COMPARATIVE STUDY OF SEISMIC RESPONSES OF MOMENT RESISTING FRAME AND SHEAR WALL FRAME SYSTEM

By

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The project entitled **"Comparative Study of Seismic Responses of Moment Resisting Frame and Shear Wall Frame System"** submitted by Muhammed Abul Hossain, Student No:16PGDEQE008P, and Session: 2016-2017 has been accepted as satisfactory in partial fulfillment of the degree of Postgraduate Diploma in Earthquake Engineering [PG. Dip. (EQE)] on 4th December 2024.

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I hereby declare that the work contained in this Project has not been previously submitted to meet the requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the Project contains no material previously published or written by another person except where due reference is cited. Furthermore, the Project complies with PLAGIARISM and ACADEMIC INTEGRITY regulation of CUET.

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Dedication

To my beloved Parents and Teachers, infinitely supportive

Approval/Declaration by the Supervisor

This is to certify that MUHAMMED ABUL HOSSAIN has carried out this research work under my supervision, and that he has fulfilled the relevant Academic Ordinance of the Chittagong University of Engineering and Technology, so that he is qualified to submit the following Project in the application for the degree of Postgraduate Diploma in Earthquake Engineering (PG. Dip. EQE). Furthermore, the Project complies with the PLAGIARISM and ACADEMIC INTEGRITY regulation of CUET.

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Abstract

Rapid urban population growth and land scarcity have significantly impacted the construction of high-rise buildings. Different structural systems can be adopted for high-rise buildings. Different codes recommend dynamic analysis like response spectrum analysis and Time history analysis (THA) for high-rise buildings based on height limits. The choice of structural system and method of structural analysis can be crucial in terms of safety, economy, and usable space area. In this research, two types of building framing systems, the frame shear wall system (FSWS) and the moment resisting frame system (MRFS), are analysed by linear time history approach applying scaled ground motion time histories for a typical site class following the Bangladesh National Building Code (BNBC). These two buildings have the same aspect ratio of 1.44, slenderness ratio of 5.77, plan area of 3900 ft^2, and height of 300 ft, with different member sections. The column steel percentage for MRFS is 1.2% and FSWS is 1.0%. The two building framing systems are compared through building responses such as story deflection and story drift, which were evaluated in both X and Y directions for scaled ground motion pairs. The research results show that story deflection and story drift for the two framing systems varied for different time history load cases. On the other hand, the usable floor area and concrete volume varied significantly in the two framing systems.

বিমূর্ত

দ্রুত শহরে জনসংখ্যা বৃদ্ধি এবং জমির স্বল্পতা, উঁচু ভবন নির্মাণকে উল্লেখযোগ্যভাবে প্রভাবিত করেছে। উঁচু ভবনের জন্য বিভিন্ন কাঠামোগত ব্যবস্থা গ্রহণ করা যেতে পারে। বিভিন্ন কোড উচ্চতা সীমার উপর ভিত্তি করে হাই-রাইজ বিল্ডিংয়ের জন্য রেসপন্স স্পেকট্রাম এ্যানালাইসিস এবং টাইম-হিস্ট্রি এনালাইসিস এর মত ডায়নামিক এ্যানালাইসিস সুপারিশ করে। কাঠামোগত পদ্ধতির পছন্দ এবং ডায়নামিক এ্যানালাইসিস পদ্ধতি নিরাপত্তা, অর্থনীতি এবং ব্যবহারযোগ্য স্থানের ক্ষেত্রে অত্যন্ত গুরুত্বপূর্ণ। এই গবেষণায়, দুই ধরণের বিল্ডিং ফ্রেমিং সিস্টেম, ফ্রেম শিয়ার-ওয়াল সিস্টেম (FSWS) এবং মোমেন্ট-রেজিস্টিং ফ্রেম সিস্টেম (MRFS) কে, লিনিয়ার টাইম হিস্ট্রি এ্যানালাইসিস করা হয় যা একটি সাধারণ সাইট ক্লাসের জন্য স্কেল্ড গ্রাউন্ড মোশন টাইম হিস্ট্রি প্রয়োগ করে বাংলাদেশ ন্যাশনাল বিল্ডিং কোড (বিএনবিসি) অনুযায়ী। এই দুইটি বিল্ডিং এর আস্পেক্ট অনুপাত ১.৪৪, স্লেন্ডারনেস অনুপাত ৫.৭৭, পরিকল্পনা এলাকা ৩৯০০ বর্গফুট, এবং ৩০০ ফুট উচ্চতা রয়েছে, তবে বিভিন্ন বিল্ডিং ফ্রেম সিস্টেম ব্যবহার করা হয়েছে। কলামের স্টিল রেশিও মোমেন্ট-রেজিস্টিং ফ্রেমের জন্য ১.২% এবং ফ্রেম শিয়ার-ওয়াল সিস্টেমের জন্য ১.০% ব্যবহার করা হয়। দুইটি বিল্ডিং ফ্রেমিং সিস্টেমের তুলনা করা হয় বিল্ডিং প্রতিক্রিয়া যেমন স্টোরি ডিফ্লেকশন এবং স্টোরি ড্রিফটের মাধ্যমে, যেগুলি ম্যাচড গ্রাউন্ড মোশন জোড়ার জন্য X এবং Y উভয় ডিরেকশনে মূল্যায়ন করা হয়েছিল। গবেষণার ফলাফলগুলি পাওয়া যায় দুইটি ফ্রেমিং সিস্টেমের জন্য স্টোরি ডিফ্লেকশন এবং স্টোরি ড্রিফট বিভিন্ন টাইম হিস্ট্রি লোডের ক্ষেত্রে পরিবর্তিত হয়। অন্যদিকে, দুইটি ফ্রেমিং সিস্টেমে ব্যবহারযোগ্য ফ্লোর এরিয়া এবং কংক্রিটের আয়তন উল্লেখযোগ্যভাবে পরিবর্তিত হয়েছে।

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List of Abbreviations

MRFS	Moment Resisting Frame System
FSWS	Frame Shear Wall System
BNBC	Bangladesh National Building Code
CCA	Chattogram City Area
CDMP	Comprehensive Disaster Management Program
CS	Compressive Stress
CSC	Compressive Strength of Concrete
DBE	Design Basis Earthquake
DI	Direct Integration
DOF	Degree of Freedom
DC	Design Code
IEER	Institute of Earthquake Engineering Research
MCE	Maximum Considered Earthquake
MSD	Maximum Story Displacement
NSP	Nonlinear Static Procedure
NDP	Nonlinear Dynamic Procedure
PGA	Peak Ground Acceleration
POA	Pushover Analysis
RSA	Response Spectrum Analysis
RC	Reinforced Concrete
RCC	Reinforced Cement Concrete
RD	Rigid Diaphragm
RCRS	Reinforced Concrete Rectangular Section
SA	Spectral Acceleration
SDR	Story Drift Ratio
THA	Time History Analysis
VDC	Virtual Data Center

Chapter 1: INTRODUCTION

1.1 GENERAL

A structural system uses a complete load transfer mechanism to carry gravity and lateral loads. Gravity loads are dead load and live load. In addition to vertical loads, earthquake and wind loads act as lateral loads on buildings. However, earthquake loads provide more lateral loads on high-rise buildings (Ahmed et al., 2024). There are different types of building framing systems, among them moment resisting frames, and frame shear wall systems are the most popular. Moment resisting frames mainly resist gravity loads and some lateral loads primarily by the flexural action of members. The moment resisting frame is classified into three types, i.e., special, intermediate, and ordinary moment resisting frames. Frame shear wall systems, taking into consideration the interaction of the dual system at all levels, resist the entire lateral force in proportion to their relative rigidity. High-rise building framing systems typically use frame shear wall special moment resisting frames (BNBC, 2020). Shear walls are structural walls made of reinforced concrete (RC) designed to resist lateral forces caused by wind or earthquakes. These walls provide sufficient stiffness and strength, along with the necessary deformation capacity to dissipate energy, which is essential to meet the seismic demands of a structure. In buildings, it is common to combine moment resisting frames to handle gravity loads with RC shear walls to resist lateral forces (Azam & Hosur, 2013). The slenderness effect comes from the frame system of the building as well as the height. The slenderness ratio, or the height-to-base ratio (H/B ratio), is a key parameter used to describe the slenderness or verticality of a building. Generally, for the structures, a low slenderness Ratio < 4, a moderate slenderness Ratio is 4 to 10, and a high slenderness ratio > 10 (Ali and Moon 2007, Smith and Coull 1991). According to BNBC, moment resisting frames (MRFS) and frame shear wall systems (FSWS) have no limit on building height in the seismic design category but should maintain special detailing to provide ductility provision.

Dynamic analysis is required for high-rise buildings. Therefore, to ensure stability, current building codes prescribe different dynamic analyses like linear dynamic analysis (response spectrum analysis or linear time history analysis) and non-linear dynamic analysis (non-linear time history analysis) based on building height and building framing system according to the importance of the structure. A linear time history analysis (LTHA) involves analysing a structure linear mathematical model to determine its response by directly integrating the differential equation of motion using multiple ground acceleration time histories that align with the site design response spectrum. For the analysis, the structure can be assumed to be fixed at the foundation, or more realistic assumptions about the foundation stiffness can be applied (BNBC, 2020). Time history analysis provides a more thorough assessment of the structure protection since it takes into account the real time-dependent behavior of the structural response (BNBC, 2020). A detailed examination of a structural dynamic response to the ground motion record of a representative earthquake is known as a time history study.

The ability of a structure to resist an earthquake depends upon its rigidity, flexibility, and building framing system. The 30-storied RC building with two different building framing systems, i.e., MRFS and FSWS building model is analysed by the linear time history analysis method applying a pair of ground motion time histories for a typical site class following BNBC. These two buildings have the same aspect ratio, slenderness ratio, plan area, and height. The member sections of these two buildings are finalized satisfying the allowable drift limits according to BNBC, 2020. The efficiency of these framing systems for a typical height of the building is evaluated in terms of maximum story displacement, story drift, usable area, and consumption of concrete volume.

1.2 OBJECTIVES WITH SPECIFIC AIMS

Based on the above background, the study aims to evaluate the comparisons of different framing systems on the seismic response of high-rise RC buildings using linear time history analysis. In this regard, two high-rise RC buildings with two different framing systems are considered to keep the same plan area, aspect ratio, slenderness ratio, and story height. Linear dynamic analysis of the buildings is performed using three earthquake ground motion time history pairs scaled according to the design response spectrum of BNBC 2020.

Motivated by the above discussion, the current work is aimed at conducting the following works:

1. To compare the seismic behaviors of the moment resisting frame system (MRFS) and frame shear wall system (FSWS) in terms of story displacement and story drift ratio.
2. To compare the usable space area and concrete volume of the moment resisting frame system (MRFS) and frame shear wall system (FSWS).

1.3 ORGANIZATION OF THE REPORT

This research report is organized into five chapters. In the present chapter short preface and objectives are presented.

In Chapter 2, a comprehensive literature review of the RC building framing system, earthquake, seismicity of Chittagong and Bangladesh, ground motion, structural analysis, response spectrum, and related research are presented.

In Chapter 3, the methodology of the whole project work is presented which includes time history analysis (THA) of the buildings as well as design response spectrum and ground motion scaling.

In Chapter 4, the displacement response at the top floor of each building model is formed from time history analysis, The Story drift ratio is determined for each floor by dividing the relative displacements of the floors by the story height as well as the maximum story displacement, story drift ratio results and story stiffness are presented. Also, the usable space area and consuming concrete volume of the two farming systems are presented.

Lastly Chapter 5, conclusions obtained from this project's work result are presented for the two RC building framing systems.

Chapter 2: LITERATURE REVIEW

2.1 GENERAL

Bangladeshi people suffer from various natural disasters; however, very few die from earthquakes, which are usually due to structural insufficiency. Bangladesh is an earthquake-prone country due to its surrounding tectonic plates and geographical location. Consequently, selecting framing systems and analysis procedures is critical for tall buildings.

2.2 RC BUILDING FRAMING SYSTEM

The budget and the seismic risk are crucial factors in determining which framing system is best. Any structure experiences distributed lateral forces based on how rigidly each component bends when in a flexural position. In structural engineering, a rigid frame is a load-bearing framework made of straight or curved components joined by primarily rigid connections that withstand movements caused at the member joints. Its members are capable of withstanding axial, shear, and bending loads. There are two categories for them: Braced-frames and Rigid-framed structures. Frameworks Two widely held beliefs about how a building frame behaves are that its parts are sufficiently interconnected that the angles they form with one another remain constant under stress and that its beams are free to spin at their connections (Titiksh and Gupta, 2015). The seismic force-resisting system is called a structural framing system. The structural system is subdivided by the types of vertical elements used to resist lateral seismic force and height limitation according to the seismic design category Table 2.1 (BNBC, 2020).

Table 2.1: Different Structural Systems (BNBC, 2020 and ASCE 7-05)

Seismic Force- Resisting system	Response Reduction Factor, *R*	System Overstrength Factor, Ω_0	Deflection Amplification factor, C_d	Seismic Design Category B	Seismic Design Category C	Seismic Design Category D
				Height Limit (m)		
A. BEARING WALL SYSTEM (no frame)						
1. Special reinforced concrete shear walls	5	2.5	5	NL	NL	50
2. Ordinary reinforced concrete shear walls	4	2.5	4	NL	NL	NP
3. Ordinary reinforced concrete shear walls	2	2.5	1.75	NL	50	NP
4. Ordinary plain masonry shear walls	1.5	2.5	1.25	18	NP	NP
B. BUILDING FRAME SYSTEMS (with bracing or shear wall)						
1. Steel eccentrically braced frames, moment resisting connections at columns away from links	8	2	4	NL	NL	50
2. Steel eccentrically braced frames, no moment resisting, connections at columns away from links	7	2	4	NL	NL	50
3. Special steel concentrically braced frames	6	2	5	NL	NL	50
4. Ordinary steel concentrically braced frames	3.25	2	3.25	NL	NL	11
5. Special reinforced concrete shear walls	6	2.5	5	NL	50	50
6. Ordinary reinforced concrete shear walls	5	2.5	4.25	NL	NL	NP
7. Ordinary reinforced masonry shear walls	2	2.5	2	NL	50	NP
8. Ordinary plain masonry shear walls	1.5	2.5	1.25	18	NP	NP
C. MOMENT RESISTING FRAME SYSTEMS (no shear wall)						

1. Special steel moment frames	8	3	5.5	NL	NL	NL
2. Intermediate steel moment frames	4.5	3	4	NL	NL	35
3. Ordinary steel moment frames	3.5	3	3	NL	NL	NP
4. Special reinforced concrete moment frames	8	3	5.5	NL	NL	NL
5. Intermediate reinforced concrete moment frames	5	3	4.5	NL	NL	NP
6. Ordinary reinforced concrete moment frames	3	3	2.5	NL	NP	NP
D. DUAL SYSTEMS: SPECIAL MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES (with bracing or shear wall)						
1. Steel eccentrically braced frames	8	2.5	4	NL	NL	NL
2. Special steel concentrically braced frames	7	2.5	5.5	NL	NL	NL
3. Special reinforced concrete shear walls	7	2.5	5.5	NL	NL	NL
4. Ordinary reinforced concrete shear walls	6	2.5	5	NL	NL	NP
E. DUAL SYSTEMS: INTERMEDIATE MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES (with bracing or shear wall)						
1. Special steel concentrically braced frames	6	2.5	5	NL	NL	11
2. Special reinforced concrete shear walls	6.5	2.5	5	NL	NL	50
3. Ordinary reinforced masonry shear walls	3	3	3	NL	50	NP
4. Ordinary reinforced concrete shear walls	5.5	2.5	4.5	NL	NL	NP
F. DUAL SHEAR WALL-FRAME SYSTEM: ORDINARY REINFORCED CONCRETE MOMENT FRAMES AND ORDINARY	4.5	2.5	4	NL	NP	NP

REINFORCED CONCRETE SHEAR WALLS						
G. STEEL SYSTEMS NOT SPECIFICALLY DETAILED FOR SEISMIC RESISTANCE	3	3	3	NL	NL	NP
NL = No limit height, NP = Not Permitted						

2.2.1 Moment Resisting Frame System (MRFS)

A moment resisting frame is a linear configuration of column and beam components with the beams tightly fastened to the columns. This frame system resists gravity loads and some lateral loads primarily by the flexural action of members. The moment resisting frame is classified into three types, i.e., ordinary, intermediate, and special moment resisting frames. Designed for resistance to mild lateral loads, Ordinary moment resisting Frames (OMRF) are primarily found in areas with little seismic activity. The intermediate moment resisting Frame (IMRF) is a moderately ductile structure intended for locations with a moderate seismic risk. The special moment resisting frame (SMRF) is intended for areas with strong seismic activity and provides a high degree of ductility but should maintain special reinforcement detailing (BNBC, 2020).

2.2.2 Frame Shear Wall System (FSWS)

Frame shear wall or dual frame systems, taking into consideration the interaction of the dual system at all levels, resist the entire lateral force in proportion to their relative rigidity. High-rise building framing systems typically use dual system special moment resisting frames (BNBC, 2020). Shear walls are structural walls made of reinforced concrete (RC) designed to resist lateral forces caused by wind or earthquakes. These walls provide sufficient stiffness and strength, along with the necessary deformation capacity to dissipate energy, which is essential to meet the seismic demands of a structure. In buildings, it is common to combine moment resisting frames to handle gravity loads with RC shear walls to resist lateral forces (Azam & Hosur, 2013). Frame shear wall systems or dual-frame systems are classified into two types i.e., Special reinforced concrete shear walls and Ordinary reinforced concrete shear walls. Ordinary reinforced concrete shear wall frames are primarily found in areas with little seismic activity does not maintain special reinforcement detailing. The special reinforced concrete shear wall frame is intended for areas with strong seismic activity and provides a high degree of ductility but should maintain special reinforcement detailing seriously (BNBC, 2020).

2.3 BUILDING ANALYSIS PROCEDURES

At the necessary design stage of an earthquake-resistant building, analysing a structural system to find distortions and forces brought on by applied loads or ground motion. The requirements for a process of structural analysis are as follows:

a) Modelling a structure.
b) Earthquake-induced ground motion.
c) Management equations are created and solved analytically. Depending on the goals of the design process analysis, many methodologies can be used, ranging from plastic assessment to dynamic analysis of full-structured models.

In structural analysis, the idea of a linear or nonlinear relationship between forces and displacements is crucial. Static and dynamic loads are components of linear analysis for structure. A dynamic structural analysis technique is one of linear time history analysis (LTHA) used to assess how well a structure performs when it is subjected to time-varying loads such as those brought on by wind, earthquakes, or other dynamic forces. Using this method, a thorough simulation of time-dependent loads is carried out to the structural model, and at each time step, the response (displacement, velocity, and acceleration) is identified (Chopra, 2012). Table 2.2 lists the structural analysis methods employed by earthquake-resistant design. (Bozorgnia & Bertero, 2004). Software utilizing one or more of the methods described in this section is used in almost all structural analyses of earthquake-resistant designs. The forces and deformities resulting from this kind of research are typically shown in contemporary software that makes use of graphic elements. Before using any new structural evaluation device, the engineer must conduct a shred of verifiable evidence to ensure correct findings (Bozorgnia and Bertero, 2004). Evaluating the force and deformation both locally and globally is the main objective when a structure is subjected to seismic pressure that indicates a hazard in a building location:

Table 2.2: Structural analysis procedures (Bozorgnia & Bertero, 2004)

Analysis procedure	Analysis method
Linear static procedure (LSP)	Linear equivalent static analysis
Linear dynamic procedure (LDP)	Response spectrum analysis (RSA)
Linear dynamic procedure (LDP)	Time history analysis (THA)
Nonlinear static procedure (NSP)	Pushover analysis (POA)
Nonlinear dynamic procedure (NDP)	Time history analysis (THA)

According to BNBC (2020), for the following buildings, dynamic analysis should be carried out to determine the design seismic force, as well as how it is distributed among the various lateral load-resisting elements and levels along the building's height:

(a) Regular constructions taller than 40 meters in Zones 2, 3, and 4, and more than 90 meters in Zone 1.

(b) Irregular structures (as described in Sec. 2.5.5.3) taller than 12 meters in Zones 2, 3, 4, and more than 40 meters in Zone 1.

If an irregular building in Zone 1 is less than 40 meters in height, dynamic analysis is advised even though it is not required.

2.3.1 Linear Time History Analysis (LTHA)

In LTHA, it is assumed that the material obeys Hooke's Law (stress is proportionate to strain) and that the structure will behave linearly throughout the analysis, i.e., no permanent deformations are expected. The study provides how the structure will react to dynamic forces by using real or artificial records of forces applied over time, such as ground motions from earthquakes. Compared to less sophisticated techniques (like static analysis), LTHA offers a more realistic depiction of a structure's dynamic behavior and sheds light on resonance, vibrations, and potential weak spots. Every time step of the approach requires computing equations of motion, which is computationally demanding, particularly for large or complicated structures (Chopra, 2012).

In linear analysis, displacement, velocity, and time can all have an impact on stiffness, damping, and load. This necessitates setting up the motion conditions iteratively. One can ascertain the dynamic behavior of a structure under random loading by time-history analysis. The basic formula for dynamic systems that need to be solved is,

$$M\ddot{u}(t)+C\dot{u}(t)+Ku(t)=F(t) \quad \ldots\ldots\ldots\ldots (1)$$

where,

M is the mass matrix of the structure.

C is the damping matrix.

K is the stiffness matrix of the structure.

u(t) is the displacement vector.

$\dot{u}(t)$ is the velocities of structures.

$\ddot{u}(t)$ is accelerations of structures.

F(t) is the force vector acting on the structure at time t, often representing dynamic loads such as earthquake ground motion.

This approach is time and force-dependent for solving the dynamic analysis structure. In ideal circumstances, the results of the above equation for a particular problem should be the same (Chopra, 2012). The following techniques can be used to solve dynamic equations.

a) Linear modal time-history analysis

The method is highly efficient, especially for structural systems with a small number of preset nonlinear elements that are essentially linear elastic. However, these cannot be considered the limitations of linear components until appropriate modes are available. The simplest way to do this is to use a significant proportion of Ritz variables. The complete stiffness matrix, K, and the mass matrix, M, are used in modal analysis. It is strongly advised that the Ritz variables method be used for the modal analysis.

b) Linear direct-integration time-history analysis

Direct integration has the following benefits even if modal superposition is usually more accurate and efficient:

• Full damping that couples the modes can be considered.

• Solving influence and wave propagation problems that could ignite a large fraction of modes may be more effectively accomplished by direct integration.

• Any kind of linearity can be taken into consideration in a linear direct integration study.

Reducing time-step values until the gradation form is small enough to not impact the results is the recommended method for doing direct-integration analysis. When conducting nonlinear direct-integration time-history analysis, the following considerations are made.

2.3.2 Ground Motion

The breaking of the bedrock beneath the surface of the earth causes earthquakes. This is related to the release of strain power that has been held at the fault position. These waves, known as seismic waves, move through the body and across the surface of the Earth in all directions. The Earth's surface, upon which those structures are built, trembles, causing seismic waves, which fall mainly into two categories: body waves and surface waves. One can measure the ground motion's displacement, acceleration, and velocity. These decreased displacements are measured by seismographs. In the vicinity of large earthquake epicentres, there is a strong shaking of the ground. Because of their design, seismographs become saturated and lose their ability to record ground displacement during high displacement shaking. Conversely, engineers are knowledgeable about the stresses involved and are interested in finding the ground vibration levels at which structures fail (as a component of a building's design). Consequently, the development of devices called accelerographs—which track the acceleration of an earthquake tremor overtime at the location of the sensor—was spurred. These instruments successfully record ground tremors, even in the closest cases of strong seismic faults.

a) Accelerograms

An accelerogram is a recording created during an earthquake using an accelerograph that displays the variation in ground acceleration over time at a particular spot on the ground. The kind of isolation found in the bedrock, the local soil, and the geology of the area along the route from the source to the earth's surface all affect the characteristics of accelerograms. Accelerograms provide detailed data about ground shaking, including peak amplitude, duration of violent shaking, and frequency response (that is, the frequencies at which the earthquake exhibits a substantial amount of vibrating force). The type of eruption, the geology along the transit route, and the geotechnical layer beneath the building are the three key factors that characterize the features of rapid ground motion at a station Fig. 2.1.

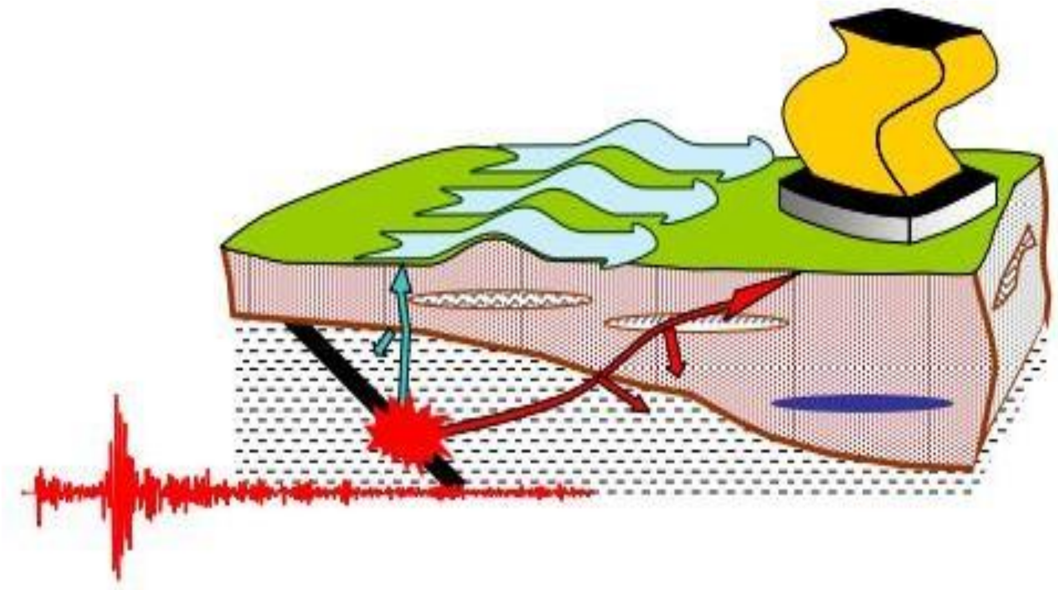


Fig. 2.1: During earthquakes, the ground shakes (Murty et.al, 2013)

A building that is resilient throughout an earthquake cannot be affected by the length of the earthquake. However, for another building that is damaged during an earthquake, the length of the earthquake matters a great deal. Building inelastic conditions are influenced by maximum ground acceleration, significant vibration duration, and frequency response.

b) Acceleration Response Spectrum of a Ground Motion

Generally, when designing a structure, the maximum force generated by an earthquake's shaking is considered. Two approaches exist for defining force: (i) the inertia force is represented by mass m times acceleration a; (ii) the elastic force is represented by stiffness k times displacement x.

$$F = ma \text{ or } F = kx \text{ .... (2)}$$

Furthermore, a distinct natural period T and SDoF are constructed for the precise damping under the ground motion of the same earthquake because the upper limit of such a response is effective in design. Based on the typical earthquake, the acceleration response spectrum for 5% damp is a response spectrum that relates to the building's acceleration. Fig. 2.2 displays the typical time history.

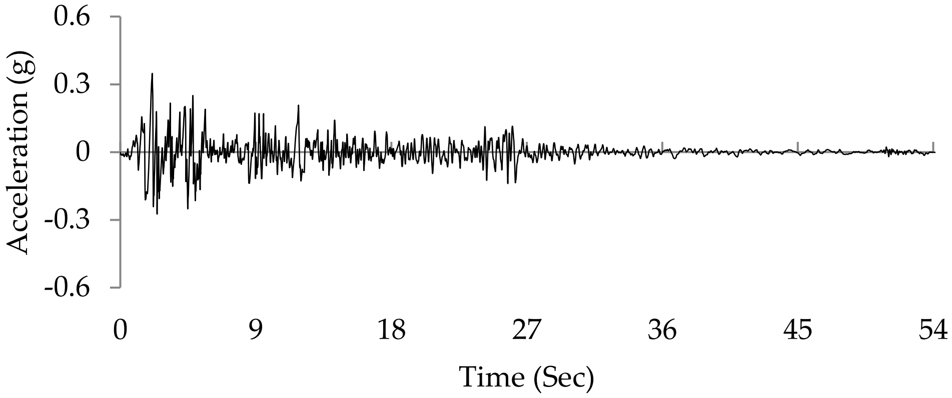


Fig. 2.2: Typical seismic ground motion accelerations of an earthquake

Seismic mass, or a building's effective mass during an earthquake, is simple to compute (Gravity G is equal to the seismic weight divided by the acceleration). This allows you to compare the overall strength of the building to the actual structure. The absolute maximum acceleration (also known as the spectral acceleration) response of the spectra of structures with varied fundamentally translatable natural periods but with the same wetness and taken into consideration ground motion is known as the acceleration response. Seismic design standards offer a design response spectrum for the design process, and the resulting force is referred to as the building's seismic design base shear or seismic design lateral load. The original typical ground motion has a maximum spectral acceleration of 0.91g. Complementary.

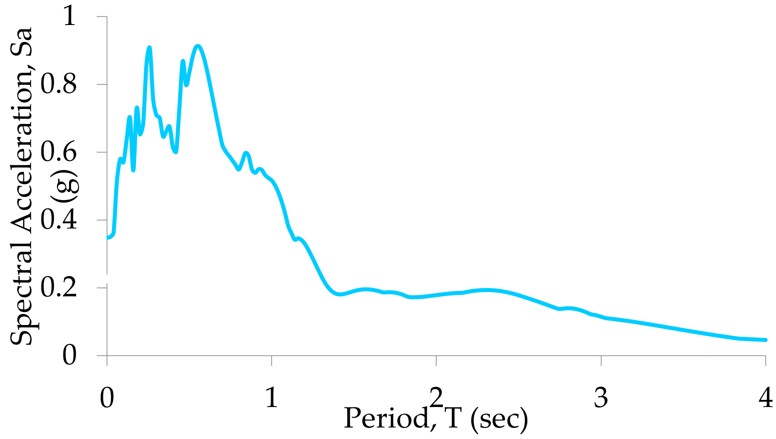


Fig. 2.3: Typical original acceleration response spectrum of an earthquake

2.3.3 Design Response Spectrum (DRS)

A response spectrum is a conceptual spectrum as opposed to the Fourier spectrum of horizontal components. The necessary time period reactions of one-degree-of-freedom (dof) subsystems at various natural harmonics are gathered in this collection. Phase shift and other crucial information are absent from the response spectrum that is shown. Moreover, hundreds of synthetic time histories can be produced using the response spectrum that is provided.

- The following determines the elastic reaction spectrum Cs for the horizontal elements of a seismic event (BNBC, 2020).

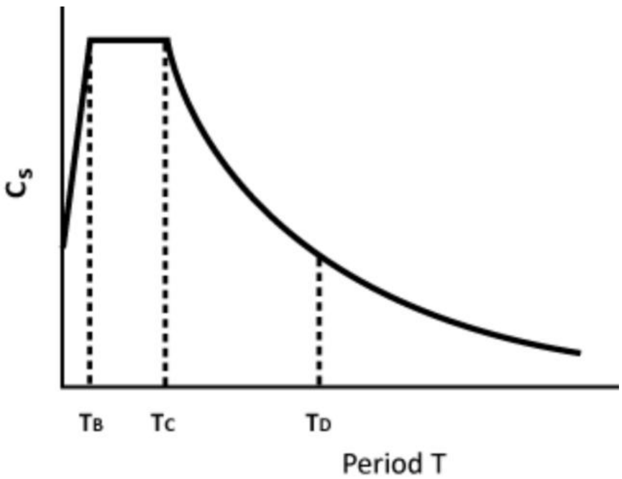


Fig. 2.4: Typical shape of the elastic response spectrum coefficient Cs (BNBC, 2020)

- The soil factor S, which characterizes the shape of the elastic reaction spectrum, and the values of the periods TB, TC, and TD are influenced by the ground variety (BNBC, 2020).
- If the earthquakes with the highest surface-wave magnitude contribute to the seismic hazard assessed for the area for probability hazard analysis, it is recommended to utilize the type 1 spectrum. Use type 2 if not (BNBC, 2020).

$$0 \leq T \leq T_B : C_s = S[1 + \frac{T}{T_B}(2.5\,\eta - 1)] \quad (2)$$

$$T_B \leq T \leq T_C : C_S = 2.5 S\eta \quad (3)$$

$$T_C \leq T \leq T_D : C_S = 2.5\, S\eta\, [\frac{T_C}{T}] \quad (4)$$

$$T_D \leq T \leq 4\ sec.: C_s = 2.5\, S\eta\, [\frac{T_C\, T_D}{T^2}] \quad (5)$$

where,

C_s is the elastic reaction spectrum.

T_B is the time of the fixed spectral acceleration chapter's upper limit.

T_C is the highest limit of the time of the spectrum's fixed displacementreaction range.

T_D is the value defining the start of the fixed displacement reaction rangeof the spectrum.

S is the soil factor.

η =1 for 5% thick damping, $\eta = \sqrt{[10/(5 + \xi)]} \geq 0.55$

2.3.4 Selection of the Ground Motion Records for THA

According to ATC-40 ground motion selection for time history analysis is the following points:

- Free-filed station > 10 km from source (or ground floor of a small building).
- Stiff or medium soil site conditions.
- Large-magnitude earthquake (M ≥ 6.5).
- Peak ground acceleration of at least 0.2g (before scaling).

According to BNBC, 2020, When analysed in three dimensions, ground motions should comprise two orthogonal horizontal directions of pairs of suitable horizontal ground motion acceleration time histories chosen and scaled from individual recorded events. From events whose magnitudes, fault distances, and source mechanisms are compatible with those governing the maximum considered earthquake, appropriate ground motions shall be chosen. In cases when the necessary quantity of recorded ground motion pairs is unavailable, suitable simulated ground motion pairs must be utilized to fulfill the total need. An SRSS spectrum will be created for each pair of horizontal ground motion components by taking the square root of the sum of the squares of the components, five percent-damped response spectra (where both components of a pair are subjected to the same scale factor). Every pair of motions must be scaled so that the average of the SRSS spectra from every scaled horizontal component pair is at least 1.3 times the corresponding ordinate of the determined design response spectrum for every period between 0.2T to 1.5T (where T is the natural period of the fundamental mode of the structure).

2.3.5 Response Evaluation

The time history analysis will yield the highest values of base shear and other structure response variables for each scaled acceleration time history. An orthogonal pair of scaled motions is applied simultaneously for three-dimensional analysis. V, the base shear, will be determined by applying the comparable static force method. All response quantities (story shear, moments, drifts, floor deflections, member forces, etc.) derived from time history analysis must be increased by multiplying by the ratio, V/Vth, in cases where the maximum base shear, Vth, as determined by linear time history analysis, is less than V. If the number of earthquake pairs employed in the study is less than seven, the maximum structural reaction obtained from separate earthquake data will be used as the design value. If the number is at least seven, the design value will be determined by the average of maximum structural responses from various earthquake data. Design displacements and drifts are derived by multiplying the above-mentioned displacements and drifts by Cd/I, as in the corresponding static analysis technique.

