Computational Engineering and Physical Modeling 3-2 (2020) 01-11

Contents lists available at **CEPM**

Computational Engineering and Physical Modeling

Journal homepage: www.jcepm.com

Seismic Analysis of Eccentric Steel Structure on a Shaking Table

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https://doi.org/10.22115/CEPM.2020.223528.1093

ARTICLE INFO

Article history:
Received: 14 March 2020
Revised: 07 April 2020
Accepted: 09 April 2020

Keywords:
Eccentric structure;
Seismic analysis;
Eccentric effects;
Shaking table.

ABSTRACT

The paper presents the experimental investigation of an eccentric steel structure under seismic loading at varying height and varying mass conditions on a shaking table. In order to test dynamic responses of a steel structure the ground and a four-storied eccentric steel structure were prepared and a dynamic analysis test was conducted. The seismic data from accelerometers attached to each story of a steel structure were recorded like acceleration, displacement, velocity, etc. According to the correlation of acceleration, displacement, velocity other seismic properties like story drift, drift ratio, inertia forces were predicted. The prototype model showed irregularities and eccentric effects on various seismic parameters. The eccentric steel model on the shaking table is a useful tool for teaching and well shows the effects of the earthquake on a structure.

1. Introduction

People need shelter to protect themselves from natural phenomenon wind, sun, rain, etc., They used to build houses local material like mud block, stone, timber, grassroots, etc., The shelters gradually increased what leads to the developments in civil engineering fields. Modern building construction trends towards more intricate eccentric and irregular structures. In this way appears the impact on the stiffness, ductility, adequate strength, damping and various seismic properties of the structure. The structural engineer and earthquake engineer

How to cite this article: Patil AE, Bhanuse MM. Seismic analysis of eccentric steel structure on a shaking table. Comput Eng Phys Model 2020;3(2):1–11. https://doi.org/10.22115/CEPM 2020.223528.1093

are challenged with the quandary of providing adequate strength, safety, and stability of the eccentric and irregular structure. Thus, it is of prime importance to give a satisfactory earthquake-proof structure with a specific end goal to discover the effect of eccentricity and irregularity in the structure with the application of varying mass and height conditions. The seismic response of a steel building depends on the dynamic characteristics of the structure and properties of the material used in the construction. Nowadays, the dynamic properties of structures are easily calculated using software analysis like STAAD PRO, ETAB, SAP, ABACUS, etc. However, various uncertain factors disturb the most closure and exact calculation of seismic properties for e.g. influence of non-structural components, the difference between experimental and software simulation, material properties, connections, loading condition, etc. A dynamic analysis predicts by various methods like shaking table tests, software analysis, manual approach, etc. The response of the prototype model is measured in terms of acceleration, displacement, velocity and other seismic properties. The dynamic properties of the structure represent in terms of natural frequencies, momentum, mode shape, drift, drift ratio, story force, inertia forces, stiffness forces, base shear, kinetic energy, potential energy, etc.

1.1. Concept of regular and irregular configuration

To respond well in a seismic event, a structure should possess four main parameters, namely stiffness, ductility, adequate lateral strength, simple and regular configuration. A structure should have uniformly distributed mass, stiffness in the plan as well as elevation and simple regular geometry. The structure much less suffers a disturbance and damage as well as an irregular configuration. The structure in this research work is irregular for the purpose to check all performance levels of the structure. All irregularity and eccentricity condition is applicable to prototype eccentric steel structure as per IS 1893 2016 Code.

1.2. General introduction

This research work concerns the seismic analysis of the irregular and eccentric steel structure fixed on a shaking table. The shaking table software records all seismic parameters like acceleration, displacement, velocity, drift, drift ratio, inertia forces, etc. The model is a useful tool for the student to watch the visual effects of seismic motion. The shaking table is digitally controlled and calibrated by the programming devices. The eccentric steel structure is a failure due to insufficient strength and eccentricity. Designers should understand the potential hazards and needs for proper strengthening in the various zones of structures. The model working on the shaking table shows the forces at work, the period of the earthquake, and the phenomenon of resonance. This research work presents the results of the experimental analysis of the eccentric steel structure.

