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EXTENDED ABSTRACT

Determining the Frequency of Pyramidal Buildings with Tube-In-Tube and Bundled Tube Structures by Analytical Method

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1. Introduction

The research on tall buildings has been increased due to the demands of suitable spaces. The use of pyramidal architecture in tall structures has several benefits including the ability to lighten the adjacent buildings and prevention from the closure of the view in urban spaces. However, the seismic behavior of pyramidal tube structures requires a closer examination of their design and probable behavior under lateral loads. One of the most important parameters in the pyramidal tapered buildings is the calculation of natural frequency of the vibrating structures (ω). In this study we have proposed new equations and methods for the mentioned calculations which has been compared with software calculations. Many researchers have calculated the free vibration of structures using different methods. One formula to obtain the natural frequency of tube structures is obtained from the fourth-order differential equation (Wang, 1996). An approximate solution in order to analyze the free vibration of tall tube-in-tube buildings have been proposed by different researchers (Lee, 2007; Lee and Bang, 2008; Lee and Tovar, 2014). The modeling of tall building using a beam with varying stiffness and mass subject to the variable axial force caused by simple weight was presented by Mohammadnejad (2015). Free vibration analysis using differential equation has been evaluated by Bozdogan (2009) and Bozdogan (2013). The first natural frequency of tall buildings with a system combined of framed tube, shear core, and belt truss has been calculated under axial force (Kamgar and Rahgozar, 2014; 2015; 2018). A new and simple method of determining the natural frequency of tube structures with tube-in-tube wall has been presented. The novelty of this method refers to the mathematical computation process which is much simpler and shorter. The effect of structure's weight on the natural frequency of structure has been considered by variable axial force. Tall building is modeled by a beam with variable stiffness and mass along the height of the building. Therefore, the partial differential equation with variable coefficients is used which have been presented by Mohammadnejad and Haji-Kazemi (2018). Furthermore, there is no regular research on the vibrational frequency calculation of pyramidal tube systems, especially by mathematical methods, or a small number of studies have been done most of which have been done on 90-degree structures with tube systems.

2. Methodology: weak form of differential equations

The governing equation for free beam vibration with variable hardness and mass is a partial differential equation with variable coefficients. Mohammadnejad and Haji-Kazemi (2018) have evaluated and analyzed mathematically the tubular structures. In this study, we have assumed the tubular structures behave like a cantilever beam and the bending and shear hardness parameters of equivalent beams are obtained from the structural stiffness matrix. Then, using this assumption, the governing differential equation is written as a weak form. The weak form of the differential equation is obtained by repeated integration of the initial equation. The

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integration goes on to obtain the differential equation in terms of integrals which uses a simpler solution than previous research to solve the differential equation. In this method, instead of four integration times, the two sides of the equation are integrated twice and finally, the natural frequency of the structure is estimated using a series. The comparison of results obtained from the calculations based on proposed method in this study with the results of finite element analysis shows the high accuracy of this method in the estimation of the natural frequency of structures. We obtain new formulas and equations for pyramidal structures and compare them with other methods. The weak solution of differential equations instead of the original equation has multiple uses.

3. Results and discussion

The variables used in this study are the pyramidal angle of the building and the type of tubular system. In order to investigate these variables, it is necessary to change the pyramidal angle in different tubular structural systems and the results should be assessed. For this purpose, two tubular structural systems are considered, including tube-in-tube and bundled tubes. For each of these systems, 3 models with 3 pyramidal angles of 0, 1.23 and 2.45 degrees with vertical deviation are considered. The number of floors in the same structural systems is also assumed to be constant. For this purpose, models with pipes and tubes of 40 and 70 stories are considered. The lengths of the openings on the tube frames are 3 meters above the ground level. In order to avoid the effects of plan shape as well as irregularities in the structure on the results of the research, the layout of all models is considered to be perfectly regular. In this section the results of numerical modeling as well as the results of mathematical method are presented and these results were compared and the mathematical method errors were analyzed. Also, the relationships between the research variables, including the pyramidal angle of the structural height and the type of structural system were investigated and their relationship was obtained.

Considering to the presented tables and Fig. 1, and comparing to the standard deviation of the errors we can find that the distribution of errors for the number of 70 stories is less than the number of 40 stories. Also, by comparing the mean errors we can find that the mathematical method for the number of 70 stories gives more frequency value than reality. The obtained values for the number of 40 stories are less than reality. The results of the tables and the obtained show that the mathematical method is most compatible with the number of stories.

4. Conclusions

One of the most important dynamic properties of tall buildings is vibrating frequency. There are no suitable classification criteria for the new class of tall tubular and tubular pyramidal buildings in the standard guidelines or it has not been mentioned properly. The present work aims to develop a simple method for the analysis of free vibration of tall buildings and calculate the frequency using differential equations used for easy solution and simple design solutions to facilitate computational efficiency in the initial design. The approximate methods of analysis can be used for calculations. The presented analytical method is in good agreement with the finite element modeling results and the use of natural frequency obtained by this method has been confirmed. The evaluations show the acceptable accuracy of the proposed mathematical method for the bundled tubular and the tube-in-tube systems. They also show the accuracy of the proposed mathematical method, even though, if the number of stories were more, the accuracy of the obtained results would be considerable. In other words, the proposed method is more compatible with a greater number of stories. The investigations have shown that the presented analytical method gives negligible error for structures without pyramidal angles which are more consistent with the presented mathematical method whereas, applying this method for pyramidal angle structures entails some error in the calculation. In order to find out the relationship between the variables, this study shows that the higher the pyramidal angle of the structure, the higher the natural frequency of the structure. But on the other hand, increasing the pyramidal angle means reducing the number of hardening elements such as beams, which reduces the structural stiffness and reduces the natural frequency that must be taken into account.

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