DYNAMIC ANALYSIS OF A GEODESIC DOME

Nilson Barbieri¹,³(∗), Diogo Rossot¹, Roberto Dalledone Machado², Lucas de Sant'Anna Víbor Barbieri¹

¹Programa de Pós-Graduação em Eng. Mecânica, Pontifícia Univ. Católica do Paraná (PUCPR), Curitiba, Brasil
²Programa de Pós-Graduação em Métodos Numéricos em Engenharia, Universidade Federal do Paraná (UFPR)
³Universidade Tecnológica Federal do Paraná (UTFPR), Curitiba, Brasil

(*) Email: nilson.barbieri@pucpr.br

ABSTRACT

In this work the dynamic behavior of a geodesic dome in aluminum alloy is analyzed through numerical models obtained by the Finite Element Method and tests carried out in the laboratory. It was noted that the numerical and experimental results have large differences. Dynamic tests were performed using impulse excitation (impact hammer) and sweep frequency through harmonic excitation (mini-shaker) to identify the natural frequencies of the structure. Using the theory of Fourier transform and "wavelet", it was possible to visualize different dynamic behavior of joints. Possible causes for the differences involve the type of joint, the fixing of the elements in the joints, the profile adopted for the elements and boundary conditions for the numerical model.

Keywords: Geodesic dome, vibrations, wavelet, Fourier transform.

INTRODUCTION

Engineers and architects have always a special interest in structures that were able to cover large spans without intermediate columns. In this context, it appears a structure known as a geodesic dome. Following the curved shape of a dome, but constructed from bars, the geodesic dome is a lightweight structure compared with other types.

The geodesic domes are structures with a resistance/weight ratio much greater than other types of structure second Ramaswamy (2002). Currently the use of geodesic domes is associated with large buildings. According Bysiec (2013) the geodesic domes can be assembled to cover spans over than 300m without intermediate columns.

The first Geodesic Dome built in history was in Germany in a city named as Jena in 1922. It was a planetary built by Walter Buersfeld for Zeiss industry according Makowski (1979). However, it is impossible speak on geodesic domes without speak on Fuller. Robert Buckminster Fuller was the bigger sponsor of Geodesic Domes second Kubic (2009). Fuller in his book Synergetics, Explorations in the Geometry of Thinking (1975) wrote about safe energy and develop a world that consume less energy. In this context he wrote about geodesic domes because it uses less raw material. Fuller has classified Geodesic Dome as a special type of Tensegrity Structures, what he considered a bigger group of structures. The name Tensegrity is the contraction between two words tensional and integrity. Fuller wrote that this kind of structures is continuous different from other structures what he classified how discontinuous. This means that this kind of structure absorb the tension better than other structures.

The design of geodesics domes are based on Platonics solids and they are formed by multiple triangles. Kenner (1976) and Clinton (1965) demonstrated the math to find the coordination of
the nodes that will generate the geodesic dome. They also classified the geodesic domes according method is used to find the coordinates.

The oil industry has used geodesic dome to cover storage tanks because geodesic domes has helped to avoid evaporation from the storage product and rain water contamination. This happens when geodesic domes are used together with the internal floating roof. The geodesic dome do not need intermediate columns to cover the tank so it allows an increase in efficiency of the internal floating roof. For more details, see Rossot (2014) and Rossot et al (2015).

In this work a physical model based on a real structure was built. The physical model was submitted to dynamic tests. A computer model with the same features of the physical model was built. Both models, physical and computational, were submitted to the same tests. The Frequency Response Function and the wavelet transform were used to investigate dynamic behavior of the joints.

**PHYSICAL MODEL DESIGN**

The physical model was based in a real structure used to cover a gasoline tank with 24 m diameter. The geodesic dome used to cover the gasoline tank is illustrated in Figure 1. Details about the design as, cross section of the bars, size and coordinates of the nodes, are according Rossot (2014). In Figure 2 is shown the pieces that were used to set the physical model and they are compared with pens to give an idea about the size. In Figure 3a is illustrated the physical model already built. Figure 3b show a detail of a node. Since the aim of this paper is to study the structure of the geodesic dome and the panels used to cover the real geodesic dome are very thin, they was not erected on the physical model.

The structure is composed of 51 beams and 130 joints (Fig. 4). The beams (L profile) were divided into 15 types (B1 to B15) (Table 1) varying according to the length. Note that the structure pattern is repeatable at every 72 ° (Fig. 5).
Fig. 2 - Demonstration of the scale of the model.

Fig. 3 - Real model finished.