1.3. Shaking Table

The shaking table is used to study the various types of buildings and complicated structures. The existing data are used for dynamic analysis. The shaking table shows how a structure will respond to an earthquake event. It is the device simulating the seismic events. The shaking table is a complexly controlled system. The computer program generates a signal which is sent to a converter, which sends a voltage sign to an amplifier, which amplifies the voltage sign and sends it to the shaking table platform. The one-degree shaking table means it will move in one direction only (lateral direction) The three-degree shaking table means it will move in x, y, z-direction (horizontal, vertical, third direction).

2. Literature review

2.1. Introduction

Strong research work has been given over the seismic behavior of various types of structures using experimental (the shaking table), analytical, numerical and software methods. Many researchers are engaged in seismic analysis of structures and its method. In this chapter, some works are discussed. Many types of research have been given over seismic analysis of various types of structures like regular and irregular structure, composite, steel, concrete, timber, glass material structure. All these structures are analyzed by different methods like numerical and experimental methods, software analysis methods, manual approach, mathematical approach, et cetera as well as the dynamic characteristics, acceleration, displacement, strain, and failure mode and different seismic property are analyzed. Shuang Hou et al. (2017) [1] used piezoelectric smart aggregate (SA) as internal stress sensor micro and full damage monitoring for concrete structure and stress, strain, acceleration, and displacement of the structure. Swaminathan et al. (2017) [2] analyzed a major role of the seismic activity in the design and analysis of the structure. This paper opened up the need for the acceptance of consideration of seismic characteristics and its overcome solution. They used the shaking table made of wood and steel. Mingzhou Su et al. (2016) [3] made a comparison in terms of shear forces, inter-story, and maximum displacement story. Donatello Cardone (2007) [4] provided the shaking table data against the seismic movement of the earth. Bairro‘s et al. (2012) [5] noted a vital role of shaking table as the basic instrument in the engineering and structural design field. His shaking table monitored the seismic ground motion and its effects on the structure. The shaking table was made of wood and steel. Branco et al. (2014) [6] conducted on a shaking table a test of a steel portal frame of non-compact member structure. Seismic shake table test on a gravity load designed frame structure in linear to nonlinear testing. 3D RC framed structure was symmetric in plan with two bays in both directions. The structure was 1:3.33 scaled model and it is part of a low-rise prototype structure. The structure was infill masonry wall built in one direction and other directions are the open frame.

To study the effect of masonry infill wall and its effect on stiffness, the stability of the wall. The test conducted on two sets shown below.

Test of the structure with masonry infill walls.

Test of the structure without masonry infill wall under the action of biaxial ground motion with increasing PGA level up to failure.

Ying et. al. (2009) [7] identified failure pattern as like, Beam column joint, developed shear crack, flexure failure of beam and column, spalling of concrete at the end of beam and columns critical region. Comparative study of the Shake table dynamics results from a test analysis. Work explains the comparative study between the analytical and experimental predicted the result of the dynamics of the shaking table test. The main objective of the shaking table test is given below.

To shed light into the dynamic performance of small to medium size, uniaxial, servo-hydraulics, displacement controlled shaking table test.

To validate a linearized dynamics model of the system (In the form of the total shaking table transfer function).

Nakashima et. al. (2008) [8] performed nonlinear shake table identification and control for near field earthquake testing. The main focus of shake table system is the re-examination of the acceleration record of testing. When testing near field earthquake that requires extreme table performance for the simulation improved identification and precise control methods required. Bagheri et. al. (2012) [9] studied the research present methodology of correct and simple effective identification, diagnosis, modelling, and control system of shake table structural system. This system was readily generalized and applied to any other similar facility. Shaking table testing of civil engineering structures lenses 3D simulator experience. [10] explained that some aspect of current experience obtained after completion of several series of test on a different type of structures. Shaking table now day valuable and important tool for assessment of civil engineering structures. Liu et. al. (2008) studied shaking table testing of a multi-tower connected hybrid structures. A multi-tower RCC-SF tall structure scaled model was designed at 1:15 scale and tested on shake table under minor, moderate, major earthquake level. RCC –STEEL frame structure was studied by Norio Inouie et. al. (2000) [11] because it's structural complexity and irregularity. Comparative study of the static and dynamic analysis of the multi-storey irregular building. The global world moves with performance-based seismic analysis and design. The designer will be performed both static and dynamic analysis for the design of the structure. Research work irregular twenty-story building modelled in ETAB 2016 and SAP 2000 for seismic zone V in India. Research work explains the effect of variation of height on the structural response on the shear wall structure and dynamic analysis on the actual earthquake in EL-CENTRO 1949 and CHI-CHI TAIWAN 1999 have been investigated. Work explains the exact and accurate comparison between Time history analysis, Equivalent static method, Response spectrum method. Shaking table test on reinforced concrete column subjected to simulated input motion with different time duration. The main focus of this research work was to investigate and analyse the difference in the elastic dynamic behaviour of reinforced concrete column subjected to stimulated input motion with different time periods. Wu et. al. (2008) [12] prescribed shaking table test on reinforced concrete short columns falling in shear. RC column failure due to insufficient transverse shear reinforcement. The study works four RC frame specimen to investigate full range structural behaviour of RC short column until complete failure and collapse. Kang et. al.(2004) [13] suggested that a shake table test and an analytical study conducted on two plates. First was a reinforced concrete plate and second was post-tensioned plate. The excellent result was obtained by Abdelbaset et. al.(2016) [14] between the analytical and experimental study by using an innovative modelling combined approach. Seismic analysis of Highrise building with transfer slabs, state of the art review. Research work explains the seismic behaviour of a high-rise structure with the transfer floor. The drawback of the transfer floor is a sudden failure. Change in lateral stiffness at its level research work explain the major effect of transfer floor on seismic design and analysis. Japanese seismic design of Highrise RC building, an example of performance-based design code and state of practice. Otani (2004) [15] reviewed of the development of seismic design criteria, requirement and construction of Highrise reinforced concrete building in Japan.