2.4 SEISMICITY

Bangladesh has five main active faults based on its geological position (Hossain, 1998). These significant flaws put Bangladesh in a precarious predicament. Every second, there are earthquakes around the planet; the minor ones (ms < 3.0) are not felt by us and do not pose a threat, while the major ones (ms > 6.0) result in dire circumstances. Seismic waves are produced when abrupt energy release happens in the Earth's crust. A region's seismic activity, or earthquake frequency, is the total number, kind, and magnitude of recorded seismic events over a specific time frame. Earthquakes are measured using the Moment Magnitude (MW) and Richter Magnitude (ML) scales. Earthquakes are frequently classified according to the depth at which they occur. Earthquakes come in two varieties: shallow and deep. Earthquakes that are shallower damage more. Furthermore, the mechanism causing shallow earthquakes is generally understood, while the mechanism causing profound earthquakes is not entirely understood. Shallow earthquakes are more common, more destructive, and more understood (Roy, 2014).

2.4.1 Seismicity in Bangladesh Region

Bangladesh is at risk for earthquakes, according to recent seismic activity as well as historical seismic data from Bangladesh and the surrounding areas Fig. 2.5. Since Bangladesh is the world's most densely populated nation, the effects of any future earthquake will be felt more widely than in other seismically active regions of the world. It is predicted by experts that this region will experience a huge earthquake soon, which will cause significant damage in terms of infrastructure and human casualties. The "circum-Pacific belt" and the "Mediterranean-Himalayan seismic belt," two clearly defined zones or belts, are the epicentres of the most destructive earthquakes, as Figure 2.5 illustrates.

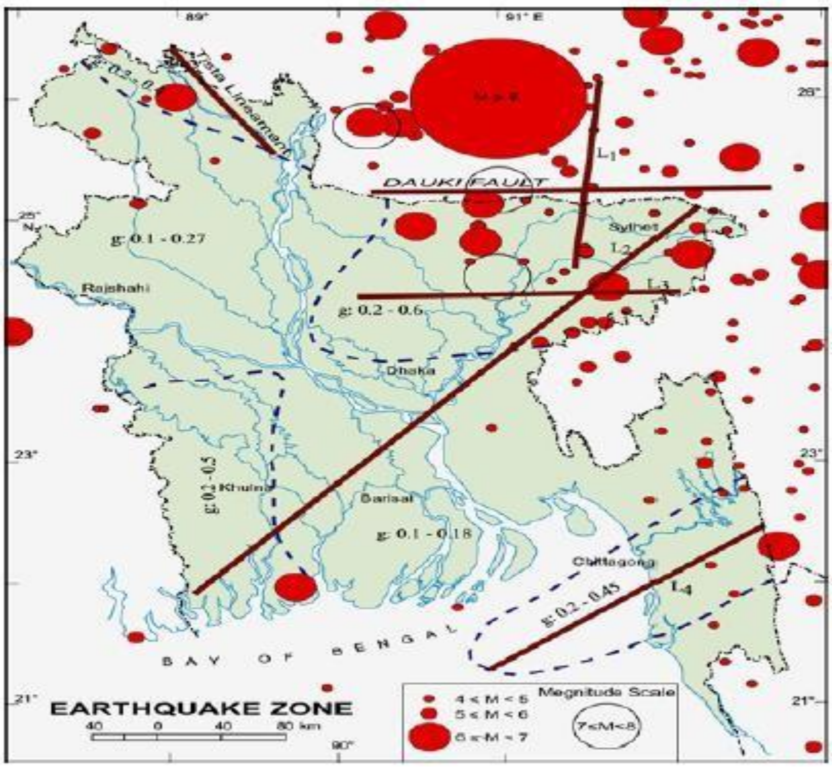


Fig. 2.5: Seismic Activity of Bangladesh (Roy, 2014)

There are no extensive earthquake monitoring systems in Bangladesh. In 1954, a seismic observatory was built in Chittagong by the Bangladesh Meteorological Department. A seismic observatory station was created in 2010 by the IEER, CUET. Furthermore, this junction area contains numerous active fault zones that are potential earthquake hotspots. Identify five major earthquake sources, mostly located in the Bangladesh region by Bolt in 1987 Table 2.3.

Table 2.3: Seismic sources in Bangladesh (Bolt, 1987)

Faults	Probable magnitude in Bangladesh (in Richter scale)
Assam fault zone	8.0
Tripura fault zone	7.0
Sub Dauki fault zone	7.3
Bogra fault zone	7.0
Shillong plateau	7.0

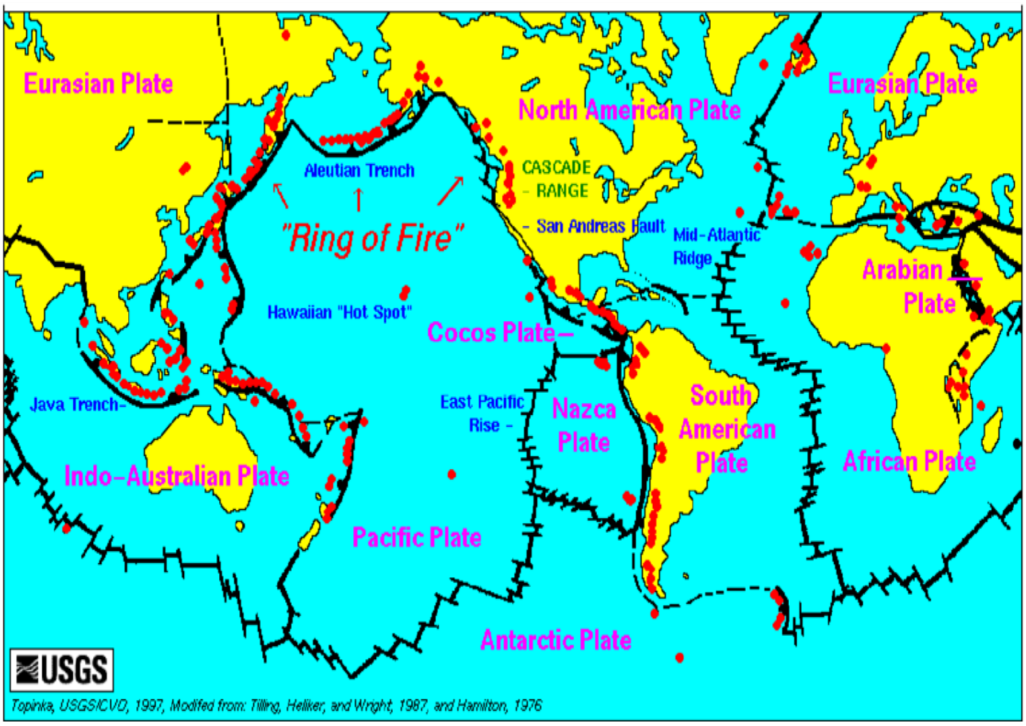


Fig. 2. 6: Active Plate Tectonics, "Hot Spots" and the "Ring of Fire"

(Wikimedia Commons)

Volcanoes arise when magma rises above the Earth's crust in addition to reaching the surface, as shown in Fig. 2.6. To do this, the magma must locate a weakness in the crustal rocks that affects the area or the area beneath the sea. Most volcanoes are found on or near the margins of tectonic plates recent review of the phase 1 project of the Comprehensive Disaster Management

Program (CDMP). According to Figure 2.7, there are five main fault zones in Bangladesh: the Madhupur fault, the Dauki fault, the Plate Boundary Fault -1, the Plate Boundary Fault -2, and the Plate Boundary Fault -3. Furthermore, five scenarios were suggested (CDMP, 2009), one of which is an extraordinary seismic scenario where a magnitude-6 earthquake is occurring beneath Chittagong town. For each City Corporation, three earthquake scenarios were chosen for the seismic losses analysis. Out of the five scenarios provided by the OIC, the first scenario produces the most amount of ground motion in the city. The second case demonstrates that the four OIC examples that remain are not wholly distinct from one another and are less than they may have been in the first scenario. In the third, unusual scenario, a magnitude six earthquake happens exactly beneath the town.

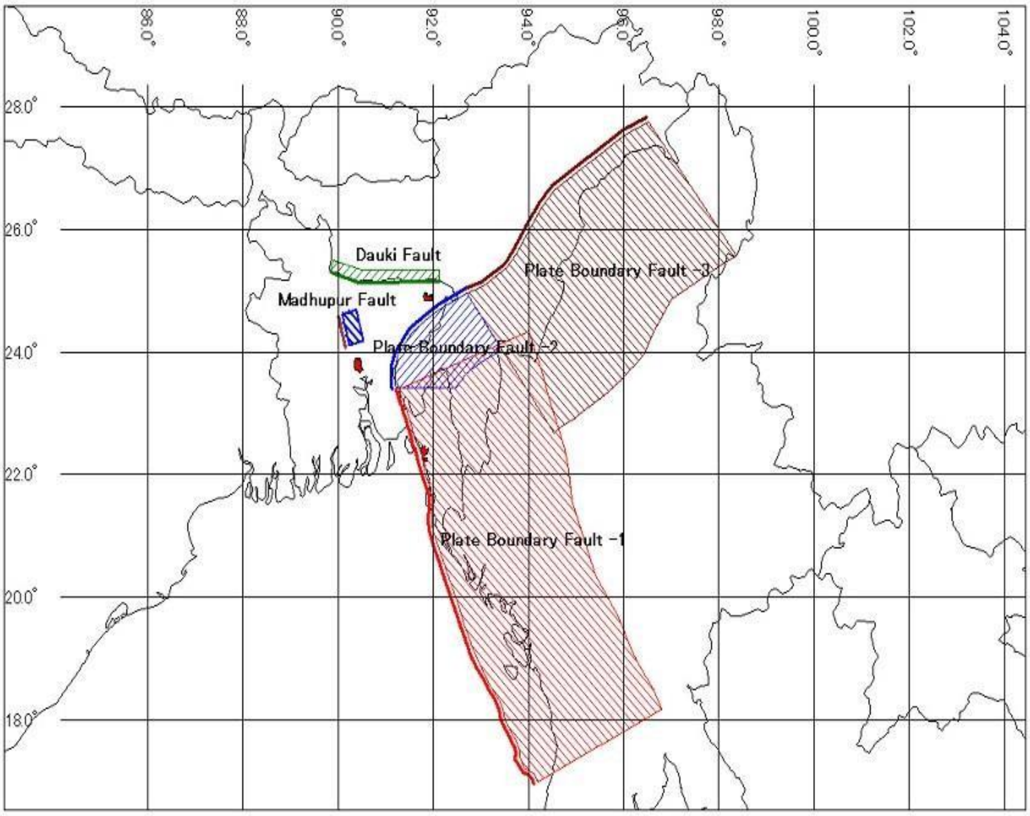


Fig. 2.7: Proposed Earthquake Fault Zones by CDMP in 2009 (CDMP, 2009)

An extensive list of historical earthquakes that have occurred in Bangladesh and its environs between 1858 and the present was compiled using a variety of sources, including catalogs and internet sites. The list of recorded earthquakes in and around Bangladesh since 1858 is displayed in Table 2.4. The largest recorded event in the vicinity of this area was the Great Indian Earthquake of 1897, which had an estimated magnitude of Ms 8.7 (Sabri, 2002). The capital city of Dhaka was fewer than 250 kilometres from the earthquake's epicentre. There was substantial damage, and 545 fatalities reported in the neighbouring city of Sylhet, which is in the northeastern part of Bangladesh. The Dauki Fault is assumed to be the source based on the trench excavation conducted at the Gabrakhari site across the Dauki Fault. The Srimangal Earthquake, which happened in 1918 close to Sylhet had a magnitude of 7.6 (Sabri, 2002), was another significant earthquake. The epicentre of the earthquake was located about 130 kilometres away from Dhaka. A few past earthquakes that have occurred in and near Bangladesh are shown in Table 2.4. Most of these occurrences are powerful earthquakes of large magnitude.

Table 2.4: Listing of Major Earthquakes influencing Bangladesh (Al-Hussaini et al., 2012)

Date	Name	Magnitude (Richter)	Epicentral Distance from Dhaka (km)	Epicentral Distance from Sylhet City (km)	Epicentral Distance from Chittagong (km)
10 January, 1869	Cachar Earthquake	7.5	250	70	280
14 July, 1885	Bengal Earthquake	7.0	170	220	350
12 June, 1897	Great Indian Earthquake	8.7	230	80	340
2 July, 1930	Srimongal Earthquake	7.6	150	60	200
2 July, 1930	Dhubri Earthquake	7.1	250	275	415
15 January, 1934	Bihar- Nepal Earthquake	8.3	510	530	580

15 August, 1950	Assam Earthquake	8.5	780	580	540

The earthquakes that occurred in and around Bangladesh between 1865 and 1995 are shown in Fig. 2.8. The seismic map from the BNBC upgrade project is shown in Fig. 2.9. The chart displays PGA values according to MCE. Local soil impacts are included in the Design Basis Earthquake (DBE) with a return period of 475 years, which corresponds to a PGA value of $\frac{2}{3}$ Zg or 0.19g. In contrast, the (BNBC, 2020) map (see Fig. 2.9) shows a coefficient of 0.28 g (MCE).

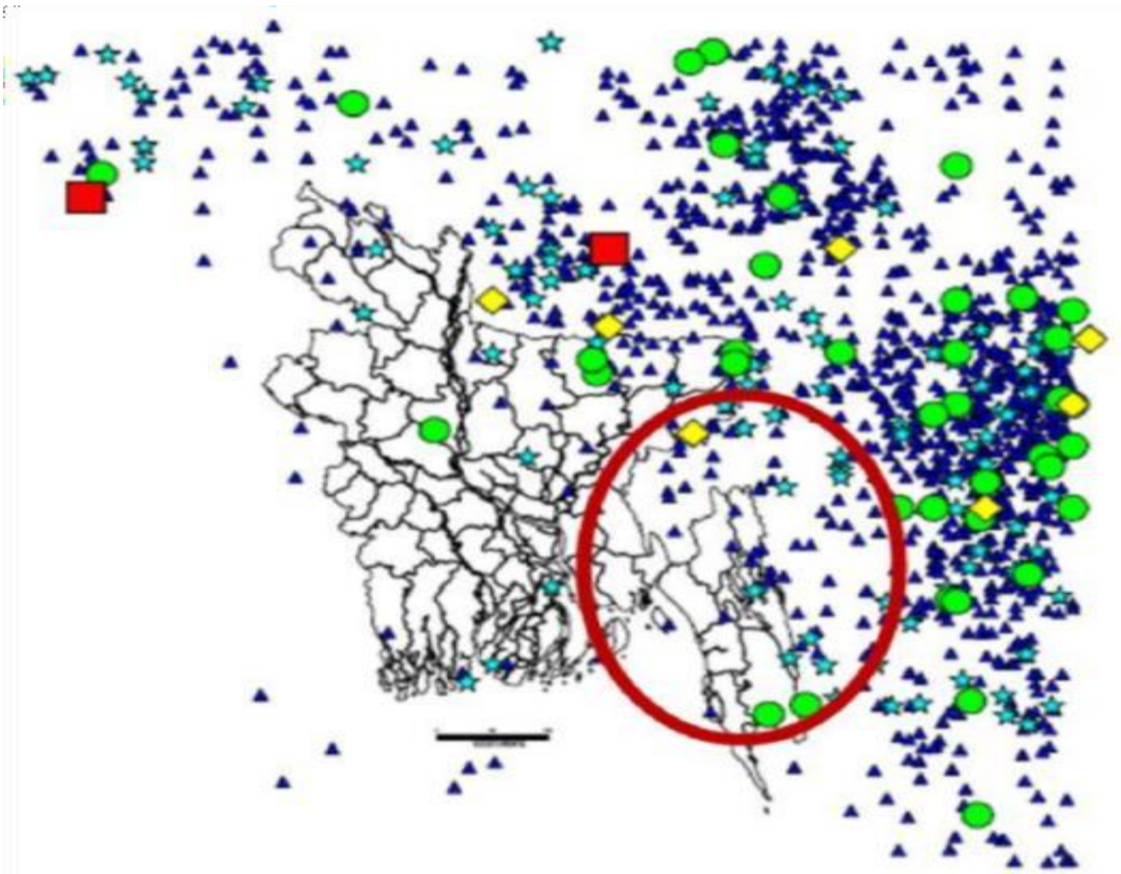


Fig. 2.8: Seismic zoning map for Bangladesh based on a return period of 2475years

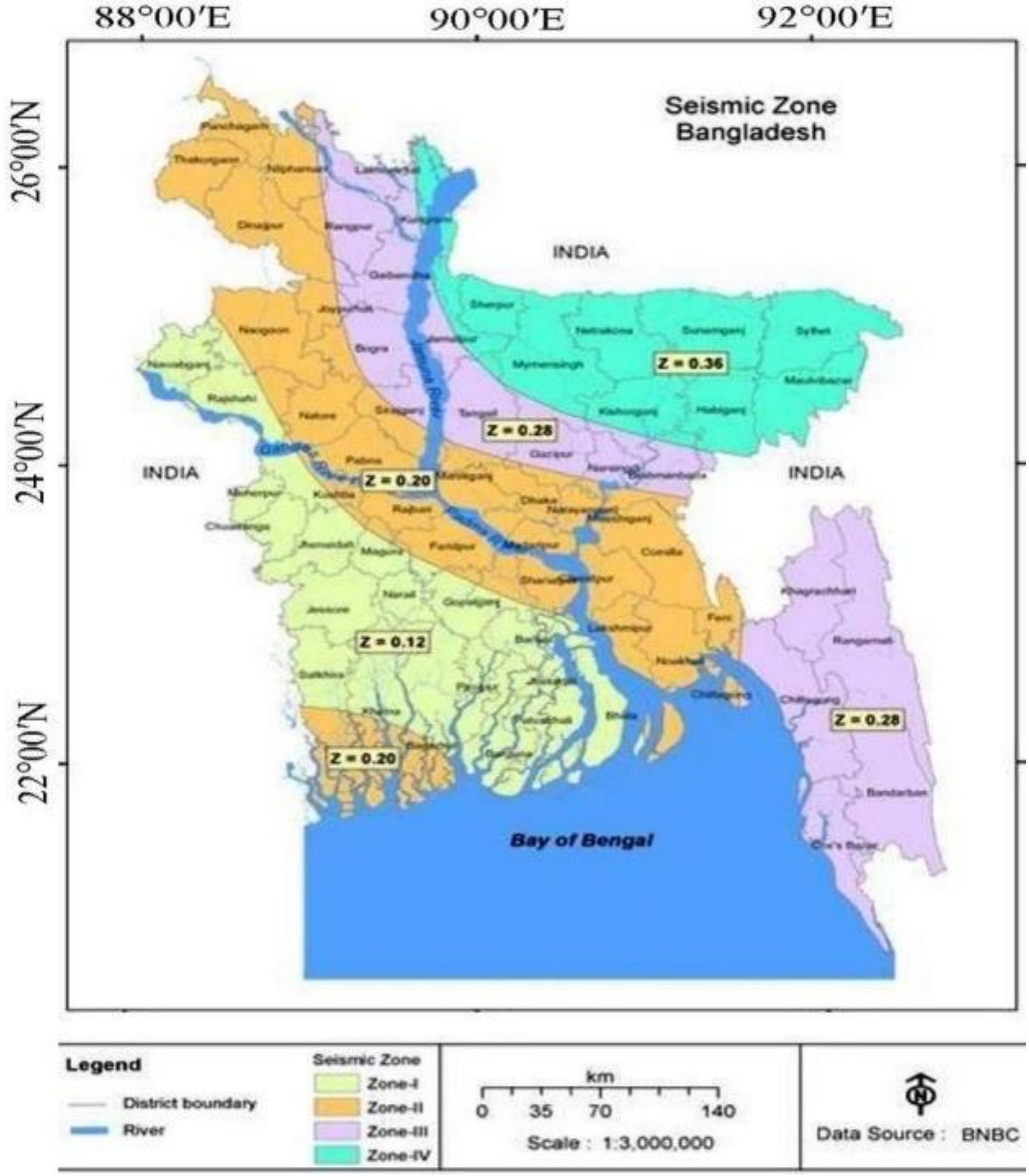


Fig. 2. 9: Earthquake Zoning Map of Bangladesh, (BNBC, 2020)

2.4.2 Seismicity in Chattogram Region

There is a lengthy history of earthquakes in Chattogram. Numerous pieces of evidence are connected to the earthquakes that rocked Chattogram and its surrounding areas in their hundreds. In 1762, one of the biggest earthquakes ever recorded struck Arakan, in the southern part of the Chattogram division. Significant damage was caused, even if the magnitude was not recorded at the time. In 1950, an earthquake of a magnitude of 8.6 struck Assam, generating significant shaking in the same region. Looking at the current state of affairs, we can see that since 1996, this region has seen about 200 light to moderate earthquakes (Karmakar, 2003). Near Myanmar's border, many of the earthquake origins were located. On the border between India and Bangladesh, the 1997 Jaintapur earthquake had a magnitude of 5.6. On November 21, it was eventually felt primarily in Chattogram, as well as in Rangpur, Sylhet, and Meghalaya. These regions were severely shaken by a magnitude 5.7 earthquake that struck Bangladesh's border with India. The entire nation was affected. However, Chattogram caused the most destruction. This time, a five-story RCC building fell, leaving twenty-three people dead. On July 22, 1999, Moheshkhali Island in the Chittagong division was devastated by another earthquake with a magnitude of 5.2. A few aftershocks of this earthquake caused considerable damage, at least six fatalities, and over 500 injuries. Cyclone shelters' concrete constructions cracked, and mud homes sustained serious damage.

On July 27, 2003, the most notable recent earthquake that rocked Chattogram City and the surrounding hill areas happened. The surface-wave magnitude of this earthquake was 5.6. According to (Ansary & Sadek, 2006; Karim, 2003; Khan, 2003) Barkal Upazila in Rangamati district, Kalabunia village was its epicentre. During the earthquake, almost three hundred people were hurt and two individuals died. Throughout the region, some 150 buildings including a school were destroyed; among them were the Union Parishad building and a health centre whose roof fell. The Rangamati district and Chattogram city are quite close. Numerous buildings, including the Polytechnic building, the Public Library, and the Chattogram Jail, acquired numerous minors to significant fissures. Additionally, there were cracks in the buildings of Sonadia Island, Kutubdia, Moheshkhali, and Cox's Bazar. Barkal and Rangamati experienced numerous minor aftershocks of varying intensities. Within a 100-kilometer radius of Chattogram, there have been about seven light-sized earthquakes in the last three years, which has made us aware of potential future safety concerns in this area. Deterministic ground-shaking scenario that was selected for the HAZUS hazard analysis.

2.5 RELATED RESEARCH

Azam & Hosur (2013) evaluated of seismic performance of multistoried RC framed buildings with shear walls, performed elastic response spectrum analysis and in-elastic non-linear static pushover analysis for the X & Y direction of buildings. Models of 6, 12, 24 & 36 storied with used various shear wall locations. Comparison of seismic performance in terms of strength, stiffness, damping, displacement & Natural period for moment resisting frame & shear wall system.

Vyas (2016) studied the behavior of moment resisting frames and shear wall-frame structures. Regarding period, top deflection, and maximum story drift, a comparison between moment resisting frames and wall-frame structures is conducted. Results of the study indicate that compared to frame structures, wall frame structures have a lower maximum drift and top story displacement.

Astriana et al. (2017) investigated the seismic performance of moment resisting frame as compared to frame shear wall system analysed by nonlinear pushover analysis yielding capacity spectrum. Same plan area & height of building model. Evaluated the damage state based on HAZUS-MH MR5 & ATC-40.

Chotaliya and Shah (2018) conducted a comparative case study of special moment resisting frame (SMRF) and shear wall RC structure under time history and response spectrum analysis. It has been observed that the structure with the R.C. shear wall is more responsive and less expensive than the identical structure with its special moment resisting frames and more concrete is consumed by MRFS than SWF.

Abou Lteaf (2019) studied which is more effective between the moment resisting frame system and the dual shear wall frame system. These two buildings have the same area and height with response spectrum analysis using ETABS-2016 software. Comparing the results of base shear force, displacements, and vibration modes, to form a comprehensive understanding of the proper use of shear walls.

Aniket et al. (2023) conducted a comparative study between SMRF & OMRF structures using ETABS software with nonlinear static analysis. From analysis results base shear and spectral acceleration are reduced, and displacement, time period, and spectral displacement are increased as the number of storeys increases. Linear static analysis showed that base shear increases as the number of stories increases. It also showed the distribution of lateral forces along the building height.

In the above-mentioned researches, it is seen that time history analysis has been done using response spectrum analysis, non-linear analysis for moment registering frame, and shear wall frame system building of different heights within 20 stories. However, the analysis of 30-storey building with the moment registering frame and shear wall frame system has not been done using the time history linear direct integration method. So, I have worked with the time history linear direct integration method to determine which of the two frame systems is better seismically and economically for 30-storey building.

2.6 SYNOPSIS

This chapter discussed the RC building framing system, i.e. the moment resisting frame and frame shear wall system. The building framing system is the most important thing in the earthquake-resistant building analysis. Then this chapter discussed the building analysis procedure. This depends on the building's importance and height of the building. Seismicity in the Bangladesh region and seismicity in the Chattogram region are discussed. Building earthquake response is influenced by ground-shaking characteristics as well as building attributes. The acceleration and displacement of the ground motion can be measured. Building a framing system is critical to the excellent seismic performance of structures. The methodologies for structural analysis utilized in earthquake-resistant design are discussed, as well as linear time history analysis.

Chapter 3: METHODOLOGY

3.1 GENERAL

In this study, a comparison of seismic responses of moment resisting frame and frame shear wall system has been evaluated using linear time history analysis as per BNBC guidelines. The methodology has been described in the following section.

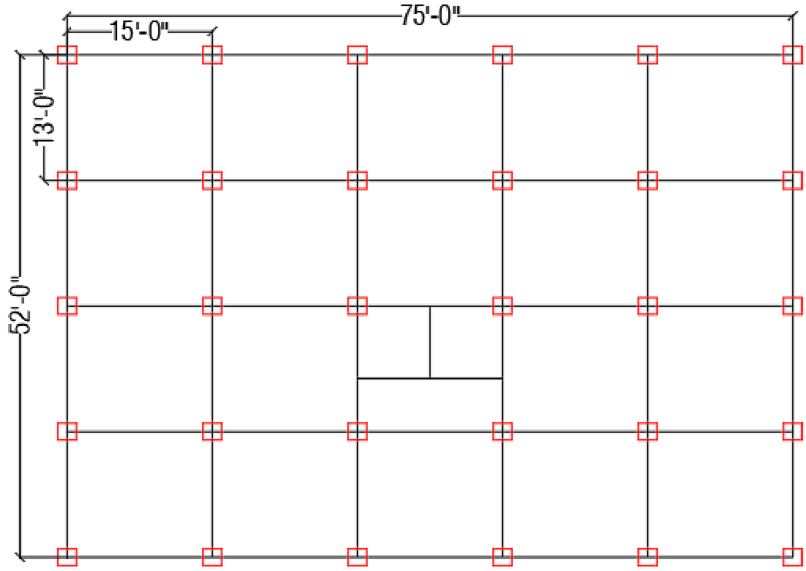
3.2 GEOMETRIC DETAILS OF BUILDING MODELS

Based on these two framing systems, a 30-storied building is modeled as shown in Fig. 3.1. The building plans in Figs. 1(a) and 1(b) represent building models with different framing systems. The first one is the moment resisting frame system (MRFS) Model 1 and the second one is the frame shear wall system (FSWS) Model 2. All buildings are modeled using ETABS. The buildings consist of an RC moment resisting frame and frame shear wall system with a 6-inch-thick solid slab. The plan dimensions for two building frame models are shown in Table 1 having the same area of 3900 ft^2. The two buildings are 30 stories with a floor height of 10 ft and a total height of 300 ft. Two framing system grids consist of 15 ft in X and 13 ft in Y directions, and the total plan area is 75 ft x 52 ft. For the moment resisting frame and wall frame system members use various sizes of columns, beams, and shear walls [Fig. 3.1]. Material properties considered for models are shown in Table 3.1.

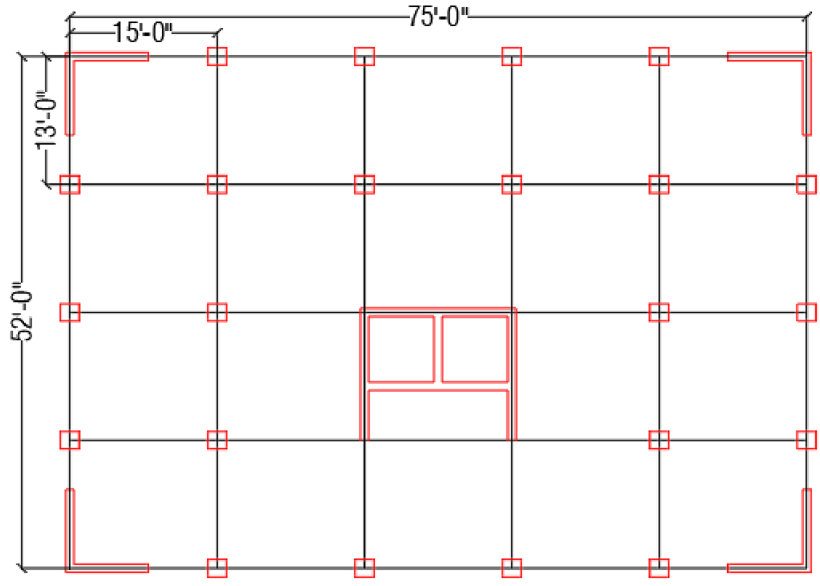
Table 3.1: Material properties

Materials	Strength (MPa)
Compressive Strength of Concrete (For Column)	48 MPa

Compressive Strength of Concrete (For Beam and Slab)	35 MPa
Steel Grade (Yield Strength)	420 MPa



(a)



(b)

Fig. 3.1: Plan of building models: (a) Model 1: MRFS (b) Model 2: FSWS

3.3 LINEAR EQUIVALENT STATIC ANALYSIS (FOR PRELIMINARY SIZE DETERMINATION)

In this study, two 30-storied buildings of the same plan area are carried out by Linear equivalent static method to estimate the size of structural components. The analysis of residential buildings is carried out through ETABS software as it is a more user-friendly and versatile program. So, ETABS software has been used to check the size of beams and columns. The details of the seismic and other various parameters are mentioned in the Tables below.

3.3.1 Details of Loading Conditions

Details of loading conditions have been determined by BNBC (2020). The loading conditions considered in the study are listed in Table 3.2.

Table 3.2: Details of loading conditions

Load type	Intensity of load
Live load: Ordinary roof	21 lb/ft^2
Live load: Floors	42 lb/ft^2
Floor finish	25 lb/ft^2
Beam wall load	500 lb/ft
Lift Load/lift	4784 lb
Stair Live Load	100 lb/ft^2

3.3.2 Seismic Parameters

The different seismic parameters are taken following the BNBC (2020) guidelines. Detailed descriptions of the seismic parameters are given in Table 3.3.

Table 3.3: Seismic parameters

Seismic Parameter	Model 1 (MRFS)	Model 2 (FSWS)
Seismic zone	III	III

Zone factor	0.28	0.28
Importance factor	1	1
Occupancy category (For Residential)	II	II
Site Class	SC, S=1.5	SC, S=1.5
Seismic Design Category	D	D
Response Reduction factor (*R*)	8	7
System Over Strength Factor (Ω_0)	3	2.5
Deflection Amplification Factor (C_d)	5.5	5.5

3.3.4 Preliminary Size Determination of Structural Components (by Equivalent Static Analysis)

Equivalent static analysis is required to determine the initial size of a building member. Seismic parameters used are from Table 3.3 for MRFS (Model 1) and (FSWS) Model 2. Equivalent static analysis was checked with story displacement and story drift ratio. The sizes of beams and columns are preliminarily checked shown in Table 3.4 for the considered loading conditions using linear equivalent static analysis. Selected dimensions of structural components are shown in Table 3.5.

Table 3.4: Preliminary Checked (by maximum story drift ratio)

Check Item	Model 1 (MRFS)		Model 2 (FSWS)		Limit (According to BNBC 2020)	Remarks
	EQ-X	EQ-Y	EQ-X	EQ-Y		
Maximum Story Drift Ratio	0.005	0.006	0.004	0.006	0.02	Safe

Table 3. 5: Preliminary dimensions of structural components (by Equivalent Static Analysis)

Model	Model 1 (MRFS)	Model 2 (FSWS)
Story height	10 ft	10 ft
Size of columns	35 in × 35 in	20 in × 25 in
Size of beams	20 in × 30 in	20 in × 30 in
Slab thickness	6 in	6 in
Shear wall thickness	----	15 in
Design code	ACI 318-14	ACI 318-14

3.4 TIME HISTORY ANALYSIS (THA) OF THE BUILDINGS

According to BNBC,2020 for the following buildings, dynamic analysis should be carried out to determine the design seismic force, as well as how it is distributed among the various lateral load-resisting parts and at different levels along the building's height:

(a) Regular structures are taller than 40 meters in Zones 2, 3, and 4, and more than 90 meters in Zone 1.

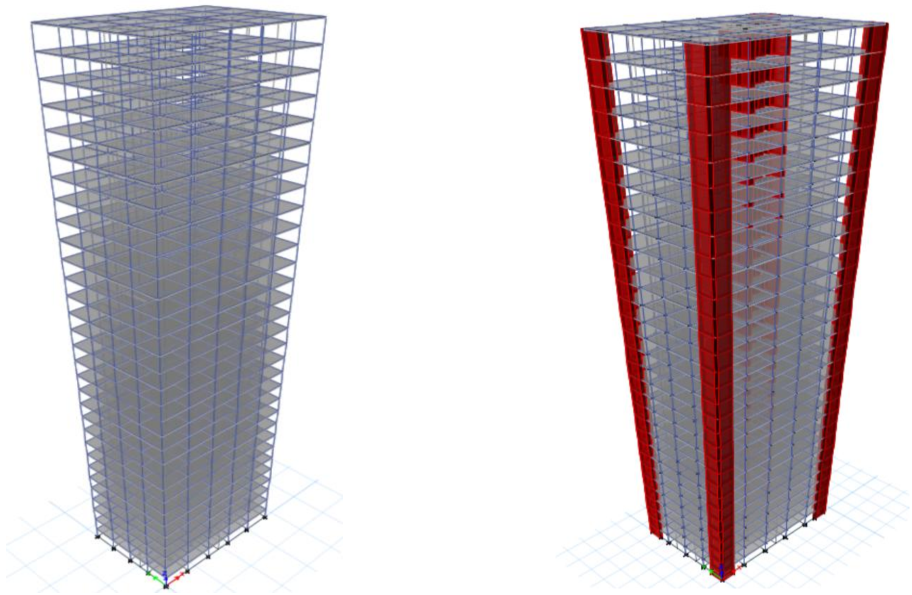
(b) Irregular structures taller than 12 meters in Zones 2, 3, and 4, and taller than 40 meters in Zone 1.

While not required, dynamic analysis is advised for irregular buildings in Zone 1 that are less than 40 meters in height.

So, from the above criteria in this study dynamic analysis is required. Time history analysis is a dynamic evaluation of the structural response under dynamic loading that may fluctuate as indicated by the specified time function. Linear time history analysis is one of the methods used to evaluate seismic performance. However, the accuracy of the analysis largely depends on the selection of ground motion accelerations that may affect the building during its service life.

