INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

Behavior of Steel frame subjected to lateral load

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OPEN ACCESS

Received: 14-05-2022

Accepted: 27-06-2022

Published: 21-07-2022

Citation: Pradeep AR, Rangaraj C, Jayaramappa N (2022) Behavior of Steel frame subjected to lateral load . Indian Journal of Science and Technology 15(28): 1381-1388. https://doi.org/10.17485/IJST/v15i28.1038

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Background: A steel frame system becomes structurally less efficient when subjected to large lateral loads such as a strong wind, earthquake. Many research efforts have been made to develop more efficient structural systems with better resistance against strong lateral loads. **Methods**: An attempt is made in this direction by both analytical and experimental studies. A bare steel framed model of size 4m x4m is chosen for G+2 storey with columns of height 4m. The particular frame is scaled down to 1:11 scale to perform shake table test for seismic zone-V in terms of modal frequencies. Same frame is modelled in Hypermesh software & analysis is done in Nastran and ETABS software's. The results obtained can be applied to 16 X 16m G+9 Multi-storeyed commercial complex structure and analysed in ETABS software for Base shear, response spectrum and pushover analysis to assess the performance of the structure. **Findings**: Prototype of G+2 storey scaled down model, ETABS and Nastran analysed models showed approximately same values of modal frequencies 10-12% which is an allowable percentage. **Novelty**: The results obtained shows that the base shear, performance point of the structural system and in terms of model frequencies are with in safer limits. The overall performance of the structure was found to be safe between operational to collapse stage. **Advantages**: The present work gives the dynamic behavior of bare steel frame subjected to lateral loads which helps in assessing the damage causing due to earthquake can be pretended to prevent the loss of life.

Keywords: Bare steel frame; Shake table; Base Shear; Response spectrum; Modal frequencies

1 Introduction

Nowadays a numerous structures are built by RCC and steel with Infilled walls. Steel and RCC frames plays an important role in the construction, failure of these framed structures due to earthquake may affect the loss of life severely [(1)]. Many researchers have analysed only RCC frames but few researchers have considered Steel frames for seismic analysis [(2)]. Leal-Graciano [(3)] analysed that frames participate in resisting the lateral loads resulting from earthquake forces depends on its rigidity, elasticity and ductility. Vail Karakale [4] assessed the possibility of development of plastic hinges in steel frames. It is important to evaluate and strengthen the structural components by various methods as per IS 1893-2002/2016 codes since they provide the guidelines for design and construction of Steel and RCC structures against earthquake forces [5].Frames were analyzed by response spectrum method to calculate the seismic displacements and stresses [6].Normally frames are constructed of RCC and steel with suitable infills. These types of frames are increasing the dead load of the structure [7].Static and dynamic analysis of buildingsgives design parameters such as base shear, story drift and etc [8].

Gauri G. Kakpure et al. showed parameters like displacement, bending moment, base shear, storey drift, Torsion, Axial Force were the focus of the study the difference of values of displacement between static and dynamic analysis is insignificant for lower stories and the difference is raised in higher stories and static analysis shows greater values compared to dynamic analysis [9]. The present research aims to evaluate the dynamic behavior of bare steel frame subjected to lateral loads which includes the study on behavior of steel frame by experimental substantiation [10]. Finite element analysis has been carried out using Nastran 2017 wherein 3D-Steel Bare frames is modeled in Hypermesh 2020. The Finite Element analysis models are validated by experimentation is conducted using shake table apparatus [11].

1.1 Objectives

The basic objective of the study is to analyse the behaviour of bare steel framed structure under seismic loading and compare the results by shake table test to experimentation.

- To assess the suitability of the basic components beams and columns sections.
- To assess the performance of the Seismic analysis of structure.
- To calculate modal frequencies and time periods.
- To analyze bare steel frame for base shear, response spectrum and pushover analysis.

2 Methodology

2.1 Material and methods

Experimental investigations are taken up as they bring out the full behavior including the elastic behavior of the structural system.

In the current work a Bare Steel frame was selected for the analysis with G+2 floors which is a commercial building located in zone V of soil profile type II.

- Selecting a workable overall structural concept.
- A 3D bare steel frame is modelled for G+2 floors in ETABS to analyses for seismic loading as per IS: 1893-2002 and IS: 1893-2016 respectively.
- The structure was modelled in Hypermesh 2020 and analysed in NASTRAN 2017.
- The prototype is modelled by 4x4 m G+2 floor model it was scaled down to 1:11 scale to perform the shake table test. Mode Shapes and modal frequencies are obtained and compered with ETABS and Nastran 2017 results.
- A plan of residential complex of size 16m x16m is chosen for G+9 building with columns of height 4m for each storey is analysed by Equivalent static method and Response spectrum method in ETABS.
- Base shear, Storey Displacements and Mode Shapes and modal frequencies. The results of analysis and experimental model are compared and conclusions are drawn.