Work explains the regulation of gravity load, snow load, wind forces, earthquake forces. Influence of local deformation of transfer structure on seismic design. Zhua (2008) [16] studied the shake table tests and numerical analysis. seismic behaviour of transfer structure was identified. Study improved seismic understanding of RC structure collective with transfer structures in lower to medium earthquake region. Experimental study by Chunyu et. al. (2012) [17] on seismic behaviour of an irregular Highrise building. a scaled 1:20 model of an office building with height 112.4 m was designed to have irregular in plan and elevation. The shake table test conducted on model under small, moderate, and large earthquake levels. The study explain irregularity leads severe damage under strong earthquake and some suggestion, guideline to contributes favourable effect on the seismic capacity of the structure. Analysis of Highrise building with transfer floor transfer floor function was to transfer load from plate to underneath system and distribute the load from the column. Lande and Takale (2018) [18] conducted a study for the understands seismic analysis of Highrise building with transfer floor. Prototype model analysed using linear response spectrum and model analysed using structural software of ETAB 2016. Seismic response of Highrise structure such as story displacement, story shear, story moment was numerically evaluated. The scaled soil-structure interaction model for shaking table testing. The testing was conducted by Goktepe et. al. (2017) [19] on a shake table. Six-story steel frame structure, natural and laminar soil container was designed and built to realistically simulate the seismic soil interaction effect on the structure. Seismic design of a super Highrise hybrid structure. Jun et. al. (2008) [20] studied the seismic design of a super Highrise hybrid structure by using linear elastic analysis and nonlinear elastoplastic analysis. Work shows a comparison between steel structure seismic performance and hybrid structure performance. Two structural design programs were utilized by Petti et. al. (2008) [21] for elastic response spectrum analysis and combined with elastic time history analysis. Seismic performance of hybrid structure evaluated by static non-linear analysis (Pushover analysis) and dynamic nonlinear analysis (Elastoplastic time history analysis). Seismic response analysis of 3D structure through simplified Non-linear procedure. Two concepts used to study the analysis of seismic behavior of the plan -asymmetric structures. The first concept was a polar spectrum and the second concept is a limit domain. Seismic performance evaluation of an irregular high-rise building. The work seismic performance of Highrise building was studied by Zhou and Lu (2006) [22] an analytical model of the structure was established in the finite element program strand pro 7. Skeleton curve of the structural member was finding out using section builder software. analytical parameter obtained with help of skeleton curve in section builder were evaluated on both the analytical study and experimental result.

3. Methodology and model development

3.1. Introduction

The experimental analysis procedure is based on vibration effects. The test conduct on the shake table and basic data is provide of the various seismic property. The shake table is typically consisting of a rectangular shape with three degree and six-degree freedom. The structural model connects the shake table and shaken in order to check their seismic and dynamic behavior. The frequency used as per IS code recommendation, various international code recommendation, recorded actual previous earthquake frequency and previous research paper applied frequency was used. The proposed work comprises a study of seismic responses of an eccentric steel structure with varying height and mass condition using experimental analysis. Shake table instruments show the model behavior with consideration of varying mass and height condition. To prepare the prototype eccentric steel structure model, and the conduct test on the prototype eccentric steel structure. shake table simulates the eccentric steel structure. Shakes table software directly gives the reading of the acceleration, velocity, displacement value, and different seismic property.

