-475.

Kato, K., T. Ueki and Y. Mukaiyama, 1997. Study of dynamic collapse of single layer reticular domes subjected to earthquake motion and the estimation of statically equivalent seismic forces. Int. J. Space Struct., 12(3-4).

Kawaguchi, K., 1997. A report on large roof structures damaged by the Great Hanshi-Awaji Earthquake. Int. J. Space Struct., 126(3-4).

Maalek, S. and A.R. Mohyeddin Kermani, 2002. Three component versus single component exciatation in the study of the seismic behavior of a triple large grid. Proceeding of the 5th International Conference on Space Structure. Thomas Telford, London, 2: 1043-1051.

Nooshin, H., 1998. Space structures and configuration processing. Prog. Struct. Eng. Mat., 1(3): 329-336.

Ogawa, T., Y. Takemoto and T. Kumagai, 2002. Dynamic behavior of rigidly jointed single-layer lattice domes subjected to vertical earthquake motion. Proceeding of the 5th International Conference on Space Structures, Surrey. Great United Kingdom, 2: 1073-1080.

Sadeghi, A., 2003. Equivalent earthquake loads for some families of barrel vaults. Ph.D. Thesis, University of Surrey.

Sadeghi, A., 2004a. Part I: Vertical effects of earthquakes on the double layer barrel vaults. J. Space Struct., 19(2).

Sadeghi, A., 2004b. Part II: Horizontal earthquake loading and linear/nonlinear seismic behavior of double layer barrel vaults. Int. J. Space Struct., 19(1).

Saka, T. and Y. Taniguchi, 1997. Damage to spatial structures by the 1995 Hyogoken-Nanbu earthquake in Japan. Int. J. Space Struct., 126 (3, 4).

Sokol, M. and J. Sumec, 2002. Seismic Response of Large-span Shell like Structures. Space Structures 5, Thomas Telford, London, pp: 1033-1042.

Specifications for the Design and Construction of Space Trusses, 2001. Int. J. Space Struct., 16(3): 177-208. Retrieved from: http:// multi-science. metapress. com/ content/ar418335n447683t/.