All the testing facilities are conceptualized, analyzed, designed and fabricated

Table 1. Details of structural members

Particular	Details	Particular	Details
Number of stories	G+2 and G+9	Density of reinforced concrete	25kN/m^3
Each Storey height	4m	Density of steel	78.56 kN/m^3
Number of bays in x -y direction	4m	Seismic zone	V
Total height of the building	40m	Importance factor	I
Bay length	4m c/c	Soil profile type	II

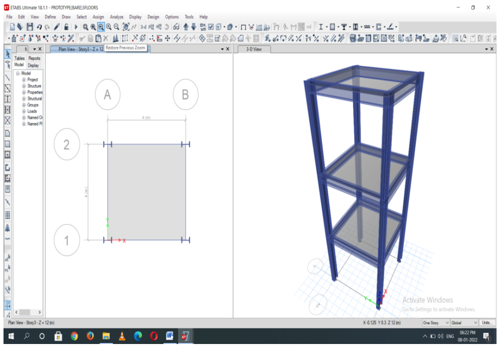

Fig 1. G+2 floor modelled in ETABS software of bare frame

Fig 2. Experimental setup of G+2 storey steel of bare frame scaled down model

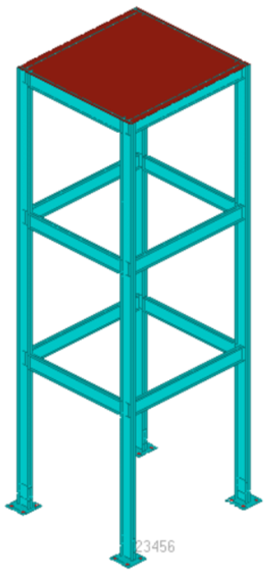

Fig 3. Hypermesh model of G+2 storey steel bare frame

Modal analysis is the process of determining the inherent dynamic characteristics of a system in forms of natural frequencies, damping factors and mode shapes, and using them to formulate a mathematical model for its dynamic behavior [12].

Modal analysis helps to determine the vibration characteristics (natural frequencies and mode shapes) of a structure, showing the movement of different parts of the structure under dynamic loading conditions, such as those due to the lateral force generated by the electrostatic actuators [13].In the above Figures 1, 2 and 3 the same model is analysed for modal analysis by ETABS, NASTRAN software's and Experimentation respectively.

Shaking table test was carried out under the fixed base condition in which the model is directly fixed on top of the table. The test was conducted using four accelerometers connected to the top floor, 3rd floor, 2nd floor, and the base of the scaled down model to measure the acceleration and displacement of the model during shake table testing subjected to the harmonic motion. The test is started with 1mm base displacement and 7 Hz of frequency and corresponding acceleration and displacements are captured through Data acquisition system. Readings were recorded for an interval of 0.5 Hz. Frequency is gradually increased until the model experiences resonance and continued till the model experiences lower acceleration and displacements.

3 Results and discussions

Shake-table in earthquake engineering is to assess seismic performance by conducting the experimentation the resonance frequency (Natural frequency) of the structure is 23 Hz and the ETABS result for the experimental model is 22.12 Hz.

The same model was analyzed in ETABS and NASTRAN software to study the model frequencies and compared with experimental values.

Table 2. Comparison of Modal frequencies Results obtained from Nastran and Experimentation analysis.

Mode no	Experiment	ETABS	NASTRAN
1	23.89	22.12	23.45
2	45.43	40.56	43.80
3	67.20	56.00	61.04
4	83.02	72.19	69.30
5	97.80	106.30	112.68
6	157.07	142.79	151.36
7	164.68	189.29	200.65
8	298.02	254.72	226.70
9	389.73	347.97	393.21
10	1856.24	1672.29	1772.63

From the above table we can see that there is a gradual increase in modal frequencies with respect to Nastran analysis and experimental model in case of Bare steel frame

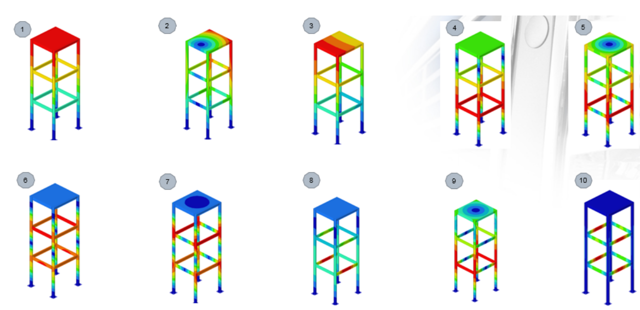

Fig 4. Model shape for the natural frequency-displacement plot for modal frequencies of steel bare frame contour plot in Nastran

The above Figure 4 shows the response of the G+2 floor steel bare frame for first 10 modal frequencies as obtained in Nastran software. The results obtained from above cases it was found the frequency and modal periods are within the safer limits with a tentative variation of 10-12% difference which are in permissible limits according to IS 1893:2016 [14].Hence, this analysis can be carried for a G+9 storied commercial building and analysed by base shear Pushover analysis, Response spectrum analysis.

