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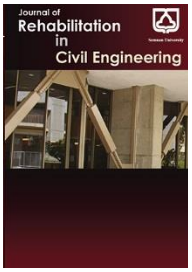

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Free Vibration Analysis of Steel Framed Structures

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ABSTRACT

This study based on free vibration analysis and study the behavior of framed structure under different frequency of vibration using ANSYS software and shaking table. A small scale uni-axial shaking table was prepared in laboratory, which can produce lower to moderate vibration, regarding frequency and velocity. Moment resisting framed structures constructed with connecting beam and column elements of mild steel wire of different dimensions were tested in shaking table and analyzed using ANSYS software. The effect of masses and stiffness of structures on its natural frequency and deflection under certain ground vibration also studied and discussed. The test results showed that, this shaking table is satisfying the general concept of free vibration. The height of structures has an inverse effect on its natural frequency for same lateral stiffness. After several shaking, structure's natural frequency started to decreases with their decreasing stiffness. Therefore, the fabricated shaking table can used in free vibration analysis.

1. Introduction

The seismic response of a building is mainly controlled by the natural period of vibration [1]. In engineering design, it is important to calculate the displacement, vibration frequencies, and mode shapes of structures under any level of external excitation [2]. It is well established that the mass, stiffness and height of building controls the building period and natural frequency of vibration. Natural frequencies of a soil- structural system have non-linear variations under different levels of excitation [3], as results the response of the structure is different at each of the different excitation. Therefore, studies are essential considering different boundary conditions of structures, different

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level of excitation and their effects on natural frequency. Researchers are trying to find out the general conclusions in regarding the vibration response of structural models. Moment resisting framed structures are more effective to resist lateral forces due to their high lateral stiffness. These structures are suggested by the civil engineers in earthquake vulnerable areas. Salama [4] studies the effect of the floor height in the period of vibration for concrete moment resisting frame buildings. Karavasilis et al. [5] studied on the influence of specific parameters, such as the number of stories, the number of bays, the joint capacity design factor and the level of inelastic deformation induced by the seismic excitation. In the study of Kanat [6] free vibration analysis of multi-storey asymmetric structures was done with masses added in floor levels to study their angular frequencies. From the results of previous study, it has been found that the number of storeys, the span length, the stiffness of the infill wall panels, the location of the soft storeys and the soil type are crucial parameters that influence the fundamental period of RC buildings [7]. First natural vibration frequency is reduced due to the increased load on structures, this phenomenon changed the total dynamic load and its pattern in structural system [8].

Free vibration analysis is the basic step to study the dynamic characteristics of structures. This analysis is useful to study the dynamic properties of any structure by findings its natural frequency and mode of vibration and displacements in structures. In the study of Azeloglu et al. [9] free vibration tests were performed and critical frequency values of the system were obtained and validated numerical modal analysis using ANSYS software. In the article of Ashory et al. [10], a new method is proposed to determine the mode shapes of linear dynamic systems excited by an impact force and mass change method is used for scaling the mode shapes.

The most challengeable factor is to increase in stiffness of structures without significant increase in mass to minimize the deflections under vibrations. In this perspective, researchers trying to explain the different structural system used in building and to modify them. A significant bracing action, affecting both the strength and stiffness [11-12]. A comparison was made using different types of steel moment resisting frames in regard to illustrate the performance subjected to strong ground motion through incremental dynamic analysis method [13]. Presently steel structures are gaining popularity for their low self-weight and high tensile strength. Therefore, steel framed model structures were chosen for laboratory test. The previous study [14] investigates the effects of using different connection in models on the seismic behavior of steel moment resisting frame buildings.

Researchers also found important conclusions from numerical analysis of dynamic behavior of structure under certain vibration conditions. Different computer programming and softwares were generalized to simulation of the structure with loading varieties. For example, Michał [15] use free vibrations analysis of thin plates by the boundary element method in non-singular approach. Nonlinear analysis of the new composite frame structure by Donglin and Li [16], using ANSYS software, they analyzed the seismic performance of extension-story concrete composite frame under low cyclic loading and analyze the restoring force model of the overall structure.

