

PERFORMANCE BASED SEISMIC EVALUATION OF A STEEL BUILDING USING LINEAR-DYNAMIC ANALYSIS METHODS

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ABSTRACT: This study evaluates the seismic performance of a G+6 L-shaped multi-bay steel building using Response Spectrum Analysis (RSA) and Time History Analysis (THA) in STAAD.Pro. The analysis is carried out as per IS 1893 (Part 1):2016 for seismic Zone IV. The seismic response is compared in terms of base shear, storey displacement, storey drift, overturning moment, and natural frequency. The results show that RSA produces higher base shear, while LTHA gives higher storey displacement and overturning moment. The study demonstrates that both methods provide useful information for assessing the seismic behavior of irregular steel structures. Two linear dynamic analysis methods, namely Time History Analysis (THA) and Response Spectrum Analysis (RSA), Basic guidelines for the preparation of a technical work for an IJRESM Journal Publication are presented. This document is itself an example of the desired layout (inclusive of this abstract) and can be used as a template.

Key word: Steel structure, Response Spectrum, Analysis Time History Analysis, Story Displacement, Storey Drift, Base shear, Overturning Moment, Earthquake loading, and Mass Participation Factors.

Chapter -1

1.1 Introduction

Seismic Analysis is a subset of analysis and is the calculation of the response of a building structure to earthquakes. It is part of the process of design, earthquake engineering or assessment and retrofit in regions where earthquakes are prevalent. The most important earthquakes are located close to the borders of the main tectonic plates

2.2 Introduction to Steel Buildings

Steel buildings have become one of the most preferred structural systems for modern multi-storey construction due to their high strength-to-weight ratio, ductility, durability, and speed of construction. Compared with reinforced concrete (RCC) structures, steel structures are lighter in weight, which significantly reduces seismic forces acting on the building during earthquakes. These characteristics make steel buildings highly suitable for commercial buildings, industrial structures, high-rise buildings, airports, railway stations, and large-span structures

1.3. Major applications include

- High-rise commercial and office buildings.
- Industrial buildings and manufacturing plants.

- Warehouses and storage structures.
- Airport terminals and railway stations.
- Shopping malls and exhibition halls.
- Hospitals and educational institutions.
- Multi-level parking structures.
- Bridges and long span roof structures.
- Power plants and heavy industrial facilities.

1.4. Time history analysis (THA)

THA is a rigorous, step-by-step dynamic analysis method used to evaluate the seismic response of a structure by subjecting it to specific ground motion records over time. It is the most realistic and accurate methods for predicting how a steel structure will behave under extreme dynamic forces

Key Characteristics & Workflow

Input Ground Motions: Instead of using simplified equivalent static loads, THA uses actual or synthetically generated historical earthquake acceleration-time records. **Dynamic Equation:** The analysis solves the dynamic equilibrium equation using step-by-step numerical integration

$$M\ddot{u} + C\dot{u} + Ku = F(t)$$

Where M is mass, C is damping, K is stiffness, and F (t) is the time-varying force.

1.5. Response Spectrum Analysis (RSA)

In the field of seismic analysis, this is one of the most popular methods. The design diagram is used to perform it. The response Spectrum method uses the idealization of a multi storey shear building by a basic assumption. The assumption used is that the mass is lumped at the roof diaphragm levels and at the floor levels. The diaphragms are assumed as infinitely rigid and the column axially in extensible but laterally flexible. The dynamic response of the structure is represented in the form of lateral displacements of the lumped mass with the degrees of dynamic freedom (or modes of vibration n) being equal to the number of masses

1.6 Seismic zones and zone Factor

Table 1.1 Seismic zones and zone Factor (Z)

Seismic Zone	Zone Factor (Z)	Seismic Hazard Level	General Description
Zone II	0.10	Low	Areas with low seismic activity. Buildings are

Seismic Zone	Zone Factor (Z)	Seismic Hazard Level	General Description
			expected to experience minor earthquake effects.
Zone III	0.16	Moderate	Areas with moderate seismic activity requiring earthquake-resistant design.
Zone IV	0.24	Severe	High seismic risk areas where stronger earthquake-resistant provisions are essential.
Zone V	0.36	Very Severe	Highest seismic risk areas, requiring special seismic design and detailing.

