Thin-Walled Structures 54 (2012) 113–125

Contents lists available at SciVerse ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Analytical and experimental studies on seismic behavior of double-layer barrel vault systems with different open angles

Jiuk Shin [a], Kihak Lee [a,*], Gee-Cheol Kim [b], Chan-Woo Jung [c], Joo-Won Kang [d]

[a] Department of Architectural Engineering, Sejong University, South Korea
[b] Department of Architecture, Seoil University, South Korea
[c] Technology Research & Engineering Institute POSCO Architects & Consultants, South Korea
[d] School of Architecture, Yeungnam University, South Korea

ARTICLE INFO

Article history:
Received 22 October 2010
Received in revised form
14 February 2012
Accepted 14 February 2012
Available online 22 March 2012

Keywords:
Double-layer barrel vault system
Thin-walled steel tubes
Open angles
Seismic behavior
Spatial structure
Experiment of barrel vault systems

ABSTRACT

This paper presents the seismic behavior of double-layer barrel vault systems with different open angles through analytical and experimental studies with modeling of thin-walled steel tubes. For the analytical study, different six open angles and four fundamental frequencies were incorporated into the barrel vault analysis models and analyzed. A total of 24 double-layer structures were developed using the MIDAS computer analysis program and these structures were subjected to three different ground motions with a 5% damping ratio. The characteristics of the dynamic responses for the *X*, *Y*, and *Z* directions of the analytical model, subjected to both horizontal and vertical earthquakes, were investigated. In addition to the analytical study, an experimental study using scaled down thin-walled steel tube models was undertaken using a shaking table test. Comparing the analytical and experimental studies, the dynamic behaviors were very similar in terms of the distributions of the acceleration responses. Both the analytical and experimental 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 of the analytical barrel vault models used in this study.

1. Introduction

A general definition of a spatial structure is a large span length covering a wide area and the ratio of the rising structure, such as an arch, barrel vault, or dome, to the span. Such a structure, as well as typical moment frame structures, is significantly affected by horizontal ground motions. However, there are differences between spatial structures and typical moment frame buildings: it is easy for spatial structures to have vertical vibrations subjected to horizontal ground motions and their vertical behavior is affected due to the rise in the span ratio. Moreover, when a span length is longer, the natural frequency of the vibration is slightly shorter. As a result, there is a high likelihood that a great magnitude of vertical vibration will affect the structures at the moment when the period of vertical vibration matches a specified fundamental period of the earthquake [1–5]. Accordingly, when engineers design and analyze spatial structures for earthquake loadings, the various factors, such as the structural shape (open angle) or a measure of height and span length, and bearing conditions, should be considered since these are the main parameters affecting the fundamental period and vibration mode vector of the spatial structures. Unlike typical moment frame buildings, because the conventional design specifications for the seismic performances of the shell and spatial structures do not stipulate a method to determine the story shear force or a guide for designing the vertical bearing capacity, it is necessary to investigate and estimate these dynamic characteristic factors [6–9].

In this study, in order to investigate the dynamic responses for barrel vault systems subjected to horizontal and vertical ground motions, analytical models that vary the open angles and natural frequencies of the systems were considered. Sadeghi [10] concluded that, since barrel vault systems have relatively smaller self-weight and larger slenderness ratio than those obtained from conventional structural systems, the analytical investigation of the barrel vault systems demonstrated brittle behavior and structural instability before reaching the inelastic range. Thus, it was noted that barrel vault systems should be designed at an elastic level within an acceptable risk range, and this has been the general approach for structural engineers when designing barrel vault systems. Therefore, in this study, when designing the analytical models, the systems were intentionally designed in

* Corresponding author. Tel.: +822 3408 3286.
E-mail address: kihaklee@sejong.ac.kr (K. Lee).

0263-8231/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tws.2012.02.008

order that the barrel vault systems remained in the elastic range in order to investigate their global behavior. In the second stage of this study, a scaled down thin-walled steel tube model for the barrel vault system was built and tested using shaking table facilities in order to evaluate the seismic behaviors. This was undertaken in order to verify the validity of the analytical model for the dynamic behavior of double-layer barrel vault systems. As a result, a comparison of the seismic responses between the barrel vault test model and analytical model is given. Fig. 1 shows the process of this research.