3.4.1 Analytical Model

The buildings are analytically modeled as a 3-dimensional beam, column, and shear wall rigid frame system as shown in Fig. 3.2. Complete modeling is performed using the structural analysis and design software ETABS (ETABS, 2017). Various material properties of concrete and steel and member section properties are defined. Then the load pattern, load combination, mass source, load case, and model case are defined, and the corresponding ground motion function is defined. The beams and columns are modeled as elastic force-based frame elements with original geometric dimensions, while the in-plane stiffness of the slab is simulated using rigid diaphragm action. The tributary loads on the slab are calculated and distributed as uniformly distributed element loads on the adjacent beams. Ground motion-coupled acceleration is applied to the base of all columns on both sides of a model. The selection of acceleration coupled to ground motion is discussed in the next section. Column and shear wall foundations are assumed to be fixed, neglecting the effect of foundation movement.



(a) (b)

Fig. 3.2: Analytical models of building: (a) Model 1 (MRFS) (b) Model 2 (FSWS)

3.4.2 Design Response Spectrum

The study buildings are assumed to be constructed in a moderate seismic zone with a zone coefficient of Z = 0.28, representing a probable PGA of 0.28 g for a seismic event with a return period of 2475 years, representing the maximum considered earthquake (MCE) (BNBC, 2020). It is also assumed that the shear wave velocity of soils beneath the building site will be in the range of 180-360 m/s, representing deep deposits of dense or medium dense sand, gravel, or stiff clay classified as soil type SC with soil factor S = 1.15 according to BNBC (BNBC, 2020). For inelastic analysis, a real design acceleration spectrum is used, where the response modification factor, R=1, and structural importance factor, I=1. The real design acceleration response spectrum is the true representation of the expected ground motion, i.e., the design basis earthquake (DBE), with a return period of 475 years, including local soil effects, and corresponding to the PGA value of 0.19 g for this case (BNBC, 2020). The design acceleration response spectrum for PGA of 0.19 g (DBE) for site class SC is shown in Fig. 3.3. Maximum spectral acceleration of the design response spectrum is 0.55 g within 0.2 to 0.6 sec.

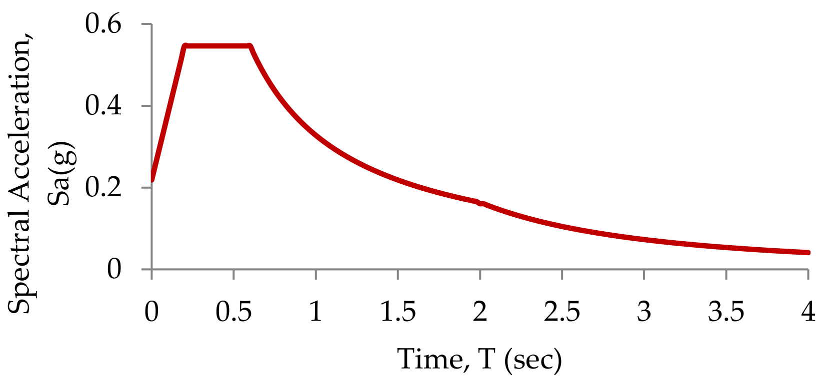


Fig. 3.3: Design acceleration response spectrum for PGA of 0.19g for site class SC

3.4.3 Ground Motions Selection for THA

The seismic resistance design guidelines for time history analysis suggest choosing a minimum of three or seven ground motion records. Not less than three ground motion sets consisting of two horizontal elements and one vertical element, if required, need to be considered (BNBC, 2020). These ground motions are selected fulfilling the criteria mentioned in ATC 40 guidelines. According to ATC 40, ground motion for THA should be (1) Free-filed station > 10 km from the source (or the ground floor of a small building). (2) Stiff or medium soil site conditions. (3) Large-magnitude earthquake ($M \geq 6.5$). (4) Peak ground acceleration of at least 0.2g (before scaling). Ground motion accelerations of the El Centro 1940 earthquake component of 180^0 and 270^0 with peak ground accelerations (PGA) of 0.35 g and 0.21 g ($g = 9.81\ m/s^2$) are recorded at the Imperial Valley site at a distance of 12.2 kilometres from the hypocentre. Kobe 1995 earthquake components of 180^0 & 270^0 with peak ground accelerations (PGA) of -0.51g and -0.50g ($g = 9.81\ m/s^2$), are recorded at the Nishi-Akashi site at a distance of 19.9 kilometres from the hypocentre. Northridge-1994 earthquake components of 180^0 & 270^0 with peak ground accelerations (PGA) of -0.45g and 0.33g ($g = 9.81\ m/s^2$), are recorded at the Northridge site at a distance of 19.1 kilometres from the hypocentre. Maximum spectral acceleration of the original El Centro 1940 (180^0 & 270^0 Component) ground motion is 0.91 g and 0.64 g respectively. Kobe 1995 (180^0 & 270^0 component) ground motion is 2.26 g and 1.5 g respectively. Northridge-1994 (180^0 & 270^0 component) ground motion is 1.72 g and 1.26 g respectively. The above earthquake records are acquired from the COSMOS Virtual Data Centre (VDC) database (COSMOS 2023). The earthquake pairs summary is shown in Table 3.6.

Table 3.6: Earthquake pair records summary

Ground Motion Number	Components	Peak Ground Acceleration (PGA)	Maximum Spectral Accelerations
1.	El-Centro 1940-180^0	0.35g	0.91g
2.	El-Centro 1940-270^0	0.22g	0.64g
3.	Kobe 1995-180^0	0.51g	2.26g
4.	Kobe 1995-270^0	0.33g	1.5g
5.	Northridge 1994-180^0	0.45g	1.72g
6.	Northridge 1994-270^0	0.33g	1.26g

If there are insufficient recorded ground motion pairs, suitable simulated ground motion pairs should be generated to reach the total required number. The related design response spectra should be at least 1.3 times greater than the initial ground motion pair average of SRSS spectra from all pairs of horizontal components of the five percent-damped where an identical scale factor (SF) is applied to components of a pair (BNBC, 2020). Using a scale factor (SF) of 0.8 on the response spectra of the three ground motion pairs, it is found that the average SRSS of the ground motion pair spectra is higher than the 1.3 times of the design response spectrum for each time period between 0.2T to 1.5T (where T is the natural period of the fundamental mode of the structure) as shown in Figures 3.4 and 3.5. The natural period of the fundamental mode for MRFS is 2.586 sec and FSWS is 2.451 sec. Therefore, for MRFS time period range is 1.29 sec to 3.88 sec. On the other hand, for FSWS time period range is 1.23 sec to 3.68 sec. Which is greater than 1.3 times the design response spectrum as shown in Figure 3.5.

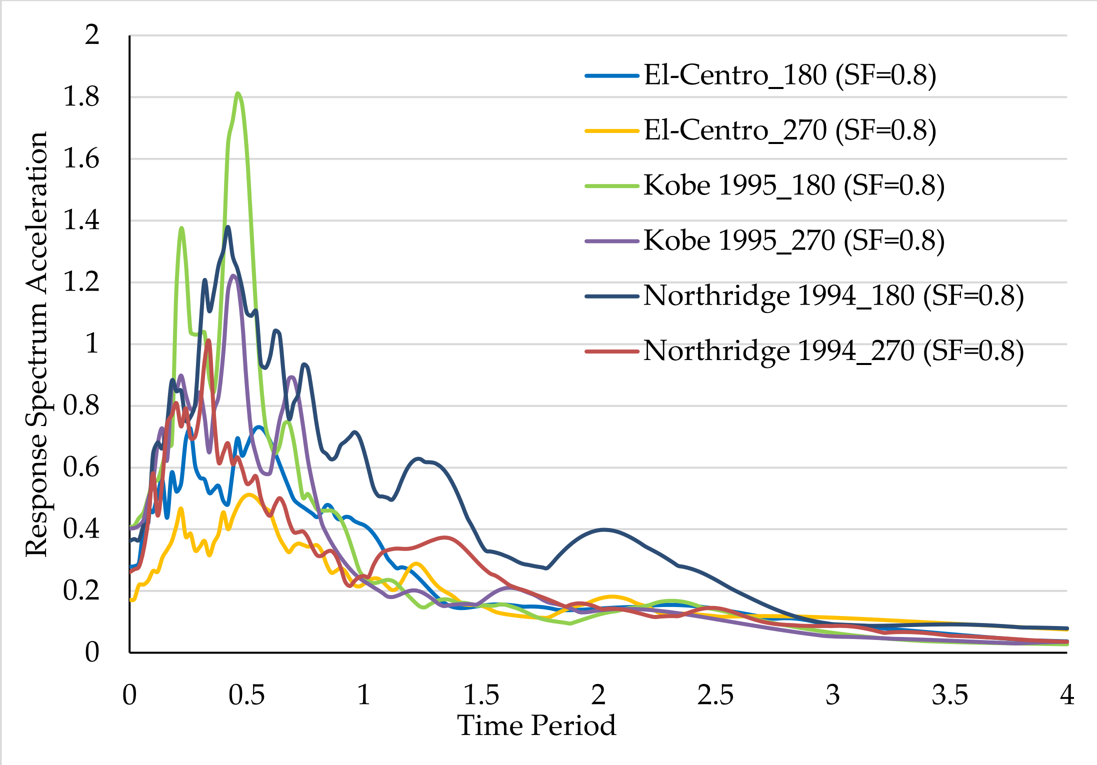


Fig. 3.4: Scaled spectral acceleration of ground motion

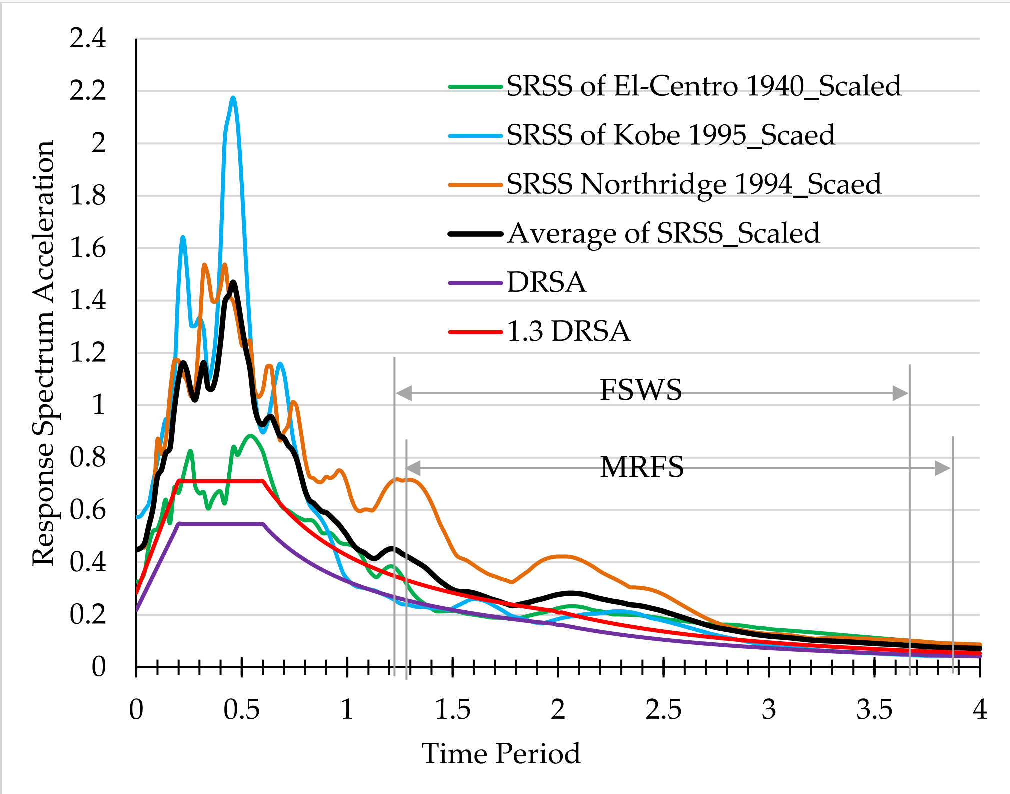


Fig. 3.5: Selected ground Motion by spectral acceleration

Therefore, in this study, the ground motion accelerations of three ground motion pairs (i.e. El-Centro 1940, Koke 1995, Northridge 1994) were scaled using a scale factor (SF) of 0.8 and used as earthquake loads in the building model.

3.4.3.1 Ground Motion Acceleration of El Centro 1940-180^0

Ground motion accelerations of the El Centro 1940 earthquake with peak ground accelerations (PGA) of 0.35g (g = 9.81 m/s^2), recorded at the Imperial Valley site at a distance of 12.2 kilometres from the hypocentre, are selected for the time history analysis. El Centro earthquake records are acquired from the COSMOS Virtual Data Centre (VDC) database Fig. 3.6.

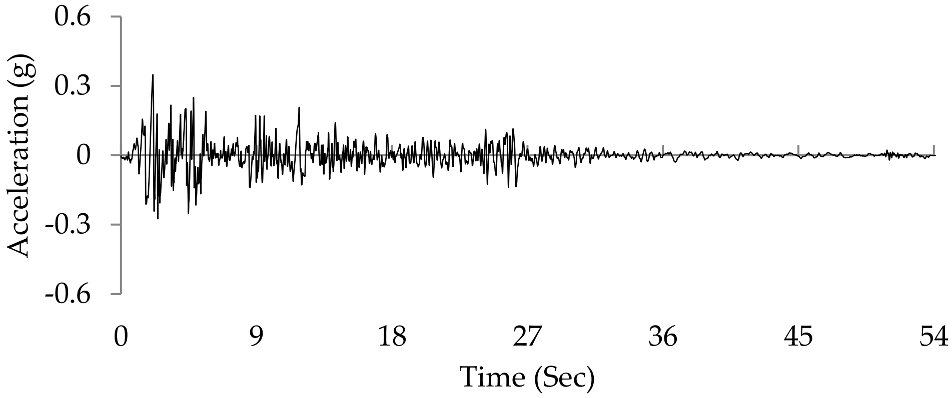


Fig. 3.6: Seismic ground motion accelerations of El Centro 1940-180^0

3.4.3.2 Ground Motion Acceleration of El Centro 1940-270^0

The ground motion accelerations of the El Centro 1940 earthquake, with peak ground accelerations (PGA) of 0.21g (g = 9.81 m/s^2), recorded at the Imperial Valley site at a distance of 12.2 kilometers from the hypocenter, are selected for the time history analysis. El Centro earthquake records are acquired from the COSMOS Virtual Data Center (VDC) database Fig. 3.7.

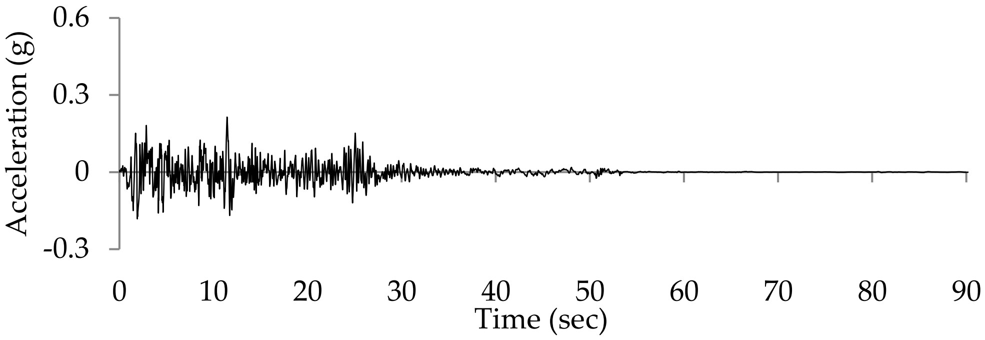


Fig. 3.7: Seismic ground motion accelerations of El Centro 1940-270^0

3.4.3.3 Ground Motion Acceleration of Kobe 1995-180^0

Ground motion accelerations of the Kobe 1995 earthquake with peak ground accelerations (PGA) of -0.51g (g = 9.81 m/s^2), recorded at the Nishi-Akashi site at a distance of 19.9 kilometers from the hypocenter, are selected for the time history analysis. Kobe earthquake records are acquired from the COSMOS Virtual Data Center (VDC) database Fig. 3.8.

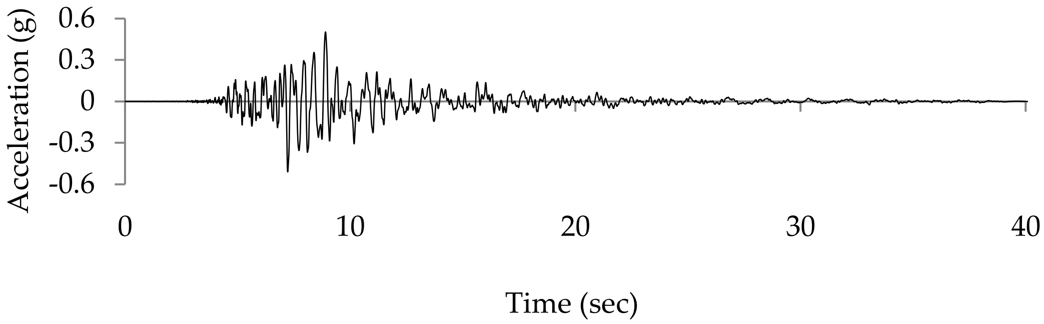


Fig. 3.8: Seismic ground motion accelerations of Kobe 1995-180^0

3.4.3.4 Ground Motion Acceleration of Kobe 1995-270^0

Ground motion accelerations of the Kobe 1995 earthquake with peak ground accelerations (PGA) of -0.50g (g = 9.81 m/s^2), recorded at the Nishi-Akashi site at a distance of 19.9 kilometers from the hypocenter, are selected for the time history analysis. Kobe earthquake records are acquired from the COSMOS Virtual Data Center (VDC) database Fig. 3.9.

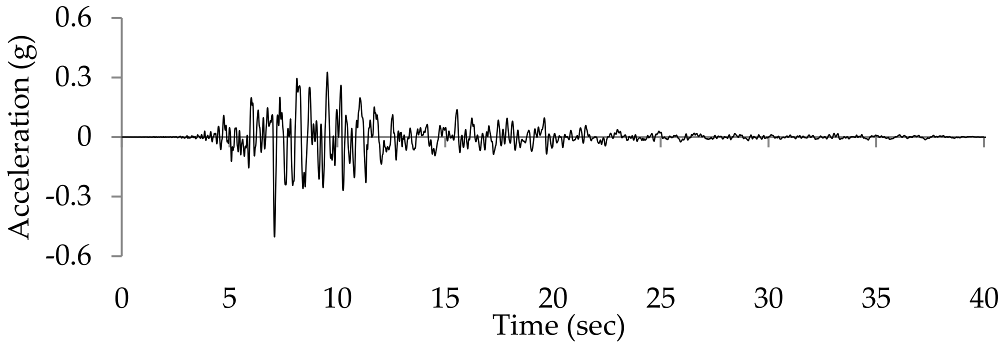


Fig. 3.9: Seismic ground motion accelerations of Kobe 1995-270^0

3.4.3.5 Ground Motion Acceleration of Northridge 1994-180^0

Ground motion accelerations of the Northridge-1994 earthquake with peak ground accelerations (PGA) of -0.45g (g = 9.81 m/s^2), recorded at the Northridge site at a distance of 19.1 kilometers from the hypocenter, are selected for the time history analysis. Kobe earthquake records are acquired from the COSMOS Virtual Data Center (VDC) database Fig. 3.10.

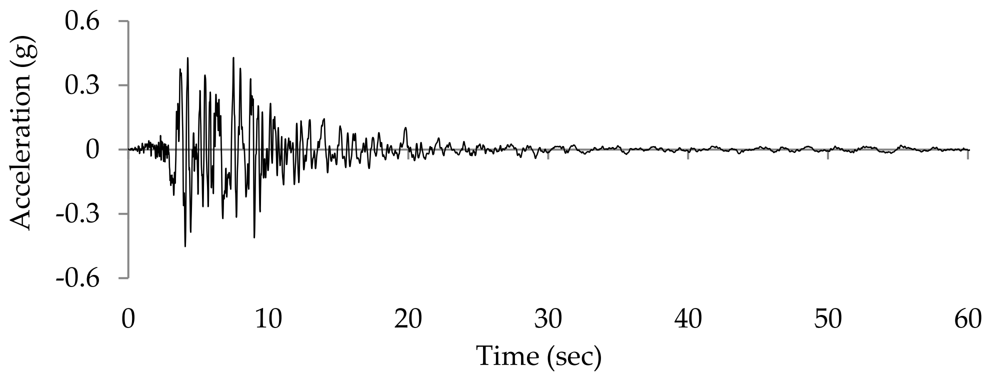


Fig. 3.10: Seismic ground motion accelerations of Northridge 1994-180^0

3.4.3.6 Ground Motion Acceleration of Northridge 1994-270^0

Ground motion accelerations of the Northridge-1994 earthquake with peak ground accelerations (PGA) of -0.33g (g = 9.81 m/s^2), recorded at the Northridge site at a distance of 19.1 kilometers from the hypocenter, are selected for the time history analysis. Kobe earthquake records are acquired from the COSMOS Virtual Data Center (VDC) database Fig. 3.11.

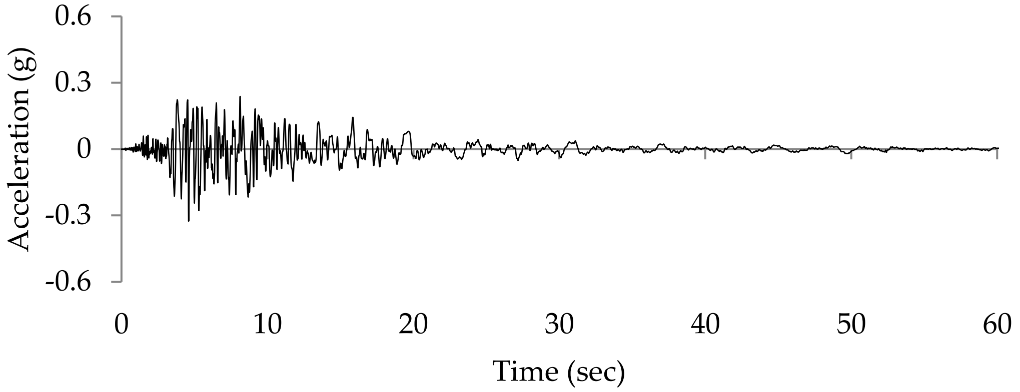


Fig. 3.11: Seismic ground motion accelerations of Northridge1994-270^0

3.4.4 Ground Motion Scaling

The magnitude, fault distance, and source mechanisms of the chosen time history should be similar to the design ground motion at the site. Selected time histories are scaled to 0.8 for each ground motion pair.

3.4.4.1 Ground Motion Acceleration Scaling of El Centro 1940-180^0

Selected ground motion El Centro 1940-180^0 acceleration time histories are scaled by 0.80 factors shown in Fig. 3.12.

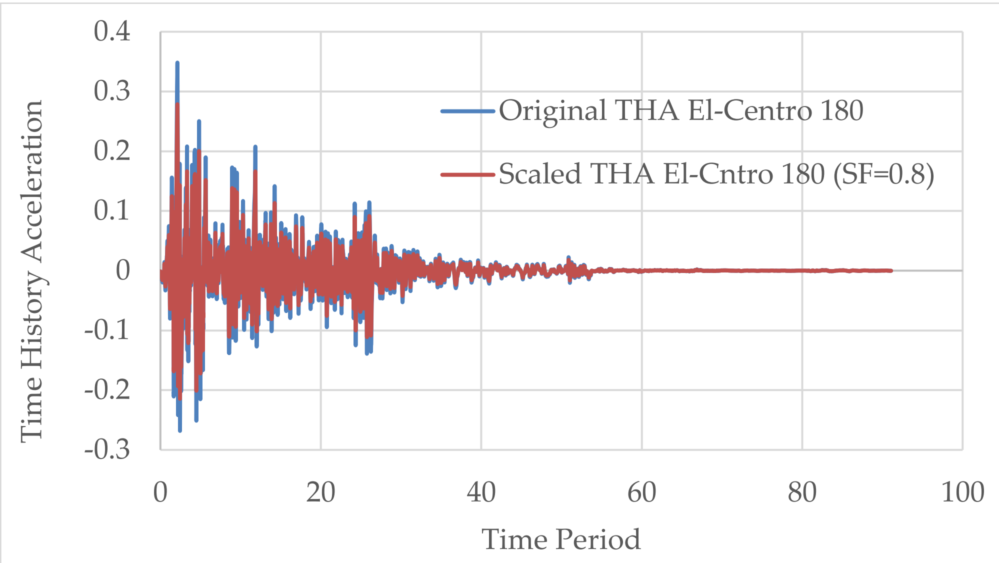


Fig. 3.12: Comparison of original acceleration and scaled acceleration time histories of El Centro 1940-180^0

3.4.4.2 Ground Motion Acceleration Scaling of El Centro 1940-270^0

Selected ground motion El Centro 1940-270^0 acceleration time histories are scaled by 0.80 factors shown in Fig. 3.13.

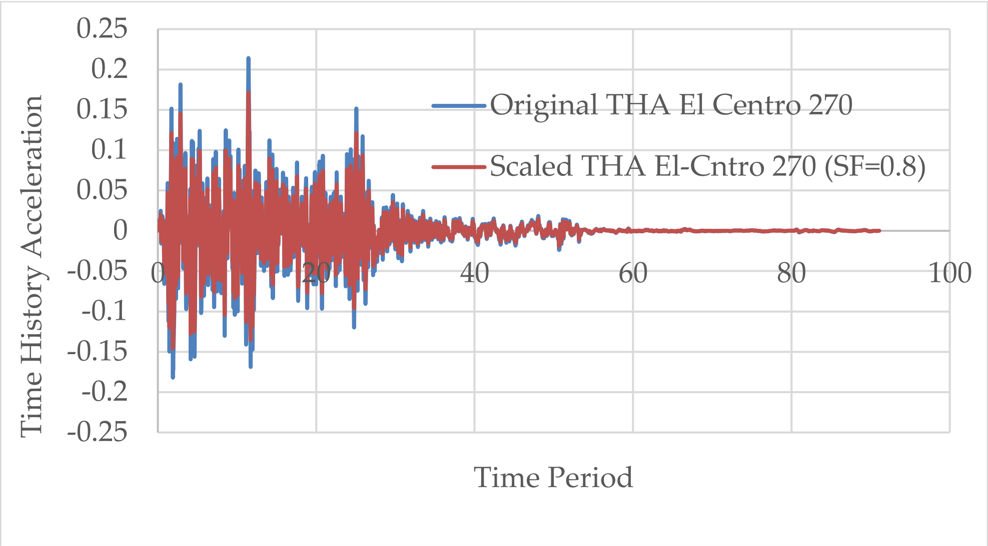


Fig. 3.13: Comparison of original acceleration and scaled acceleration time histories of El Centro 1940-270^0

3.4.4.3 Ground Motion Acceleration Scaling of Kobe 1995-180^0

Selected ground motion Kobe 1995-180^0 acceleration time histories are scaled by 0.80 factors shown in Fig. 3.14.

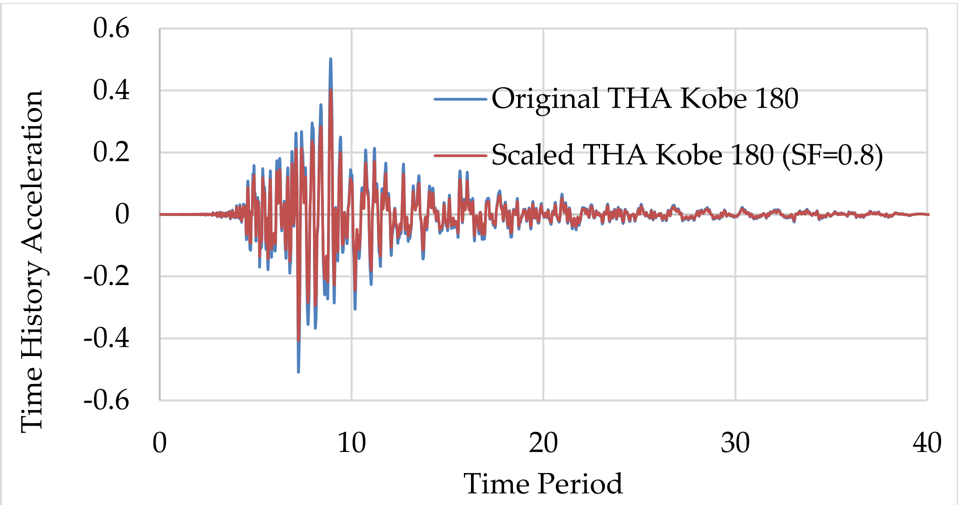


Fig. 3.14: Comparison of original acceleration and scaled acceleration time histories of Kobe 1995-180^0

3.4.4.4 Ground Motion Acceleration Scaling of Kobe 1995-270⁰

Selected ground motion Kobe 1995-270^0 acceleration time histories are scaled by 0.80 factors shown in Fig. 3.15.

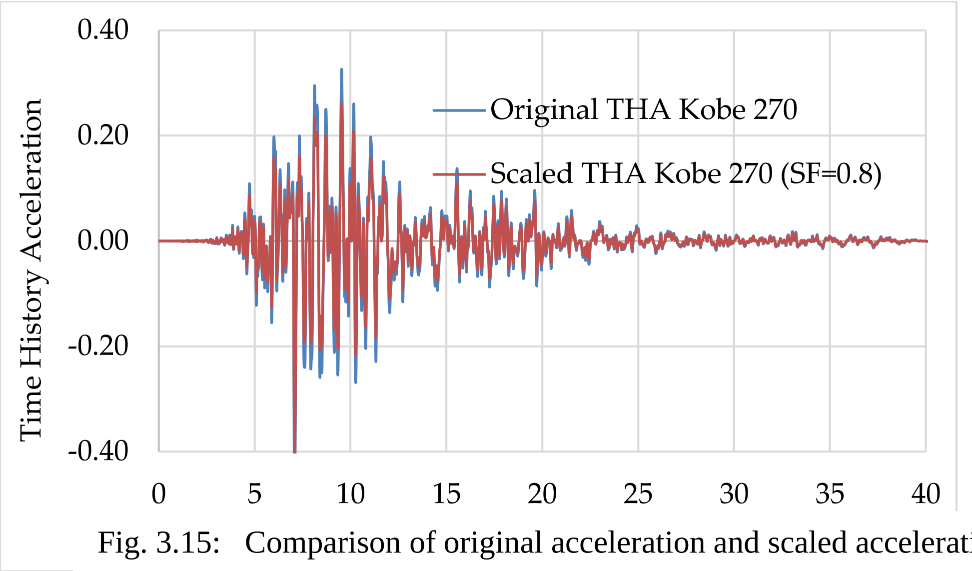


Fig. 3.15: Comparison of original acceleration and scaled acceleration time histories of Kobe 1995-270^0

3.4.4.5 Ground Motion Acceleration Scaling of Northridge-1994-180⁰

Selected ground motion Northridge-1994-180^0 acceleration time histories are scaled by 0.80 factors shown in Fig. 3.16.

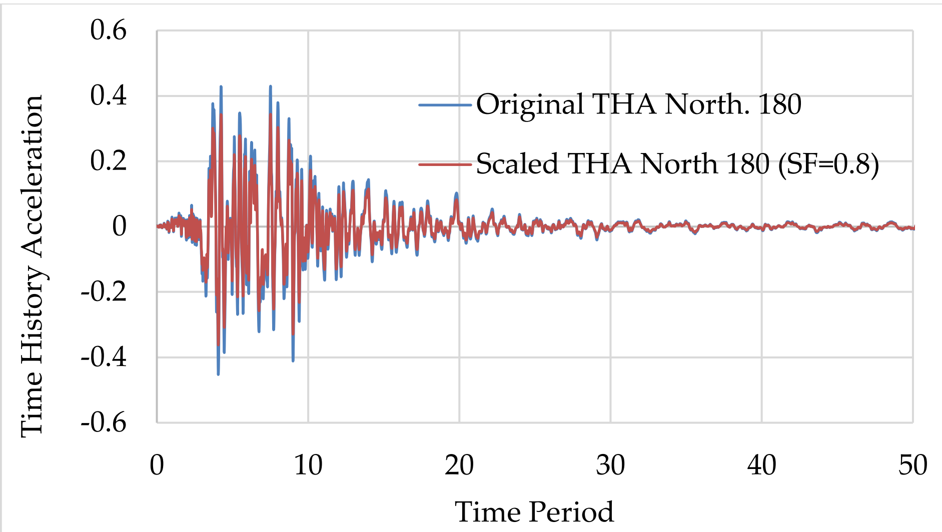


Fig. 3.16: Comparison of original acceleration and scaled acceleration time histories of Northridge-1994-180^0

3.4.4.6 Ground Motion Acceleration Scaling of Northridge-1994-270^0

Selected ground motion Northridge-1994-270^0 acceleration time histories are scaled by 0.80 factors shown in Fig. 3.17.

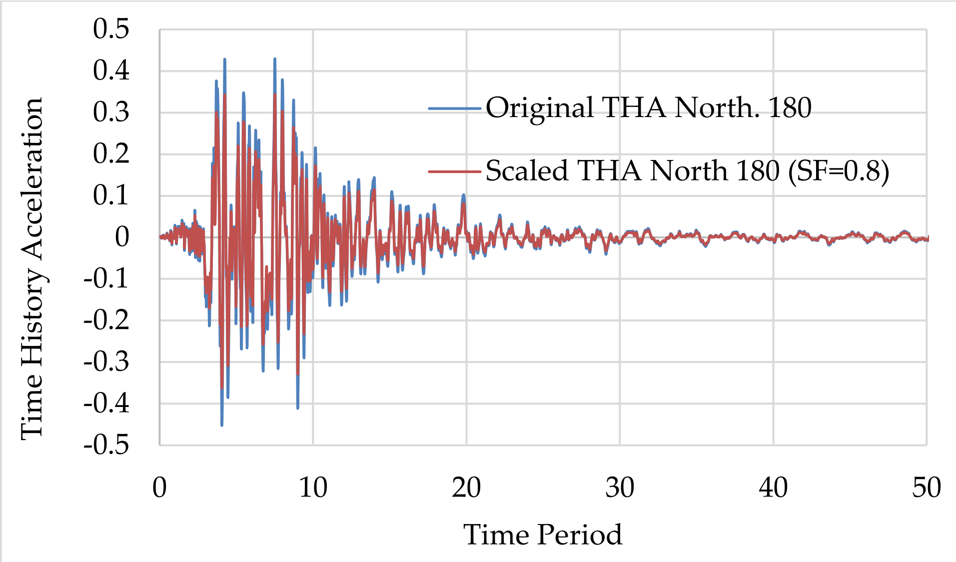


Fig. 3.17: Comparison of original acceleration and scaled acceleration time histories of Northridge-1994-270^0

3.4.5 Ground Motion Acceleration Scaling Summary

Selected ground motion acceleration time histories are scaled with 80% of the original acceleration time histories. After scaling response spectrum acceleration and time history acceleration of El Centro 1940, Kobe 1995 & Northridge 1994 ground motion pairs components of 180^0 and 270^0 respectively are shown in Table 3.7.

Table 3.7: Ground motion scaling with identical scale factor

Ground Motion Pairs Component	Original spectral acceleration	Scaled spectral acceleration	Original time history acceleration	Scaled time history acceleration
1. El Centro 1940-180^0	0.91g	0.73g	0.35g	0.28g
2. El Centro 1940-270^0	0.64g	0.51g	0.22g	0.18g
3. Kobe 1995-180^0	2.26g	1.81g	0.51g	0.41g

4. Kobe 1995-270^0	1.5g	1.2g	0.33g	0.26g
5. Northridge 1994-180^0	1.72g	1.38g	0.45g	0.36g
6. Northridge 1994-270^0	1.26g	1.00g	0.33g	0.26g

3.5 LINEAR TIME HISTORY ANALYSIS

The scaled acceleration time histories pair is applied simultaneously to two building models of ETABS in both directions of X and Y according to Table 3.8. Dynamic time-history loads (accelerations or forces) fluctuate per different load diagrams in the existing time domain. The magnitude of the load applied to the structure is determined by the dynamic time-history load of their constant nominal value and the variable load factor calculated from their load curve (accelerogram) at any given time. The first scaled time history pair function is defined and shown in Fig. 3.18 then the load case pair defined in ETABS software is shown in Table 3.8 and Fig. 3.19 to Fig. 3.22. Then direct integration damping by the natural time period of the building is shown in Fig. 3.23.