CHAPTER-2

LITERATURE REVIEW

2.1 Review of Literature

Md. Faisal Haque et.al (2025) This research proposes various configured multi-storied reinforced concrete (RC) structures for the evaluation of roof displacement, ductility, strength ratio, and response reduction factor under seismic loading by using nonlinear static analysis.

Kanchanmani Poudel (2024) The seismic design of the frame building proposed in this project is based on IS 1893-2002 and IS 800. The aim of the present project is to determine the multi-storey and multi-bay (G+5) building frame according to seismic forces The frame is six-fold, with three partitions in the horizontal direction and five partitions in the horizontal direction

Dimitrios S. Sophianopoulos et.al (2024) In this work, the seismic response of a multi-story, multi-bay special truss moment frame (STMF) with Ni-Ti shape memory alloys (SMAs) incorporated in the form of X-diagonal braces in the special segment is investigated. The diameter of the SMAs per diagonal in each floor was initially determined, considering the expected ultimate strength of the special segment, developed

when the frame reaches its target drift and the desirable collapse mechanism

Apoorv Joshi & Rahul Yadav (2023) The research focused around Multi-story structures applicable to residential and commercial G+10 and G+30 RCC and steel structures were analysed using STAAD.Pro under seismic Zone IV conditions. The study compared the effects of building height and structural frame type on seismic response.

Ayman Z. Abdulhameed et.al (2023) In this study, a multi-story steel building is designed using the ETABS v16 software under vertical loads only. Subsequently, seismic performance was enhanced by employing five different Mega braced frames (MBFs) systems in two cases: in the first case, the five bracing systems are placed within a frame located 6 meters away from the outer frame, while in the second case; the bracing systems were placed within a frame located 12 meters away from the outer frame.

2.2 Research Gap

Based on the literature review, it is observed that most previous studies have focused on the seismic analysis of regular reinforced concrete (RC) and steel buildings using Response Spectrum Analysis. Although a few researchers have performed Time History Analysis, limited studies have compared the seismic behavior of irregular multi-bay steel buildings using both Response Spectrum Analysis (RSA) and Linear Time History Analysis (LTHA) in accordance with the latest IS 1893 (Part 1): 2016

Furthermore, very few studies have investigated the seismic response of an L-shaped G+6 steel building by comparing important performance parameters such as base shear, storey displacement, storey drift, overturning moment, and natural frequency using both dynamic analysis methods Therefore, this research aims to fill this gap by performing a detailed comparative seismic evaluation of an L-shaped G+6 multi-bay steel building using Response Spectrum Analysis (RSA) and Time History Analysis (THA) in STAAD.Pro.

2.3 OBJECTIVE

The primary objective of this thesis is to perform a comparative seismic analysis of a multistory and multi-bay steel building frame using both the Response Spectrum Method (RSM) and the Time History Analysis (THA) as per IS 1893 (Part 1):2016 are as follows: To develop a G+6 multi-bay L-shaped steel building model in STAAD.Pro for seismic analysis. To determine and compare the inter-storey drift obtained by the Response Spectrum Method, and Time History Analysis to analyze the reasons for the observed variations in displacement values. To compare the storey shear and base shear values Derived from both methods and examine the implications

of overestimation or underestimation in simplified static analysis.

To compare the seismic performance of the building in terms of:

- Base Shear
- Storey Displacement
- Storey Drift
- Overturning Moment
- Natural Frequency

Table No. 4.1- Plan Configuration of the Building Model

Table No. 4.1- Plan Configuration of the Building Model	
Parameter	Specification
Plan Configuration	L-Shaped Steel Frame
Overall Dimensions	40 m × 40 m
Bay Spacing	10 m × 10 m
Number of Bays (X-direction)	4
Number of Bays (Z-direction)	4
Number of Grid Lines	5 × 5
Missing Portion	Lower-right 3 × 3 bay portion removed
Actual Plan Area	700 m ² (7 bays × 100 m ² each)

CHAPTER-3 METHODOLOGY

3.1 Methodology

The initial step is preliminary design of building frame. The procedure involved are selection of sections of members of the frame. Since the dynamic action effects are a function of member stiffness, the process unavoidably involves much iteration. The example considered here involves a building in which seismic resistance is provide by moment resisting frames (MRF), in both x and z directions. Moment resisting frames (MRF) are known to be flexible structures. Thus their design is often governed by the need to satisfy deformation criteria under service earthquake loading

3.2 Overview

The following procedure is adopted to modelling the structure in STAAD.Pro CONNECT Edition-A new Space Structure model was created in STAAD.Pro CONNECT Edition. An L-shaped steel building was modelled with four bays of 10 m in both X and Z -Direction's.