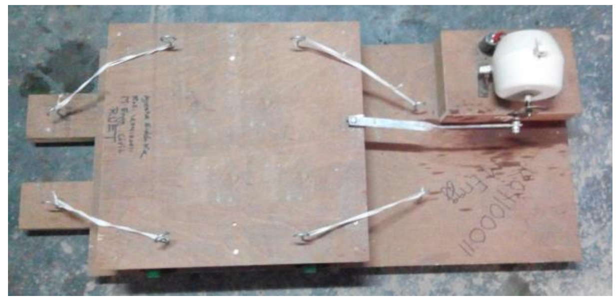
The essential equipment for the study of behavior of structural system under dynamic loading is a shake table, which can produce vibration of different frequencies. Shaking table test has been carried out previously [17-19] to illustrate the behavior of structures under different types of loading. In the present study, a uni-axial shaking table is prepared to test moment resisting framed model buildings and observed their frequency and deflection pattern under different level of excitation.

2. Experimental Procedure

2.1. Preparatıon of Shakıng Table

Shake table is useful to produce vibration and to test the model structure under specified level of excitation. Seismic analysis of structure means to provide equivalent distributed lateral force acting at various lumped level of structure above ground based on the ground motion at that site [20]. For simple nature of dynamic analysis, the behavior of structure is analyzed when horizontal ground shaking occurs. Horizontal shaking of shake table is representing the horizontal shaking of ground. Single translation (horizontal) degree of freedom shaking tables is useful for laboratory testing to study behavior of structures. From this perspective, low cost uni-axial shaking tables were designed & fabricated by Researchers [20-23]. From these concepts a uni-axial earthquake shaking table (Fig. 1) was prepared in laboratory using locally available material.

a) Foundation of shaking table.



b) Shaking table.

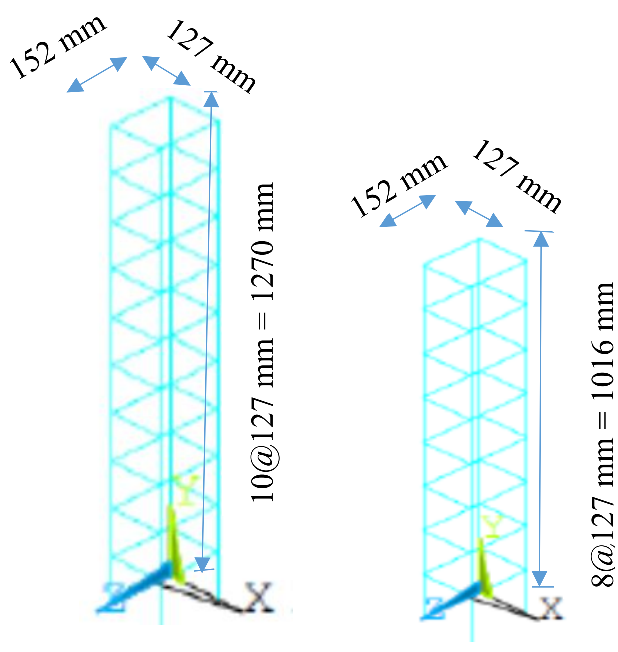
Fig. 1. Preparation of shaking table.

An electric motor with variable speed regulator is used to construct vibration production unit of the shaking table. At first the arrangement shown in Fig. 1a) was made by using plywood platform and PVC pipe fencing by bolts with rubber washer. Plywood base is placed over PVC pipe dowels to move back and forth due to rotation of motor and armature connected with base and motor. Rubber bands were used to prevent any vertical vibration as shown in Fig 1b). This shaking table is suitable for small scale model tests and able to produce only uni-axial vibration with frequency ranged from 0.85 Hz to 1.65 Hz and velocity of base found from 5.95 cm/sec to 11.55 cm/sec. The vibration which can be produced by this shaking table is not same as real earthquake in accordance with all dynamic properties, but for laboratory test this motion of vibration can be classified as similar to 3.9-5.1 magnitude of earthquake (Richter scale) vibration approximately from

United States Geological Survey [24] reports and data. The vibration of base of shaking table remains constant through its application time, therefore it may called undamped ground vibration also.

2.2. Properties of Structural Models

In laboratory four models (Model 1, Model 2, Model 3 and Model 4) were tested on shaking table and analyzed. Mild steel wire of different diameters used to construct models. 10 storey models 1 and 2 constructed using 2.5 mm diameter mild steel wire. All models were constructed as beam column connected moment resisting frame, where welded connections were used to connect the beam and column of mild steel wire as shown in Figs. 2 and 3.



a) Model 1 b) Model 3

Fig. 2. Structural models.

