# DYNAMIC CHARACTERISTICS OF LARGE REINFORCED CONCRETE DOMES

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## ABSTRACT :

The United Arab Emirates (UAE) is adjacent to the Iranian plateau which is one of the most seismically active areas of the world. Recently, Northern Emirates have been affected directly by seismic activities in Zagros Fault Belt and other faults in the region. Qeshm (South Iran) earthquake of November 27, 2005 of magnitude 5.9 in the Richter scale and its several aftershocks sent waves that shock buildings in major UAE cities including Dubai, Sharjah and Ras Al-Khaima and sent hundreds of thousands of rattled residence to the streets. Large span reinforced concrete domes with different shapes (spherical, ellipsoidal and paraboloidal) are becoming increasing common roof structures, especially in modern government buildings, mosques and university buildings. Behavior of large span reinforced concrete domes under earthquake loading and the interaction between these domes and the rest of the structure is not well studied. This issue did not receive much attention by the research community due to the scarcity of such structures worldwide. To assess the seismic vulnerability of buildings with large domes, the dynamic characteristics and behavior of large reinforced concrete domes with long spans need to be studied and their susceptibility to damage need to be evaluated. This paper, specifically presents a parametric study of reinforced concrete domes and the effect of the variation of their thickness, height and span on their dynamic characteristics such as frequencies of vibration. This study presents the first step towards the assessment of seismic vulnerability of buildings with large reinforced concrete domes.

**KEYWORDS:** Reinforced concrete domes, Dynamic characteristics of domes, Spherical domes, Parabolic domes.

## 1. INTRODUCTION

The superiority of domes as roofs is in their stiffness and strength that they stand without the support of columns. Domes are very strong and durable and in a realistic situation would probably still be standing when all conventional structures had failed (www.monolithic.com). Domes are among the most efficient structures available, especially as roof structures. However the complexity of their analysis, design and fabrication sometimes limit their use. The coupling among the bending and the axial behaviors of domes make them difficult to analyze (Leissa 1993, Soedel 2004). As a roof structure, the main force that a dome bears is its own weight. Thus its function is largely affected by its shape and geometry. Reinforced concrete shell structures (domes) undergo different load combinations with three-dimensional geometrical complexity, as well as three dimensional nonlinear behaviors of its material. These complex conditions make analyzing the structural behavior for predicting its respond imprecise (Liessa 1980, Hejazi 2003). For investigating the dynamic response of domes to applied loads, the variables that affect their behavior are cut down to a limited number and are mainly dome shape, thickness, span length, and height. Domes may be located in seismic zones and therefore they will be subjected to dynamic loads. Although the dynamic forces on a concrete dome generally do not control the design, however, in earthquake prone areas the most disastrous force that can be applied on a dome is earthquake load. Several researchers have studied the vibration characteristics of shells in general and formulated three dimensional analytical solutions (Leissa 1993, Chakravorty 1995, Tan 1998, Soedel 2004, Zhang et al. 2006). This paper presents a study of dynamic behavior of reinforced concrete domes and the effect of the variation of their thickness, span and height on their dynamic characteristics such as frequencies of vibration. This is the first step for evaluation of susceptibility of buildings with domes to earthquake damage and the assessment of their seismic risk and vulnerability due to earthquakes (Abdalla et al. 2006). The rationale for conducting this research and the reasons are that: (1) The UAE is located in the Eastern end of the Arabian Platform which is relatively close to the seismically active zones of Zagros fault and Makran subduction zone – long period effect have been recorded in UAE as a result of far field earthquakes; (2) There is a rapid increase in the number of buildings with domes in addition there is noticeable increase in domes' size, span and height as well that warrant the study of damage potential of domes under earthquakes; and (3) The relative scarcity of comprehensive study of dynamic response of reinforced concrete domes with large spans.

## 2. TYPES OF DOMES

Domes are types of thin shells in the form of surface of revolution, which serve primarily as roof structures. A surface of revolution is obtained by the rotation of a plane curve about an axis lying in the plane of the curve. Domes can be classified based on type of curvature, boundary shape and boundary constraints (Leissa 1993). There are several types of domes that can be categorized based on their shapes (Billington 1965, Soedel 2004). Spherical domes are in the shape of sphere and transfer the loads into uniform load over the dome surface. Some domes are in the shape of parabola and are called paraboloidal shells or domes. Ellipsoidal domes are the result of revolution of ellipses and they have elliptic shapes. Another shape of dome that is considered as a recent innovation is called geodesic dome that is known to be a tension/compression type of structure (Bradshaw et al. 2002). In general, dimensions of the domes are determined in accordance with the size of the building. Material used for dome construction varies from concrete to steel, to combination of both in one, two, and more layers (Bradshaw et al. 2002). Rectangle truss domes are also being used because of the ability of the truss structure in effective transference of the loads. As the innovation in dome construction increases the ability of the dome to resist the applied load increases as well. Also, the study of dynamic behavior of domes become important. Several researchers have studied the free vibration response of spherical shells (Kunieda 1982, Kang et al. 2000, Liew et al. 2002 and Lee et al. 2002), paraboloidal shells (Kang et al. 2005) and ellipsoidal shells (Shim et al. 2004).