The typical storey height was taken as 3.0 m.

- Fixed supports were assigned at all base nodes.
- Steel material Fe-355 and section ST I800I2B55012 were assigned to all members.

- Dead load, live load, Response Spectrum load and Time History load were defined

- The Structure was analyzed using Response Spectrum Analysis and Linear Time History Analysis as per IS 1893 (Part 1): 2016.

The results such as base shear, storey displacement, storey drift,

CHAPTER-4 BUILDING MODELLING

4.2 PROBLEM STATEMENT

The structure consisting of Total seven stories with four bays in horizontal direction and four bays in lateral direction is taken and analyzed it by both Time History Method and Response Spectrum Analysis and designed.

The storey height is 3.0 meters, the horizontal spacing between bays is 10 meters, and lateral spacing of bays is 10 meters

The seismic parameters

Seismic zone	IV
Zone factor "Z"	0.24
Building frame system	steel moment resisting frame designed as per SP:6
Response reduction factor	5.0
Importance factor	1.2
Damping ratio	5%

Table 4.2:- The seismic parameters

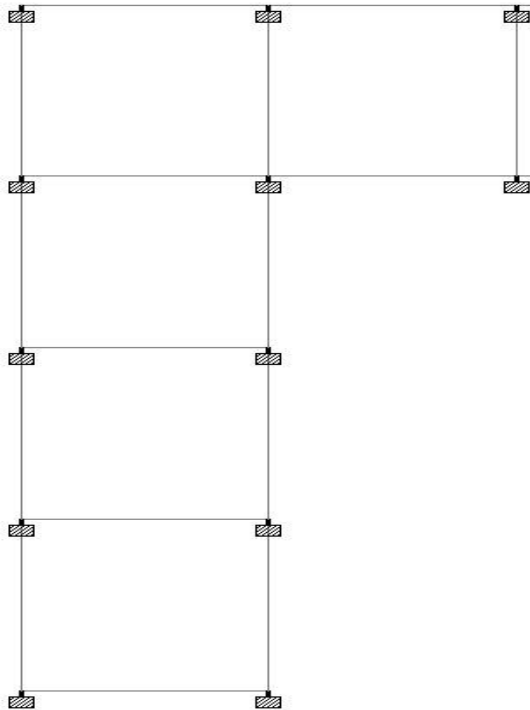
4.3 LOAD PARAMETERS

Table 4.3 - Load Parameter

LOAD PARAMETERS	
dead load is taken as	= 5 KN/m ² and
live load is taken as	= 1.5 KN/m ² Load Calculation
Member load is taken as	=15.5 KN/M

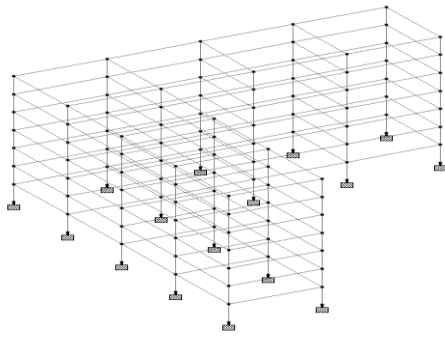
Load combinations as per IS 1893-2016

- DL + LL + RSX
- DL + LL - RSX
- DL + LL + RSZ
- DL + LL - RSZ
- DL + LL - THX
- DL + LL + THZ
- DL + LL - THZ

Where:**DL** = Dead Load**LL** = Live Load**RSX** = Response Spectrum in X-direction**RSZ** = Response Spectrum in Z-direction**THX** = Time History in X-direction**THZ** = Time History in Z-direction**4.4 Building Model Specifications**Table No.4.4 **Building Model Specifications****4.5 Plan Configuration of the L-Shaped Steel Building**

