Effect of increasing floors number on the natural frequency compared with further masses added to steel building models

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Abstract. This paper investigates the change in the natural frequency of whole building due to the increase or decrease of the number of floors of a steel building model. Five steel building models were adopted in the present study to investigate the natural frequency required to be identified in each model. The first model represents a one floor building model, the second building model contains two floors and so on. The first four models were subjected to further masses distributed upon four points within the last floor. Each model consists of the same structural details that are proposed in the other models such as details of the beams, columns and slabs. The herein parameters are the number of floors and the further added masses upon the models up to four floors. All models were analyzed using ANSYS software to identify the natural frequencies for the extracted modes of vibration about X, Y, and Z building axes. The study is aimed to produce a relationship between the change of floors number and the further mass addition in the field of structural frequency attenuation based on the indication of the first identified mode. Results show that higher masses required to be added to attenuate value of natural frequency for the one floor building model than the further masses required for building with two floors to achieve the same purpose. This relationship continues for the other models with higher number of floors but with less further required masses.

1. Introduction

The attention towards the role of floors vibration in the structural design was noticed since the early of 19th century [1]. At that time, the researchers declared that the stiffening of the structural elements is required to minimize the floor vibration produced by the human activities or other sources as much as possible [1]. Other researchers [2] investigated the full-height non-structural partitions effect on the dynamic properties of the composite floor. Both of the previous techniques are related with the vibration of the floor itself as a local behaviour for a certain part vibration in the building while present study focuses on the global vibration behaviour of the building due to the increase in floors numbers as aforementioned by some researchers in literature [3-4].

The natural frequency is an important measure of vibration rate of any structural system in which either be in cycles per second (Hertz) or in radians per second. It is important to the designers to identify the natural frequency for each structure in order to insure that it is not coincide with the frequency obtained by the excitation forces to avoid the resonance phenomena [5]. In this way, attenuating frequency of a certain structural system is an important aim in which the system will be with an insufficient time that had been already changed due to the frequency attenuation to react with the cyclic load [5]. Here, cyclic load is the causative of excitation which could be due to different reasons such as human activities, traffic vibration or any other reason. As an example, if the cyclic load has a sufficient time to complete one cycle, then this will allow the building to react and response to the excitation load sufficiently, and
vice versa [5]. Hence, the attenuation of frequency should be taken into account by the designers to produce acceptable dynamical designed systems. Present study investigates the relationship between the increasing floors number of steel structures and the natural frequencies produced in these structures. This relationship is compared with the frequency attenuated based on the addition of further masses as a specified attenuation technique [6-8] according to the indication of first identified mode.

2. Adopted models
Due to the widely use of steel structures in the societies [9], five steel structural models were adopted in the present study. Starting with a one floor building model, additional floor was added to each one of the other four models to produce models with two, three, four and five floors. Later, models up to four floors were subjected to further masses added on the last floor distributed on four points so that the total adopted models become nine models. All the details of the beams, columns and slabs are the same for each floor. Thus, only the one floor building model is shown in Figure 1 and other models with additional floors are similar.

As shown in Figure 1, four beams are existed in each floor with I-shape and the dimensions details shown in Figure 2a. Also, there are four steel columns with a hollow square cross section shown in Figure 2b carry a steel slab with 50 mm thickness.

![Figure 1. One floor steel model.](image)

![Figure 2a. Beam dimensions.](image)

![Figure 2b. Column dimensions.](image)
Each model was simulated using ANSYS software based on the following details, the height of each floor (in Z-direction) is 3000 mm, distance between columns centre to centre is 4000 mm in Y-direction while it is 5000 mm in X-direction. The Element Type (ET) was used as Beam4 for the beams and columns, element type of Shell63 was used to simulate the slab and element type of Mass21 to represent the further masses. Only one Material Property (MP) was considered for all elements in the structure represented by the steel material that has modulus of elasticity of 200 GPa, Poisson's ratio of 0.3 and density of 7860 kg/m³. The columns are completely fixed in all directions in their ends within the ground level during the analyzing process. Each one meter length, of the beams or columns, has been divided into 10 elements in the finite element model so that the total elements for the slab will be 40×50 total existed elements.

3. Application of modal analysis

Each model was analyzed based on modal analysis via ANSYS software to identify natural frequencies and the shape for each of the three considered modes of: first bending about X-axis, first bending about Y-axis and first torsion about Z-axis. Figure 3 shows the mode shapes and values of natural frequencies for the models without further added masses based on the number of floors.