Remaining seismic properties of the numerically and manually predicted as like story drift, drift ratio, inertia forces and its effect on the structural member, fundamental, other seismic property.

Completion of all seismic analysis, research gap, silent features are identified and validate the studied data.

3.2. Model description

This research aims to evaluate the feasibility of prototype eccentric steel structure under seismic loading for the varying height and mass condition. Which is helpful for the improve the accuracy in prediction of the seismic design and prototype modeling. For this purpose, ground floor plus four-storied prototype eccentric steel structure are designed as shown in Fig No. 1 The prototype model, storey height is 20 cm and a total five storey height of the structure is 100 cm. The prototype steel structure is constructed in four steps. The beam and column are the same sizes that are 1.2 cm X 1.2 cm hollow square and cut the twenty-two-gauge, steel plate as a size 40 cm X 20 cm. This plate used as a floor slab. According to the prototype model design requirement to cut the five-steel plate, as size 40cm X 20cm. Eccentric portion is required four hollows, ten-centimeter height square column and 40 cm long four beams (parallel to longer face) and 10 cm long hallow square four beams. All eccentric portions beam and column size is 1.2 cm X 1.2 cm hollow square. Column and base plate connection is welded. As same fashion first, second, third, fourth floors column and beams respectively connected to using 4.36 mm size bolts, etc. all joints in the structure are bolted connection excluding base plate connection. Total weight of the structure is 12.479 Kg and each story weight is approximately 2.4958 Kg.

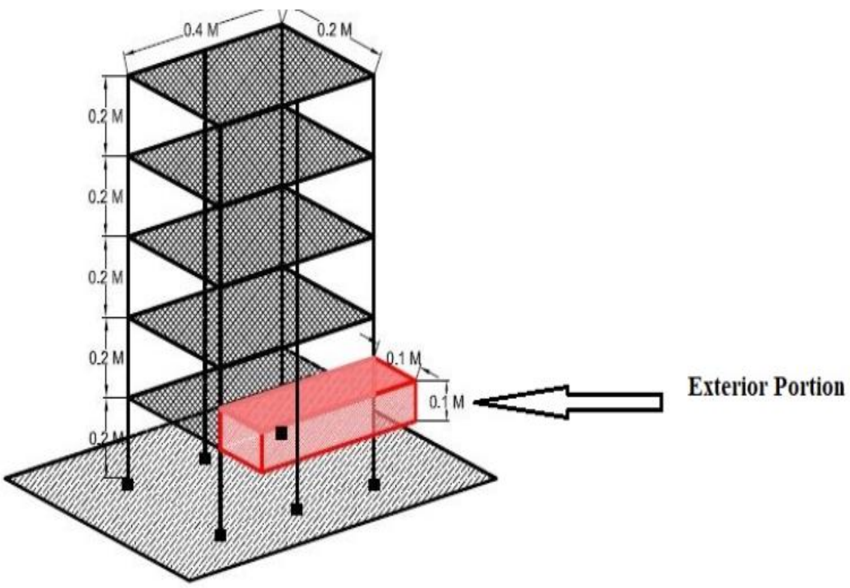

Fig. 1. Testing arrangements for First load Case.

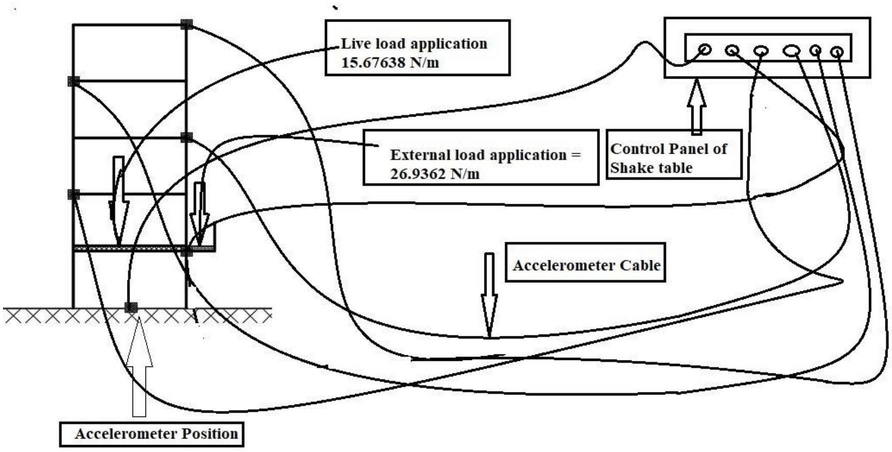

Fig. 2. Setup for the First load Case (Side View).