4.6 .Three-Dimensional model of the Steel Building

Category	Parameter	Specification
General	Structure Type	G+6 Steel Space Frame
	Plan Configuration	L-Shaped
	Analysis Software	STAAD.Pro
	Analysis Methods	Response Spectrum Analysis (RSA) and Time History Analysis (THA)
Geometry	Total Height	21.0 m
	Number of Storeys	Ground +6
	Typical Storey Height	3.0 m
	Overall Plan Dimensions	40 m × 40 m
	Actual Floor Area	700 m ²
	Bay Spacing	10 m × 10 m
	Bays in X-direction	4
	Bays in Z-direction	4
Structural Model	Number of Joints	135
	Number of Members	266
	Number of Supports	16 Fixed Supports
Material	Steel Grade	Fe 355
	Section	ST I800I2B55012
	Modulus of Elasticity	205 GPa
	Density	77 kN/m ³
	Poisson's Ratio	0.30
Seismic Parameters (IS 1893:2016)	Seismic Zone	IV
	Zone Factor (Z)	0.24
	Importance Factor (I)	1.2
	Response Reduction Factor (R)	5.0
	Soil Type	Type II (Medium Soil)
	Damping Ratio	5%
	Model Combination	CQC
	Accidental Torsion	Included
	Missing Mass Correction	Applied (MIS = 0)
	Response Scale Factor	4.982
	Zero Period Acceleration (ZPA)	6.9178 (X), 7.2465 (Z)



4.7. Rendered View of the Steel Building

Direction	TH Overturning (kN·m)	RS Overturning (kN·m)
X	170,400	135,000
Z	104,531	92,000



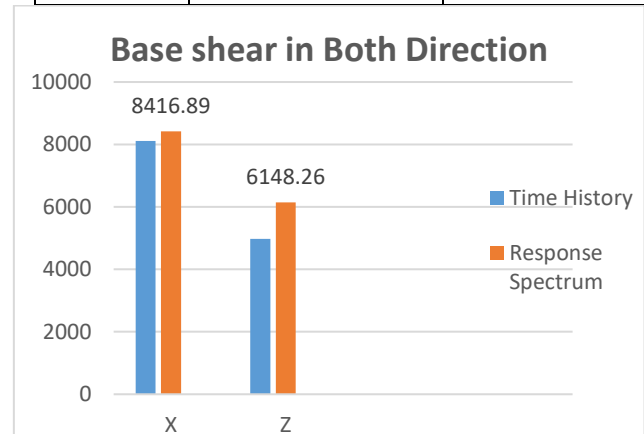
Chapter 5

RESULTS AND DISCUSSION

5.1 Base shear in X and Z Directions

Direction	Time History	Response Spectrum
X	8114.28	8416.89

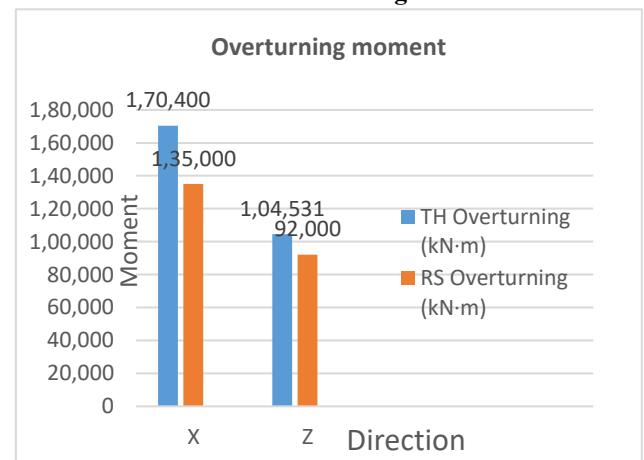
Z	4977.68	6148.26
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Graph. 5.1 Base shear in X and Z Directions