Figure 1 shows different types of reinforced concrete domes (spherical, ellipsoidal and paraboloidal) used in several buildings at University City of the American University of Sharjah in UAE. The thickness, span and height of these domes vary from one building to another.

Figure 1 Use of different types of domes (courtesy of the American University of Sharjah)

## 3. DESCRIPTION OF THE BUILDING AND ITS DOME

The spherical dome shown in Figure 2a represents a typical dome that is placed on top of several buildings in universities and government buildings in UAE. Such spherical dome usually is placed on top of a ring beam. Due to its relatively small thickness of 0.2 m compared to its span of 13.7 m and height of 6.85 m, it can be treated as a thin shell. The dome is usually constructed and placed on top of the building as one big piece. Figure 2a shows the front view of the dome and Figure 2b shows a section of the dome and Figure 2c shows a plan view of the dome. Domes of different thickness, heights and spans are used in this study.

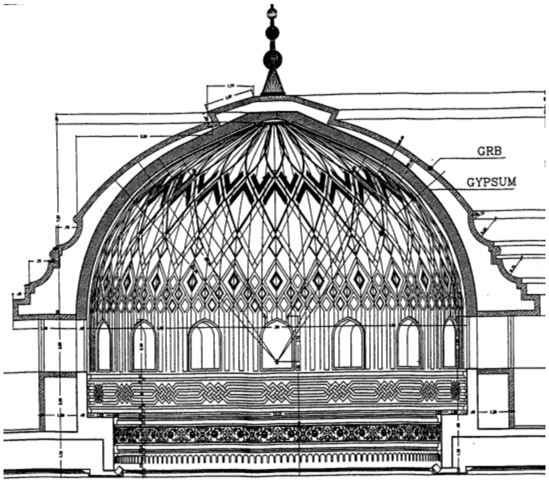

Figure 2a: Front view of the Dome (courtesy of AUS)

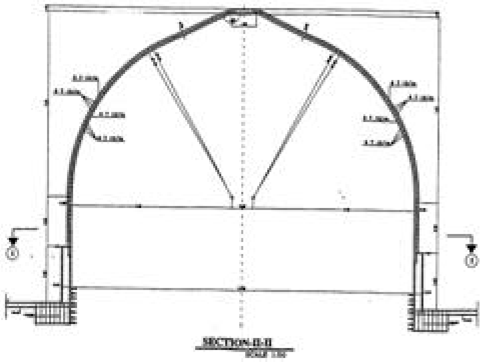

Figure 2b: Section of the Dome (courtesy of AUS)

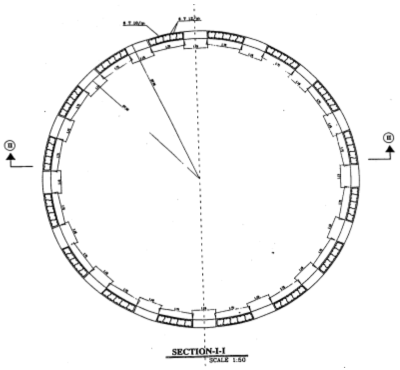

Figure 2c: Plan view of the Dome (courtesy of AUS)

## 4. DYNAMIC CHARACTERISTICS AND PARAMETRIC STUDY

In this study 51 spherical domes and 37 paraboloidal domes were modeled as shell structures using SAP2000. The four-node quadrilateral shell element was used to analyze the domes. Modal analysis was carried out to determine the inherent dynamic characteristic of the dome such as natural frequencies and mode shapes using different dome thicknesses and different dome heights. In carrying out parametric studies, several parameters have been used. As a thin shell, the thickness plays an important role in the dynamic characteristics of the dome and its load carrying capacity. Thus one of the parameters taken into consideration is the thickness of the dome. Modal analysis has been carried out for several cases as follows using SAP2000 (SAP2000 2006). Four cases were presented in this investigation: (1) Spherical dome with fixed span, L = 13.7 m, fixed height, H = 6.85 m, and variable thickness (0.01 – 2.5 m); (2) Spherical dome with fixed thickness, t = 0.2 m, and variable height or span (13.7 – 16.0 m); (3) Paraboloidal dome with fixed span, L = 2x13.7 m, fixed height, H = 13.7 m, and variable thickness (0.05 – 1.0 m); and (4) Paraboloidal dome with fixed thickness, t = 0.2 m, and variable height (1.0 – 16.0 m).