With respect to models with further masses that were added to the models up to four floors, the shape of adopted modes were the same as in the case of models without further added masses. So that only values of natural frequencies were changed for the models up to four floors. The comparison between natural frequencies values identified form models without further masses and the corresponding values obtained by models with further masses was executed based on indication of the first mode only which is the bending about X-axis mode and therefore they are listed in Table 1. Also, Table 1 shows values of masses that were added to the models based on their floors and the attenuated frequency value due to the mass addition for each model.

| Number of floors | 1   | 2   | 3   | 4   |
|------------------|-----|-----|-----|-----|
| Value of additional mass (Ton) | 80  | 30  | 20  | 10  |
| Attenuated frequency of the first bending about X-axis mode (Hz) | 2.67 | 1.53 | 1.03 | 0.85 |
Figure 3. Shape of modes and values of natural frequencies for the adopted modes.
4. Results and Discussion

Values of natural frequencies were obtained based on two response:

4.1. Frequency response to additional floors

For the adopted mode and based on the modal analysis, the relationship between value of the natural frequency and the number of floors for the models without further added masses are plotted in Figure 4. It is clearly shown that the values of natural frequencies were decreased as the number of floors was increased as an adversely relationship. The curve of first mode (bending moment about X-axis) shown in Figure 4 decreases sharply for the models with one and two floors while it decreases with lesser sharpness when the number of floors are increased.

![Figure 4. Values of natural frequencies for the first three modes with respect to floors number.](image)

4.2. Frequency response to further masses

For each model, further masses were added to attenuate its frequency to a value nearly equal to that of the model with one additional floor. Here, the aim is to reach a low frequency value for each model without additional floor. In this case, only the first mode (dominant mode) was investigated to be as the indicator for the frequency attenuation. Starting with the model of one floor, further masses were added gradually to reach a value of frequency nearly equal to that of two floor model. The same procedure was repeated then for the model with two floors to reach a value of frequency close to that of the three floor model and so on. Results of the procedure are plotted in the bar chart shown in Figure 5.
Figure 5. Attenuating frequency by additional masses compared with increasing floors number.

Based on Table 1 and Figure 5, further masses of 80 ton was required to attenuate the first mode in the one floor building model to reach a frequency value approaching to that of the corresponding first mode in the two floors building model. Next, further masses of 30 ton was required to attenuate the frequency value of the two floor model to produce a frequency value close to that of the corresponding three floors model without further masses. The repeated procedures applied upon the three and four floors building model produce 20 and 10 ton, respectively, to attenuate natural frequencies such that they respectively approach to frequencies values of the four and five floors. Both groups’ results of natural frequencies obtained by models without further masses and the corresponding group values obtained by models with further masses are plotted in Figure 6 to recognize the relationship based on the results of the first bending about x-axis mode. The relationship exhibits high difference (5.33 Hz) between values of natural frequency for models with further masses and the corresponding natural frequency values of models without further masses. The difference is gradually decreased to 0.219 Hz as the number of floors is increased, as shown in Table 2.

Table 2. Differences between values of the first mode natural frequencies for models without further masses and the corresponding values of models with further masses.

| Number of floors | 1    | 2    | 3    | 4    |
|------------------|------|------|------|------|
| Further masses   | 80   | 30   | 20   | 10   |
| Frequency (Hz)   | 8.0122 | 2.9164 | 1.6094 | 1.0709 |
| Frequency (Hz)   | 2.6729 | 1.5338 | 1.0349 | 0.8517 |
| Difference (Hz)  | 5.3393 | 1.3826 | 0.5745 | 0.2192 |
5. Conclusions
In the field of frequency attenuation, present study exhibits the following conclusions:
1. Increasing the number of floors in the building model decreases natural frequency values as the same action of further added masses.
2. Attenuating values of natural frequencies for the one floor building model requires high value of further mass (80 ton) to approximately become as the frequency value of two floor building model without further masses. The required value of further masses becomes smaller (30 ton) to make the frequency values of two floors model with further masses close to the frequency value of the three floors model without further masses. Required masses decrease to values of 20 ton and 10 ton added to the three and four floors models, respectively, to approach the frequency values of the corresponding four and five floors models without additional masses.
3. For both cases of increasing floors number or further mass addition, the relationship of reduction in values of the natural frequencies starts sharply for the models with one and two floors and becomes lesser sharpness for the models of higher floors number.
4. The differences between the values of natural frequencies of models without further masses and that of models with further masses start highly, with difference of 5.33 Hz, and gradually decreased to 0.219 Hz as the number of floors is increased.

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