4. Result and discussion

4.1. Results and analysis

In the following tabular format test results are record. The entire test is conducted on the shake table, and the test result are recorded. Test records displacement, acceleration, velocity, inertia forces, drift, drift ratio, etc

Table 1
Story Drift Results.

Name of Floor	**First load Case (Story Drift in X-Direction) (mm)**	**Second load Case (Story Drift in X-Direction) (mm)**	**Third load Case (Story Drift in X-Direction) (mm)**	**Fourth load Case (Story Drift in X-Direction) (mm)**	**Fifth Load Case (Story Drift in X-Direction) (mm)**
First Floor	5.2935	4.149	5.7165	3.961	3.5497
Second Floor	4.86	3.222	3.179	2.955	5.132
Third Floor	11.667	5.296	0.957	4.533	5.204
Fourth Floor	4.328	5.297	2.983	6.726	15.419
Fifth Floor	10.503	5.709	6.461	0.838	15.637

Table 2
Drift ratio Results.

Name of Floor	**First load Case (Drift ratio in X-Direction)**	**Second load Case (Drift ratio in X-Direction)**	**Third load Case (Drift ratio in X-Direction)**	**Fourth load Case (Drift ratio in X-Direction)**	**Fifth Load Case (Drift ratio in X-Direction)**
First Floor	0.026467	0.020745	0.028582	0.019805	0.017749
Second Floor	0.0243	0.01611	0.015895	0.014775	0.02566
Third Floor	0.058335	0.02648	0.004785	0.022665	0.02602
Fourth Floor	0.02164	0.026485	0.014915	0.03363	0.07709
Fifth Floor	0.052515	0.028545	0.032305	0.00419	0.078185