5.2 Overturning moment

Table 5.2 Overturning moment

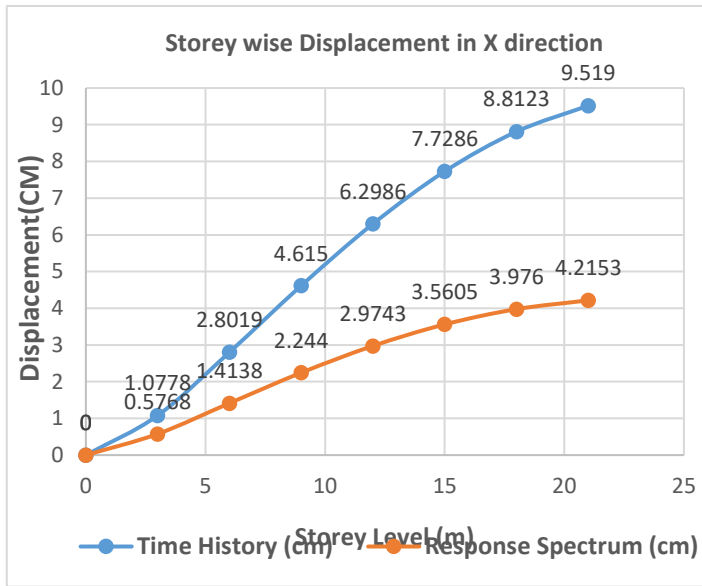


Graph 5.2 Overturning moment

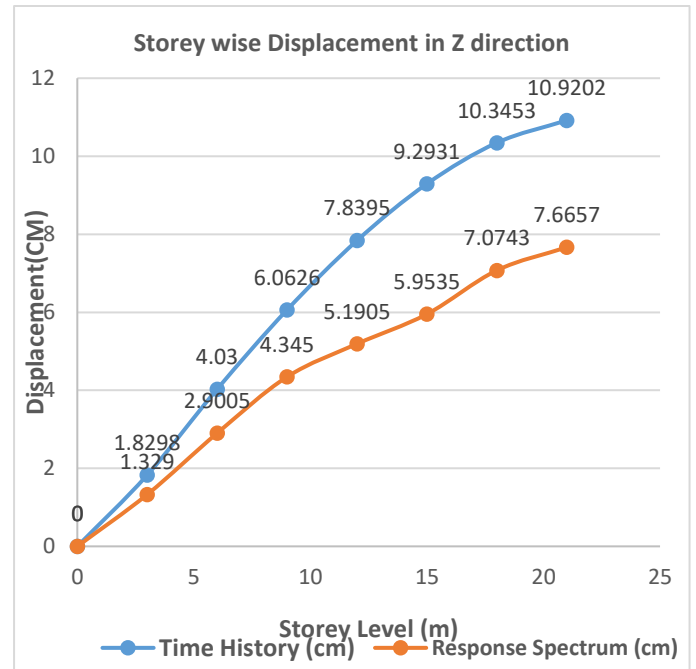
5.3 Storey wise Displacement in X- Direction

Table 5.3 Storey wise Displacement in X – Direction

Storey (m)	Level	Time History (cm)	Response (cm)
0		0	0
3		1.0778	0.5768
6		2.8019	1.4138
9		4.6150	2.2440
12		6.2986	2.9743
15		7.7286	3.5605
18		8.8123	3.9760
21		9.5190	4.2153



Graph 5.3 Storey wise Displacement in X - Direction



Graph 5.4 Storey wise Displacement in Z-Direction

5.4 Storey wise Displacement in Z- Direction

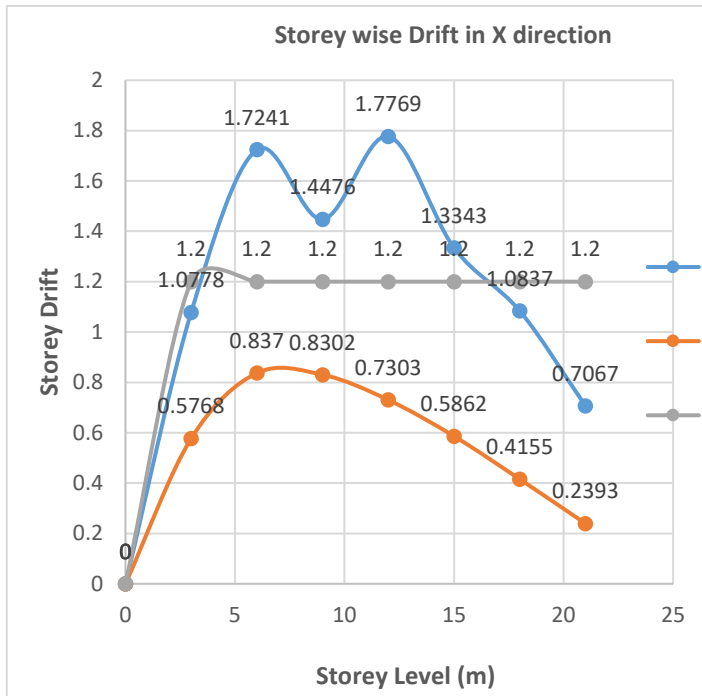
Table 5.4 Storey wise Displacement in Z- Direction