Table 3.8: Time history pair load case

Ground Motion	Time history Load Case	U1 (X)	U2 (Y)
El-Centro 1940	THLC-1	Scaled 180^0	30% of Scaled 270^0
	THLC-2	30% of Scaled 270^0	Scaled 180^0
	THLC-3	Scaled 270^0	30% of Scaled 180^0
	THLC-4	30% of Scaled 180^0	Scaled 270^0
Kobe 1995	THLC-1	Scaled 180^0	30% of Scaled 270^0
	THLC-2	30% of Scaled 270^0	Scaled 180^0
	THLC-3	Scaled 270^0	30% of Scaled 180^0
	THLC-4	30% of Scaled 180^0	Scaled 270^0
Northridge 1994	THLC-1	Scaled 180^0	30% of Scaled 270^0
	THLC-2	30% of Scaled 270^0	Scaled 180^0
	THLC-3	Scaled 270^0	30% of Scaled 180^0
	THLC-4	30% of Scaled 180^0	Scaled 270^0

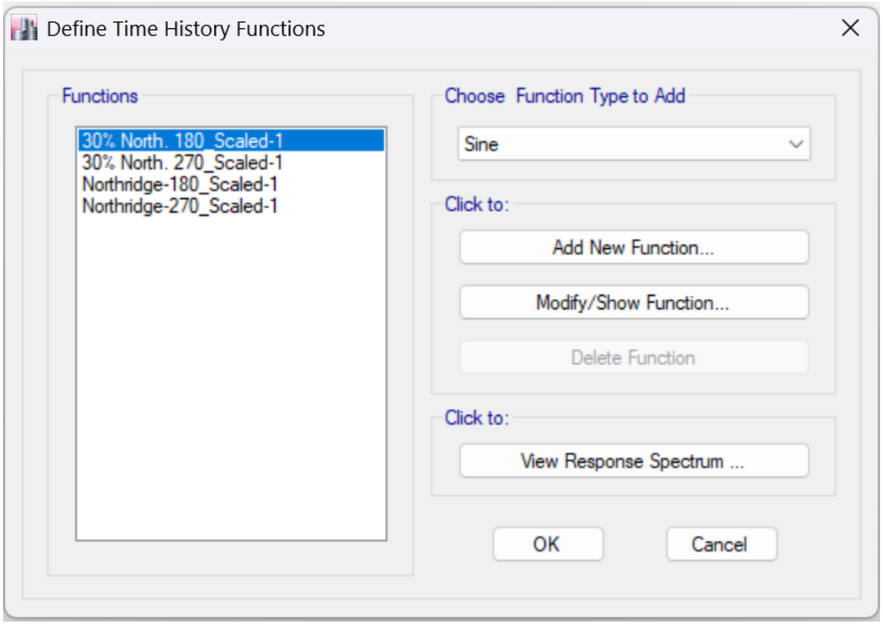


Fig. 3.18: Defined scaled time history pair function

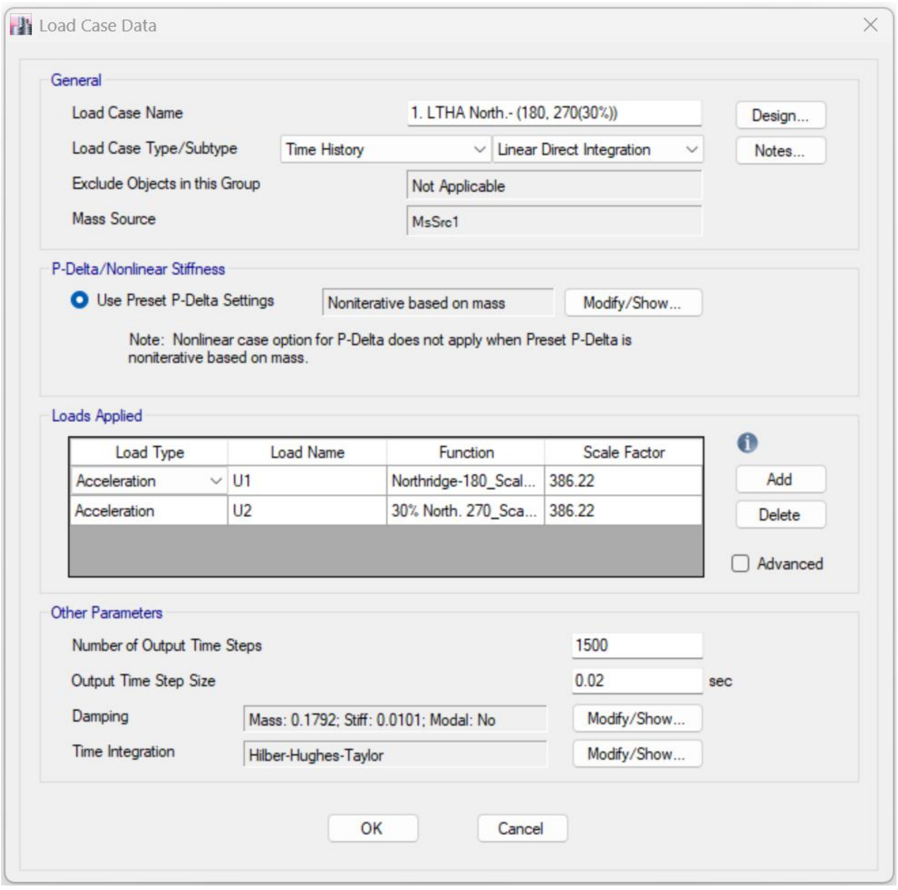


Fig. 3.19: Defined scaled time history pair load case (THLC-1)

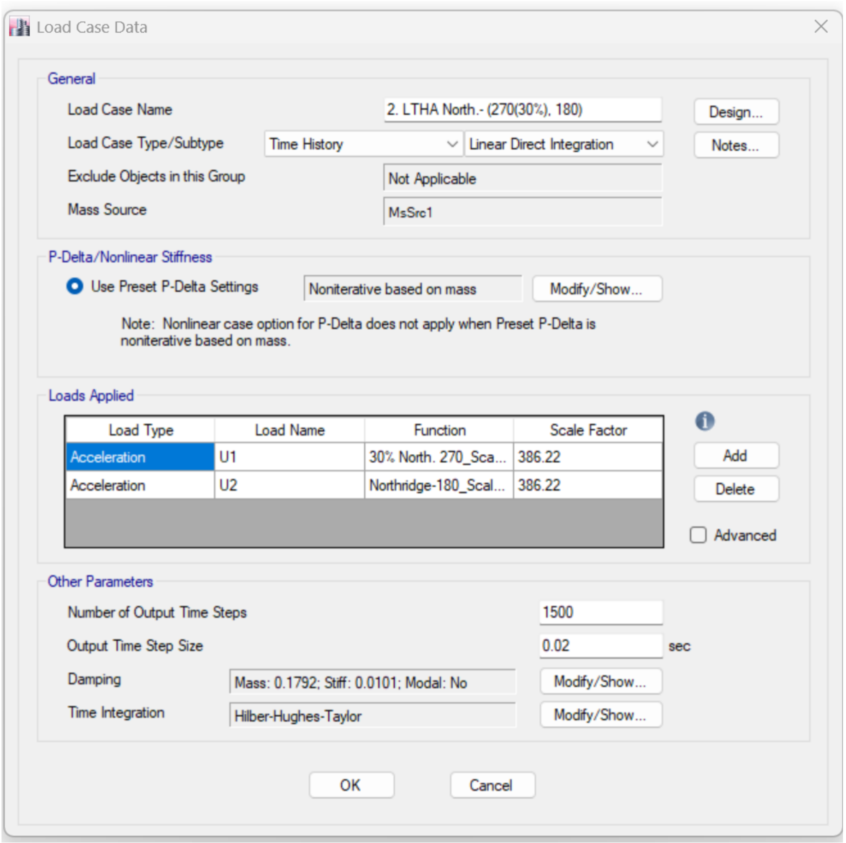


Fig. 3.20: Defined scaled time history pair load case (THLC-2)

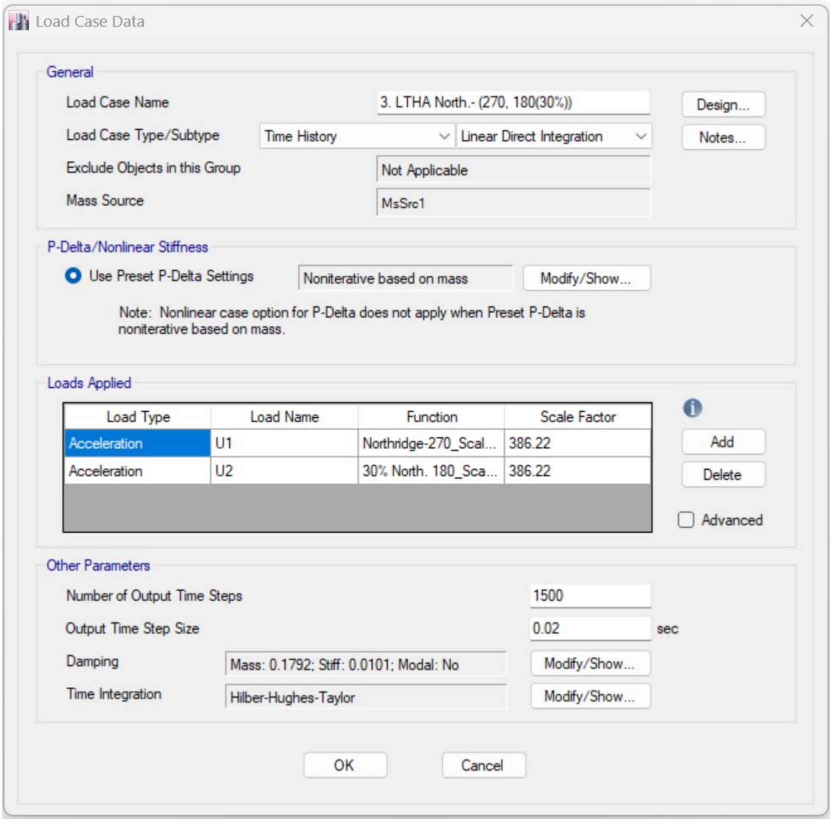


Fig. 3.21: Defined scaled time history pair load case (THLC-3)

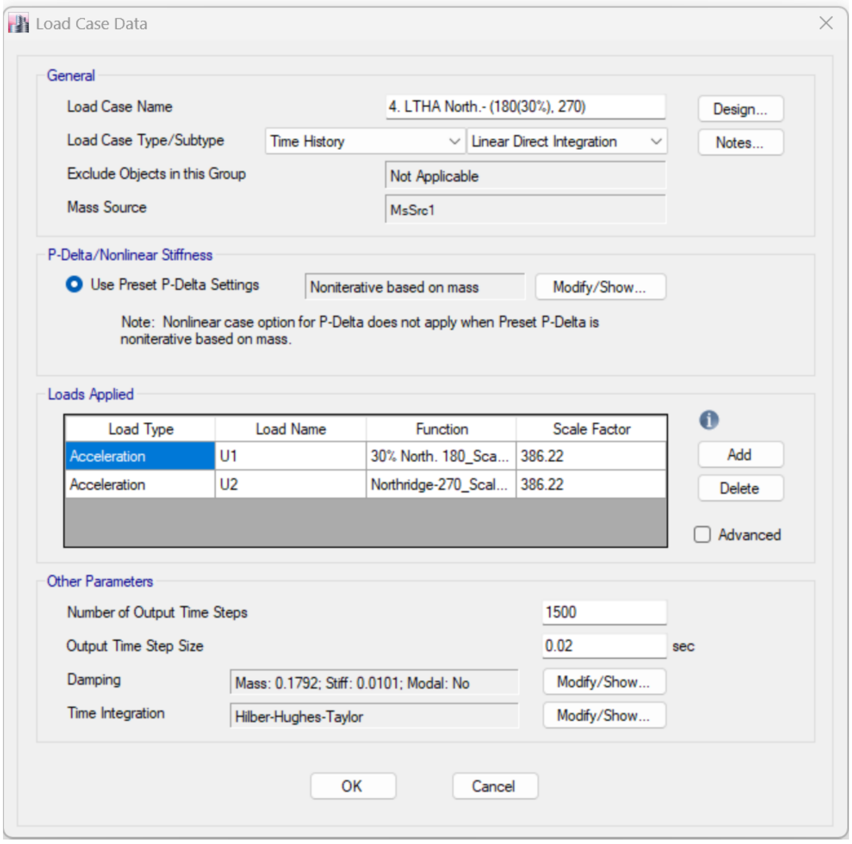


Fig. 3.22: Defined scaled time history pair load case (THLC-4)

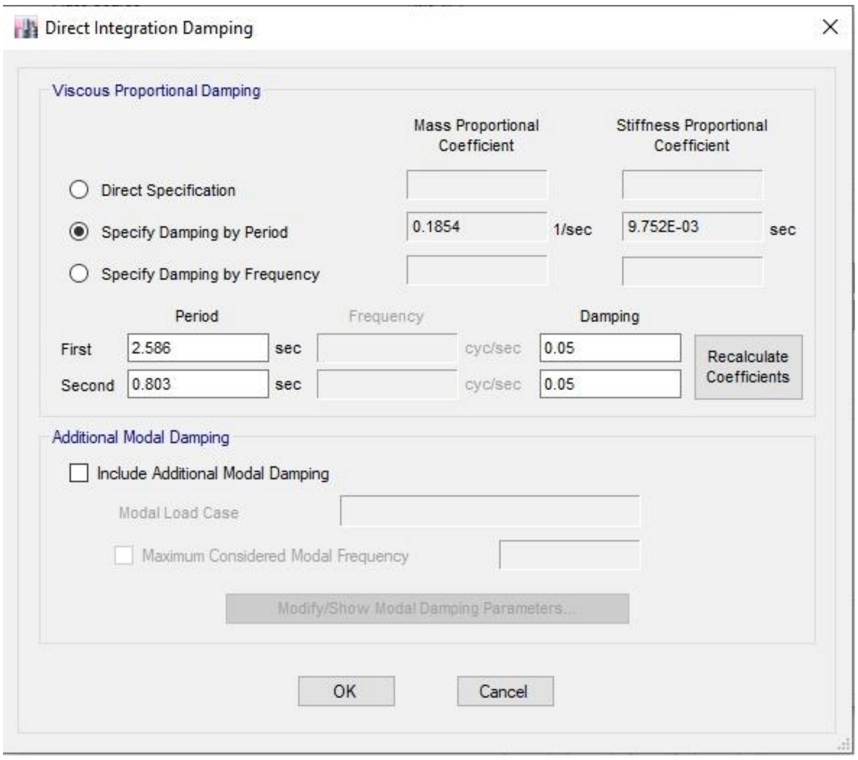


Fig. 3.23: Defined direct integration damping by the natural time period

Starting from the initial sections, after several trials and errors these dimensions are found to be adequate for the time history load combination as shown in Table 3.9 according to BNBC, 2020.

Table 3.9: Design load combination

Comb1: 1.4D
Comb2: 1.2D + 1.6Lr + 1.0L
Comb3: 1.2D + 1.6Lr + 0.8Wx0^0
Comb4: 1.2D + 1.6Lr + 0.8Wx180^0
Comb5: 1.2D + 1.6Lr + 0.8Wy90^0
Comb6: 1.2D + 1.6Lr + 0.8Wy270^0
Comb7: 1.2D + 1.6Wx0 + 1.0L + 0.5Lr
Comb8: 1.2D + 1.6Wx180 + 1.0L + 0.5Lr
Comb9: 1.2D + 1.6Wy90 + 1.0L + 0.5Lr
Comb10: 1.2D + 1.6Wy270 + 1.0L + 0.5Lr
Comb11: 1.2D + 1.6L + 0.5Lr
Comb12: 0.9D + 1.6Wx0
Comb13: 0.9D + 1.6Wx180
Comb14: 0.9D + 1.6Wy90
Comb15: 0.9D + 1.6Wy270
LTHA01: 1.2D + 0.107D + 1.0L + THLC-1 [180, 270 (30%)]
LTHA02: 1.307D + 0.107D + 1.0L + THLC-2 [270 (30%), 180]
LTHA03: 1.307D + 0.107D + 1.0L + THLC-3 [270, 180 (30%)]
LTHA04: 1.307D + 0.107D + 1.0L + THLC-4 [180(30%), 270]
LTHA05: 0.9D - 0.107D + THLC-1 [180, 270 (30%)]
LTHA06: 0.9D - 0.107D + THLC-2 [270 (30%), 180]
LTHA07: 0.9D - 0.107D + THLC-3 [270, 180 (30%)]
LTHA08: 0.9D - 0.107D + THLC-4 [180(30%),270]

Finally, both structural components are fixed for time history analysis shown in Table 3.10 then the response of the two building models is observed for the application of three different scaled ground motion time histories. Finally computed, the column steel percentage for MRFS is 1.2% and FSWS is 1.0%.

Table 3.10: Adequate dimensions of structural components for time history analysis

Model Component	Model 1 (MRFS)	Model 2 (FSWS)
Story height	10 ft	10 ft
Size of columns	45 in × 45 in	30 in × 30 in
Size of beams	25 in × 35 in	25 in × 35 in
Slab thickness	6 in	6 in
Shear wall thickness	----	20 in
Design code	ACI 318-14	ACI 318-14

According to BNBC 2020, special moment frames capable of resisting at least 25% of prescribed seismic forces and 75% or less resisted by shear walls are called dual systems. In this study model 2 (FSWS) column resists above 25% prescribed seismic forces.

3.6 SYNOPSIS

Two 30-storied buildings with the same plan area, height, slenderness ratio, building aspect ratio, and different building members are modelled in ETABS software. The selected three ground motion histories (El Centro 1940, Kobe 1995, and Northridge 1994) are used in the analysis after scaling with the identical scale factor. The scaled acceleration time histories pair is applied at the base of all columns in the X and Y directions simultaneously. Finally, the responses of the building models are observed to investigate the comparison of moment resisting frame and frame shear wall system.

Chapter 4: RESULTS AND DISCUSSION

4.1 GENERAL

The seismic responses of building models are evaluated in terms of maximum story displacement, the story drifts and stiffness in both X and Y directions combinedly. Maximum story displacements occur on the top floor of the buildings. Inter-story drifts or story drifts are then determined for each floor by dividing the relative displacements of the floors by the story height. These two building models also compare the usable space area and concrete volume of both framing systems.

4.2 ADEQUACY OF STRUCTURAL COMPONENT

Building models 1 & 2 (i.e. the MRFS & FSWS) component adequacy was checked for scaled El-Centro 1940, scaled Kobe 1995, and scaled Northridge 1994 ground motion pairs by story drift ratio (SDR). Also, stiffness will be checked.

4.2.1 Story Drift Ratio Check for THLC Load Case

4.2.1.1 SDR Check for MRFS (Model 1) by THLC-1

The maximum permissible limit for story drift ratio is 0.020 (BNBC, 2020). The maximum story drift ratio among all the time history load cases ≤ 0.020; hence building model 1 for THLC-1 is found safe for all ground motion pairs in terms of story drift ratio as shown in Tables 4.1, 4.2, and 4.3.

Table 4.1: SDR Check for Model 1 (MRFS) by scaled El Centro 1940-THLC-1

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	46.21	0.52	0.004	14.11	0.24	0.002	≤0.02	OK
29	10 ft	45.69	0.65	0.005	13.87	0.26	0.002	≤0.02	OK
28	10 ft	45.04	0.74	0.006	13.61	0.28	0.002	≤0.02	OK
27	10 ft	44.30	0.85	0.007	13.33	0.31	0.003	≤0.02	OK
26	10 ft	43.45	0.95	0.008	13.02	0.34	0.003	≤0.02	OK
25	10 ft	42.50	1.05	0.009	12.68	0.37	0.003	≤0.02	OK
24	10 ft	41.45	1.15	0.010	12.32	0.39	0.003	≤0.02	OK
23	10 ft	40.30	1.25	0.010	11.93	0.41	0.003	≤0.02	OK
22	10 ft	39.04	1.34	0.011	11.52	0.43	0.004	≤0.02	OK
21	10 ft	37.70	1.37	0.011	11.09	0.45	0.004	≤0.02	OK
20	10 ft	36.33	1.18	0.010	10.64	0.47	0.004	≤0.02	OK
19	10 ft	35.15	1.27	0.011	10.17	0.48	0.004	≤0.02	OK
18	10 ft	33.87	1.35	0.011	9.69	0.49	0.004	≤0.02	OK
17	10 ft	32.52	1.46	0.012	9.20	0.49	0.004	≤0.02	OK
16	10 ft	31.06	1.58	0.013	8.70	0.48	0.004	≤0.02	OK
15	10 ft	29.49	1.69	0.014	8.22	0.47	0.004	≤0.02	OK
14	10 ft	27.80	1.77	0.015	7.75	0.48	0.004	≤0.02	OK
13	10 ft	26.03	1.89	0.016	7.27	0.48	0.004	≤0.02	OK
12	10 ft	24.14	2.00	0.017	6.79	0.50	0.004	≤0.02	OK
11	10 ft	22.14	2.11	0.018	6.29	0.51	0.004	≤0.02	OK
10	10 ft	20.03	2.21	0.018	5.78	0.53	0.004	≤0.02	OK
9	10 ft	17.82	2.30	0.019	5.25	0.55	0.005	≤0.02	OK
8	10 ft	15.51	2.36	0.020	4.69	0.57	0.005	≤0.02	OK
7	10 ft	13.15	2.10	0.017	4.12	0.59	0.005	≤0.02	OK
6	10 ft	11.05	2.25	0.019	3.53	0.61	0.005	≤0.02	OK
5	10 ft	8.80	1.93	0.016	2.92	0.61	0.005	≤0.02	OK
4	10 ft	6.87	1.63	0.014	2.31	0.61	0.005	≤0.02	OK
3	10 ft	5.24	1.47	0.012	1.71	0.59	0.005	≤0.02	OK
2	10 ft	3.77	0.52	0.004	1.12	0.55	0.005	≤0.02	OK
1	10 ft	3.24	1.83	0.015	0.57	0.42	0.004	≤0.02	OK
0	10 ft	1.41	1.41	0.015	0.14	0.14	0.002	≤0.02	OK

Table 4.2: SDR Check for Model 1 (MRFS) by scaled Kobe 1995-THLC-1

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	43.32	0.85	0.007	13.19	0.30	0.003	≤0.02	OK

29	10 ft	42.48	0.90	0.008	12.89	0.34	0.003	≤0.02	OK
28	10 ft	41.57	0.97	0.008	12.55	0.39	0.003	≤0.02	OK
27	10 ft	40.61	1.01	0.008	12.16	0.43	0.004	≤0.02	OK
26	10 ft	39.60	1.01	0.008	11.73	0.47	0.004	≤0.02	OK
25	10 ft	38.59	0.99	0.008	11.26	0.51	0.004	≤0.02	OK
24	10 ft	37.60	0.95	0.008	10.75	0.53	0.004	≤0.02	OK
23	10 ft	36.64	0.91	0.008	10.22	0.55	0.005	≤0.02	OK
22	10 ft	35.74	0.88	0.007	9.67	0.53	0.004	≤0.02	OK
21	10 ft	34.85	0.87	0.007	9.14	0.47	0.004	≤0.02	OK
20	10 ft	33.98	0.90	0.008	8.66	0.40	0.003	≤0.02	OK
19	10 ft	33.08	0.95	0.008	8.26	0.35	0.003	≤0.02	OK
18	10 ft	32.13	1.02	0.008	7.92	0.34	0.003	≤0.02	OK
17	10 ft	31.11	1.12	0.009	7.58	0.35	0.003	≤0.02	OK
16	10 ft	30.00	1.22	0.010	7.23	0.38	0.003	≤0.02	OK
15	10 ft	28.77	1.35	0.011	6.85	0.40	0.003	≤0.02	OK
14	10 ft	27.42	1.49	0.012	6.45	0.43	0.004	≤0.02	OK
13	10 ft	25.93	1.62	0.013	6.02	0.45	0.004	≤0.02	OK
12	10 ft	24.31	1.75	0.015	5.58	0.47	0.004	≤0.02	OK
11	10 ft	22.57	1.87	0.016	5.11	0.48	0.004	≤0.02	OK
10	10 ft	20.69	1.97	0.016	4.63	0.49	0.004	≤0.02	OK
9	10 ft	18.72	2.07	0.017	4.14	0.50	0.004	≤0.02	OK
8	10 ft	16.66	2.14	0.018	3.64	0.46	0.004	≤0.02	OK
7	10 ft	14.52	2.18	0.018	3.18	0.47	0.004	≤0.02	OK
6	10 ft	12.34	2.20	0.018	2.71	0.47	0.004	≤0.02	OK
5	10 ft	10.14	2.20	0.018	2.24	0.46	0.004	≤0.02	OK
4	10 ft	7.94	2.15	0.018	1.78	0.47	0.004	≤0.02	OK
3	10 ft	5.79	2.05	0.017	1.31	0.46	0.004	≤0.02	OK
2	10 ft	3.73	1.85	0.015	0.85	0.42	0.004	≤0.02	OK
1	10 ft	1.89	1.41	0.012	0.43	0.33	0.003	≤0.02	OK
0	10 ft	0.47	0.47	0.004	0.11	0.11	0.001	≤0.02	OK

Table 4.3: SDR Check for Model 1 (MRFS) by scaled Northridge 1994-THLC-1

Story	Story Height	X			Y			Story Drift Ratio Limit	
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		Remarks
30	10 ft	54.28	0.81	0.007	14.07	0.24	0.002	≤0.02	OK
29	10 ft	53.47	0.95	0.008	13.84	0.25	0.002	≤0.02	OK
28	10 ft	52.52	1.12	0.009	13.59	0.27	0.002	≤0.02	OK
27	10 ft	51.40	1.29	0.011	13.32	0.29	0.002	≤0.02	OK
26	10 ft	50.10	1.46	0.012	13.02	0.30	0.003	≤0.02	OK
25	10 ft	48.64	1.62	0.013	12.72	0.31	0.003	≤0.02	OK
24	10 ft	47.03	1.75	0.015	12.41	0.33	0.003	≤0.02	OK
23	10 ft	45.27	1.88	0.016	12.07	0.35	0.003	≤0.02	OK

22	10 ft	43.40	1.98	0.017	11.73	0.37	0.003	≤0.02	OK
21	10 ft	41.41	2.04	0.017	11.36	0.39	0.003	≤0.02	OK
20	10 ft	39.37	2.09	0.017	10.97	0.40	0.003	≤0.02	OK
19	10 ft	37.28	2.05	0.017	10.57	0.42	0.004	≤0.02	OK
18	10 ft	35.23	1.89	0.016	10.14	0.44	0.004	≤0.02	OK
17	10 ft	33.34	1.94	0.016	9.70	0.47	0.004	≤0.02	OK
16	10 ft	31.40	1.96	0.016	9.23	0.49	0.004	≤0.02	OK
15	10 ft	29.44	2.01	0.017	8.75	0.50	0.004	≤0.02	OK
14	10 ft	27.43	2.04	0.017	8.25	0.44	0.004	≤0.02	OK
13	10 ft	25.39	2.07	0.017	7.81	0.47	0.004	≤0.02	OK
12	10 ft	23.32	2.09	0.017	7.34	0.50	0.004	≤0.02	OK
11	10 ft	21.23	2.10	0.018	6.84	0.54	0.004	≤0.02	OK
10	10 ft	19.13	2.11	0.018	6.31	0.57	0.005	≤0.02	OK
9	10 ft	17.03	2.00	0.017	5.74	0.59	0.005	≤0.02	OK
8	10 ft	15.02	1.93	0.016	5.15	0.62	0.005	≤0.02	OK
7	10 ft	13.10	1.95	0.016	4.53	0.64	0.005	≤0.02	OK
6	10 ft	11.14	1.95	0.016	3.89	0.66	0.005	≤0.02	OK
5	10 ft	9.19	1.97	0.016	3.23	0.67	0.006	≤0.02	OK
4	10 ft	7.22	1.92	0.016	2.55	0.67	0.006	≤0.02	OK
3	10 ft	5.30	1.87	0.016	1.88	0.66	0.005	≤0.02	OK
2	10 ft	3.43	1.69	0.014	1.23	0.60	0.005	≤0.02	OK
1	10 ft	1.73	1.30	0.011	0.62	0.47	0.004	≤0.02	OK
0	10 ft	0.44	0.44	0.005	0.16	0.16	0.002	≤0.02	OK

4.2.1.2 SDR Check for FSWS (Model 2) by THLC-1

The maximum permissible limit for story drift ratio is 0.020 (BNBC, 2020). The maximum story drift ratio among all the time history load cases ≤ 0.020; hence Building Model 2 for THLC-1 is found safe for all ground motion pairs in terms of story drift ratio as shown in Tables 4.4, 4.5, and 4.6.

Table 4.4: SDR Check for Model 2 (FSWS) by scaled El Centro 1940-THLC-1

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	49.52	1.06	0.009	13.61	0.41	0.003	≤0.02	OK
29	10 ft	48.46	1.10	0.009	13.20	0.42	0.004	≤0.02	OK
28	10 ft	47.35	1.16	0.010	12.78	0.44	0.004	≤0.02	OK
27	10 ft	46.20	1.22	0.010	12.33	0.46	0.004	≤0.02	OK
26	10 ft	44.98	1.29	0.011	11.88	0.47	0.004	≤0.02	OK
25	10 ft	43.69	1.36	0.011	11.41	0.48	0.004	≤0.02	OK
24	10 ft	42.34	1.43	0.012	10.92	0.48	0.004	≤0.02	OK

23	10 ft	40.90	1.51	0.013	10.44	0.48	0.004	≤0.02	OK
22	10 ft	39.39	1.58	0.013	9.96	0.47	0.004	≤0.02	OK
21	10 ft	37.81	1.66	0.014	9.49	0.46	0.004	≤0.02	OK
20	10 ft	36.15	1.73	0.014	9.03	0.46	0.004	≤0.02	OK
19	10 ft	34.42	1.78	0.015	8.57	0.46	0.004	≤0.02	OK
18	10 ft	32.64	1.85	0.015	8.11	0.46	0.004	≤0.02	OK
17	10 ft	30.79	1.90	0.016	7.66	0.47	0.004	≤0.02	OK
16	10 ft	28.89	1.95	0.016	7.19	0.44	0.004	≤0.02	OK
15	10 ft	26.94	1.99	0.017	6.75	0.44	0.004	≤0.02	OK
14	10 ft	24.95	2.03	0.017	6.31	0.46	0.004	≤0.02	OK
13	10 ft	22.92	2.05	0.017	5.85	0.47	0.004	≤0.02	OK
12	10 ft	20.87	2.07	0.017	5.38	0.48	0.004	≤0.02	OK
11	10 ft	18.80	2.07	0.017	4.90	0.48	0.004	≤0.02	OK
10	10 ft	16.73	2.06	0.017	4.42	0.49	0.004	≤0.02	OK
9	10 ft	14.67	2.04	0.017	3.93	0.50	0.004	≤0.02	OK
8	10 ft	12.63	1.99	0.017	3.43	0.50	0.004	≤0.02	OK
7	10 ft	10.64	1.93	0.016	2.93	0.50	0.004	≤0.02	OK
6	10 ft	8.71	1.85	0.015	2.43	0.49	0.004	≤0.02	OK
5	10 ft	6.86	1.73	0.014	1.94	0.47	0.004	≤0.02	OK
4	10 ft	5.13	1.58	0.013	1.47	0.44	0.004	≤0.02	OK
3	10 ft	3.55	1.38	0.012	1.03	0.40	0.003	≤0.02	OK
2	10 ft	2.17	1.13	0.009	0.64	0.33	0.003	≤0.02	OK
1	10 ft	1.04	0.78	0.006	0.31	0.23	0.002	≤0.02	OK
0	10 ft	0.26	0.26	0.003	0.08	0.08	0.001	≤0.02	OK

Table 4.5: SDR Check for Model 2 (FSWS) by scaled Kobe 1995-THLC-1

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	53.56	1.24	0.010	15.03	0.58	0.005	≤0.02	OK
29	10 ft	52.31	1.30	0.011	14.45	0.60	0.005	≤0.02	OK
28	10 ft	51.02	1.36	0.011	13.85	0.63	0.005	≤0.02	OK
27	10 ft	49.66	1.43	0.012	13.21	0.66	0.006	≤0.02	OK
26	10 ft	48.22	1.51	0.013	12.55	0.69	0.006	≤0.02	OK
25	10 ft	46.71	1.59	0.013	11.86	0.71	0.006	≤0.02	OK
24	10 ft	45.12	1.68	0.014	11.15	0.73	0.006	≤0.02	OK
23	10 ft	43.44	1.76	0.015	10.42	0.73	0.006	≤0.02	OK
22	10 ft	41.67	1.84	0.015	9.69	0.65	0.005	≤0.02	OK
21	10 ft	39.83	1.92	0.016	9.03	0.29	0.002	≤0.02	OK
20	10 ft	37.91	1.99	0.017	8.75	0.25	0.002	≤0.02	OK
19	10 ft	35.92	2.05	0.017	8.50	0.25	0.002	≤0.02	OK
18	10 ft	33.87	2.11	0.018	8.25	0.27	0.002	≤0.02	OK
17	10 ft	31.76	2.16	0.018	7.98	0.30	0.003	≤0.02	OK

16	10 ft	29.60	2.19	0.018	7.68	0.34	0.003	≤0.02	OK
15	10 ft	27.41	2.22	0.018	7.34	0.39	0.003	≤0.02	OK
14	10 ft	25.20	2.23	0.019	6.95	0.43	0.004	≤0.02	OK
13	10 ft	22.97	2.23	0.019	6.53	0.47	0.004	≤0.02	OK
12	10 ft	20.74	2.22	0.018	6.06	0.51	0.004	≤0.02	OK
11	10 ft	18.52	2.19	0.018	5.55	0.54	0.004	≤0.02	OK
10	10 ft	16.32	2.15	0.018	5.02	0.56	0.005	≤0.02	OK
9	10 ft	14.17	2.09	0.017	4.45	0.58	0.005	≤0.02	OK
8	10 ft	12.08	2.02	0.017	3.87	0.59	0.005	≤0.02	OK
7	10 ft	10.06	1.73	0.014	3.28	0.58	0.005	≤0.02	OK
6	10 ft	8.33	1.64	0.014	2.70	0.57	0.005	≤0.02	OK
5	10 ft	6.69	1.59	0.013	2.13	0.53	0.004	≤0.02	OK
4	10 ft	5.10	1.51	0.013	1.60	0.49	0.004	≤0.02	OK
3	10 ft	3.59	1.36	0.011	1.11	0.43	0.004	≤0.02	OK
2	10 ft	2.23	1.14	0.010	0.68	0.35	0.003	≤0.02	OK
1	10 ft	1.09	0.81	0.007	0.33	0.24	0.002	≤0.02	OK
0	10 ft	0.28	0.28	0.003	0.08	0.08	0.001	≤0.02	OK

Table 4.6: SDR Check for Model 2 (FSWS) by scaled Northridge 1994-THLC-1

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	53.32	1.33	0.011	14.85	0.43	0.004	≤0.02	OK
29	10 ft	52.00	1.38	0.012	14.42	0.43	0.004	≤0.02	OK
28	10 ft	50.61	1.42	0.012	13.98	0.45	0.004	≤0.02	OK
27	10 ft	49.19	1.45	0.012	13.54	0.47	0.004	≤0.02	OK
26	10 ft	47.74	1.54	0.013	13.07	0.48	0.004	≤0.02	OK
25	10 ft	46.21	1.57	0.013	12.59	0.49	0.004	≤0.02	OK
24	10 ft	44.64	1.63	0.014	12.09	0.51	0.004	≤0.02	OK
23	10 ft	43.01	1.72	0.014	11.59	0.53	0.004	≤0.02	OK
22	10 ft	41.29	1.72	0.014	11.06	0.54	0.005	≤0.02	OK
21	10 ft	39.57	1.81	0.015	10.52	0.55	0.005	≤0.02	OK
20	10 ft	37.76	1.89	0.016	9.97	0.56	0.005	≤0.02	OK
19	10 ft	35.87	1.88	0.016	9.41	0.57	0.005	≤0.02	OK
18	10 ft	33.99	1.96	0.016	8.83	0.58	0.005	≤0.02	OK
17	10 ft	32.03	2.02	0.017	8.25	0.58	0.005	≤0.02	OK
16	10 ft	30.01	1.61	0.013	7.67	0.59	0.005	≤0.02	OK
15	10 ft	28.40	1.67	0.014	7.08	0.60	0.005	≤0.02	OK
14	10 ft	26.73	1.78	0.015	6.48	0.59	0.005	≤0.02	OK
13	10 ft	24.95	1.84	0.015	5.89	0.58	0.005	≤0.02	OK
12	10 ft	23.12	1.90	0.016	5.31	0.45	0.004	≤0.02	OK
11	10 ft	21.22	1.99	0.017	4.86	0.46	0.004	≤0.02	OK
10	10 ft	19.22	2.07	0.017	4.40	0.47	0.004	≤0.02	OK

9	10 ft	17.15	2.13	0.018	3.93	0.49	0.004	≤0.02	OK
8	10 ft	15.02	2.15	0.018	3.44	0.49	0.004	≤0.02	OK
7	10 ft	12.87	2.15	0.018	2.95	0.50	0.004	≤0.02	OK
6	10 ft	10.72	2.13	0.018	2.45	0.49	0.004	≤0.02	OK
5	10 ft	8.58	2.07	0.017	1.96	0.47	0.004	≤0.02	OK
4	10 ft	6.52	1.94	0.016	1.48	0.44	0.004	≤0.02	OK
3	10 ft	4.57	1.74	0.015	1.04	0.40	0.003	≤0.02	OK
2	10 ft	2.83	1.46	0.012	0.65	0.33	0.003	≤0.02	OK
1	10 ft	1.37	1.02	0.009	0.32	0.23	0.002	≤0.02	OK
0	10 ft	0.35	0.35	0.004	0.08	0.08	0.001	≤0.02	OK

4.2.1.3 SDR Check for MRFS (Model 1) by THLC-2

The maximum permissible limit for story drift ratio is 0.020 (BNBC, 2020). The maximum story drift ratio among all the time history load cases ≤ 0.020; hence Building Model 1 for THLC-2 is found safe for all ground motion pairs in terms of story drift ratio as shown in Tables 4.7, 4.8, and 4.9.