### *4.1. Spherical Domes with Variable Thickness*

Figure 3 shows the variation of the spherical dome frequency of vibration and its thickness for a dome of span L = 13.7 m and height H = 6.85. It is observed from Figure 3 that, there is a sharp increase in frequency of vibration when the dome thickness is small and ranges from 0.01 to 0.03. As the weight of the dome increases by increasing the dome thickness the fundamental frequency of vibration of the spherical dome and that of the second mode of vibration show slight increase as compared to the frequency of vibration of higher modes, which shows, relatively more rate of increase.

### *4.2. Spherical Domes with Variable Span*

Figure 4 shows the variation of frequency of vibration of the spherical dome with its height or span for a dome of thickness t = 0.2 m. It is observed that there is a decrease in the frequency of vibration of all the four modes as the dome span increases and the rate of decrease is the same and is linear.

### *4.3. Paraboloidal Domes with Variable Thickness*

Figure 5 shows the variation of dome frequency of vibration with dome thickness for a dome of height H = 13.7 m and span L = 2x13.7 m. It is observed that the frequency of vibration increases gradually with the increase in the paraboliodal dome thickness for all modes but at different rates. However, all modes tend to converge toward certain values. They specifically have the same frequency value when the thickness is about 0.55 m as shown in Figure 4.

### *4.4. Paraboloidal Domes with Variable Span*

Figure 6 shows the variation of frequency of vibration with dome height for a dome of thickness t = 0.2 m and a span L = 2x13.7 m. There is a nonlinear decrease in the frequency of vibration of the domes with the increase in the dome's height as shown in Figure 6.