Storey (m)	Level	Time History (cm)	Response (cm)
0		0	0
3		1.8298	1.3290
6		4.0300	2.9005
9		6.0626	4.3450
12		7.8395	5.1905
15		9.2931	5.9535
18		10.3453	7.0743
21		10.9202	7.6657

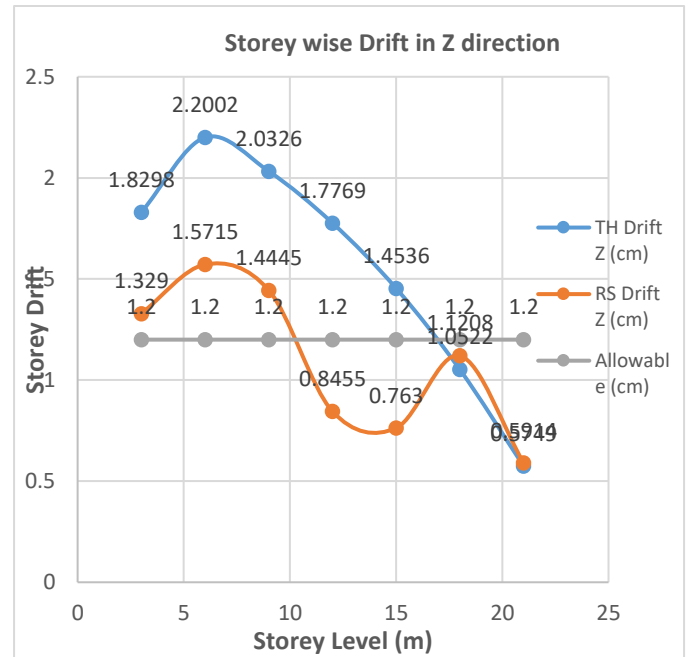
5.5 Storey wise Drift in X-Direction

Table 5.5 Storey wise Drift in X-Direction

Storey Level (m)	TH Drift X (cm)	RS Drift X (cm)	Allowable (cm)	TH Status	RS Status
21	0.7067	0.2393	1.20	OK	OK
18	1.0837	0.4155	1.20	OK	OK
15	1.3343	0.5862	1.20	FAIL	OK
12	1.7769	0.7303	1.20	FAIL	OK
9	1.4476	0.8302	1.20	FAIL	OK
6	1.7241	0.8370	1.20	FAIL	OK
3	1.0778	0.5768	1.20	OK	OK



Graph-5.5 Storey wise Drift in X-Direction



Graph 5.6 Storey wise Drift in Z direction

5.6 Storey wise Drift in Z –Direction

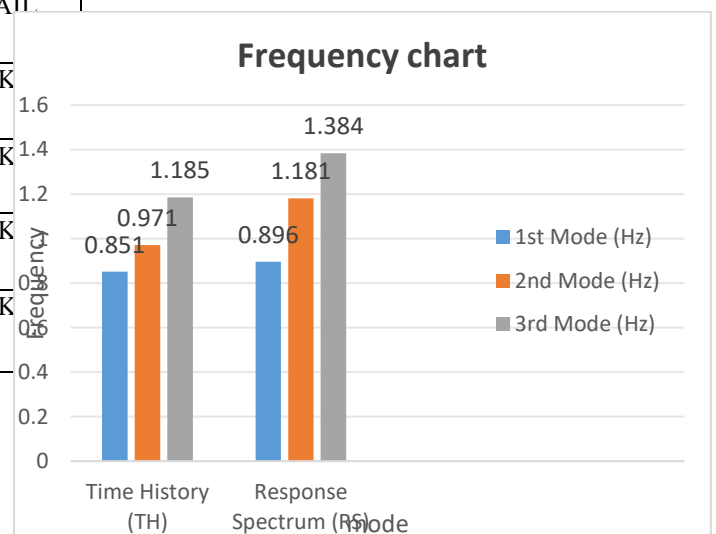
Table 5.6 Storey wise Drift in Z –Direction