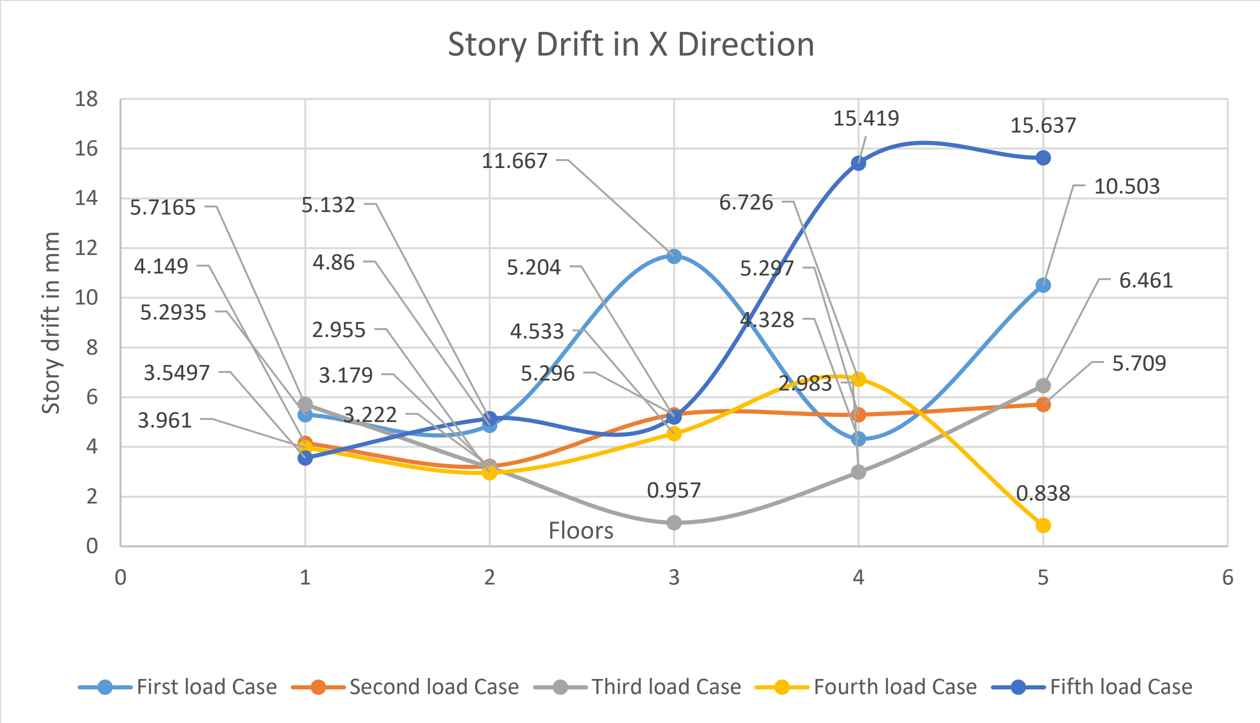

Fig.3. Story Drift in X Direction.

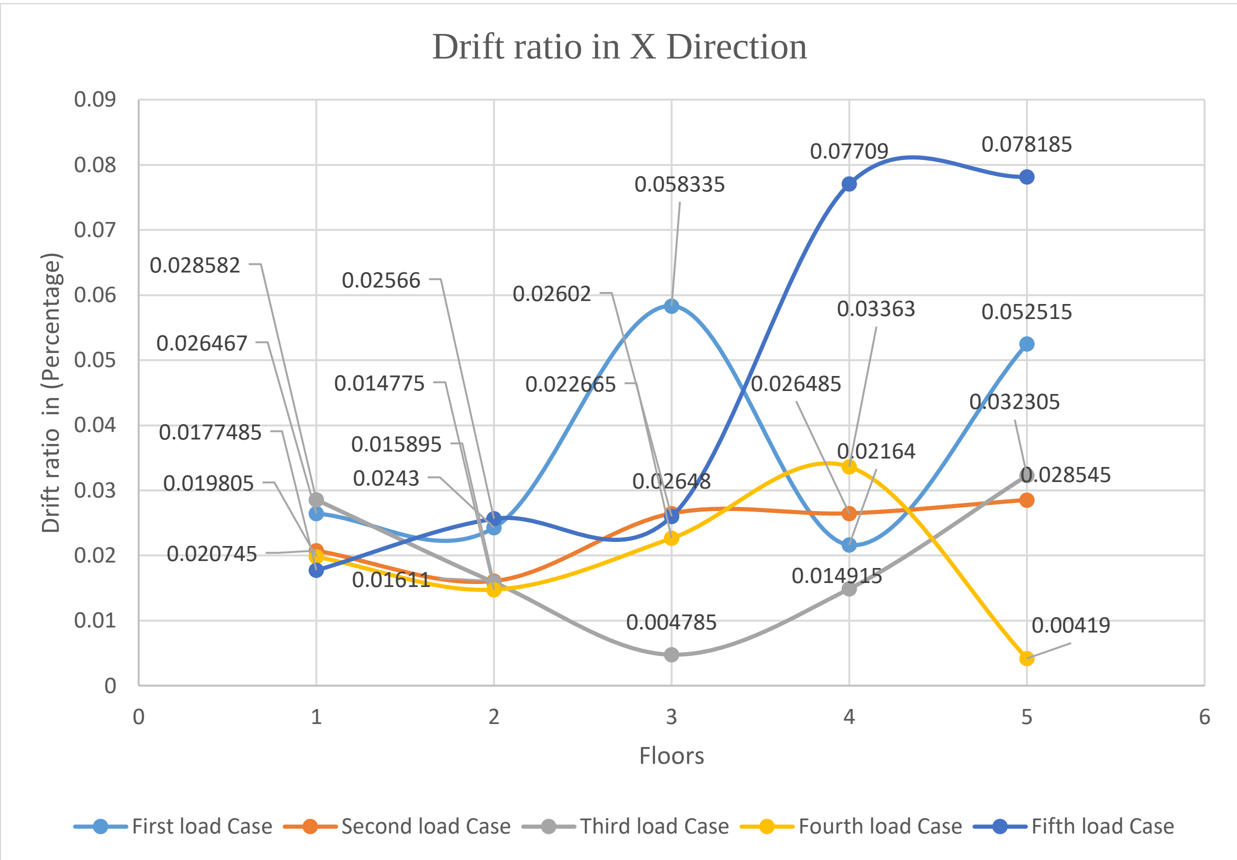

Fig.4. Drift ratios in X Direction.

Table 3
Inertia force results.