Table 4.7: SDR Check for Model 1 (MRFS) by scaled El Centro 1940-THLC-2

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	12.47	0.14	0.001	50.76	0.92	0.008	≤0.02	OK
29	10 ft	12.33	0.15	0.001	49.83	1.00	0.008	≤0.02	OK
28	10 ft	12.18	0.17	0.001	48.83	1.10	0.009	≤0.02	OK
27	10 ft	12.01	0.19	0.002	47.73	1.20	0.010	≤0.02	OK
26	10 ft	11.82	0.20	0.002	46.53	1.31	0.011	≤0.02	OK
25	10 ft	11.62	0.22	0.002	45.22	1.16	0.010	≤0.02	OK
24	10 ft	11.40	0.25	0.002	44.05	1.23	0.010	≤0.02	OK
23	10 ft	11.15	0.27	0.002	42.82	1.30	0.011	≤0.02	OK
22	10 ft	10.88	0.31	0.003	41.52	1.38	0.011	≤0.02	OK
21	10 ft	10.57	0.34	0.003	40.14	1.44	0.012	≤0.02	OK
20	10 ft	10.23	0.37	0.003	38.71	1.51	0.013	≤0.02	OK
19	10 ft	9.86	0.40	0.003	37.19	1.58	0.013	≤0.02	OK
18	10 ft	9.46	0.44	0.004	35.61	1.66	0.014	≤0.02	OK
17	10 ft	9.02	0.47	0.004	33.95	1.73	0.014	≤0.02	OK
16	10 ft	8.55	0.50	0.004	32.23	1.79	0.015	≤0.02	OK
15	10 ft	8.05	0.53	0.004	30.43	1.86	0.015	≤0.02	OK
14	10 ft	7.52	0.55	0.005	28.57	1.92	0.016	≤0.02	OK
13	10 ft	6.97	0.56	0.005	26.65	1.98	0.016	≤0.02	OK
12	10 ft	6.41	0.53	0.004	24.67	2.03	0.017	≤0.02	OK
11	10 ft	5.88	0.43	0.004	22.64	2.08	0.017	≤0.02	OK

10	10 ft	5.44	0.43	0.004	20.56	2.12	0.018	≤0.02	OK
9	10 ft	5.02	0.45	0.004	18.45	2.15	0.018	≤0.02	OK
8	10 ft	4.56	0.50	0.004	16.30	2.16	0.018	≤0.02	OK
7	10 ft	4.06	0.54	0.005	14.14	2.17	0.018	≤0.02	OK
6	10 ft	3.52	0.57	0.005	11.97	2.16	0.018	≤0.02	OK
5	10 ft	2.95	0.59	0.005	9.81	2.14	0.018	≤0.02	OK
4	10 ft	2.36	0.61	0.005	7.67	2.09	0.017	≤0.02	OK
3	10 ft	1.75	0.60	0.005	5.58	1.98	0.017	≤0.02	OK
2	10 ft	1.15	0.56	0.005	3.60	1.78	0.015	≤0.02	OK
1	10 ft	0.59	0.44	0.004	1.82	1.36	0.011	≤0.02	OK
0	10 ft	0.15	0.15	0.002	0.46	0.46	0.005	≤0.02	OK

Table 4.8: SDR Check for Model 1 (MRFS) by scaled Kobe 1995-THLC-2

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	12.83	0.20	0.002	44.62	0.87	0.007	≤0.02	OK
29	10 ft	12.63	0.23	0.002	43.75	0.93	0.008	≤0.02	OK
28	10 ft	12.40	0.27	0.002	42.82	0.99	0.008	≤0.02	OK
27	10 ft	12.13	0.31	0.003	41.83	1.04	0.009	≤0.02	OK
26	10 ft	11.81	0.35	0.003	40.79	1.04	0.009	≤0.02	OK
25	10 ft	11.46	0.39	0.003	39.75	1.02	0.009	≤0.02	OK
24	10 ft	11.07	0.43	0.004	38.72	0.98	0.008	≤0.02	OK
23	10 ft	10.63	0.47	0.004	37.74	0.94	0.008	≤0.02	OK
22	10 ft	10.16	0.51	0.004	36.81	0.91	0.008	≤0.02	OK
21	10 ft	9.65	0.54	0.005	35.90	0.90	0.007	≤0.02	OK
20	10 ft	9.10	0.57	0.005	35.00	0.93	0.008	≤0.02	OK
19	10 ft	8.53	0.58	0.005	34.07	0.97	0.008	≤0.02	OK
18	10 ft	7.96	0.44	0.004	33.10	1.05	0.009	≤0.02	OK
17	10 ft	7.52	0.37	0.003	32.05	1.15	0.010	≤0.02	OK
16	10 ft	7.15	0.35	0.003	30.90	1.26	0.011	≤0.02	OK
15	10 ft	6.79	0.36	0.003	29.64	1.40	0.012	≤0.02	OK
14	10 ft	6.44	0.37	0.003	28.24	1.53	0.013	≤0.02	OK
13	10 ft	6.07	0.40	0.003	26.71	1.67	0.014	≤0.02	OK
12	10 ft	5.67	0.42	0.004	25.04	1.80	0.015	≤0.02	OK
11	10 ft	5.25	0.40	0.003	23.24	1.93	0.016	≤0.02	OK
10	10 ft	4.85	0.41	0.003	21.32	2.03	0.017	≤0.02	OK
9	10 ft	4.44	0.43	0.004	19.29	2.13	0.018	≤0.02	OK
8	10 ft	4.01	0.46	0.004	17.16	2.20	0.018	≤0.02	OK
7	10 ft	3.54	0.49	0.004	14.96	2.25	0.019	≤0.02	OK
6	10 ft	3.06	0.51	0.004	12.71	2.27	0.019	≤0.02	OK
5	10 ft	2.54	0.53	0.004	10.44	2.26	0.019	≤0.02	OK
4	10 ft	2.01	0.53	0.004	8.18	2.22	0.018	≤0.02	OK

3	10 ft	1.48	0.52	0.004	5.96	2.11	0.018	≤0.02	OK
2	10 ft	0.96	0.47	0.004	3.85	1.90	0.016	≤0.02	OK
1	10 ft	0.48	0.36	0.003	1.94	1.46	0.012	≤0.02	OK
0	10 ft	0.12	0.12	0.001	0.49	0.49	0.005	≤0.02	OK

Table 4.9: SDR Check for Model 1 (MRFS) by scaled Northridge 1994-THLC-2

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	12.21	0.17	0.001	53.26	1.16	0.010	≤0.02	OK
29	10 ft	12.04	0.20	0.002	52.10	1.28	0.011	≤0.02	OK
28	10 ft	11.85	0.22	0.002	50.82	1.41	0.012	≤0.02	OK
27	10 ft	11.62	0.24	0.002	49.40	1.56	0.013	≤0.02	OK
26	10 ft	11.39	0.27	0.002	47.84	1.70	0.014	≤0.02	OK
25	10 ft	11.12	0.26	0.002	46.14	1.82	0.015	≤0.02	OK
24	10 ft	10.86	0.27	0.002	44.33	1.85	0.015	≤0.02	OK
23	10 ft	10.59	0.25	0.002	42.47	1.90	0.016	≤0.02	OK
22	10 ft	10.34	0.24	0.002	40.57	1.92	0.016	≤0.02	OK
21	10 ft	10.10	0.24	0.002	38.66	1.91	0.016	≤0.02	OK
20	10 ft	9.85	0.24	0.002	36.75	1.97	0.016	≤0.02	OK
19	10 ft	9.61	0.25	0.002	34.78	1.99	0.017	≤0.02	OK
18	10 ft	9.36	0.27	0.002	32.79	2.06	0.017	≤0.02	OK
17	10 ft	9.08	0.30	0.003	30.73	2.12	0.018	≤0.02	OK
16	10 ft	8.78	0.33	0.003	28.61	1.89	0.016	≤0.02	OK
15	10 ft	8.45	0.37	0.003	26.72	1.79	0.015	≤0.02	OK
14	10 ft	8.08	0.41	0.003	24.93	1.79	0.015	≤0.02	OK
13	10 ft	7.67	0.44	0.004	23.14	1.82	0.015	≤0.02	OK
12	10 ft	7.23	0.48	0.004	21.32	1.80	0.015	≤0.02	OK
11	10 ft	6.75	0.51	0.004	19.52	1.83	0.015	≤0.02	OK
10	10 ft	6.23	0.55	0.005	17.69	1.82	0.015	≤0.02	OK
9	10 ft	5.69	0.58	0.005	15.86	1.83	0.015	≤0.02	OK
8	10 ft	5.11	0.60	0.005	14.04	1.84	0.015	≤0.02	OK
7	10 ft	4.51	0.63	0.005	12.19	1.83	0.015	≤0.02	OK
6	10 ft	3.88	0.65	0.005	10.36	1.84	0.015	≤0.02	OK
5	10 ft	3.23	0.67	0.006	8.52	1.83	0.015	≤0.02	OK
4	10 ft	2.56	0.67	0.006	6.69	1.79	0.015	≤0.02	OK
3	10 ft	1.89	0.66	0.005	4.90	1.72	0.014	≤0.02	OK
2	10 ft	1.23	0.60	0.005	3.18	1.56	0.013	≤0.02	OK
1	10 ft	0.63	0.47	0.004	1.62	1.21	0.010	≤0.02	OK
0	10 ft	0.16	0.16	0.002	0.41	0.41	0.004	≤0.02	OK

4.2.1.4 SDR Check for FSWS (Model 2) by THLC-2

The maximum permissible limit for story drift ratio is 0.020 (BNBC, 2020). The maximum story drift ratio among all the time history load cases ≤ 0.020; hence Building Model 2 for THLC-2 is found safe for all ground motion pairs in terms of story drift ratio as shown in Tables 4.10, 4.11, and 4.12.

Table 4.10: SDR Check for Model 2 (FSWS) by scaled El Centro 1940-THLC-2

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	13.06	0.26	0.002	58.46	1.62	0.013	≤0.02	OK
29	10 ft	12.80	0.25	0.002	56.84	1.66	0.014	≤0.02	OK
28	10 ft	12.55	0.25	0.002	55.18	1.72	0.014	≤0.02	OK
27	10 ft	12.29	0.24	0.002	53.46	1.78	0.015	≤0.02	OK
26	10 ft	12.06	0.24	0.002	51.68	1.85	0.015	≤0.02	OK
25	10 ft	11.82	0.24	0.002	49.83	1.92	0.016	≤0.02	OK
24	10 ft	11.57	0.25	0.002	47.91	1.99	0.017	≤0.02	OK
23	10 ft	11.32	0.26	0.002	45.92	2.05	0.017	≤0.02	OK
22	10 ft	11.06	0.29	0.002	43.87	2.11	0.018	≤0.02	OK
21	10 ft	10.77	0.31	0.003	41.76	2.15	0.018	≤0.02	OK
20	10 ft	10.46	0.34	0.003	39.60	2.20	0.018	≤0.02	OK
19	10 ft	10.13	0.37	0.003	37.40	2.24	0.019	≤0.02	OK
18	10 ft	9.75	0.41	0.003	35.17	2.27	0.019	≤0.02	OK
17	10 ft	9.35	0.43	0.004	32.90	2.29	0.019	≤0.02	OK
16	10 ft	8.91	0.46	0.004	30.61	2.30	0.019	≤0.02	OK
15	10 ft	8.45	0.50	0.004	28.30	2.30	0.019	≤0.02	OK
14	10 ft	7.95	0.53	0.004	26.00	2.30	0.019	≤0.02	OK
13	10 ft	7.42	0.57	0.005	23.70	2.29	0.019	≤0.02	OK
12	10 ft	6.85	0.59	0.005	21.41	1.95	0.016	≤0.02	OK
11	10 ft	6.26	0.61	0.005	19.46	1.94	0.016	≤0.02	OK
10	10 ft	5.65	0.63	0.005	17.52	1.99	0.017	≤0.02	OK
9	10 ft	5.02	0.64	0.005	15.54	2.02	0.017	≤0.02	OK
8	10 ft	4.38	0.65	0.005	13.52	2.03	0.017	≤0.02	OK
7	10 ft	3.73	0.65	0.005	11.49	2.01	0.017	≤0.02	OK
6	10 ft	3.09	0.63	0.005	9.49	1.95	0.016	≤0.02	OK
5	10 ft	2.45	0.60	0.005	7.54	1.86	0.015	≤0.02	OK
4	10 ft	1.85	0.56	0.005	5.68	1.73	0.014	≤0.02	OK
3	10 ft	1.29	0.50	0.004	3.95	1.53	0.013	≤0.02	OK
2	10 ft	0.80	0.41	0.003	2.42	1.26	0.010	≤0.02	OK
1	10 ft	0.38	0.29	0.002	1.17	0.87	0.007	≤0.02	OK
0	10 ft	0.10	0.10	0.001	0.30	0.30	0.003	≤0.02	OK

Table 4.11: SDR Check for Model 2 (FSWS) by scaled Kobe 1995-THLC-2

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	14.30	0.43	0.004	51.50	1.36	0.011	≤0.02	OK
29	10 ft	13.87	0.45	0.004	50.15	1.39	0.012	≤0.02	OK
28	10 ft	13.42	0.48	0.004	48.76	1.43	0.012	≤0.02	OK
27	10 ft	12.94	0.37	0.003	47.33	1.47	0.012	≤0.02	OK
26	10 ft	12.57	0.38	0.003	45.85	1.52	0.013	≤0.02	OK
25	10 ft	12.19	0.40	0.003	44.33	1.58	0.013	≤0.02	OK
24	10 ft	11.79	0.42	0.004	42.75	1.62	0.014	≤0.02	OK
23	10 ft	11.36	0.45	0.004	41.13	1.67	0.014	≤0.02	OK
22	10 ft	10.92	0.47	0.004	39.46	1.72	0.014	≤0.02	OK
21	10 ft	10.45	0.49	0.004	37.74	1.77	0.015	≤0.02	OK
20	10 ft	9.97	0.50	0.004	35.98	1.80	0.015	≤0.02	OK
19	10 ft	9.46	0.52	0.004	34.17	1.85	0.015	≤0.02	OK
18	10 ft	8.94	0.54	0.004	32.32	1.89	0.016	≤0.02	OK
17	10 ft	8.40	0.55	0.005	30.43	1.93	0.016	≤0.02	OK
16	10 ft	7.86	0.56	0.005	28.50	1.96	0.016	≤0.02	OK
15	10 ft	7.30	0.57	0.005	26.54	1.99	0.017	≤0.02	OK
14	10 ft	6.73	0.57	0.005	24.55	2.02	0.017	≤0.02	OK
13	10 ft	6.16	0.57	0.005	22.53	2.03	0.017	≤0.02	OK
12	10 ft	5.59	0.57	0.005	20.50	1.62	0.014	≤0.02	OK
11	10 ft	5.01	0.57	0.005	18.88	1.70	0.014	≤0.02	OK
10	10 ft	4.44	0.56	0.005	17.18	1.79	0.015	≤0.02	OK
9	10 ft	3.88	0.55	0.005	15.39	1.86	0.016	≤0.02	OK
8	10 ft	3.32	0.54	0.004	13.52	1.91	0.016	≤0.02	OK
7	10 ft	2.79	0.51	0.004	11.61	1.93	0.016	≤0.02	OK
6	10 ft	2.28	0.45	0.004	9.67	1.92	0.016	≤0.02	OK
5	10 ft	1.84	0.44	0.004	7.75	1.87	0.016	≤0.02	OK
4	10 ft	1.40	0.41	0.003	5.88	1.76	0.015	≤0.02	OK
3	10 ft	0.99	0.37	0.003	4.13	1.58	0.013	≤0.02	OK
2	10 ft	0.61	0.31	0.003	2.55	1.31	0.011	≤0.02	OK
1	10 ft	0.30	0.22	0.002	1.24	0.92	0.008	≤0.02	OK
0	10 ft	0.08	0.08	0.001	0.32	0.32	0.003	≤0.02	OK

Table 4.12: SDR Check for Model 2 (FSWS) by scaled Northridge 1994-THLC-2

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	15.20	0.36	0.003	52.72	1.53	0.013	≤0.02	OK
29	10 ft	14.84	0.37	0.003	51.19	1.57	0.013	≤0.02	OK
28	10 ft	14.47	0.39	0.003	49.61	1.63	0.014	≤0.02	OK
27	10 ft	14.08	0.41	0.003	47.98	1.69	0.014	≤0.02	OK
26	10 ft	13.67	0.43	0.004	46.29	1.76	0.015	≤0.02	OK
25	10 ft	13.24	0.46	0.004	44.53	1.74	0.015	≤0.02	OK
24	10 ft	12.78	0.48	0.004	42.79	1.67	0.014	≤0.02	OK
23	10 ft	12.30	0.50	0.004	41.12	1.67	0.014	≤0.02	OK
22	10 ft	11.80	0.52	0.004	39.45	1.67	0.014	≤0.02	OK
21	10 ft	11.28	0.54	0.005	37.78	1.68	0.014	≤0.02	OK
20	10 ft	10.74	0.56	0.005	36.10	1.71	0.014	≤0.02	OK
19	10 ft	10.18	0.58	0.005	34.39	1.75	0.015	≤0.02	OK
18	10 ft	9.60	0.59	0.005	32.64	1.78	0.015	≤0.02	OK
17	10 ft	9.01	0.60	0.005	30.86	1.83	0.015	≤0.02	OK
16	10 ft	8.41	0.61	0.005	29.03	1.88	0.016	≤0.02	OK
15	10 ft	7.80	0.62	0.005	27.15	1.90	0.016	≤0.02	OK
14	10 ft	7.18	0.62	0.005	25.25	1.95	0.016	≤0.02	OK
13	10 ft	6.56	0.62	0.005	23.31	1.99	0.017	≤0.02	OK
12	10 ft	5.94	0.61	0.005	21.32	2.02	0.017	≤0.02	OK
11	10 ft	5.32	0.60	0.005	19.29	2.05	0.017	≤0.02	OK
10	10 ft	4.72	0.59	0.005	17.24	2.05	0.017	≤0.02	OK
9	10 ft	4.13	0.58	0.005	15.20	2.05	0.017	≤0.02	OK
8	10 ft	3.55	0.56	0.005	13.15	2.03	0.017	≤0.02	OK
7	10 ft	2.98	0.54	0.005	11.12	1.99	0.017	≤0.02	OK
6	10 ft	2.44	0.52	0.004	9.13	1.92	0.016	≤0.02	OK
5	10 ft	1.92	0.49	0.004	7.21	1.81	0.015	≤0.02	OK
4	10 ft	1.43	0.44	0.004	5.40	1.66	0.014	≤0.02	OK
3	10 ft	0.99	0.39	0.003	3.74	1.46	0.012	≤0.02	OK
2	10 ft	0.60	0.32	0.003	2.28	1.19	0.010	≤0.02	OK
1	10 ft	0.29	0.21	0.002	1.09	0.81	0.007	≤0.02	OK
0	10 ft	0.07	0.07	0.001	0.28	0.28	0.003	≤0.02	OK

4.2.1.5 SDR Check for MRFS (Model 1) by THLC-3

The maximum permissible limit for story drift ratio is 0.020 (BNBC, 2020). The maximum story drift ratio among all the time history load cases ≤ 0.020; hence building model 1 for THLC-1 is found safe for all ground motion pairs in terms of story drift ratio as shown in Tables 4.13, 4.14, and 4.15.

Table 4.13: SDR Check for Model 1 (MRFS) by scaled El Centro 1940-THLC-3

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	41.56	0.46	0.004	15.34	0.28	0.002	≤0.02	OK
29	10 ft	41.10	0.51	0.004	15.06	0.30	0.003	≤0.02	OK
28	10 ft	40.59	0.57	0.005	14.76	0.33	0.003	≤0.02	OK
27	10 ft	40.02	0.63	0.005	14.43	0.36	0.003	≤0.02	OK
26	10 ft	39.39	0.68	0.006	14.07	0.36	0.003	≤0.02	OK
25	10 ft	38.72	0.73	0.006	13.70	0.35	0.003	≤0.02	OK
24	10 ft	37.98	0.82	0.007	13.35	0.37	0.003	≤0.02	OK
23	10 ft	37.17	0.92	0.008	12.98	0.39	0.003	≤0.02	OK
22	10 ft	36.25	1.02	0.009	12.59	0.41	0.003	≤0.02	OK
21	10 ft	35.23	1.12	0.009	12.18	0.43	0.004	≤0.02	OK
20	10 ft	34.11	1.23	0.010	11.74	0.46	0.004	≤0.02	OK
19	10 ft	32.88	1.34	0.011	11.28	0.48	0.004	≤0.02	OK
18	10 ft	31.54	1.45	0.012	10.81	0.50	0.004	≤0.02	OK
17	10 ft	30.08	1.57	0.013	10.30	0.52	0.004	≤0.02	OK
16	10 ft	28.52	1.67	0.014	9.78	0.54	0.005	≤0.02	OK
15	10 ft	26.84	1.78	0.015	9.24	0.56	0.005	≤0.02	OK
14	10 ft	25.07	1.84	0.015	8.67	0.58	0.005	≤0.02	OK
13	10 ft	23.22	1.87	0.016	8.09	0.60	0.005	≤0.02	OK
12	10 ft	21.35	1.76	0.015	7.49	0.62	0.005	≤0.02	OK
11	10 ft	19.59	1.45	0.012	6.87	0.63	0.005	≤0.02	OK
10	10 ft	18.14	1.42	0.012	6.24	0.64	0.005	≤0.02	OK
9	10 ft	16.72	1.51	0.013	5.60	0.65	0.005	≤0.02	OK
8	10 ft	15.21	1.66	0.014	4.95	0.66	0.005	≤0.02	OK
7	10 ft	13.54	1.81	0.015	4.29	0.66	0.005	≤0.02	OK
6	10 ft	11.74	1.89	0.016	3.63	0.66	0.005	≤0.02	OK
5	10 ft	9.85	1.97	0.016	2.98	0.65	0.005	≤0.02	OK
4	10 ft	7.88	2.03	0.017	2.33	0.63	0.005	≤0.02	OK
3	10 ft	5.84	2.01	0.017	1.70	0.60	0.005	≤0.02	OK
2	10 ft	3.83	1.87	0.016	1.09	0.54	0.005	≤0.02	OK
1	10 ft	1.96	1.47	0.012	0.55	0.41	0.003	≤0.02	OK
0	10 ft	0.50	0.50	0.005	0.14	0.14	0.001	≤0.02	OK

Table 4.14: SDR Check for Model 1 (MRFS) by scaled Kobe 1995-THLC-3

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	42.77	0.66	0.006	13.43	0.26	0.002	≤0.02	OK
29	10 ft	42.10	0.77	0.006	13.17	0.28	0.002	≤0.02	OK
28	10 ft	41.33	0.91	0.008	12.89	0.30	0.002	≤0.02	OK
27	10 ft	40.42	1.04	0.009	12.59	0.31	0.003	≤0.02	OK
26	10 ft	39.38	1.18	0.010	12.28	0.31	0.003	≤0.02	OK
25	10 ft	38.20	1.31	0.011	11.97	0.30	0.003	≤0.02	OK
24	10 ft	36.89	1.44	0.012	11.67	0.29	0.002	≤0.02	OK
23	10 ft	35.45	1.58	0.013	11.38	0.28	0.002	≤0.02	OK
22	10 ft	33.87	1.70	0.014	11.10	0.27	0.002	≤0.02	OK
21	10 ft	32.17	1.82	0.015	10.83	0.27	0.002	≤0.02	OK
20	10 ft	30.35	1.90	0.016	10.56	0.28	0.002	≤0.02	OK
19	10 ft	28.45	1.93	0.016	10.28	0.29	0.002	≤0.02	OK
18	10 ft	26.52	1.47	0.012	9.99	0.32	0.003	≤0.02	OK
17	10 ft	25.05	1.23	0.010	9.67	0.35	0.003	≤0.02	OK
16	10 ft	23.82	1.17	0.010	9.33	0.38	0.003	≤0.02	OK
15	10 ft	22.65	1.19	0.010	8.95	0.42	0.004	≤0.02	OK
14	10 ft	21.46	1.24	0.010	8.53	0.46	0.004	≤0.02	OK
13	10 ft	20.22	1.32	0.011	8.06	0.50	0.004	≤0.02	OK
12	10 ft	18.90	1.41	0.012	7.56	0.54	0.005	≤0.02	OK
11	10 ft	17.49	1.33	0.011	7.02	0.58	0.005	≤0.02	OK
10	10 ft	16.16	1.35	0.011	6.44	0.61	0.005	≤0.02	OK
9	10 ft	14.80	1.44	0.012	5.82	0.64	0.005	≤0.02	OK
8	10 ft	13.36	1.55	0.013	5.18	0.66	0.006	≤0.02	OK
7	10 ft	11.82	1.63	0.014	4.52	0.68	0.006	≤0.02	OK
6	10 ft	10.19	1.72	0.014	3.84	0.69	0.006	≤0.02	OK
5	10 ft	8.47	1.76	0.015	3.15	0.68	0.006	≤0.02	OK
4	10 ft	6.71	1.78	0.015	2.47	0.67	0.006	≤0.02	OK
3	10 ft	4.93	1.74	0.014	1.80	0.64	0.005	≤0.02	OK
2	10 ft	3.19	1.58	0.013	1.16	0.57	0.005	≤0.02	OK
1	10 ft	1.61	1.21	0.010	0.59	0.44	0.004	≤0.02	OK
0	10 ft	0.40	0.40	0.004	0.15	0.15	0.002	≤0.02	OK

Table 4.15: SDR Check for Model 1 (MRFS) by scaled Northridge 1994-THLC-3

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	40.71	0.57	0.005	16.04	0.35	0.003	≤0.02	OK
29	10 ft	40.14	0.66	0.005	15.70	0.39	0.003	≤0.02	OK
28	10 ft	39.48	0.74	0.006	15.31	0.43	0.004	≤0.02	OK
27	10 ft	38.75	0.79	0.007	14.89	0.47	0.004	≤0.02	OK
26	10 ft	37.95	0.89	0.007	14.41	0.51	0.004	≤0.02	OK
25	10 ft	37.07	0.86	0.007	13.90	0.55	0.005	≤0.02	OK
24	10 ft	36.20	0.89	0.007	13.35	0.56	0.005	≤0.02	OK
23	10 ft	35.31	0.85	0.007	12.79	0.58	0.005	≤0.02	OK
22	10 ft	34.46	0.81	0.007	12.22	0.58	0.005	≤0.02	OK
21	10 ft	33.65	0.81	0.007	11.64	0.58	0.005	≤0.02	OK
20	10 ft	32.84	0.80	0.007	11.06	0.59	0.005	≤0.02	OK
19	10 ft	32.03	0.84	0.007	10.47	0.60	0.005	≤0.02	OK
18	10 ft	31.19	0.92	0.008	9.87	0.62	0.005	≤0.02	OK
17	10 ft	30.28	1.01	0.008	9.25	0.64	0.005	≤0.02	OK
16	10 ft	29.27	1.11	0.009	8.61	0.57	0.005	≤0.02	OK
15	10 ft	28.17	1.24	0.010	8.04	0.54	0.004	≤0.02	OK
14	10 ft	26.93	1.36	0.011	7.50	0.54	0.004	≤0.02	OK
13	10 ft	25.57	1.48	0.012	6.96	0.55	0.005	≤0.02	OK
12	10 ft	24.09	1.60	0.013	6.42	0.54	0.005	≤0.02	OK
11	10 ft	22.49	1.71	0.014	5.88	0.55	0.005	≤0.02	OK
10	10 ft	20.78	1.82	0.015	5.32	0.55	0.005	≤0.02	OK
9	10 ft	18.96	1.92	0.016	4.78	0.55	0.005	≤0.02	OK
8	10 ft	17.04	2.01	0.017	4.22	0.55	0.005	≤0.02	OK
7	10 ft	15.03	2.10	0.017	3.67	0.55	0.005	≤0.02	OK
6	10 ft	12.93	2.17	0.018	3.12	0.54	0.005	≤0.02	OK
5	10 ft	10.76	2.22	0.019	2.58	0.53	0.004	≤0.02	OK
4	10 ft	8.53	2.24	0.019	2.04	0.54	0.004	≤0.02	OK
3	10 ft	6.29	2.19	0.018	1.51	0.52	0.004	≤0.02	OK
2	10 ft	4.10	2.01	0.017	0.98	0.48	0.004	≤0.02	OK
1	10 ft	2.08	1.56	0.013	0.50	0.37	0.003	≤0.02	OK
0	10 ft	0.53	0.53	0.005	0.13	0.13	0.001	≤0.02	OK

4.2.1.6 SDR Check for FSWS (Model 2) by THLC-3

The maximum permissible limit for story drift ratio is 0.020 (BNBC, 2020). The maximum story drift ratio among all the time history load cases ≤ 0.020; hence Building Model 2 for THLC-1 is found safe for all ground motion pairs in terms of story drift ratio as shown in Tables 4.16, 4.17, and 4.18.