2. Analytical models of barrel vault structures

A square-on-square offset method was applied as the grid form of the analytical model in this study. The size of the barrel vault was 20 m × 20 m as shown in Fig. 2, and the height of the top and bottom chord (D) was 1 m. The depth (1 m) and length (20 m) for the span of the analysis model was chosen using a 1/20 ratio because current research has shown that when this ratio is between 1/15 and 1/20, the layer depth is in the most economic range [11,12]. Additionally, a module that is the distance between

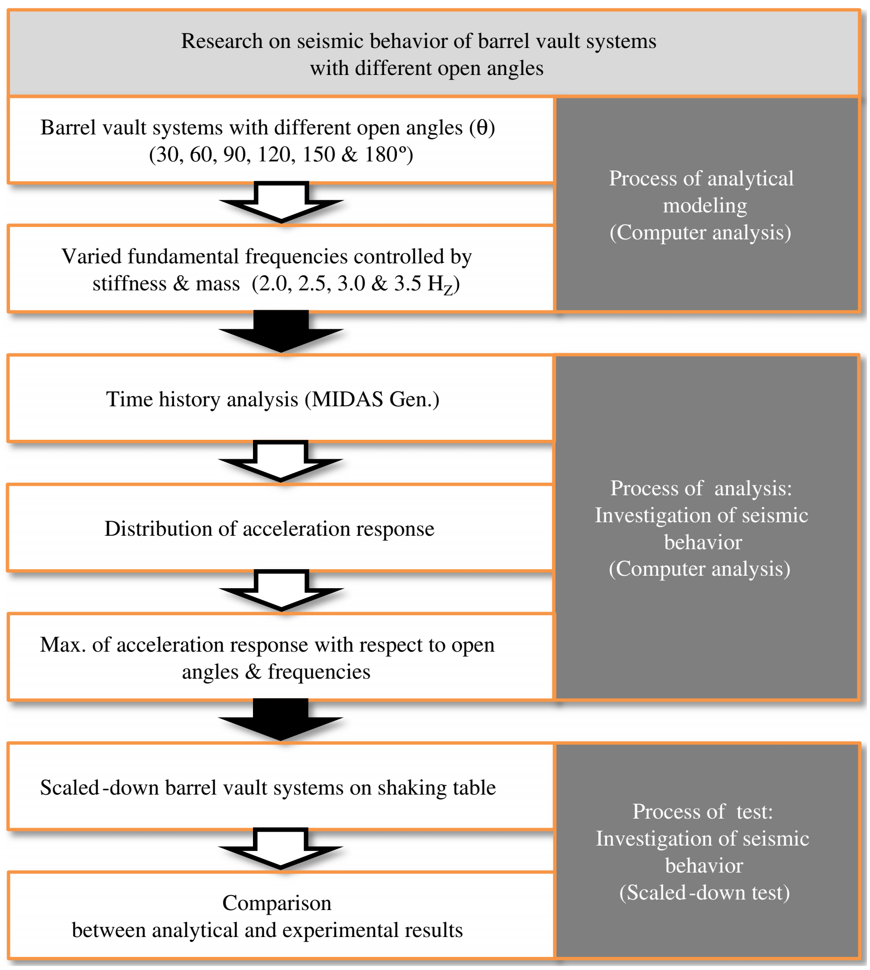

Fig. 1. Research flow chart.

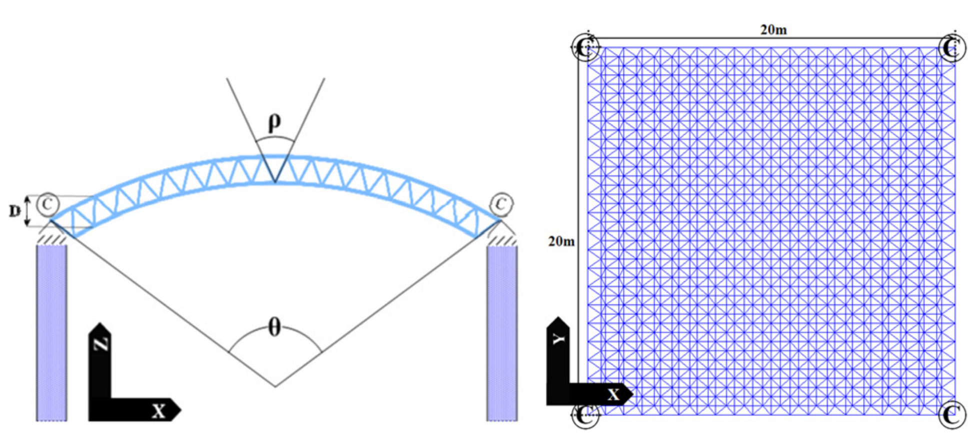

Fig. 2. Modeling information of barrel vault system.