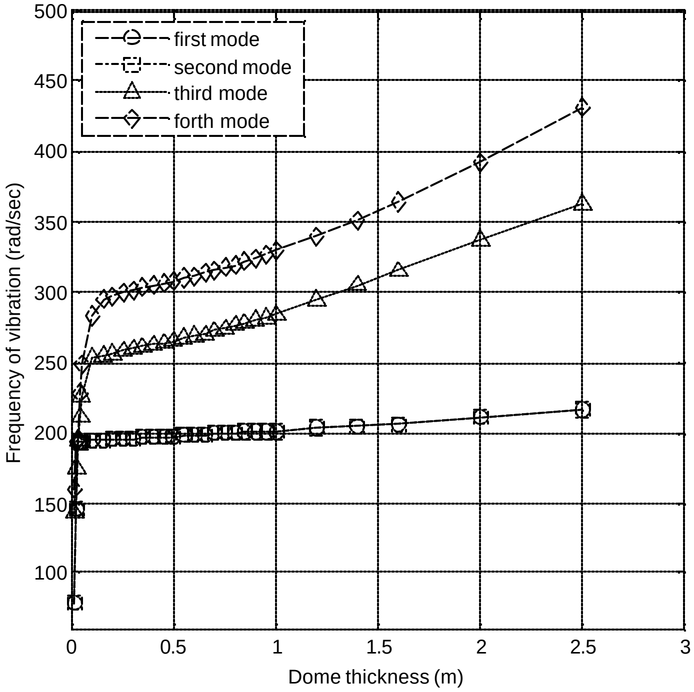

Figure 3: Variation of frequency of vibration with thickness for spherical domes

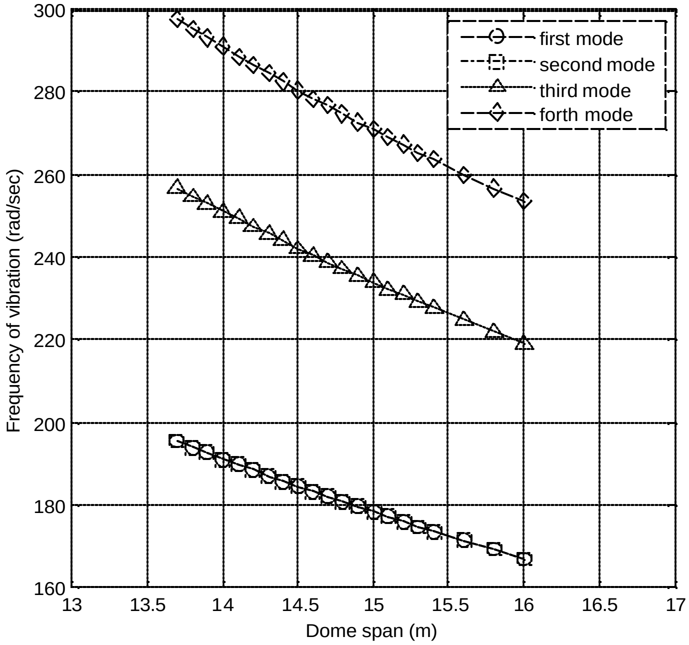

Figure 4: Variation of frequency of vibration with span for spherical domes

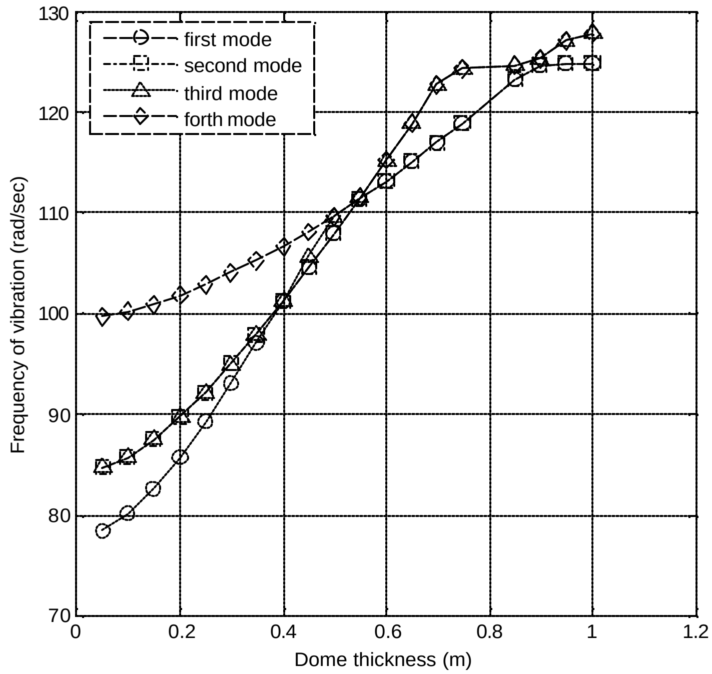

Figure 5: Variation of frequency of vibration with thickness for paraboloidal domes

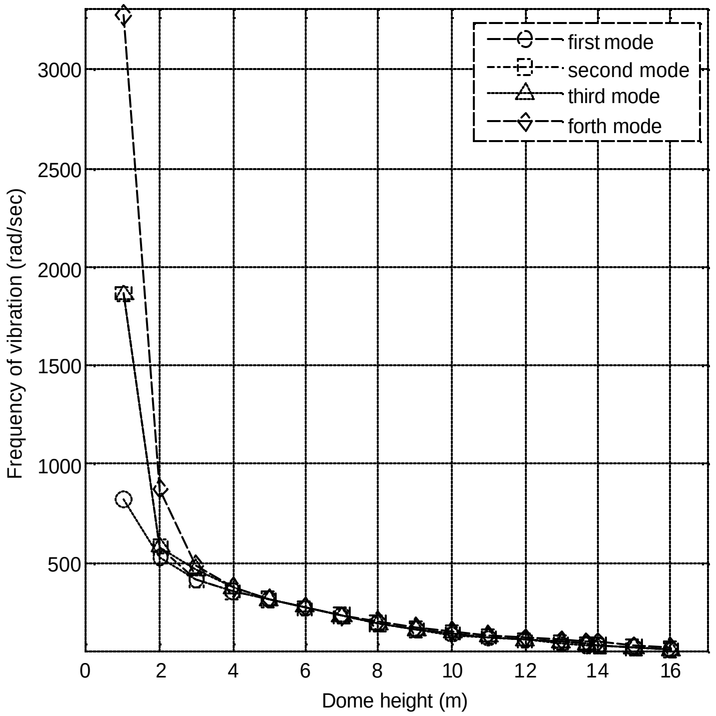

Figure 6: Variation of frequency of vibration with height for paraboloidal domes

## 5. CONCLUSIONS

This paper presented a parametric study of the relationship between reinforced concrete dome shape, thickness, height and span and their dynamic characteristics, specifically, frequency of vibration. Although the frequencies of vibration of domes are closely spaced and not distinctly separable, especially the ones of the lower modes of vibration, there is still variation in frequencies with respect to dome thickness, dome height and dome span.

- It can be concluded from this study that the increase in the dome thickness increases the frequency of vibration of both spherical and paraboloidal domes while the increase in dome height decreases the frequency of vibration of both spherical and paraboloidal domes, however linearly for the former one and nonlinearly for the later one.
- At large heights the frequencies of vibrations at all modes tend to converge to similar values for paraboloidal domes while they remain distinct for spherical domes.
- For large dome thickness, the frequencies of vibrations of spherical domes diverge from each other while for parabolidal domes they have the tendency to converge at certain values.

In order to assess the seismic vulnerability of reinforced concrete buildings with large domes, further studies need to be carried out that include: (1) investigation of the interaction between domes and buildings; (2) study of the dynamic response of different types of domes to different ground motion records; and (3) assessment of seismic vulnerability of reinforced concrete buildings with large domes to earthquake ground motion using nonlinear dynamic time-history and nonlinear static pushover analysis procedures.

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