Table 4.16: SDR Check for Model 2 (FSWS) by scaled El Centro 1940-THLC-3

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	43.54	0.88	0.007	17.57	0.49	0.004	≤0.02	OK
29	10 ft	42.67	0.84	0.007	17.08	0.50	0.004	≤0.02	OK
28	10 ft	41.82	0.84	0.007	16.58	0.52	0.004	≤0.02	OK
27	10 ft	40.98	0.79	0.007	16.06	0.54	0.004	≤0.02	OK
26	10 ft	40.19	0.81	0.007	15.53	0.56	0.005	≤0.02	OK
25	10 ft	39.39	0.80	0.007	14.97	0.58	0.005	≤0.02	OK
24	10 ft	38.58	0.84	0.007	14.39	0.60	0.005	≤0.02	OK
23	10 ft	37.74	0.88	0.007	13.79	0.62	0.005	≤0.02	OK
22	10 ft	36.86	0.97	0.008	13.17	0.63	0.005	≤0.02	OK
21	10 ft	35.89	1.02	0.009	12.54	0.65	0.005	≤0.02	OK
20	10 ft	34.87	1.12	0.009	11.89	0.66	0.005	≤0.02	OK
19	10 ft	33.75	1.24	0.010	11.24	0.67	0.006	≤0.02	OK
18	10 ft	32.52	1.35	0.011	10.57	0.68	0.006	≤0.02	OK
17	10 ft	31.16	1.45	0.012	9.89	0.69	0.006	≤0.02	OK
16	10 ft	29.72	1.55	0.013	9.20	0.69	0.006	≤0.02	OK
15	10 ft	28.17	1.67	0.014	8.51	0.69	0.006	≤0.02	OK
14	10 ft	26.50	1.78	0.015	7.82	0.61	0.005	≤0.02	OK
13	10 ft	24.72	1.89	0.016	7.21	0.58	0.005	≤0.02	OK
12	10 ft	22.83	1.97	0.016	6.63	0.59	0.005	≤0.02	OK
11	10 ft	20.86	2.03	0.017	6.04	0.61	0.005	≤0.02	OK
10	10 ft	18.84	2.09	0.017	5.44	0.62	0.005	≤0.02	OK
9	10 ft	16.74	2.14	0.018	4.82	0.63	0.005	≤0.02	OK
8	10 ft	14.60	2.16	0.018	4.19	0.62	0.005	≤0.02	OK
7	10 ft	12.44	2.15	0.018	3.57	0.62	0.005	≤0.02	OK
6	10 ft	10.28	2.11	0.018	2.95	0.60	0.005	≤0.02	OK
5	10 ft	8.18	2.00	0.017	2.34	0.58	0.005	≤0.02	OK
4	10 ft	6.18	1.86	0.016	1.77	0.54	0.004	≤0.02	OK
3	10 ft	4.31	1.66	0.014	1.23	0.48	0.004	≤0.02	OK
2	10 ft	2.66	1.37	0.011	0.75	0.39	0.003	≤0.02	OK
1	10 ft	1.28	0.96	0.008	0.36	0.27	0.002	≤0.02	OK
0	10 ft	0.33	0.33	0.003	0.09	0.09	0.001	≤0.02	OK

Table 4.17: SDR Check for Model 2 (FSWS) by scaled Kobe 1995-THLC-3

Story	Story Height	X			Y			Story Drift Ratio Limit	
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		Remarks
30	10 ft	47.68	1.44	0.012	15.89	0.41	0.003	≤0.02	OK
29	10 ft	46.24	1.51	0.013	15.47	0.42	0.004	≤0.02	OK
28	10 ft	44.73	1.60	0.013	15.05	0.43	0.004	≤0.02	OK
27	10 ft	43.13	1.22	0.010	14.62	0.45	0.004	≤0.02	OK
26	10 ft	41.91	1.27	0.011	14.17	0.47	0.004	≤0.02	OK
25	10 ft	40.64	1.34	0.011	13.71	0.48	0.004	≤0.02	OK
24	10 ft	39.29	1.42	0.012	13.23	0.50	0.004	≤0.02	OK
23	10 ft	37.88	1.49	0.012	12.73	0.51	0.004	≤0.02	OK
22	10 ft	36.39	1.55	0.013	12.22	0.53	0.004	≤0.02	OK
21	10 ft	34.84	1.62	0.014	11.69	0.54	0.004	≤0.02	OK
20	10 ft	33.22	1.68	0.014	11.15	0.55	0.005	≤0.02	OK
19	10 ft	31.54	1.74	0.014	10.60	0.57	0.005	≤0.02	OK
18	10 ft	29.80	1.79	0.015	10.03	0.58	0.005	≤0.02	OK
17	10 ft	28.01	1.83	0.015	9.45	0.59	0.005	≤0.02	OK
16	10 ft	26.19	1.86	0.016	8.86	0.60	0.005	≤0.02	OK
15	10 ft	24.33	1.89	0.016	8.26	0.61	0.005	≤0.02	OK
14	10 ft	22.44	1.91	0.016	7.65	0.62	0.005	≤0.02	OK
13	10 ft	20.53	1.92	0.016	7.03	0.63	0.005	≤0.02	OK
12	10 ft	18.62	1.91	0.016	6.40	0.63	0.005	≤0.02	OK
11	10 ft	16.70	1.90	0.016	5.77	0.55	0.005	≤0.02	OK
10	10 ft	14.80	1.88	0.016	5.21	0.54	0.005	≤0.02	OK
9	10 ft	12.92	1.84	0.015	4.67	0.57	0.005	≤0.02	OK
8	10 ft	11.08	1.79	0.015	4.11	0.58	0.005	≤0.02	OK
7	10 ft	9.29	1.69	0.014	3.53	0.59	0.005	≤0.02	OK
6	10 ft	7.60	1.48	0.012	2.94	0.58	0.005	≤0.02	OK
5	10 ft	6.12	1.45	0.012	2.35	0.57	0.005	≤0.02	OK
4	10 ft	4.67	1.38	0.011	1.79	0.53	0.004	≤0.02	OK
3	10 ft	3.29	1.24	0.010	1.25	0.48	0.004	≤0.02	OK
2	10 ft	2.05	1.05	0.009	0.77	0.40	0.003	≤0.02	OK
1	10 ft	1.00	0.74	0.006	0.37	0.28	0.002	≤0.02	OK
0	10 ft	0.26	0.26	0.003	0.10	0.10	0.001	≤0.02	OK

Table 4.18: SDR Check for Model 2 (FSWS) by scaled Northridge 1994-THLC-3

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	50.66	1.19	0.010	16.24	0.47	0.004	≤0.02	OK
29	10 ft	49.47	1.24	0.010	15.77	0.48	0.004	≤0.02	OK
28	10 ft	48.23	1.30	0.011	15.29	0.50	0.004	≤0.02	OK
27	10 ft	46.94	1.37	0.011	14.79	0.52	0.004	≤0.02	OK
26	10 ft	45.57	1.44	0.012	14.27	0.53	0.004	≤0.02	OK
25	10 ft	44.13	1.52	0.013	13.74	0.50	0.004	≤0.02	OK
24	10 ft	42.60	1.60	0.013	13.24	0.50	0.004	≤0.02	OK
23	10 ft	41.00	1.66	0.014	12.74	0.51	0.004	≤0.02	OK
22	10 ft	39.34	1.73	0.014	12.23	0.51	0.004	≤0.02	OK
21	10 ft	37.61	1.80	0.015	11.72	0.51	0.004	≤0.02	OK
20	10 ft	35.81	1.87	0.016	11.21	0.52	0.004	≤0.02	OK
19	10 ft	33.94	1.93	0.016	10.69	0.54	0.004	≤0.02	OK
18	10 ft	32.01	1.97	0.016	10.15	0.55	0.005	≤0.02	OK
17	10 ft	30.03	2.00	0.017	9.60	0.56	0.005	≤0.02	OK
16	10 ft	28.03	2.04	0.017	9.03	0.58	0.005	≤0.02	OK
15	10 ft	25.99	2.07	0.017	8.45	0.59	0.005	≤0.02	OK
14	10 ft	23.92	2.07	0.017	7.86	0.60	0.005	≤0.02	OK
13	10 ft	21.86	2.07	0.017	7.26	0.62	0.005	≤0.02	OK
12	10 ft	19.79	2.04	0.017	6.64	0.63	0.005	≤0.02	OK
11	10 ft	17.75	2.01	0.017	6.02	0.64	0.005	≤0.02	OK
10	10 ft	15.74	1.97	0.016	5.38	0.64	0.005	≤0.02	OK
9	10 ft	13.76	1.94	0.016	4.74	0.64	0.005	≤0.02	OK
8	10 ft	11.83	1.88	0.016	4.10	0.63	0.005	≤0.02	OK
7	10 ft	9.95	1.82	0.015	3.47	0.62	0.005	≤0.02	OK
6	10 ft	8.13	1.73	0.014	2.85	0.60	0.005	≤0.02	OK
5	10 ft	6.40	1.62	0.014	2.25	0.57	0.005	≤0.02	OK
4	10 ft	4.78	1.48	0.012	1.68	0.52	0.004	≤0.02	OK
3	10 ft	3.30	1.29	0.011	1.16	0.46	0.004	≤0.02	OK
2	10 ft	2.01	1.05	0.009	0.70	0.37	0.003	≤0.02	OK
1	10 ft	0.96	0.72	0.006	0.33	0.25	0.002	≤0.02	OK
0	10 ft	0.24	0.24	0.003	0.08	0.08	0.001	≤0.02	OK

4.2.1.7 SDR Check for MRFS (Model 1) by THLC-4

The maximum permissible limit for story drift ratio is 0.020 (BNBC, 2020). The maximum story drift ratio among all the time history load cases ≤ 0.020; hence Building Model 1 for THLC-2 is found safe for all ground motion pairs in terms of story drift ratio as shown in Tables 4.19, 4.20, and 4.21.

Table 4.19: SDR Check for Model 1 (MRFS) by scaled El Centro 1940-THLC-4

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	14.87	0.17	0.001	46.31	0.80	0.007	≤0.02	OK
29	10 ft	14.70	0.19	0.002	45.51	0.86	0.007	≤0.02	OK
28	10 ft	14.50	0.22	0.002	44.65	0.95	0.008	≤0.02	OK
27	10 ft	14.28	0.25	0.002	43.70	1.04	0.009	≤0.02	OK
26	10 ft	14.03	0.28	0.002	42.66	1.13	0.009	≤0.02	OK
25	10 ft	13.74	0.32	0.003	41.53	1.22	0.010	≤0.02	OK
24	10 ft	13.43	0.35	0.003	40.30	1.31	0.011	≤0.02	OK
23	10 ft	13.08	0.38	0.003	38.99	1.39	0.012	≤0.02	OK
22	10 ft	12.70	0.40	0.003	37.60	1.46	0.012	≤0.02	OK
21	10 ft	12.30	0.41	0.003	36.14	1.50	0.013	≤0.02	OK
20	10 ft	11.89	0.35	0.003	34.64	1.56	0.013	≤0.02	OK
19	10 ft	11.53	0.38	0.003	33.08	1.60	0.013	≤0.02	OK
18	10 ft	11.15	0.40	0.003	31.49	1.62	0.013	≤0.02	OK
17	10 ft	10.75	0.44	0.004	29.87	1.60	0.013	≤0.02	OK
16	10 ft	10.31	0.47	0.004	28.27	1.56	0.013	≤0.02	OK
15	10 ft	9.84	0.51	0.004	26.71	1.56	0.013	≤0.02	OK
14	10 ft	9.33	0.53	0.004	25.16	1.56	0.013	≤0.02	OK
13	10 ft	8.80	0.57	0.005	23.60	1.59	0.013	≤0.02	OK
12	10 ft	8.23	0.60	0.005	22.01	1.63	0.014	≤0.02	OK
11	10 ft	7.63	0.63	0.005	20.38	1.67	0.014	≤0.02	OK
10	10 ft	7.00	0.66	0.006	18.71	1.73	0.014	≤0.02	OK
9	10 ft	6.33	0.69	0.006	16.98	1.79	0.015	≤0.02	OK
8	10 ft	5.64	0.71	0.006	15.19	1.83	0.015	≤0.02	OK
7	10 ft	4.93	0.73	0.006	13.36	1.84	0.015	≤0.02	OK
6	10 ft	4.21	0.74	0.006	11.52	1.93	0.016	≤0.02	OK
5	10 ft	3.47	0.74	0.006	9.60	1.99	0.017	≤0.02	OK
4	10 ft	2.72	0.74	0.006	7.60	1.99	0.017	≤0.02	OK
3	10 ft	1.98	0.71	0.006	5.61	1.95	0.016	≤0.02	OK
2	10 ft	1.28	0.64	0.005	3.67	1.80	0.015	≤0.02	OK
1	10 ft	0.64	0.48	0.004	1.87	1.39	0.012	≤0.02	OK
0	10 ft	0.16	0.16	0.002	0.47	0.47	0.005	≤0.02	OK

Table 4.20: SDR Check for Model 1 (MRFS) by scaled Kobe 1995-THLC-4

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	13.03	0.12	0.001	43.94	1.01	0.008	≤0.02	OK
29	10 ft	12.91	0.12	0.001	42.93	1.14	0.009	≤0.02	OK
28	10 ft	12.79	0.13	0.001	41.79	1.29	0.011	≤0.02	OK
27	10 ft	12.66	0.13	0.001	40.51	1.44	0.012	≤0.02	OK
26	10 ft	12.53	0.13	0.001	39.07	1.57	0.013	≤0.02	OK
25	10 ft	12.40	0.13	0.001	37.50	1.69	0.014	≤0.02	OK
24	10 ft	12.28	0.13	0.001	35.82	1.79	0.015	≤0.02	OK
23	10 ft	12.14	0.15	0.001	34.03	1.86	0.015	≤0.02	OK
22	10 ft	12.00	0.16	0.001	32.17	1.82	0.015	≤0.02	OK
21	10 ft	11.83	0.19	0.002	30.35	1.63	0.014	≤0.02	OK
20	10 ft	11.64	0.22	0.002	28.72	1.37	0.011	≤0.02	OK
19	10 ft	11.42	0.26	0.002	27.35	1.14	0.010	≤0.02	OK
18	10 ft	11.17	0.30	0.002	26.21	1.11	0.009	≤0.02	OK
17	10 ft	10.87	0.34	0.003	25.10	1.15	0.010	≤0.02	OK
16	10 ft	10.53	0.39	0.003	23.95	1.23	0.010	≤0.02	OK
15	10 ft	10.14	0.44	0.004	22.72	1.32	0.011	≤0.02	OK
14	10 ft	9.71	0.49	0.004	21.40	1.40	0.012	≤0.02	OK
13	10 ft	9.22	0.54	0.004	20.00	1.48	0.012	≤0.02	OK
12	10 ft	8.68	0.59	0.005	18.53	1.53	0.013	≤0.02	OK
11	10 ft	8.09	0.64	0.005	16.99	1.59	0.013	≤0.02	OK
10	10 ft	7.45	0.68	0.006	15.40	1.63	0.014	≤0.02	OK
9	10 ft	6.77	0.72	0.006	13.77	1.65	0.014	≤0.02	OK
8	10 ft	6.05	0.75	0.006	12.12	1.54	0.013	≤0.02	OK
7	10 ft	5.30	0.78	0.006	10.58	1.55	0.013	≤0.02	OK
6	10 ft	4.52	0.80	0.007	9.03	1.56	0.013	≤0.02	OK
5	10 ft	3.73	0.80	0.007	7.47	1.57	0.013	≤0.02	OK
4	10 ft	2.93	0.79	0.007	5.90	1.56	0.013	≤0.02	OK
3	10 ft	2.14	0.76	0.006	4.33	1.51	0.013	≤0.02	OK
2	10 ft	1.38	0.68	0.006	2.82	1.38	0.012	≤0.02	OK
1	10 ft	0.69	0.52	0.004	1.44	1.07	0.009	≤0.02	OK
0	10 ft	0.17	0.17	0.002	0.36	0.36	0.004	≤0.02	OK

Table 4.21: SDR Check for Model 1 (MRFS) by scaled Northridge 1994-THLC-4

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	16.28	0.24	0.002	46.78	0.77	0.006	≤0.02	OK
29	10 ft	16.04	0.29	0.002	46.01	0.82	0.007	≤0.02	OK
28	10 ft	15.76	0.34	0.003	45.19	0.88	0.007	≤0.02	OK
27	10 ft	15.42	0.39	0.003	44.31	0.95	0.008	≤0.02	OK
26	10 ft	15.03	0.44	0.004	43.36	1.01	0.008	≤0.02	OK
25	10 ft	14.59	0.48	0.004	42.35	1.07	0.009	≤0.02	OK
24	10 ft	14.11	0.53	0.004	41.28	1.14	0.010	≤0.02	OK
23	10 ft	13.58	0.56	0.005	40.14	1.18	0.010	≤0.02	OK
22	10 ft	13.02	0.59	0.005	38.96	1.25	0.010	≤0.02	OK
21	10 ft	12.42	0.61	0.005	37.71	1.30	0.011	≤0.02	OK
20	10 ft	11.81	0.63	0.005	36.41	1.36	0.011	≤0.02	OK
19	10 ft	11.18	0.62	0.005	35.05	1.43	0.012	≤0.02	OK
18	10 ft	10.57	0.57	0.005	33.62	1.49	0.012	≤0.02	OK
17	10 ft	10.00	0.58	0.005	32.13	1.54	0.013	≤0.02	OK
16	10 ft	9.42	0.59	0.005	30.59	1.62	0.013	≤0.02	OK
15	10 ft	8.83	0.60	0.005	28.97	1.69	0.014	≤0.02	OK
14	10 ft	8.23	0.61	0.005	27.29	1.49	0.012	≤0.02	OK
13	10 ft	7.62	0.62	0.005	25.80	1.55	0.013	≤0.02	OK
12	10 ft	7.00	0.63	0.005	24.24	1.66	0.014	≤0.02	OK
11	10 ft	6.37	0.63	0.005	22.58	1.77	0.015	≤0.02	OK
10	10 ft	5.74	0.63	0.005	20.81	1.87	0.016	≤0.02	OK
9	10 ft	5.11	0.60	0.005	18.94	1.95	0.016	≤0.02	OK
8	10 ft	4.51	0.58	0.005	16.99	2.04	0.017	≤0.02	OK
7	10 ft	3.93	0.59	0.005	14.95	2.12	0.018	≤0.02	OK
6	10 ft	3.34	0.59	0.005	12.83	2.18	0.018	≤0.02	OK
5	10 ft	2.76	0.59	0.005	10.65	2.22	0.018	≤0.02	OK
4	10 ft	2.17	0.58	0.005	8.43	2.22	0.019	≤0.02	OK
3	10 ft	1.59	0.56	0.005	6.21	2.17	0.018	≤0.02	OK
2	10 ft	1.03	0.51	0.004	4.04	1.98	0.017	≤0.02	OK
1	10 ft	0.52	0.39	0.003	2.06	1.54	0.013	≤0.02	OK
0	10 ft	0.13	0.13	0.001	0.52	0.52	0.005	≤0.02	OK

4.2.1.8 SDR Check for FSWS (Model 2) by THLC-4

The maximum permissible limit for story drift ratio is 0.020 (BNBC, 2020). The maximum story drift ratio among all the time history load cases ≤

0.020; hence Building Model 2 for THLC-2 is found safe for all ground motion pairs in terms of story drift ratio as shown in Tables 4.22, 4.23, and 4.24.

Table 4.22: SDR Check for Model 2 (FSWS) by scaled El Centro 1940-THLC-4

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	14.86	0.32	0.003	44.48	1.37	0.011	≤0.02	OK
29	10 ft	14.54	0.33	0.003	43.11	1.40	0.012	≤0.02	OK
28	10 ft	14.21	0.35	0.003	41.71	1.45	0.012	≤0.02	OK
27	10 ft	13.86	0.37	0.003	40.26	1.48	0.012	≤0.02	OK
26	10 ft	13.49	0.39	0.003	38.78	1.51	0.013	≤0.02	OK
25	10 ft	13.11	0.41	0.003	37.27	1.52	0.013	≤0.02	OK
24	10 ft	12.70	0.43	0.004	35.75	1.52	0.013	≤0.02	OK
23	10 ft	12.27	0.45	0.004	34.23	1.49	0.012	≤0.02	OK
22	10 ft	11.82	0.48	0.004	32.74	1.48	0.012	≤0.02	OK
21	10 ft	11.34	0.50	0.004	31.26	1.47	0.012	≤0.02	OK
20	10 ft	10.85	0.52	0.004	29.79	1.44	0.012	≤0.02	OK
19	10 ft	10.33	0.54	0.004	28.35	1.47	0.012	≤0.02	OK
18	10 ft	9.79	0.55	0.005	26.87	1.47	0.012	≤0.02	OK
17	10 ft	9.24	0.57	0.005	25.41	1.49	0.012	≤0.02	OK
16	10 ft	8.67	0.59	0.005	23.92	1.52	0.013	≤0.02	OK
15	10 ft	8.08	0.60	0.005	22.39	1.53	0.013	≤0.02	OK
14	10 ft	7.48	0.61	0.005	20.86	1.57	0.013	≤0.02	OK
13	10 ft	6.88	0.62	0.005	19.29	1.59	0.013	≤0.02	OK
12	10 ft	6.26	0.62	0.005	17.70	1.61	0.013	≤0.02	OK
11	10 ft	5.64	0.62	0.005	16.09	1.64	0.014	≤0.02	OK
10	10 ft	5.02	0.62	0.005	14.45	1.64	0.014	≤0.02	OK
9	10 ft	4.40	0.61	0.005	12.80	1.65	0.014	≤0.02	OK
8	10 ft	3.79	0.60	0.005	11.15	1.65	0.014	≤0.02	OK
7	10 ft	3.19	0.58	0.005	9.50	1.62	0.014	≤0.02	OK
6	10 ft	2.61	0.55	0.005	7.88	1.59	0.013	≤0.02	OK
5	10 ft	2.06	0.52	0.004	6.29	1.53	0.013	≤0.02	OK
4	10 ft	1.54	0.47	0.004	4.76	1.42	0.012	≤0.02	OK
3	10 ft	1.07	0.41	0.003	3.34	1.28	0.011	≤0.02	OK
2	10 ft	0.65	0.34	0.003	2.06	1.06	0.009	≤0.02	OK
1	10 ft	0.31	0.23	0.002	1.00	0.75	0.006	≤0.02	OK
0	10 ft	0.08	0.08	0.001	0.26	0.26	0.003	≤0.02	OK

Table 4.23: SDR Check for Model 2 (FSWS) by scaled Kobe 1995-THLC-4

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	16.07	0.37	0.003	49.01	1.90	0.016	≤0.02	OK
29	10 ft	15.69	0.39	0.003	47.11	1.96	0.016	≤0.02	OK
28	10 ft	15.30	0.41	0.003	45.14	2.05	0.017	≤0.02	OK
27	10 ft	14.90	0.43	0.004	43.10	2.14	0.018	≤0.02	OK
26	10 ft	14.47	0.45	0.004	40.95	2.23	0.019	≤0.02	OK
25	10 ft	14.01	0.48	0.004	38.72	2.31	0.019	≤0.02	OK
24	10 ft	13.54	0.50	0.004	36.42	2.36	0.020	≤0.02	OK
23	10 ft	13.03	0.53	0.004	34.06	2.39	0.020	≤0.02	OK
22	10 ft	12.50	0.55	0.005	31.67	2.19	0.018	≤0.02	OK
21	10 ft	11.95	0.58	0.005	29.48	0.82	0.007	≤0.02	OK
20	10 ft	11.37	0.60	0.005	28.66	0.77	0.006	≤0.02	OK
19	10 ft	10.78	0.62	0.005	27.89	0.82	0.007	≤0.02	OK
18	10 ft	10.16	0.63	0.005	27.07	0.89	0.007	≤0.02	OK
17	10 ft	9.53	0.65	0.005	26.18	1.02	0.008	≤0.02	OK
16	10 ft	8.88	0.66	0.005	25.16	1.14	0.010	≤0.02	OK
15	10 ft	8.22	0.66	0.006	24.02	1.29	0.011	≤0.02	OK
14	10 ft	7.56	0.67	0.006	22.73	1.43	0.012	≤0.02	OK
13	10 ft	6.89	0.67	0.006	21.30	1.56	0.013	≤0.02	OK
12	10 ft	6.22	0.67	0.006	19.73	1.68	0.014	≤0.02	OK
11	10 ft	5.55	0.66	0.005	18.05	1.78	0.015	≤0.02	OK
10	10 ft	4.90	0.65	0.005	16.27	1.85	0.015	≤0.02	OK
9	10 ft	4.25	0.63	0.005	14.42	1.90	0.016	≤0.02	OK
8	10 ft	3.62	0.60	0.005	12.52	1.92	0.016	≤0.02	OK
7	10 ft	3.02	0.52	0.004	10.61	1.90	0.016	≤0.02	OK
6	10 ft	2.50	0.49	0.004	8.71	1.84	0.015	≤0.02	OK
5	10 ft	2.01	0.48	0.004	6.87	1.74	0.014	≤0.02	OK
4	10 ft	1.53	0.45	0.004	5.13	1.59	0.013	≤0.02	OK
3	10 ft	1.08	0.41	0.003	3.54	1.38	0.011	≤0.02	OK
2	10 ft	0.67	0.34	0.003	2.16	1.12	0.009	≤0.02	OK
1	10 ft	0.33	0.24	0.002	1.04	0.78	0.006	≤0.02	OK
0	10 ft	0.08	0.08	0.001	0.27	0.27	0.003	≤0.02	OK

Table 4.24: SDR Check for Model 2 (FSWS) by scaled Northridge 1994-THLC-4

Story	Story Height	X			Y			Story Drift Ratio Limit	Remarks
		Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio	Amplified Displacement δx	Story Drift Δx = δx-δx-1	Story Drift Ratio		
30	10 ft	16.00	0.40	0.003	48.47	1.43	0.012	≤0.02	OK
29	10 ft	15.60	0.42	0.003	47.05	1.47	0.012	≤0.02	OK
28	10 ft	15.18	0.43	0.004	45.58	1.50	0.013	≤0.02	OK
27	10 ft	14.76	0.43	0.004	44.08	1.53	0.013	≤0.02	OK
26	10 ft	14.32	0.46	0.004	42.55	1.59	0.013	≤0.02	OK
25	10 ft	13.86	0.47	0.004	40.96	1.65	0.014	≤0.02	OK
24	10 ft	13.39	0.49	0.004	39.31	1.65	0.014	≤0.02	OK
23	10 ft	12.90	0.52	0.004	37.66	1.71	0.014	≤0.02	OK
22	10 ft	12.39	0.52	0.004	35.95	1.76	0.015	≤0.02	OK
21	10 ft	11.87	0.54	0.005	34.19	1.77	0.015	≤0.02	OK
20	10 ft	11.33	0.57	0.005	32.42	1.81	0.015	≤0.02	OK
19	10 ft	10.76	0.56	0.005	30.60	1.86	0.015	≤0.02	OK
18	10 ft	10.20	0.59	0.005	28.74	1.88	0.016	≤0.02	OK
17	10 ft	9.61	0.61	0.005	26.87	1.89	0.016	≤0.02	OK
16	10 ft	9.00	0.48	0.004	24.98	1.91	0.016	≤0.02	OK
15	10 ft	8.52	0.50	0.004	23.06	1.93	0.016	≤0.02	OK
14	10 ft	8.02	0.53	0.004	21.14	1.92	0.016	≤0.02	OK
13	10 ft	7.49	0.55	0.005	19.21	1.57	0.013	≤0.02	OK
12	10 ft	6.93	0.57	0.005	17.65	1.46	0.012	≤0.02	OK
11	10 ft	6.36	0.60	0.005	16.19	1.52	0.013	≤0.02	OK
10	10 ft	5.77	0.62	0.005	14.66	1.58	0.013	≤0.02	OK
9	10 ft	5.15	0.64	0.005	13.09	1.62	0.014	≤0.02	OK
8	10 ft	4.51	0.64	0.005	11.46	1.65	0.014	≤0.02	OK
7	10 ft	3.86	0.65	0.005	9.82	1.66	0.014	≤0.02	OK
6	10 ft	3.21	0.64	0.005	8.16	1.64	0.014	≤0.02	OK
5	10 ft	2.57	0.62	0.005	6.52	1.58	0.013	≤0.02	OK
4	10 ft	1.95	0.58	0.005	4.94	1.48	0.012	≤0.02	OK
3	10 ft	1.37	0.52	0.004	3.46	1.33	0.011	≤0.02	OK
2	10 ft	0.85	0.44	0.004	2.14	1.10	0.009	≤0.02	OK
1	10 ft	0.41	0.31	0.003	1.04	0.77	0.006	≤0.02	OK
0	10 ft	0.11	0.11	0.001	0.27	0.27	0.003	≤0.02	OK

4.2.2 Story Stiffness Check

Soft story as one where the average lateral stiffness of the three stories above irregularity is less than 70% of the story above or less than 80% of that BNBC 2020 define. When a storeys lateral stiffness is less than 60% of the story above's or less than 70% of the average lateral stiffness of the three storeys above, it is considered extremely soft. Maximum story stiffness checks for both model MRFS and FSWS.

4.2.2.1 Story Stiffness Check for Model 1 (MRFS)

Maximum story stiffness shows on the ground floor and minimum story stiffness shows on the roof floor. Story stiffness check is shown in Table 4.25 and Table 4.26.

Table 4.25: Story stiffness check for Model 1 (MRFS) X direction

Stiffness Check for X direction											
Stiffness Irregularity Check							Extreme Stiffness Irregularity Check				
Storey	Stiffness (X) Kip/in	K_{i+1}/K_i	Check	$(K_{i+1}+K_{i+2}+K_{i+3})/3$	$[(K_{i+1}+K_{i+2}+K_{i+3})/3]/K_i$	Check	K_{i+1}/K_i	Check	$(K_{i+1}+K_{i+2}+K_{i+3})/3$	$[(K_{i+1}+K_{i+2}+K_{i+3})/3]/K_i$	Check
		0.7			0.8		0.6			0.7	
30	2179	-	-				-	-			
29	4635	2.1	Reg.				2.1	Reg.			
28	6205	1.3	Reg.				1.3	Reg.			
27	7237	1.2	Reg.	4340	1.7	Reg.	1.2	Reg.	4340	1.7	Reg.
26	7956	1.1	Reg.	6026	1.3	Reg.	1.1	Reg.	6026	1.3	Reg.
25	8485	1.1	Reg.	7133	1.2	Reg.	1.1	Reg.	7133	1.2	Reg.
24	8893	1.0	Reg.	7893	1.1	Reg.	1.0	Reg.	7893	1.1	Reg.
23	9219	1.0	Reg.	8445	1.1	Reg.	1.0	Reg.	8445	1.1	Reg.
22	9487	1.0	Reg.	8866	1.1	Reg.	1.0	Reg.	8866	1.1	Reg.
21	9714	1.0	Reg.	9200	1.1	Reg.	1.0	Reg.	9200	1.1	Reg.
20	9911	1.0	Reg.	9473	1.0	Reg.	1.0	Reg.	9473	1.0	Reg.
19	10085	1.0	Reg.	9704	1.0	Reg.	1.0	Reg.	9704	1.0	Reg.
18	10242	1.0	Reg.	9903	1.0	Reg.	1.0	Reg.	9903	1.0	Reg.
17	10387	1.0	Reg.	10079	1.0	Reg.	1.0	Reg.	10079	1.0	Reg.
16	10524	1.0	Reg.	10238	1.0	Reg.	1.0	Reg.	10238	1.0	Reg.
15	10655	1.0	Reg.	10384	1.0	Reg.	1.0	Reg.	10384	1.0	Reg.
14	10783	1.0	Reg.	10522	1.0	Reg.	1.0	Reg.	10522	1.0	Reg.
13	10910	1.0	Reg.	10654	1.0	Reg.	1.0	Reg.	10654	1.0	Reg.
12	11039	1.0	Reg.	10783	1.0	Reg.	1.0	Reg.	10783	1.0	Reg.
11	11170	1.0	Reg.	10911	1.0	Reg.	1.0	Reg.	10911	1.0	Reg.
10	11307	1.0	Reg.	11040	1.0	Reg.	1.0	Reg.	11040	1.0	Reg.
9	11452	1.0	Reg.	11172	1.0	Reg.	1.0	Reg.	11172	1.0	Reg.
8	11609	1.0	Reg.	11310	1.0	Reg.	1.0	Reg.	11310	1.0	Reg.
7	11783	1.0	Reg.	11456	1.0	Reg.	1.0	Reg.	11456	1.0	Reg.

6	11989	1.0	Reg.	11615	1.0	Reg.	1.0	Reg.	11615	1.0	Reg.
5	12255	1.0	Reg.	11793	1.0	Reg.	1.0	Reg.	11793	1.0	Reg.
4	12652	1.0	Reg.	12009	1.1	Reg.	1.0	Reg.	12009	1.1	Reg.
3	13361	1.1	Reg.	12299	1.1	Reg.	1.1	Reg.	12299	1.1	Reg.
2	14926	1.1	Reg.	12756	1.2	Reg.	1.1	Reg.	12756	1.2	Reg.
1	19663	1.3	Reg.	13646	1.4	Reg.	1.3	Reg.	13646	1.4	Reg.
0	59123	3.0	Reg.	15983	3.7	Reg.	3.0	Reg.	15983	3.7	Reg.

* K_i = Which Story Stiffness. K_{i+1} = Above 1st Story Stiffness, K_{i+2} = Above 2nd Story Stiffness K_{i+3} = Above 3rd Story Stiffness

Table 4.26: Story stiffness check for Model 1 (MRFS) Y direction

Stiffness Check for Y direction											
Stiffness Irregularity Check							Extreme Stiffness Irregularity Check				
Storey	Stiffness (Y) Kip/in	K_{i+1}/K_i	Check	$(K_{i+1}+K_{i+2}+K_{i+3})/3$	$[(K_{i+1}+K_{i+2}+K_{i+3})/3]/K_i$	Check	K_{i+1}/K_i	Check	$(K_{i+1}+K_{i+2}+K_{i+3})/3$	$[(K_{i+1}+K_{i+2}+K_{i+3})/3]/K_i$	Check
		0.7			0.8		0.6			0.7	
30	1403	-	-				-	-			
29	3152	2.2	Reg.				2.2	Reg.			
28	4448	1.4	Reg.				1.4	Reg.			
27	5417	1.2	Reg.	3001	1.8	Reg.	1.2	Reg.	3001	1.8	Reg.
26	6166	1.1	Reg.	4339	1.4	Reg.	1.1	Reg.	4339	1.4	Reg.
25	6761	1.1	Reg.	5344	1.3	Reg.	1.1	Reg.	5344	1.3	Reg.
24	7248	1.1	Reg.	6115	1.2	Reg.	1.1	Reg.	6115	1.2	Reg.
23	7656	1.1	Reg.	6725	1.1	Reg.	1.1	Reg.	6725	1.1	Reg.
22	8005	1.0	Reg.	7222	1.1	Reg.	1.0	Reg.	7222	1.1	Reg.
21	8310	1.0	Reg.	7636	1.1	Reg.	1.0	Reg.	7636	1.1	Reg.
20	8581	1.0	Reg.	7990	1.1	Reg.	1.0	Reg.	7990	1.1	Reg.
19	8827	1.0	Reg.	8299	1.1	Reg.	1.0	Reg.	8299	1.1	Reg.
18	9053	1.0	Reg.	8572	1.1	Reg.	1.0	Reg.	8572	1.1	Reg.
17	9267	1.0	Reg.	8820	1.1	Reg.	1.0	Reg.	8820	1.1	Reg.
16	9471	1.0	Reg.	9049	1.0	Reg.	1.0	Reg.	9049	1.0	Reg.
15	9670	1.0	Reg.	9264	1.0	Reg.	1.0	Reg.	9264	1.0	Reg.
14	9867	1.0	Reg.	9469	1.0	Reg.	1.0	Reg.	9469	1.0	Reg.
13	10066	1.0	Reg.	9669	1.0	Reg.	1.0	Reg.	9669	1.0	Reg.
12	10269	1.0	Reg.	9868	1.0	Reg.	1.0	Reg.	9868	1.0	Reg.
11	10480	1.0	Reg.	10067	1.0	Reg.	1.0	Reg.	10067	1.0	Reg.
10	10702	1.0	Reg.	10272	1.0	Reg.	1.0	Reg.	10272	1.0	Reg.
9	10938	1.0	Reg.	10484	1.0	Reg.	1.0	Reg.	10484	1.0	Reg.
8	11195	1.0	Reg.	10707	1.0	Reg.	1.0	Reg.	10707	1.0	Reg.
7	11478	1.0	Reg.	10945	1.0	Reg.	1.0	Reg.	10945	1.0	Reg.
6	11803	1.0	Reg.	11204	1.1	Reg.	1.0	Reg.	11204	1.1	Reg.
5	12195	1.0	Reg.	11492	1.1	Reg.	1.0	Reg.	11492	1.1	Reg.

4	12724	1.0	Reg.	11825	1.1	Reg.	1.0	Reg.	11825	1.1	Reg.
3	13564	1.1	Reg.	12241	1.1	Reg.	1.1	Reg.	12241	1.1	Reg.
2	15260	1.1	Reg.	12828	1.2	Reg.	1.1	Reg.	12828	1.2	Reg.
1	20162	1.3	Reg.	13849	1.5	Reg.	1.3	Reg.	13849	1.5	Reg.
0	60541	3.0	Reg.	16329	3.7	Reg.	3.0	Reg.	16329	3.7	Reg.
* K_i = Which Story Stiffness. K_{i+1} = Above 1st Story Stiffness, K_{i+2} = Above 2nd Story Stiffness K_{i+3} = Above 3rd Story Stiffness											

4.2.2.1 Story Stiffness Check for Model 2 (FSWS)

Maximum story stiffness shows on the ground floor and minimum story stiffness shows on the roof floor. Story stiffness check is shown in Table 4.27 and Table 4.28.