Storey Level (m)	TH Drift Z (cm)	RS Drift Z (cm)	Allowable (cm)	TH Status	RS Status
3	1.8298	1.3290	1.20	FAIL	FAIL
6	2.2002	1.5715	1.20	FAIL	FAIL
9	2.0326	1.4445	1.20	FAIL	FAIL
12	1.7769	0.8455	1.20	FAIL	OK
15	1.4536	0.7630	1.20	FAIL	OK
18	1.0522	1.1208	1.20	OK	OK
21	0.5749	0.5914	1.20	OK	OK

5.7 Frequency of TH and RS

Table 5.8 Frequency

Method	1st Mode (Hz)	2nd Mode (Hz)	3rd Mode (Hz)
Time History (TH)	0.851	0.971	1.185
Response Spectrum (RS)	0.896	1.181	1.384



Graph 5.9 Frequency Of TH and RS

5.8 Mode shapes: Time History Method

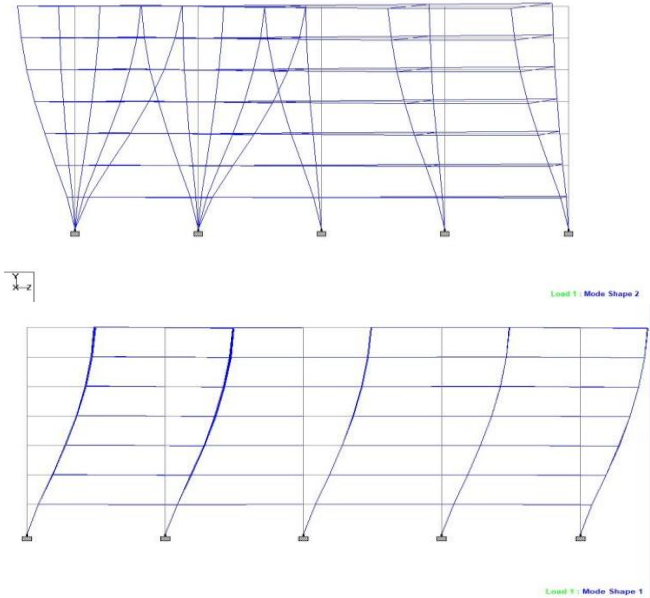


Figure 5.1 Mode shapes of Time History Method

5.9 Mode shapes: Response Spectrum analysis Method

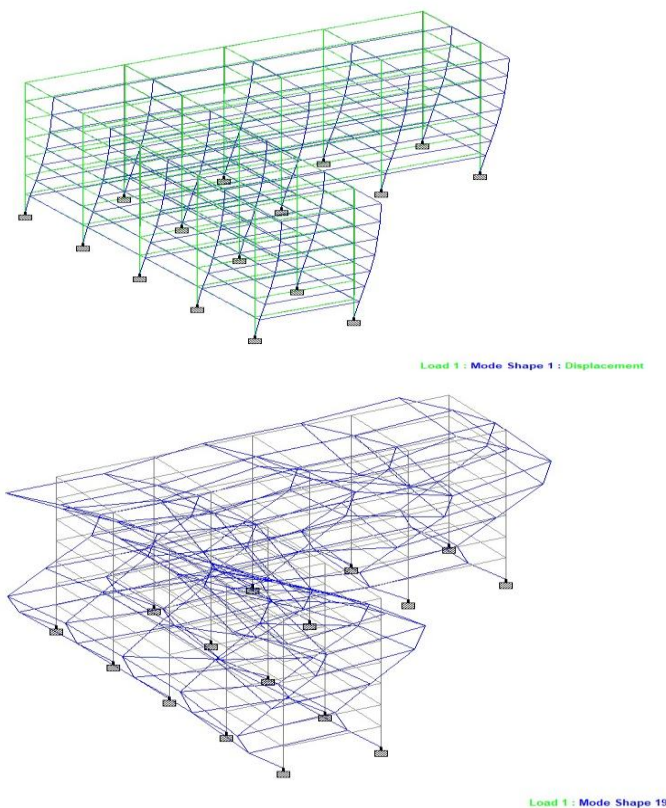


Figure 5.2 (a) Mode shapes: Response Method:

5.10 Comparative Summary of RSA and TSA

Table 5.10 Comparative Summary of RSA and TSA

S. No	Parameter	THA	RSA	Higher Value
1	Base Shear – X Direction	8114.28 KN	8416.89 KN	RSA
2	Base Shear – Z Direction	4977.68 KN	6148.26 KN	RSA
3	Overturning Moment – X Direction	170,400 KN - M	135,000 KN - M	THA
4	Overturning Moment – Z Direction	104,531 KN - M	92,000 KN - M	THA
5	Maximum Storey Displacement – X Direction	9.519 cm	4.2153 cm	THA
6	Maximum Storey Displacement – Z Direction	10.9202 cm	7.6657 cm	THA
7	Natural Frequency – 1st Mode	0.851 Hz	0.896 Hz	—
8	Natural Frequency – 2nd Mode	0.971 Hz	1.181 Hz	—
9	Natural Frequency – 3rd Mode	1.185 Hz	1.384 Hz	—

5.11 DISCUSSION

The comparison shows that the Response Spectrum Analysis gives higher base shear than the Time History Analysis in both the X and Z directions. The base shear obtained from RSA is 8416.89 kN in the X direction and 6148.26 kN in the Z direction, whereas THA gives 8114.28 kN and 4977.68 kN, respectively. In contrast, the Time History Analysis produces higher overturning moments in both directions. The maximum overturning moment obtained from THA is 170,400 KN-M in the X direction and 104,531 KN-M in the Z direction, compared with 135,000 KN-M and 92,000 KN-M obtained from RSA. Overall, the comparison demonstrates that RSA provides higher base shear for the considered structural model, whereas THA gives higher overturning moment and storey displacement. Therefore, both methods provide useful information for evaluating the seismic behavior of the irregular

L-shaped steel building. The combined interpretation of base shear, displacement, and drift, overturning moment, natural frequency and mass participation provides a more comprehensive assessment of the seismic performance of the structure

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion:

The present study evaluated the seismic performance of a G+6 L-shaped multi-bay steel building using Response Spectrum Analysis (RSA) and Time History Analysis (THA) in STAAD.Pro under Seismic Zone IV. The results showed that RSA produced higher base shear, while THA resulted in higher displacement, storey drift, and overturning moment. The Z-direction was found to be more critical due to higher drift and deformation. The irregular L-shaped configuration significantly influenced the seismic response because of non-uniform mass and stiffness distribution. Overall, the study confirms that both RSA and THA should be considered for reliable seismic evaluation of irregular steel buildings, with special attention to controlling excessive storey drift.

6.2 Future Scope

The present study compares the seismic performance of a G+6 multi-bay steel building using Time History Analysis and Response Spectrum Analysis. Based on this research, the following areas are recommended for future research:

1. The study can be extended to **high-rise steel buildings (G+15, G+20, or taller)** to evaluate seismic behavior under increased structural height.
2. Different **plan configurations** such as **T-shaped, U-shaped, C-shaped**, and irregular buildings can be analyzed
3. The effect of **different seismic zones (Zone II, III, IV, and V)** as per IS 1893 (Part 1): 2016 can be investigated.
4. Future research may include the use of **base isolation systems** and **seismic dampers (viscous, friction, tuned mass dampers)** to improve earthquake resistance.
5. **Nonlinear static (Pushover Analysis) and Nonlinear Time History Analysis** can be carried out to study the inelastic behavior of the structure under severe earthquakes.
6. The influence of **soil-structure interaction (SSI)** on seismic response may be incorporated for analysis that is more

realistic.

7.

The effect of **different bracing systems** (X-bracing, Chevron bracing, K-bracing, Eccentric bracing) on structural performance can be evaluated.

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