Name of Floor	**First load Case (Inertia Force in X-Direction) (N)**	**Second load Case (Inertia Force in X-Direction) (N)**	**Third load Case (Inertia Force in X-Direction) (N)**	**Fourth load Case (Inertia Force in X-Direction) (N)**	**Fifth Load Case (Inertia Force in X-Direction) (N)**
First Floor	0.453057	0.5931	0.82118	0.87744	0.30698
Second Floor	0.928	0.97663	0.675126	0.6607	0.856059
Third Floor	1.6639	2.115034	1.431398	0.734118	1.70213
Fourth Floor	3.51736	2.7771	2.0708	1.188572	2.21627
Fifth Floor	4.698	3.76572	2.94069	1.87025	3.017422

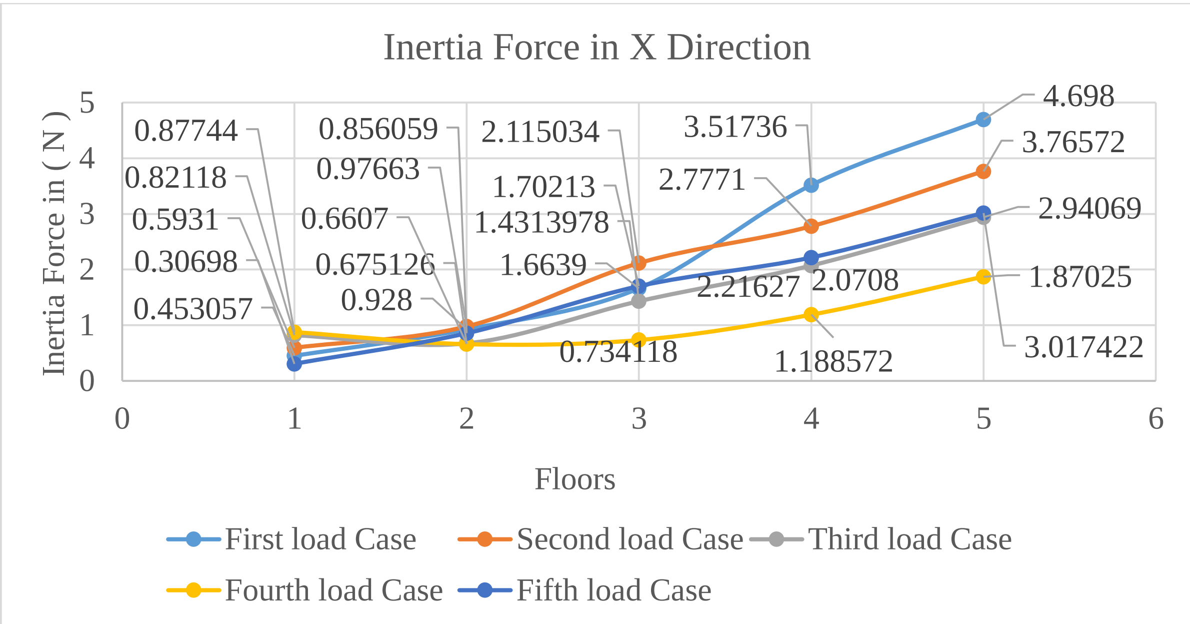

Fig. 5. Inertia Forces results.

5. Conclusion

From the study, some concluding remarks are mention in the following points

1) Based on the shake table analysis studies, it is going to predicted that the eccentric prototype steel structure will not collapse when it subjected to major earthquake, which having frequency up to a range between 4 to 6 Hz under the observation of varying mass and height condition.

2) No physical phenomenon has been shown in the eccentrically loaded floors in each load case but without loaded floor was shaken slightly due to sudden change in height, inertia force and load as well as the mass distribution system.

3) Measurement of deformation and displacement of the structure acts as a good indicator assessing for the structural failure. The story drift of different floors can associate with the

failure of the structure. It has been found that eccentric prototype steel structure will have trivial cracking at joints of column and beam if story drift approaches between 15 mm to 20 mm on each floor.

4) It is observed that the significant reduction of drift, drift ratio, inertia forces, when the specific floor is loaded as compare to other floors.

5) Inertia forces, drift and drift ratio can provide a general guideline on the degree of damage of the structure.

6) Shake table procedure useful to define analytical strategies was presented. The experimental procedure has allowed the optimization of the seismic design of the actual structure. Shaking table test most susceptible and money-spinning information and seismic design recommendation to be obtained at end shake table analysis.

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