Table 4.27: Story stiffness check for Model 2 (FSWS) X direction

Stiffness Check for X direction											
Stiffness Irregularity Check							Extreme Stiffness Irregularity Check				
Storey	Stiffness (X) Kip/in	K_{i+1}/K_i	Check	$(K_{i+1}+K_{i+2}+K_{i+3})/3$	$[(K_{i+1}+K_{i+2}+K_{i+3})/3]/K_i$	Check	K_{i+1}/K_i	Check	$(K_{i+1}+K_{i+2}+K_{i+3})/3$	$[(K_{i+1}+K_{i+2}+K_{i+3})/3]/K_i$	Check
		0.7			0.8		0.6			0.7	
30	1448	-	-				-	-			
29	3336	2.3	Reg.				2.3	Reg.			
28	4922	1.5	Reg.				1.5	Reg.			
27	6226	1.3	Reg.	3235	1.9	Reg.	1.3	Reg.	3235	1.9	Reg.
26	7288	1.2	Reg.	4828	1.5	Reg.	1.2	Reg.	4828	1.5	Reg.
25	8153	1.1	Reg.	6145	1.3	Reg.	1.1	Reg.	6145	1.3	Reg.
24	8862	1.1	Reg.	7222	1.2	Reg.	1.1	Reg.	7222	1.2	Reg.
23	9453	1.1	Reg.	8101	1.2	Reg.	1.1	Reg.	8101	1.2	Reg.
22	9952	1.1	Reg.	8823	1.1	Reg.	1.1	Reg.	8823	1.1	Reg.
21	10378	1.0	Reg.	9422	1.1	Reg.	1.0	Reg.	9422	1.1	Reg.
20	10750	1.0	Reg.	9928	1.1	Reg.	1.0	Reg.	9928	1.1	Reg.
19	11082	1.0	Reg.	10360	1.1	Reg.	1.0	Reg.	10360	1.1	Reg.
18	11386	1.0	Reg.	10737	1.1	Reg.	1.0	Reg.	10737	1.1	Reg.
17	11672	1.0	Reg.	11072	1.1	Reg.	1.0	Reg.	11072	1.1	Reg.
16	11950	1.0	Reg.	11380	1.1	Reg.	1.0	Reg.	11380	1.1	Reg.
15	12222	1.0	Reg.	11669	1.0	Reg.	1.0	Reg.	11669	1.0	Reg.
14	12499	1.0	Reg.	11948	1.0	Reg.	1.0	Reg.	11948	1.0	Reg.
13	12795	1.0	Reg.	12224	1.0	Reg.	1.0	Reg.	12224	1.0	Reg.
12	13118	1.0	Reg.	12505	1.0	Reg.	1.0	Reg.	12505	1.0	Reg.
11	13483	1.0	Reg.	12804	1.1	Reg.	1.0	Reg.	12804	1.1	Reg.
10	13907	1.0	Reg.	13132	1.1	Reg.	1.0	Reg.	13132	1.1	Reg.
9	14420	1.0	Reg.	13503	1.1	Reg.	1.0	Reg.	13503	1.1	Reg.

8	15060	1.0	Reg.	13937	1.1	Reg.	1.0	Reg.	13937	1.1	Reg.
7	15872	1.1	Reg.	14462	1.1	Reg.	1.1	Reg.	14462	1.1	Reg.
6	16941	1.1	Reg.	15117	1.1	Reg.	1.1	Reg.	15117	1.1	Reg.
5	18414	1.1	Reg.	15958	1.2	Reg.	1.1	Reg.	15958	1.2	Reg.
4	20550	1.1	Reg.	17076	1.2	Reg.	1.1	Reg.	17076	1.2	Reg.
3	23970	1.2	Reg.	18635	1.3	Reg.	1.2	Reg.	18635	1.3	Reg.
2	30033	1.3	Reg.	20978	1.4	Reg.	1.3	Reg.	20978	1.4	Reg.
1	42350	1.4	Reg.	24851	1.7	Reg.	1.4	Reg.	24851	1.7	Reg.
0	126341	3.0	Reg.	32118	3.9	Reg.	3.0	Reg.	32118	3.9	Reg.
* K_i = Which Story Stiffness. K_{i+1} = Above 1st Story Stiffness, K_{i+2} = Above 2nd Story Stiffness K_{i+3} = Above 3rd Story Stiffness											

Table 4.28: Story stiffness check for Model 2 (FSWS) Y direction

Stiffness Check for Y direction											
Stiffness Irregularity Check							Extreme Stiffness Irregularity Check				
Storey	Stiffness (Y) Kip/in	K_{i+1}/K_i	Check	$(K_{i+1}+K_{i+2}+K_{i+3})/3$	$[(K_{i+1}+K_{i+2}+K_{i+3})/3]/K_i$	Check	K_{i+1}/K_i	Check	$(K_{i+1}+K_{i+2}+K_{i+3})/3$	$[(K_{i+1}+K_{i+2}+K_{i+3})/3]/K_i$	Check
		0.7			0.8		0.6			0.7	
30	949	-	-				-	-			
29	2210	2.3	Reg.				2.3	Reg.			
28	3302	1.5	Reg.				1.5	Reg.			
27	4230	1.3	Reg.	2154	2.0	Reg.	1.3	Reg.	2154	2.0	Reg.
26	5016	1.2	Reg.	3247	1.5	Reg.	1.2	Reg.	3247	1.5	Reg.
25	5682	1.1	Reg.	4182	1.4	Reg.	1.1	Reg.	4182	1.4	Reg.
24	6253	1.1	Reg.	4976	1.3	Reg.	1.1	Reg.	4976	1.3	Reg.
23	6745	1.1	Reg.	5650	1.2	Reg.	1.1	Reg.	5650	1.2	Reg.
22	7176	1.1	Reg.	6227	1.2	Reg.	1.1	Reg.	6227	1.2	Reg.
21	7558	1.1	Reg.	6724	1.1	Reg.	1.1	Reg.	6724	1.1	Reg.
20	7903	1.0	Reg.	7159	1.1	Reg.	1.0	Reg.	7159	1.1	Reg.
19	8221	1.0	Reg.	7546	1.1	Reg.	1.0	Reg.	7546	1.1	Reg.
18	8519	1.0	Reg.	7894	1.1	Reg.	1.0	Reg.	7894	1.1	Reg.
17	8804	1.0	Reg.	8214	1.1	Reg.	1.0	Reg.	8214	1.1	Reg.
16	9085	1.0	Reg.	8515	1.1	Reg.	1.0	Reg.	8515	1.1	Reg.
15	9366	1.0	Reg.	8803	1.1	Reg.	1.0	Reg.	8803	1.1	Reg.
14	9655	1.0	Reg.	9085	1.1	Reg.	1.0	Reg.	9085	1.1	Reg.
13	9960	1.0	Reg.	9369	1.1	Reg.	1.0	Reg.	9369	1.1	Reg.
12	10289	1.0	Reg.	9661	1.1	Reg.	1.0	Reg.	9661	1.1	Reg.
11	10653	1.0	Reg.	9968	1.1	Reg.	1.0	Reg.	9968	1.1	Reg.
10	11066	1.0	Reg.	10301	1.1	Reg.	1.0	Reg.	10301	1.1	Reg.
9	11546	1.0	Reg.	10669	1.1	Reg.	1.0	Reg.	10669	1.1	Reg.
8	12122	1.0	Reg.	11088	1.1	Reg.	1.0	Reg.	11088	1.1	Reg.
7	12837	1.1	Reg.	11578	1.1	Reg.	1.1	Reg.	11578	1.1	Reg.
6	13759	1.1	Reg.	12169	1.1	Reg.	1.1	Reg.	12169	1.1	Reg.

5	15010	1.1	Reg.	12906	1.2	Reg.	1.1	Reg.	12906	1.2	Reg.
4	16825	1.1	Reg.	13869	1.2	Reg.	1.1	Reg.	13869	1.2	Reg.
3	19729	1.2	Reg.	15198	1.3	Reg.	1.2	Reg.	15198	1.3	Reg.
2	25119	1.3	Reg.	17188	1.5	Reg.	1.3	Reg.	17188	1.5	Reg.
1	35550	1.4	Reg.	20558	1.7	Reg.	1.4	Reg.	20558	1.7	Reg.
0	107566	3.0	Reg.	26799	4.0	Reg.	3.0	Reg.	26799	4.0	Reg.
* K_i = Which Story Stiffness. K_{i+1} = Above 1st Story Stiffness, K_{i+2} = Above 2nd Story Stiffness K_{i+3} = Above 3rd Story Stiffness											

From the above table, story stiffness is regular for normal and extreme conditions for both model X and Y directions.

4.2.3 Base Shear Check

Base shear force is the proportion of the total mass of the structure. The static force in the first model is greater than in the second model, but the value in the time history load case of linear time history analysis in the first model is greater than in the second model in both directions. Additionally, a base shear V is computed using the corresponding static force. All response quantities (story shear, moments, drifts, floor deflections, member forces, etc.) determined by time history analysis shall be enhanced by multiplying with the ratio V/V_{th}, in cases where the maximum base shear, V_{th}, estimated by linear time history analysis, is less than V. But scale factor is not required due to Vth being greater than V. The current study does not require a scale factor as V is always less than V_{th} for all earthquakes. The base shear is shown in Table 4.29 and Table 4.30.

Table 4.29: Base shear of Models 1 (MRFS) in both directions

Load Case	Base Shear (kip)							
	Model 1 (MRFS)							
	THLC-1		THLC-2		THLC-3		THLC-4	
	X	Y	X	Y	X	Y	X	Y
EQ-X, Y (V)	1356	1356	1356	1356	1356	1356	1356	1356
El-Centro-X, Y	5624	1730	1721	5209	5735	1563	1687	5768

(V_{th})								
Kobe-X, Y (V_{th})	6549	1443	1484	6164	4947	1849	1965	4809
Northridge-X, Y (V_{th})	4814	1530	1565	4731	5218	1419	1444	5100

Table 4.30: Base shear of Models 2 (FSWS) in both directions

Load Case	Base Shear (kip)							
	Model 2 (FSWS)							
	THLC-1		THLC-2		THLC-3		THLC-4	
	X	Y	X	Y	X	Y	X	Y
EQ-X, Y (V)	1301	1301	1301	1301	1301	1301	1301	1301
El-Centro-X, Y (V_{th})	6391	1642	2317	6544	7725	1963	1917	5472
Kobe-X, Y (V_{th})	6544	1518	1797	6279	5991	1884	1963	5062
Northridge-X, Y (V_{th})	7759	1710	1752	6313	5841	1894	2328	5702

4.3 RESPONSE OF BUILDINGS

The displacement response at the top floor of each building model is formed from time history analysis.

4.3.1 Response for El Centro 1940: THLC-1, THLC-2, THLC-3 and THLC-4

The displacement response of the two-building models in the time history load case El Centro 1940-THLC-1 is shown in Fig. 4.1 to 4.4.

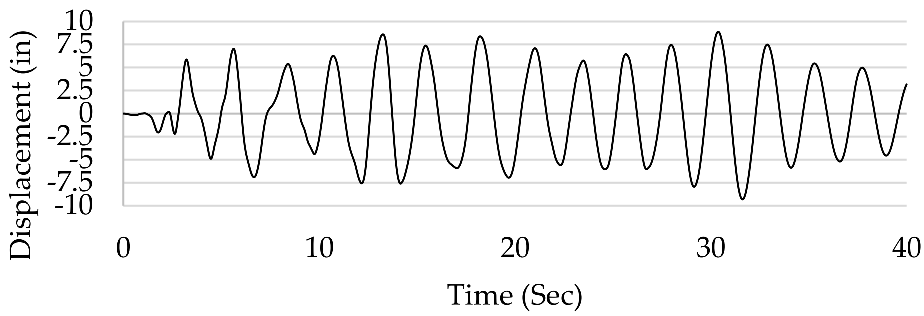


Fig. 4.1: Displacement of El-Centro 1940-THLC-1, model 1 (MRFS) X direction

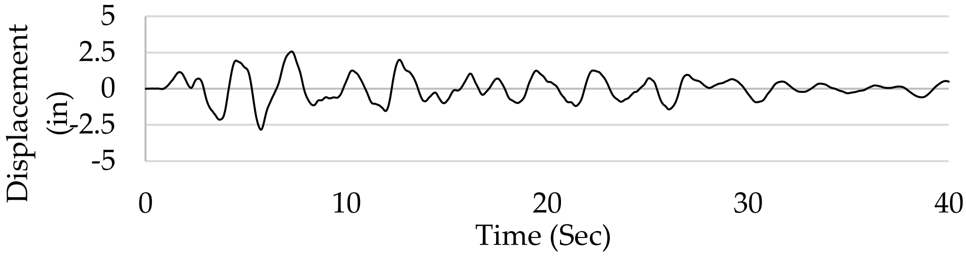


Fig. 4.2: Displacement of El-Centro 1940-THLC-1, model 1 (MRFS) Y direction

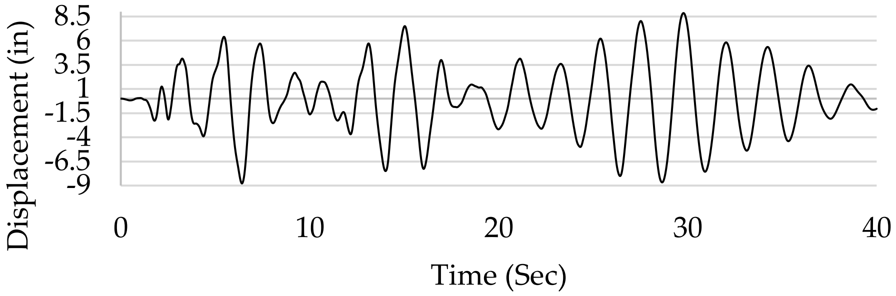


Fig. 4.3: Displacement of El-Centro 1940-THLC-1, model 2 (FSWS) X direction

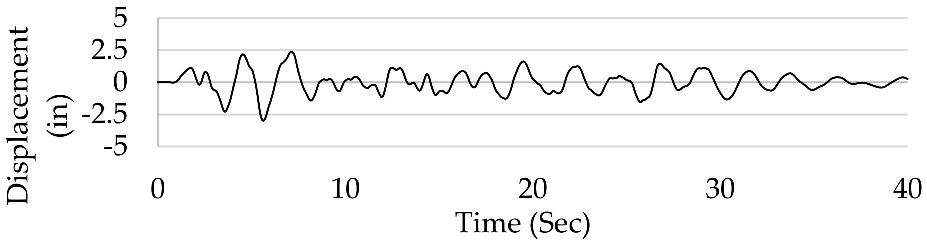


Fig. 4.4: Displacement of El-Centro 1940-THLC-1, model 2 (FSWS) Y direction

The displacement response of the two-building models in the time history load case El Centro 1940-THLC-2 is shown in Fig. 4.5 to 4.8.

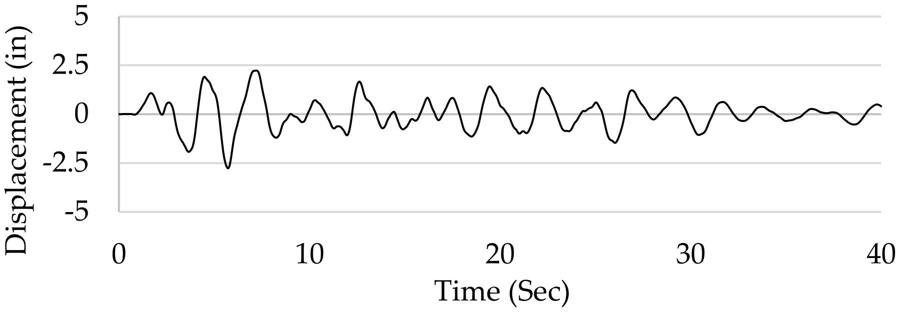


Fig. 4.5: Displacement of El-Centro 1940-THLC-2, model 1 (MRFS) X direction

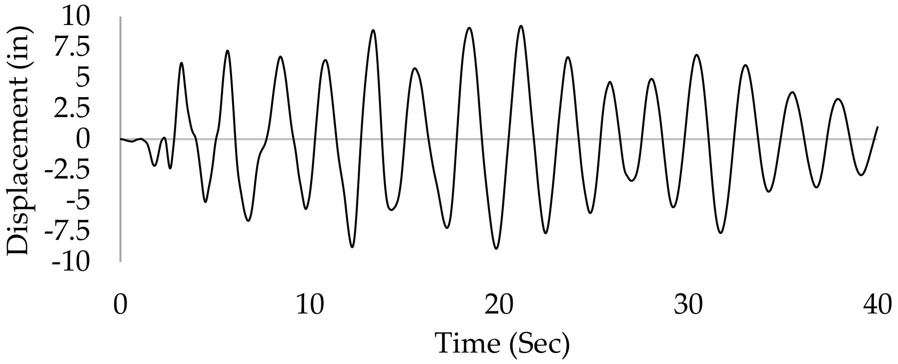


Fig. 4.6: Displacement of El-Centro 1940-THLC-2, model 1 (MRFS) Y direction

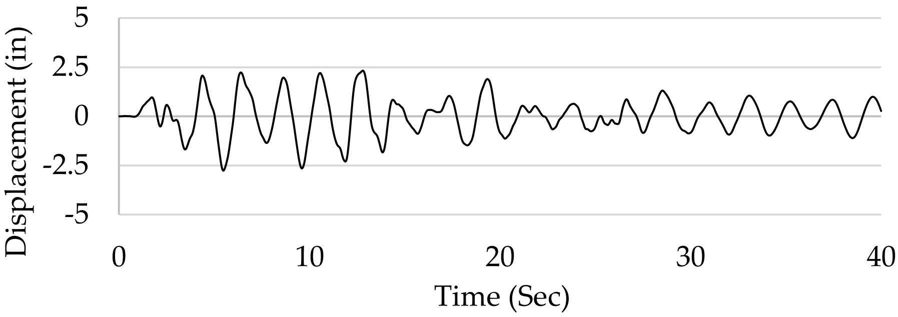


Fig. 4.7: Displacement of El-Centro 1940-THLC-2, model 2 (FSWS) X direction

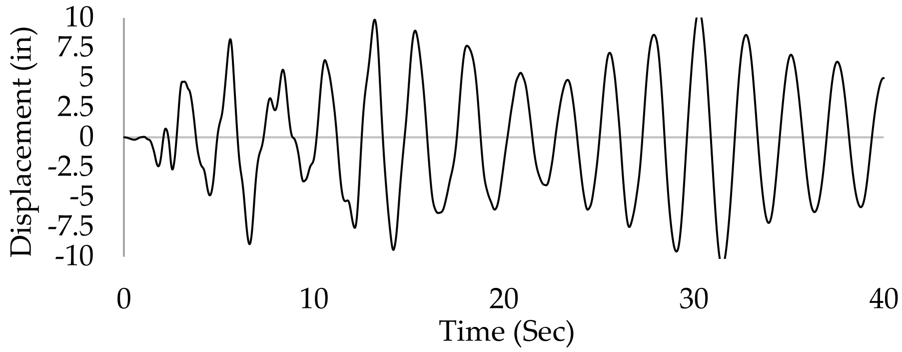


Fig. 4.8: Displacement of El-Centro 1940-THLC-2, model 2 (FSWS) Y direction

The displacement response of the two-building models in the time history load case El Centro 1940-THLC-3 is shown in Fig. 4.9 to 4.12.

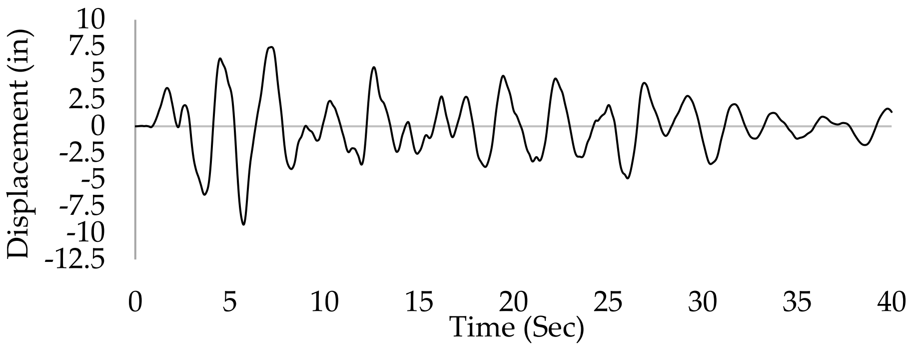


Fig. 4.9: Displacement of El-Centro 1940-THLC-3, model 1 (MRFS) X direction

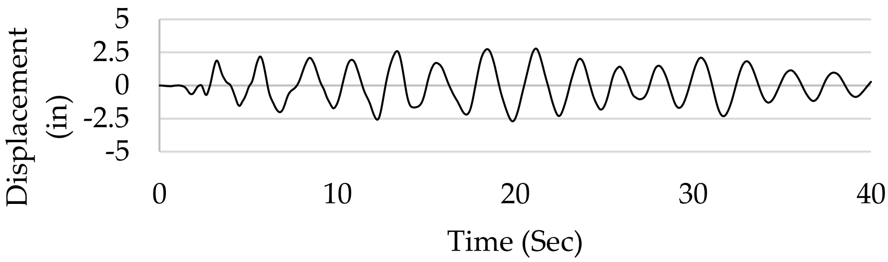


Fig. 4.10: Displacement of El-Centro 1940-THLC-3, model 1 (MRFS) Y direction

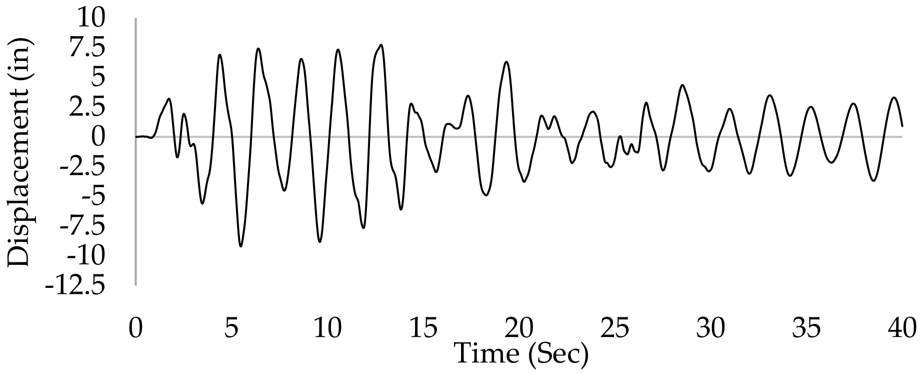


Fig. 4.11: Displacement of El-Centro 1940-THLC-3, model 2 (FSWS) X direction

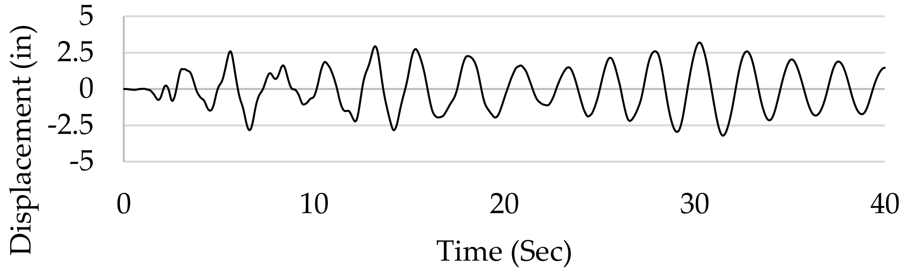


Fig. 4.12: Displacement of El-Centro 1940-THLC-3, model 2 (FSWS) Y direction

The displacement response of the two-building models in the time history load case El Centro 1940-THLC-4 is shown in Fig. 4.13 to 4.16.

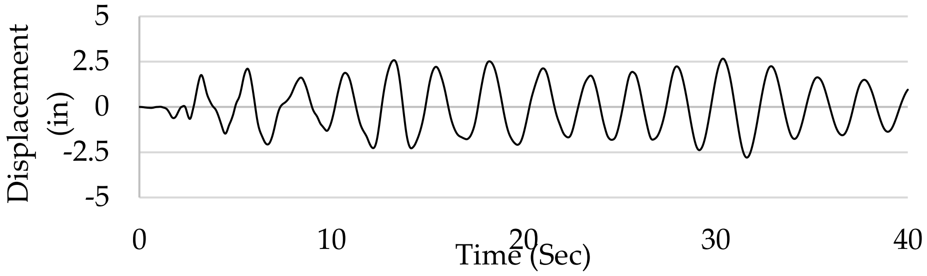


Fig. 4.13: Displacement of El-Centro 1940-THLC-4, model 1 (MRFS) X direction

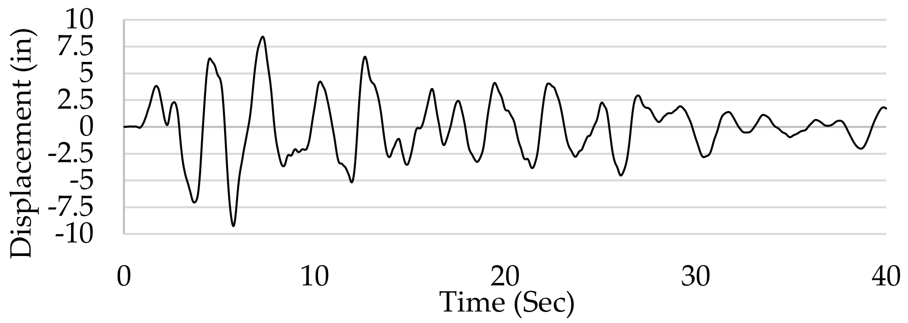


Fig. 4.14: Displacement of El-Centro 1940-THLC-4, model 1 (MRFS) Y direction

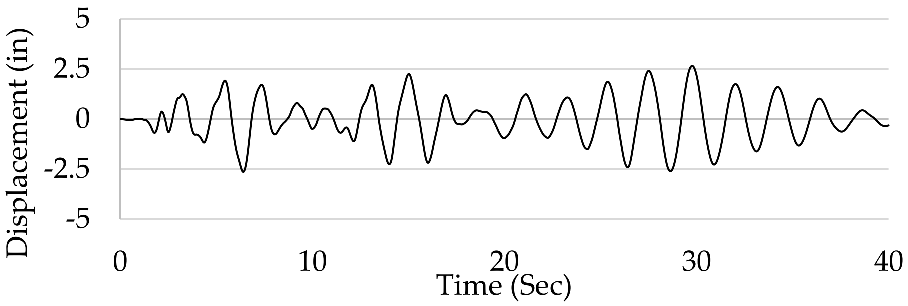


Fig. 4.15: Displacement of El-Centro 1940-THLC-4, model 2 (FSWS) X direction

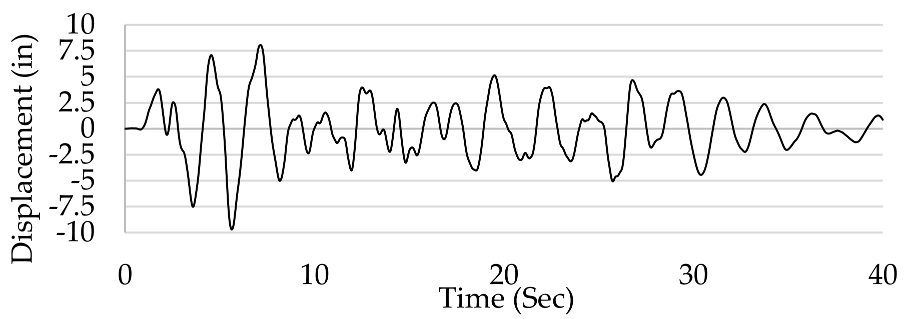


Fig. 4.16: Displacement of El-Centro 1940-THLC-4, model 2 (FSWS) Y direction

4.3.2 Response for Kobe 1995: THLC-1 & THLC-2, THLC-3 and THLC-4

The displacement response of the two-building models in the time history load case Kobe 1995-THLC-1 is shown in Fig. 4.17 to 4.20.

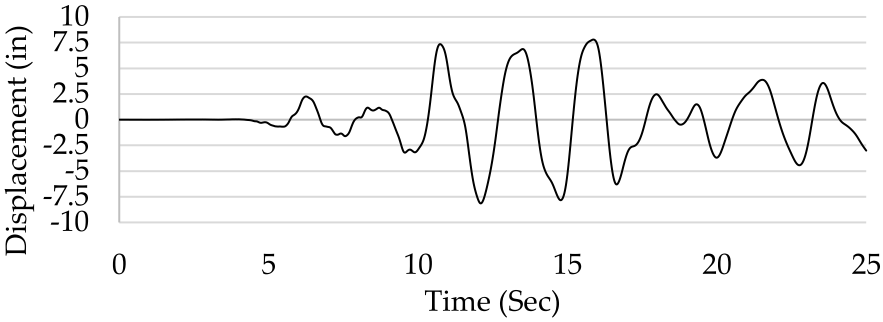


Fig. 4.17: Displacement of Kobe 1995-THLC-1 model 1 (MRFS) X direction

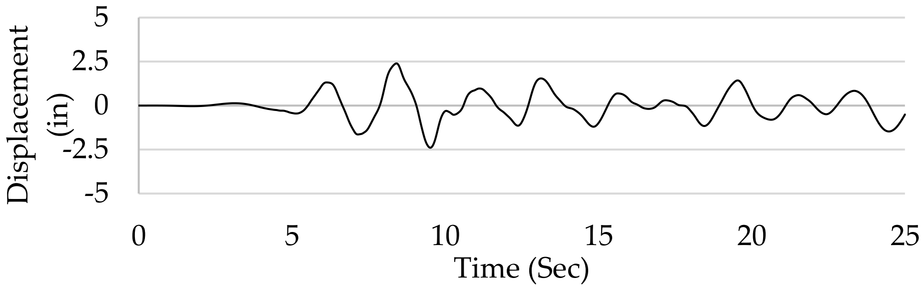


Fig. 4.18: Displacement of Kobe 1995-THLC-1 model 1 (MRFS) Y direction

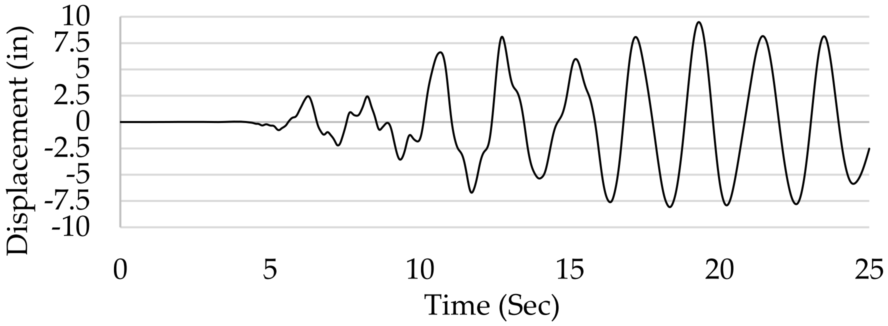


Fig. 4.19: Displacement of Kobe 1995-THLC-1 model 2 (FSWS) X direction

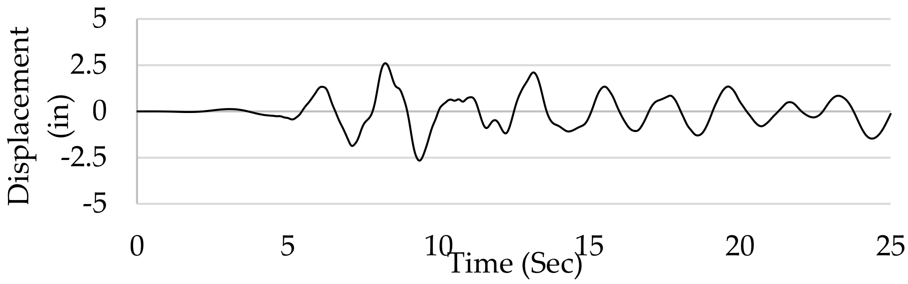


Fig. 4.20: Displacement of Kobe 1995-THLC-1 model 2 (FSWS) Y direction

The displacement response of the two-building models in the time history load case Kobe 1995-THLC-2 is shown in Fig. 4.21 to 4.24.

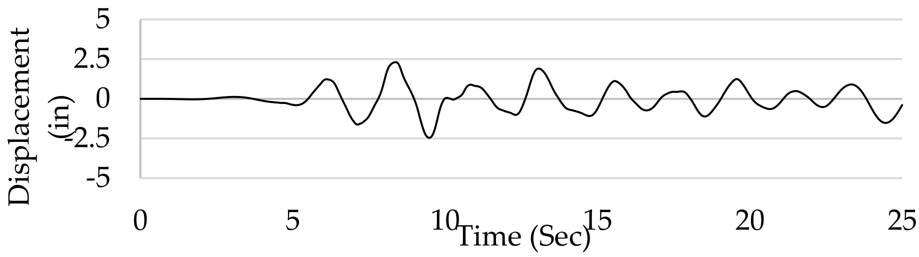


Fig. 4.21: Displacement of Kobe 1995-THLC-2 model 1 (MRFS) X direction

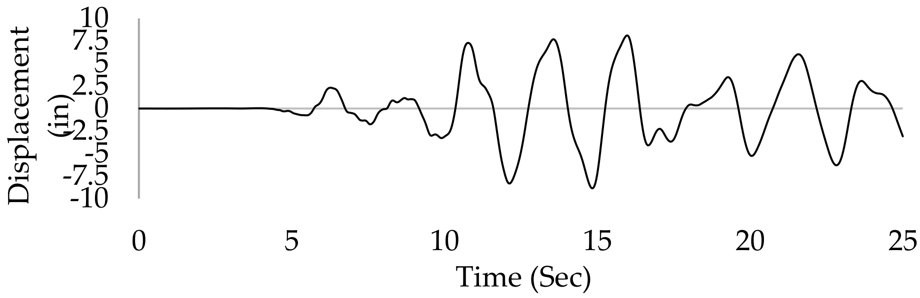


Fig. 4.22: Displacement of Kobe 1995-THLC-2 model 1 (MRFS) Y direction

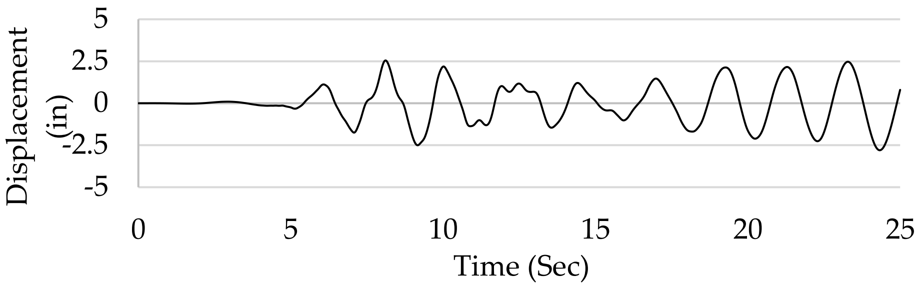


Fig. 4.23: Displacement of Kobe 1995-THLC-2 model 2 (FSWS) X direction

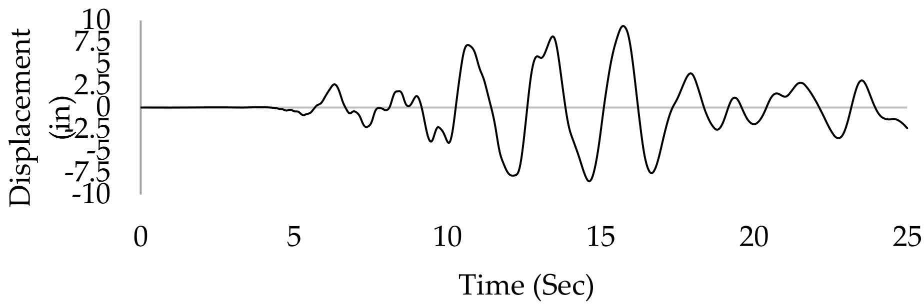


Fig. 4.24: Displacement of Kobe 1995-THLC-2 model 2 (FSWS) Y direction

The displacement response of the two-building models in the time history load case Kobe 1995-THLC-3 is shown in Fig. 4.25 to 4.28.