Similarly 8 storey models 3 and 4 constructed using 2 mm mild steel wire. Models 2 and 4 were made with slab on every floor. Slabs were made using steel sheet plate of 0.07 mm thickness and 32 gm weight. These slab just act as mass on structural models.

a) Model 1 b) Model 2

Fig. 3. Models under shaking table test.

Figure 3(a) shows the model 1 and Figure 3(b) shows model 2 under test. Dimensions and other properties of models is listed in Table 1. Theoretical natural frequency of model calculated according to Beer et al. [25] and Chopra [26]. Where the natural frequency of any moment resisting frame structure was given by following equation (1):

$$f = \frac{1}{2\pi}\sqrt{\frac{K_{tot}}{M_{tot}}}\ \text{Hz} \qquad (1)$$

To find the total mass (M_{tot}) simply sum the mass of each floor (M_1, M_2, M_3, . . M_n). The total stiffness is found as following equation (2):

$$k_{tot} = \left(\frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \ldots.. \frac{1}{k_n}\right)^{-1} \qquad (2)$$

Where: k_1, k_2, k_3 and k_n are the stiffness of the first, second, third floor and nth floor respectively. Again stiffness of each storey can be calculated as following equation (3):

k = Number of column$\times\frac{12EI}{h^3}$ (3)

Where, I=Moment of inertia of the column section, E= modulus of elasticity of column material and h= height of each storey.

2.3. Shakıng Table Test

At first model 1 was fixed on the center of vibrating platform of shaking table by screw and corner attached with the columns. Then vibration given to the model structure with ground frequency 1.0 Hz for 5 second and stopped. Then counted manually the number of vibration cycle for 10 sec, 15 sec and 20 sec and maximum deflection of model in the direction of ground vibration. From the number of vibration cycle (n) and required time (t) the frequency of vibration of model (n/t) was calculated.

Table 1. Dimensions and theoretical natural frequency of models.

Model ID	Element Diameter (mm)	Height of Each Floor (mm)	Lateral Dimension (mm × mm)	No of Storeys	Theoretical Natural Frequency of Model (Hz)
Model-1	2.5	127	127×152	10	7.44
Model-2 (with slab)	2.5	127	127×152	10	5.58
Model-3	2.0	127	127×152	8	7.45
Model-4 (with slab)	2.0	127	127×152	8	5.01

Table 2. Shaking table test results.

Frequency of Ground Vibration (Hz)	Time of vibration (sec)	Vibration Frequency of Model (Hz)				Maximum Deflection of Model (mm)			
		Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
1.0	5.0	3.36	3.03	3.40	2.96	3.0	3.0	3.0	3.0
1.10	5.0	3.38	3.10	3.39	3.10	2.5	2.5	3.0	3.5
1.30	5.0	3.32	2.96	3.21	3.11	3.0	3.5	3.5	3.5
1.48	5.0	3.22	2.87	3.16	2.85	3.0	3.5	3.5	3.5
1.60	5.0	3.05	2.88	3.10	2.90	3.5	3.5	3.5	3.0

After vibration of model stopped, vibration frequency of shaking platform increased up to 1.10 Hz and given to structure for 5 sec and stopped and counted the frequency of vibration of model and deflection. This process repeated for five stage of increasing frequency of vibration of shaking platform for 1.0, 1.10, 1.30, 1.48 and 1.60 Hz. After the test of model 1, it removed from the shaking table and model 2, 3 and 4 was attached and tested as model 1 successively. The results found after certain test of models is listed in Table 2.

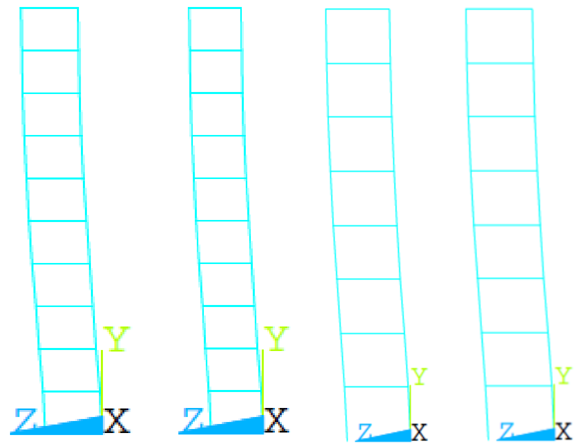
2.4.Numerical Analysıs Usıng ANSYS

To match with actual models tested in laboratory, element BEAM4 and section properties was selected from ANSYS 11 library. Circular solid section CSOLID was selected for the beam and column of model. The models 1 configured using 44 key points and 80 elements. Models 3 and 4 consists of 36 key points and 64 elements. The bottom end of the columns were considered as fixed support to maintain the similarity of shaking table test and actual building condition. The studied models were considered as made of mild steel wire elements, which was assumed as isotropic and elastic material.