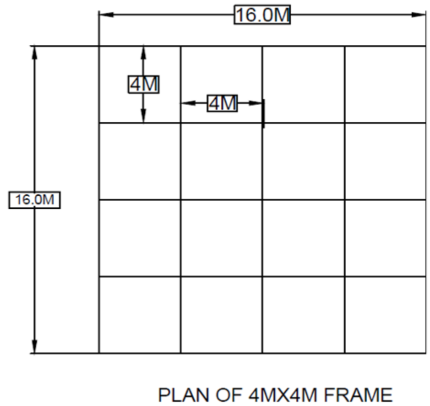

Fig 5. Plan of 16x16 bare frame

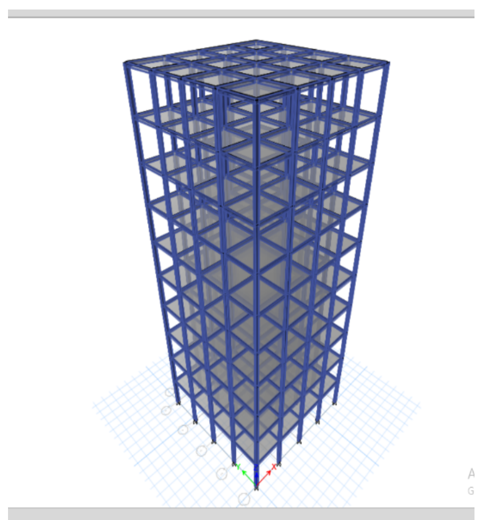

Fig 6. Base reaction of bare frame from software

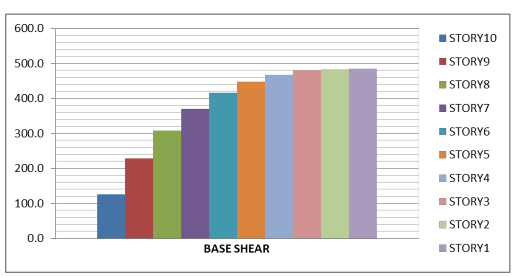

Fig 7. Base reaction of bare frame manual calculation.

For bare steel frame Base shear on the structure by seismic coefficient method in ETABS is 488.369 kN and 488.39 kN and by response spectrum method is 488.369 kN and 488.39 kN along X and Y directions respectively The calculated values and the ETABS analysis values are approximately

Table 3. Storey shear and base shear calculation manually forG+9 storey baresteel frame

Floor level	W_i (kN)	h_i (m)	Wi hi2	Story force(Q_i)=	Base force (kN)
STORY10	1699.27	40	2718832	126.1	126.1
STORY9	1699.27	36	2202253.92	102.1	228.2
STORY8	1699.27	32	1740052.48	80.7	309.0
STORY7	1699.27	28	1332227.68	61.8	370.7
STORY6	1699.27	24	978779.52	45.4	416.1
STORY5	1699.27	20	679708	31.5	447.7
STORY4	1699.27	16	435013.12	20.2	467.8
STORY3	1699.27	12	244694.88	11.3	479.2
STORY2	1699.27	8	108753.28	5.0	484.2
STORY1	1699.27	4	27188.32	1.3	485.5
			10467503.2	485.5	

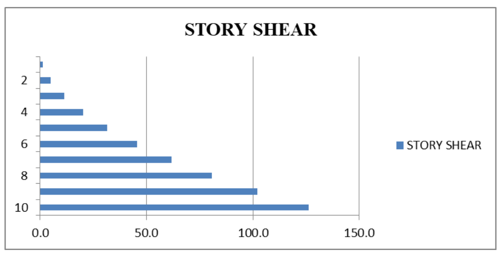

Fig 8. Storey shear reaction of bare frame by manual calculation,

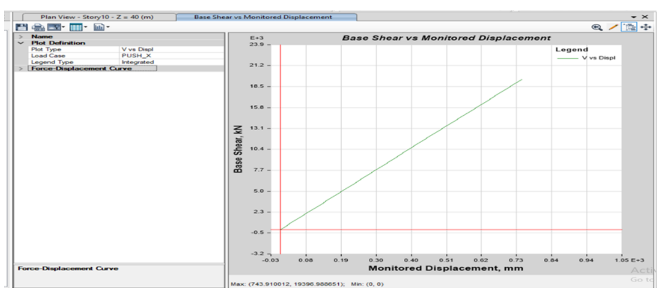

Fig 9. Maximum base shear for the structure along x-direction ispush-x – 2128859 KN and for the displacement is 89.5 mm