Fig. 4 - Representation of the beams in the structure.
Table 1 - Size and number of beams in the structure

<table>
<thead>
<tr>
<th>Beam</th>
<th>Length (mm)</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>227.93</td>
<td>5</td>
</tr>
<tr>
<td>B2</td>
<td>377.80</td>
<td>10</td>
</tr>
<tr>
<td>B3</td>
<td>290.75</td>
<td>15</td>
</tr>
<tr>
<td>B4</td>
<td>281.14</td>
<td>10</td>
</tr>
<tr>
<td>B5</td>
<td>349.40</td>
<td>10</td>
</tr>
<tr>
<td>B6</td>
<td>246.44</td>
<td>10</td>
</tr>
<tr>
<td>B7</td>
<td>253.51</td>
<td>5</td>
</tr>
<tr>
<td>B8</td>
<td>267.58</td>
<td>5</td>
</tr>
<tr>
<td>B9</td>
<td>281.40</td>
<td>10</td>
</tr>
<tr>
<td>B10</td>
<td>272.90</td>
<td>10</td>
</tr>
<tr>
<td>B11</td>
<td>264.30</td>
<td>10</td>
</tr>
<tr>
<td>B12</td>
<td>275.58</td>
<td>5</td>
</tr>
<tr>
<td>B13</td>
<td>296.19</td>
<td>5</td>
</tr>
<tr>
<td>B14</td>
<td>418.80</td>
<td>10</td>
</tr>
<tr>
<td>B15</td>
<td>450.82</td>
<td>10</td>
</tr>
</tbody>
</table>

**DYNAMIC TESTS**

Dynamic tests were performed in the laboratory to obtain the modal parameters. The first dynamic tests were carried out using an impact hammer for the system excitation and vibratory data were obtained from six accelerometers placed on the structure (Fig. 6).

The basic idea of this paper is to obtain Function Frequency Response FRF of the structure. This parameter is the most used for modal identification of structures. Through the analysis of the curves it is possible to identify energy concentration regions associated with the natural frequencies of the system. In a further analysis, the inverse of the FRF signals were converted
for the time domain to the use of wavelet theory. The goal was to identify energy concentration regions using the joint vibration signals. Fig. 7 shows the force and Fig. 8 the acceleration signals in time domain. In this case was used four impulsive force to obtain the average of the signals. Figure 9 shows the FRF curve of one accelerometer and Fig. 10 the correspondent IFRF curves. It can be noted in Fig. 9 that there is a region of energy concentration near to frequency band of 30 Hz. This frequency of resonance is not present in the numerical results, where the first natural frequency is around 200 Hz order.

Fig. 6 - Impulsive test using impact hammer.

Fig. 7 - Impulsive force.
Fig. 8 - Acceleration signal.

Fig. 9 - FRF curve.

Fig. 10 - IFRF curves.
The continuous wavelet transform (CWT) is defined as follows:

$$ C(a,b) = \int_{-\infty}^{+\infty} f(t) \psi_{a,b}(t) dt $$

where

$$ \psi_{a,b}(t) = a^{1/2} \psi \left( \frac{t-b}{a} \right) $$

is a window function called the mother wavelet, where $a$ is a scale and $b$ is a translation. An energy index based on (2) was used to analyze the dynamic behavior of the joints. In this case, the analyzed signal was the inverse of the FRF. Figure 11 shows two different curves of energy for two different joints (symmetrical in the model).

It is evident from the figures that there are large differences in signal behavior in the joints. These energy concentration regions are related to different resonance frequencies of the system.

CONCLUSIONS

Dynamic tests using two different techniques, i.e., force impulsive (impact hammer) and sweep sine excitation using a mini-shaker were performed. The signals obtained from accelerometers and impedance head were treated in Matlab to obtain the curves of Function Frequency Response. All curves evidenced energy concentration regions to low frequencies between 25 and 100 Hz. These frequencies were not contained in the numerical results. The lowest rate was around 25 Hz (first vibrate mode). In an attempt to identify possible joints (nodes) that had different behaviors used an energy parameter based on wavelet transform. Doing a sweep of the major joints, it was noticed a large different behavior for one joint. Visually it was verified that this joint presented a large displacement by applying a small external force.

Several factors may have influenced this difference in numeric and experimental values of the natural frequencies. These factors may be related to the way of fixing elements (circular piece and screws that may have gaps); the type of element used (L beam) that for fixing it was necessary to decrease the contact area; the properties of the material (aluminum alloy); the boundary conditions used in the numerical model (the elements of the ends are fixed on a circular structure that was not considered in the numerical model).
REFERENCES