Using ANSYS processor, modal analysis was selected for finding frequencies and mode shapes of models. Using modal analysis with LANB (Block lanczos) solver command 1st mode shapes are shown in Fig. 4 and frequencies was solved and listed in Table 3.

Table 3. Results from analysis using ANSYS.

Model ID	1st Mode Frequency (Hz)
Model-1	6.45
Model-2	4.95
Model-3	6.53
Model-4	4.51



a) Model 1 b) Model 2 c) Model 3 d) Model 4

Fig. 4 1st mode shape of structural models.

3. Results and Discussions

3.1. Factors Affecting Natural Frequency

Small buildings vibrate with high frequency by short and frequent excitation, where, large structures or high rise buildings are more affected by low-frequency, or slow shaking. From shaking table test results it was observed that the 8 storey model (Model 3) vibrates with high frequency than 10 storey model (Model 1) for same excitation, because the stiffness of model 3 is much higher than model 1. Therefore, if height of building increases its free vibration frequency decreases, and possibility of resonance with small ground vibration increases.

In general, when extra mass added to the building, it increased its natural period. In this test it is found that free vibration frequency model 2 is lower than model 1, due to increase in mass. Therefore, height, mass and stiffness are very important properties to calculate natural frequency. Therefore, the combined effect of stiffness, mass, height and external excitation finally results the change in natural frequency of structures.

Initially frequency of vibration was high, after application of several excitations, frequency of vibration of model starts to decreases. This phenomenon occurs due to decreases in stiffness. Free vibration frequency of model obtained from analysis of theoretical and ANSYS approach was much higher than obtained from shaking table testing, which is shown in Fig. 5. This phenomenon occurs due to damping in shaking table test system, which was not accounted in numerical analysis.

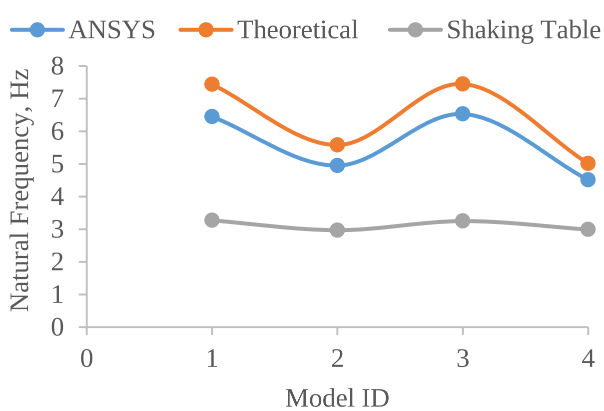


Fig. 5. Natural frequency of models obtained from different analysis.

Therefore, this shaking table needs concern to overcome the problems of damping as well as supporting system of model.

3.2. Deflection of Structures

Stiffness is the main controlling factor of maximum amplitude of vibration of structures. Analysis showed that, when stiffness increased, natural frequency also increased inversely maximum deflection decreased. Model 1 and 2 are same in height and dimension. Therefore, stiffness are also same, only mass are different due to slab. But the increased in mass in model 2 from model 1 results decreased in natural frequency. Similar case occurred for model 3 and 4. Due to more stiffness maximum deflection in model 1 is smaller than model 3. Therefore, it concluded that, if stiffness increased without change in other properties, deflection due to external excitation will be minimized.

4. Conclusions

Prepared shaking table is suitable for small scale model tests, and able to produce only uniform ground vibration (the amplitude of vibration of base of shaking table remain constant through its application time) with frequency range from 0.85 Hz to 1.65 Hz. Free vibration frequency of structures decreases with increase in mass of structures. Vibration frequency of structures produced from external excitation decreases with height of structures. Stiffness of structure decreases with long term vibration which causes the decreased in natural frequency. Therefore, this shaking table satisfy the general theory of natural frequency of moment resisting frame structures and may be helpful for free vibration study.

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Conflict of Interest: The authors declare that they have no conflict of interest.

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