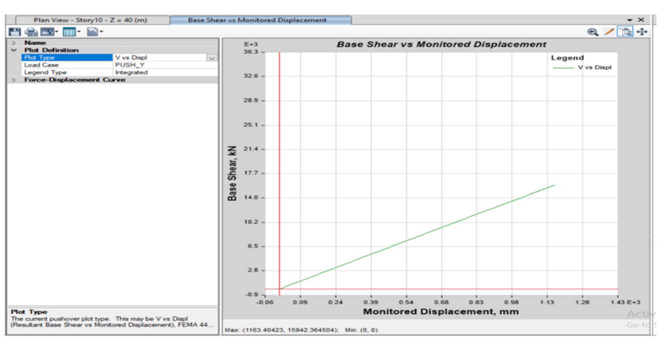

Fig 10. Maximum base shear for the structure along y-direction is push-y-2128859kn and for the displacement is 93.1 mm**.** which are in permissible limits according to IS 1893:2016 [14].

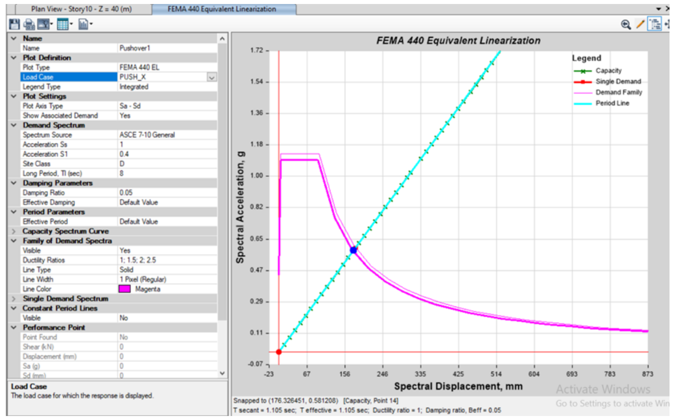

Fig 11. Performance point by FEMA 440 EL capacity spectrum method X-Dir = (5799.48 kN, 221.137 mm)

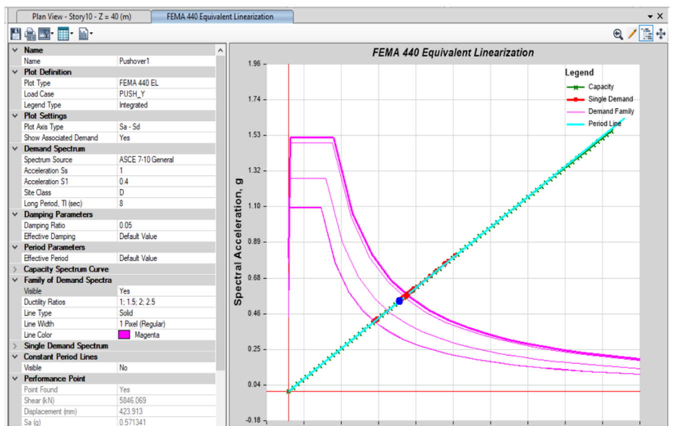

Fig 12. Performance point by FEMA 440 EL Displacement coefficient method is Y-Dir = (4222.45 kN, 306.174 mm) which are in permissible limits according to IS 1893:2016 and FEMA [14].

4 Conclusion

The structure is analyzed and designed for seismic zone V, it satisfies all the requirements according to IS1893-2016 and IS456-2000.

• Capacity based design procedure helps the engineers to have an insight into the behavior of structure subjected to design ground motions and allows the buildings to be designed for specific performance levels.

• Shake table test data of scaled down model shows that the natural frequency (resonance frequency) of 23 Hz is very close to the analysis value of 22.12 Hz with difference of 3.81% for experimental bare frame model.

• Shake table test shows the behavior of structure under harmonic vibration and the effect of resonance.

• The frequency form modal analysis was found to be 22.12 Hz by ETABS, 23.45Hz by Nastran and 23.89 by experimentation where all the values are approximately nearer for G+2 scaled down model.

• Base shear on the structure by seismic coefficient method by ETABS is 488.369 kN which is approximately same from manual calculation for G+9 storied model which are in permissible limits [5].

• Performance point by capacity spectrum method is found to be 5799.48 kN for G+9 storey model in ETABS according to IS 1893:2016 [14].

• Analytical and experimental results show similar behavior with a difference of 10-12% in values of modal frequencies due to manual errors during experimentation which are in permissible limits as per the previous researchers this difference may be acceptable [5].

5 Acknowledgement

We thank for the anonymous reviewers for their useful suggestions and comments on this study. The authors greatly acknowledge with gratitude to SSAHE University, Tumakuru for providing the required inputs to accomplish this work.

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