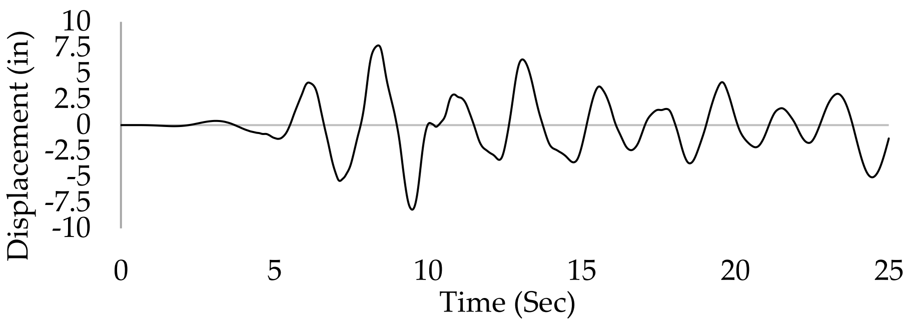


Fig. 4.25: Displacement of Kobe 1995-THLC-3 model 1 (MRFS) X direction

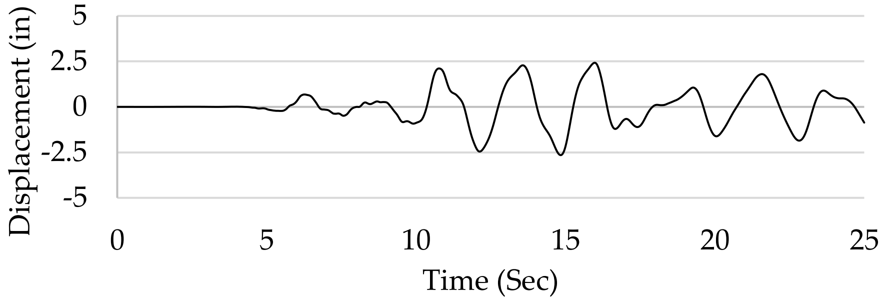


Fig. 4.26: Displacement of Kobe 1995-THLC-3 model 1 (MRFS) Y direction

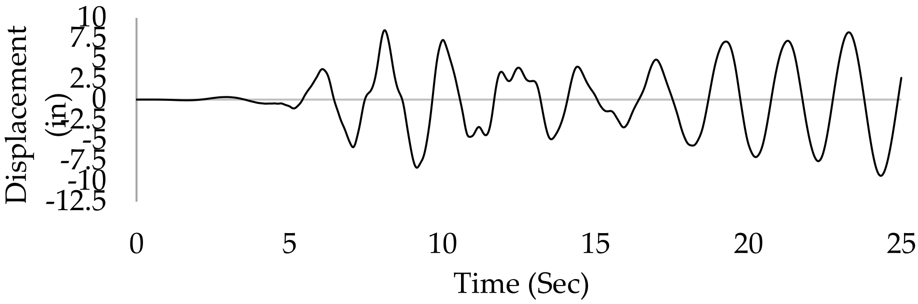


Fig. 4.27: Displacement of Kobe 1995-THLC-3 model 2 (FSWS) X direction

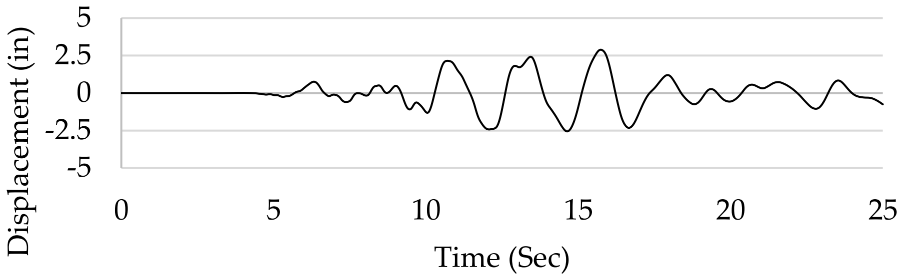


Fig. 4.28: Displacement of Kobe 1995-THLC-3 model 2 (FSWS) Y direction

The displacement response of the two-building models in the time history load case Kobe 1995-THLC-4 is shown in Fig. 4.29 to 4.32.

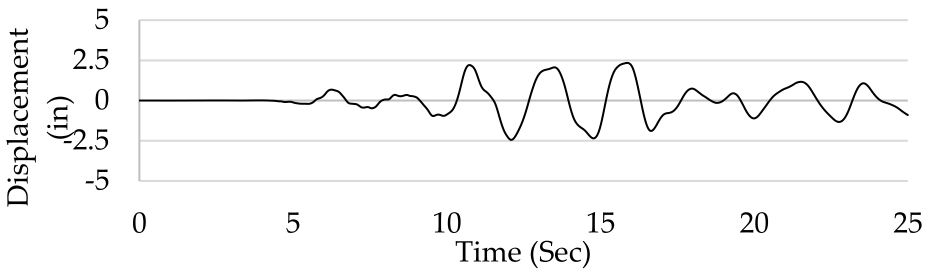


Fig. 4.29: Displacement of Kobe 1995-THLC-4 model 1 (MRFS) X direction

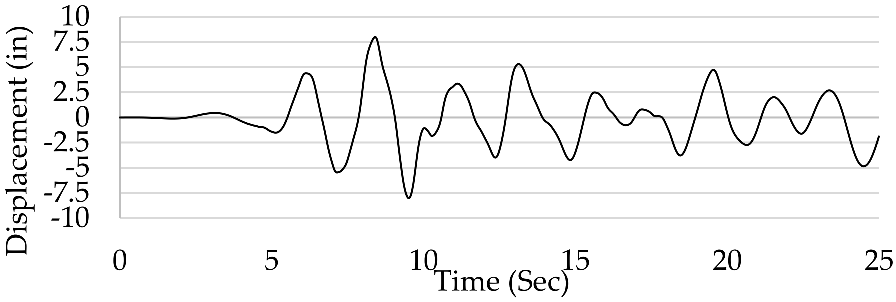


Fig. 4.30: Displacement of Kobe 1995-THLC-4 model 1 (MRFS) Y direction

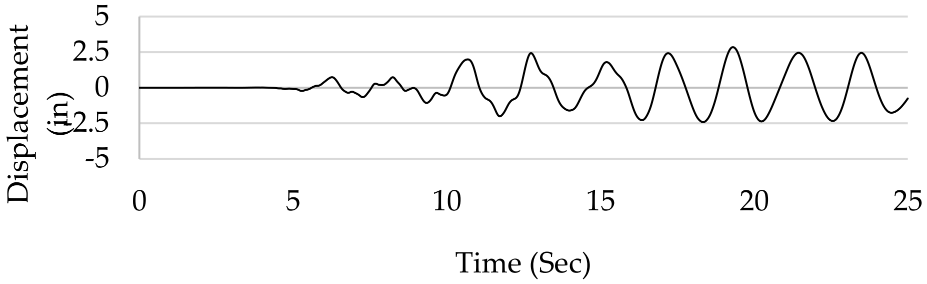


Fig. 4.31: Displacement of Kobe 1995-THLC-4 model 2 (FSWS) X direction

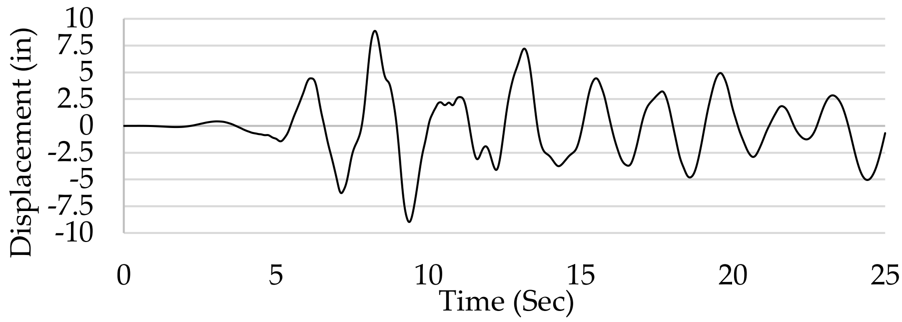


Fig. 4.32: Displacement of Kobe 1995-THLC-4 model 2 (FSWS) Y direction

4.3.3 Response for Northridge 1994: THLC-1 & THLC-2, THLC-3 and THLC-4

The displacement response of the two-building models in the time history load case Northridge 1994-THLC-1 is shown in Fig. 4.33 to 4.36.

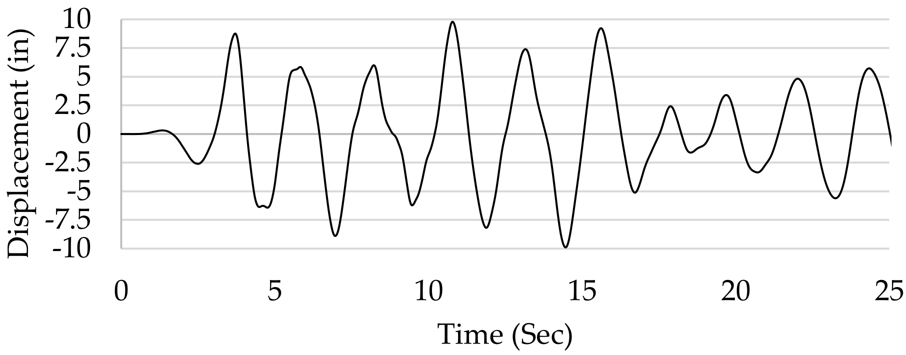


Fig. 4.33: Displacement of Northridge-1994-THLC-1 model 1 (MRFS) X direction

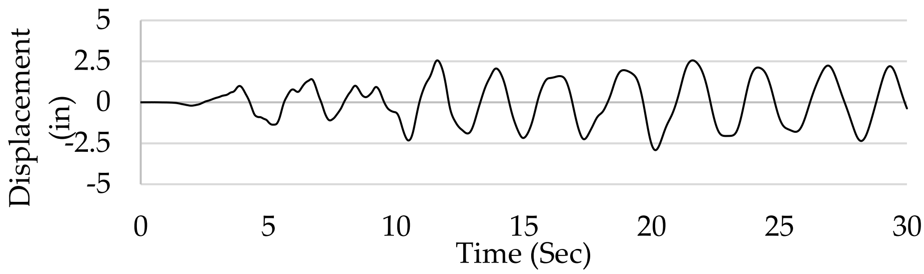


Fig. 4.34: Displacement of Northridge-1994-THLC-1 model 1 (MRFS) Y direction

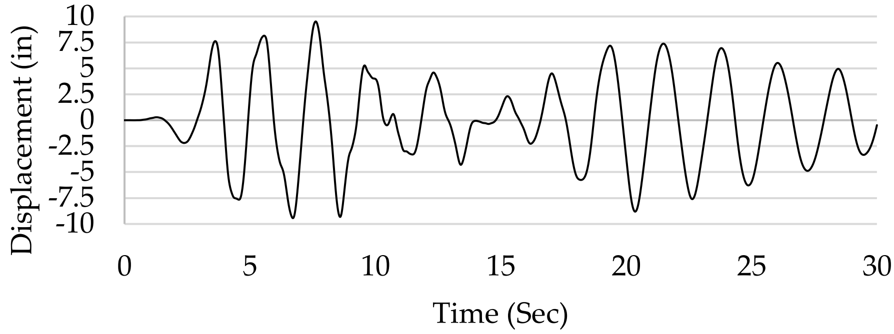


Fig. 4.35: Displacement of Northridge-1994-THLC-1 model 2 (FSWS) X direction

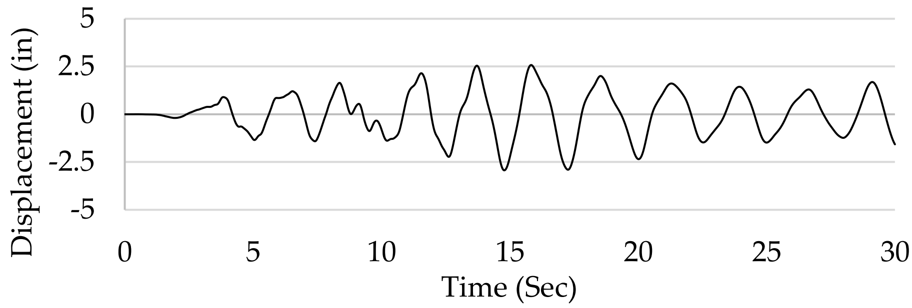


Fig. 4.36: Displacement of Northridge-1994-THLC-1 model 2 (FSWS) Y direction

The displacement response of the two-building models in the time history load case Northridge 1994-THLC-2 is shown in Fig. 4.37 to 4.40.

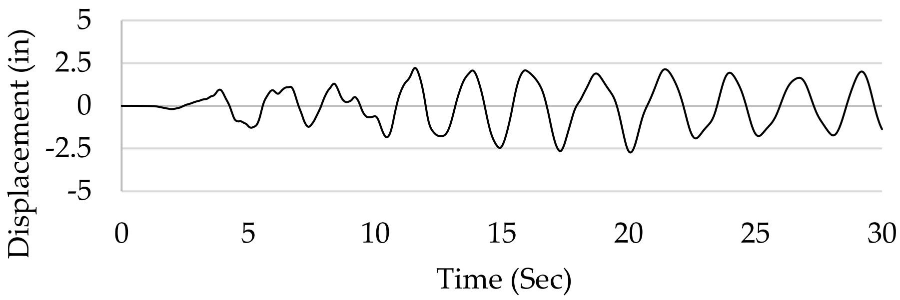


Fig. 4.37: Displacement of Northridge-1994-THLC-2 model 1 (MRFS) X direction

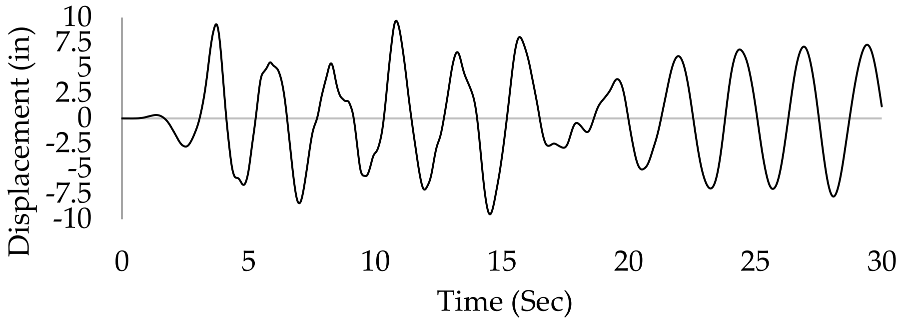


Fig. 4.38: Displacement of Northridge-1994-THLC-2 model 1 (MRFS) Y direction

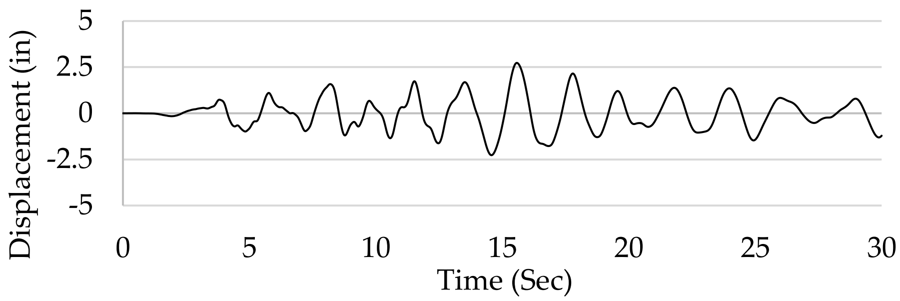


Fig. 4.39: Displacement of Northridge-1994-THLC-2 model 2 (FSWS) X direction

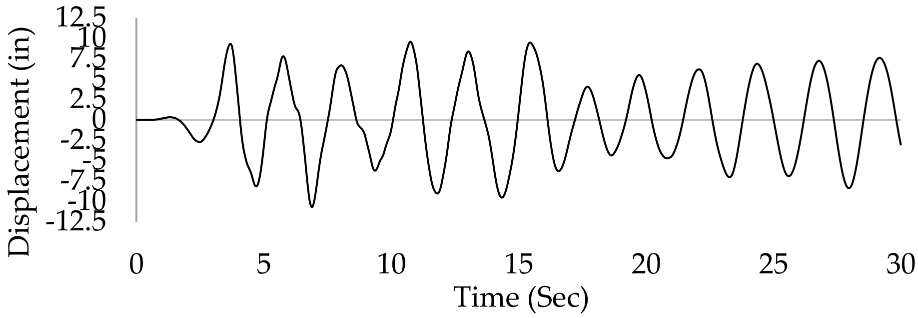


Fig. 4.40: Displacement of Northridge-1994-THLC-2 model 2 (FSWS) Y direction

The displacement response of the two-building models in the time history load case Northridge 1994-THLC-3 is shown in Fig. 4.41 to 4.44.

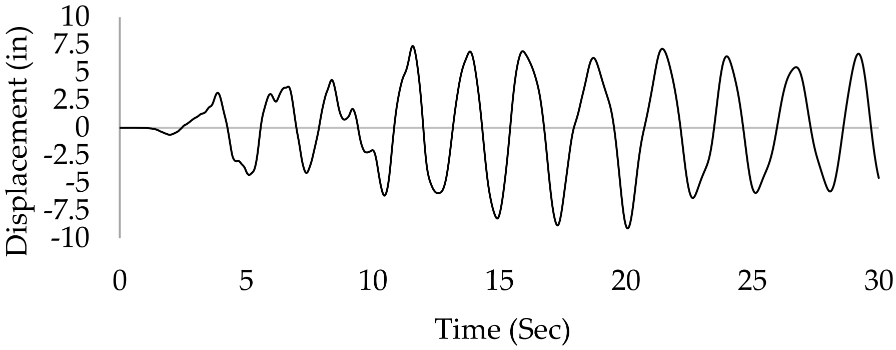


Fig. 4.41: Displacement of Northridge-1994-THLC-3 model 1 (MRFS) X direction

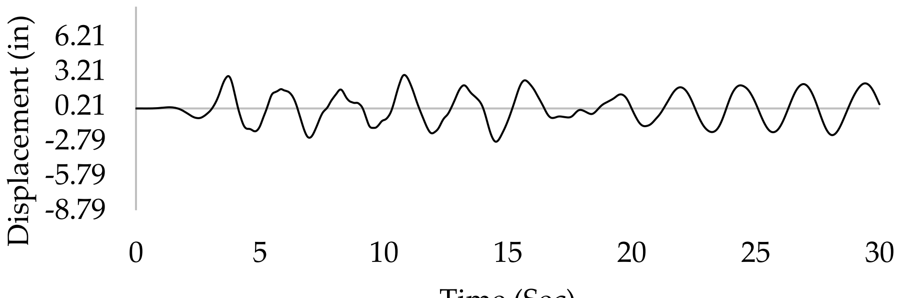


Fig. 4.42: Displacement of Northridge-1994-THLC-3 model 1 (MRFS) Y direction

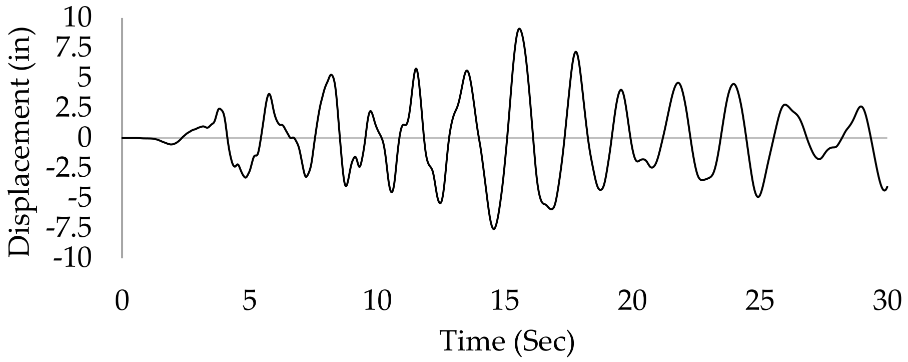


Fig. 4.43: Displacement of Northridge-1994-THLC-3 model 2 (FSWS) X direction

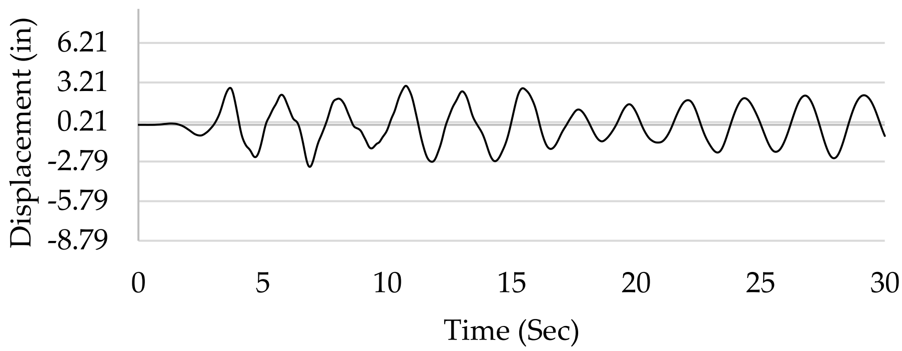


Fig. 4.44: Displacement of Northridge-1994-THLC-3 model 2 (FSWS) Y direction

The displacement response of the two-building models in the time history load case Northridge 1994-THLC-4 is shown in Fig. 4.45 to 4.48.

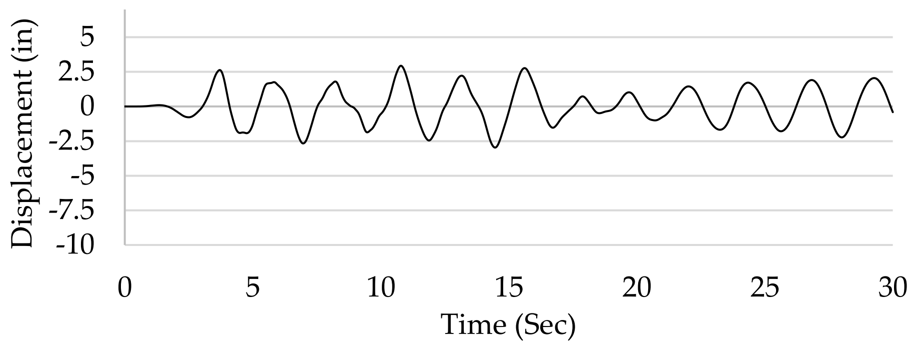


Fig. 4.45: Displacement of Northridge-1994-THLC-4 model 1 (MRFS) X direction

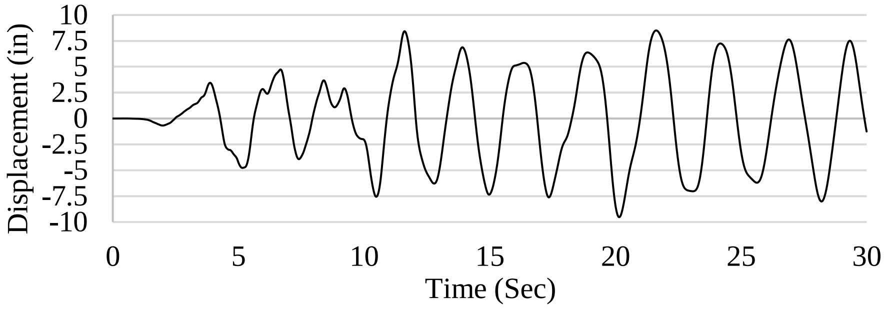


Fig. 4.46: Displacement of Northridge-1994-THLC-4 model 1 (MRFS) Y direction

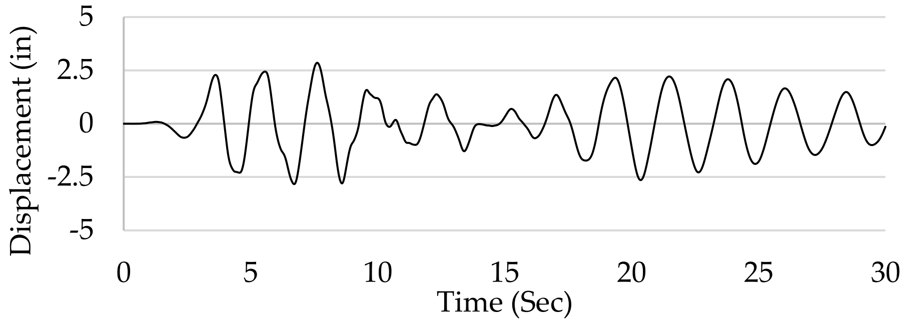


Fig. 4.47: Displacement of Northridge-1994-THLC-4 model 2 (FSWS) X direction

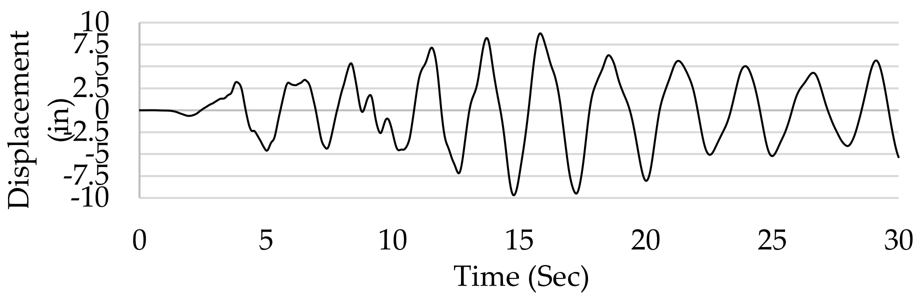


Fig. 4.48: Displacement of Northridge-1994-THLC-4 model 2 (FSWS) Y direction

4.4 MAXIMUM STORY DISPLACEMENT

The maximum story displacement values in all-time history load cases X and Y for models 1 & 2 are described there.

4.4.1 El Centro 1940

The maximum story displacement values in time history load cases X and Y for models 1 and 2 are shown in Table 4.31.

Table 4.31: Maximum Story displacement in X & Y for El-Centro time history pairs load case

Time History Load Case	Maximum Story Displacement			
	Model 1 (MRFS)		Model 2 (FSWS)	
	X (in)	Y (in)	X (in)	Y (in)
El-Centro 1940-THLC-1	8.40	2.57	8.85	2.37
El-Centro 1940-THLC-2	2.23	9.23	2.32	10.62
El-Centro 1940-THLC-3	7.44	2.79	7.74	3.19
El-Centro 1940-THLC-4	2.66	8.42	2.65	8.05

4.4.2 Kobe 1995

The maximum story displacement values in time history load cases X and Y for models 1 and 2 are shown in Table 4.32.

Table 4.32: Maximum Story displacement in X & Y for Kobe time history pairs load case

Time History Load Case	Maximum Story Displacement			
	Model 1 (MRFS)		Model 2 (FSWS)	
	X (in)	Y (in)	X (in)	Y (in)
Kobe 1995-THLC-1	7.88	2.40	9.49	2.60
Kobe 1995-THLC-2	2.32	8.11	2.54	9.36
Kobe 1995-THLC-3	7.71	2.42	8.48	2.88
Kobe 1995-THLC-4	2.34	7.99	2.84	8.87

4.4.3 Northridge 1994

The maximum story displacement values in time history load cases X and Y for models 1 and 2 are shown in Table 4.33.

Table 4.33: Maximum Story displacement in X & Y for Northridge time history pairs load case

Time History Load Case	Maximum Story Displacement (in)			
	Model 1 (MRFS)		Model 2 (FSWS)	
	X (in)	Y (in)	X (in)	Y (in)
Northridge 1994-THLC-1	9.79	2.56	9.51	2.57
Northridge 1994-THLC-2	2.22	9.68	2.73	9.58
Northridge 1994-THLC-3	7.39	2.89	9.10	2.95
Northridge 1994-THLC-4	2.94	8.51	2.85	8.77

4.5 STORY DRIFT RATIO

The story drift ratio values in all-time history load cases X and Y for models 1 & 2 are described there.

4.5.1 El-Centro 1940

The story drift ratio has been compared for two building models with two framing systems in both X and Y directions are shown in Table 4.34 and Table 4.35 Fig. 4.49 & Fig. 4.50 respectively. For Model 1 (MRFS), the maximum story drift ratio is found for the time history load case El-Centro-THLC-1. Along X and Y directions maximum story drift ratio is 0.02 at the 8th story level and 0.005 at the 2nd story level respectively. For time-history load case El-Centro -THLC-2. Along X and Y directions maximum story drift ratio is 0.005 at the 2nd story level and 0.018 at the 5th story level respectively. For time-history load case El-Centro -THLC-3. Along X and Y directions maximum story drift ratio is 0.017 at the 3rd story level and 0.005 at the 2nd story level respectively. For time-history load case El-Centro -THLC-4. Along X and Y directions maximum story drift ratio is 0.016 at the 3rd story level and 0.017 at the 4th story level respectively. On the other hand, for Model 2 (FSWS), the maximum story drift ratio is found for the time history load case El-Centro-THLC-1. Along X and Y directions maximum story drift ratio is 0.017 at the 8th story level and 0.004 at the 4th story level respectively. For time-history load case El-Centro -THLC-2 maximum story drift ratio. Along X and Y directions maximum story drift ratio is 0.005 at the 4th story level and 0.019 at the 13th story level respectively. For time-history load case El-Centro -THLC-3. Along X and Y directions maximum story drift ratio is 0.018 at the 6th story level and 0.006 at the 15th story level respectively. For time-history load case El-Centro - THLC-4. Along X and Y directions maximum story drift ratio is 0.005 at the 6th story level and 0.014 at the 7th story level respectively. Structural behavior maximum bending shifted upward in FSWS compared to MRFS, as the maximum story drift ratio is found at story 8 in MRFS and story 15 in FSWS.

Table 4.34: Story Drift Ratio in X & Y for El-Centro THLC-1 & THLC-2

Story	Story Drift Ratio							
	Model 1 (MRFS)				Model 2 (FSWS)			
	Load case El-Centro 1940-THLC-1		Load case El-Centro 1940-THLC-2		Load case El-Centro 1940-THLC-1		Load case El-Centro 1940-THLC-2	
	X	Y	X	Y	X	Y	X	Y
30	0.004	0.002	0.001	0.008	0.009	0.003	0.002	0.013
29	0.005	0.002	0.001	0.008	0.009	0.004	0.002	0.014
28	0.006	0.002	0.001	0.009	0.010	0.004	0.002	0.014
27	0.007	0.003	0.002	0.010	0.010	0.004	0.002	0.015
26	0.008	0.003	0.002	0.011	0.011	0.004	0.002	0.015
25	0.009	0.003	0.002	0.010	0.011	0.004	0.002	0.016
24	0.010	0.003	0.002	0.010	0.012	0.004	0.002	0.017
23	0.010	0.003	0.002	0.011	0.013	0.004	0.002	0.017
22	0.011	0.004	0.003	0.011	0.013	0.004	0.002	0.018
21	0.011	0.004	0.003	0.012	0.014	0.004	0.003	0.018
20	0.010	0.004	0.003	0.013	0.014	0.004	0.003	0.018
19	0.011	0.004	0.003	0.013	0.015	0.004	0.003	0.019
18	0.011	0.004	0.004	0.014	0.015	0.004	0.003	0.019
17	0.012	0.004	0.004	0.014	0.016	0.004	0.004	0.019
16	0.013	0.004	0.004	0.015	0.016	0.004	0.004	0.019
15	0.014	0.004	0.004	0.015	0.017	0.004	0.004	0.019
14	0.015	0.004	0.005	0.016	0.017	0.004	0.004	0.019
13	0.016	0.004	0.005	0.016	0.017	0.004	0.005	0.019
12	0.017	0.004	0.004	0.017	0.017	0.004	0.005	0.016
11	0.018	0.004	0.004	0.017	0.017	0.004	0.005	0.016
10	0.018	0.004	0.004	0.018	0.017	0.004	0.005	0.017
9	0.019	0.005	0.004	0.018	0.017	0.004	0.005	0.017

8	0.020	0.005	0.004	0.018	0.017	0.004	0.005	0.017
7	0.017	0.005	0.005	0.018	0.016	0.004	0.005	0.017
6	0.019	0.005	0.005	0.018	0.015	0.004	0.005	0.016
5	0.016	0.005	0.005	0.018	0.014	0.004	0.005	0.015
4	0.014	0.005	0.005	0.017	0.013	0.004	0.005	0.014
3	0.008	0.005	0.005	0.017	0.012	0.003	0.004	0.013
2	0.009	0.005	0.005	0.015	0.009	0.003	0.003	0.010
1	0.015	0.004	0.004	0.011	0.006	0.002	0.002	0.007
0	0.015	0.002	0.002	0.005	0.003	0.001	0.001	0.003

Table 4.35: Story Drift Ratio in X & Y for El-Centro THLC-3 & THLC-4

Story	Story Drift Ratio							
	Model 1 (MRFS)				Model 2 (FSWS)			
	Load case El-Centro 1940-THLC-3		Load case El-Centro 1940-THLC-4		Load case El-Centro 1940-THLC-3		Load case El-Centro 1940-THLC-4	
	X	Y	X	Y	X	Y	X	Y
30	0.004	0.002	0.001	0.007	0.007	0.004	0.003	0.011
29	0.004	0.003	0.002	0.007	0.007	0.004	0.003	0.012
28	0.005	0.003	0.002	0.008	0.007	0.004	0.003	0.012
27	0.005	0.003	0.002	0.009	0.007	0.004	0.003	0.012
26	0.006	0.003	0.002	0.009	0.007	0.005	0.003	0.013
25	0.006	0.003	0.003	0.010	0.007	0.005	0.003	0.013
24	0.007	0.003	0.003	0.011	0.007	0.005	0.004	0.013
23	0.008	0.003	0.003	0.012	0.007	0.005	0.004	0.012
22	0.009	0.003	0.003	0.012	0.008	0.005	0.004	0.012
21	0.009	0.004	0.003	0.013	0.009	0.005	0.004	0.012
20	0.010	0.004	0.003	0.013	0.009	0.005	0.004	0.012
19	0.011	0.004	0.003	0.013	0.010	0.006	0.004	0.012
18	0.012	0.004	0.003	0.013	0.011	0.006	0.005	0.012
17	0.013	0.004	0.004	0.013	0.012	0.006	0.005	0.012
16	0.014	0.005	0.004	0.013	0.013	0.006	0.005	0.013
15	0.015	0.005	0.004	0.013	0.014	0.006	0.005	0.013
14	0.015	0.005	0.004	0.013	0.015	0.005	0.005	0.013
13	0.016	0.005	0.005	0.013	0.016	0.005	0.005	0.013
12	0.015	0.005	0.005	0.014	0.016	0.005	0.005	0.013
11	0.012	0.005	0.005	0.014	0.017	0.005	0.005	0.014
10	0.012	0.005	0.006	0.014	0.017	0.005	0.005	0.014
9	0.013	0.005	0.006	0.015	0.018	0.005	0.005	0.014
8	0.014	0.005	0.006	0.015	0.018	0.005	0.005	0.014
7	0.015	0.005	0.006	0.015	0.018	0.005	0.005	0.014
6	0.016	0.005	0.006	0.016	0.018	0.005	0.005	0.013

5	0.016	0.005	0.006	0.017	0.017	0.005	0.004	0.013
4	0.017	0.005	0.006	0.017	0.016	0.004	0.004	0.012
3	0.017	0.005	0.006	0.016	0.014	0.004	0.003	0.011
2	0.016	0.005	0.005	0.015	0.011	0.003	0.003	0.009
1	0.012	0.003	0.004	0.012	0.008	0.002	0.002	0.006
0	0.005	0.001	0.002	0.005	0.003	0.001	0.001	0.003

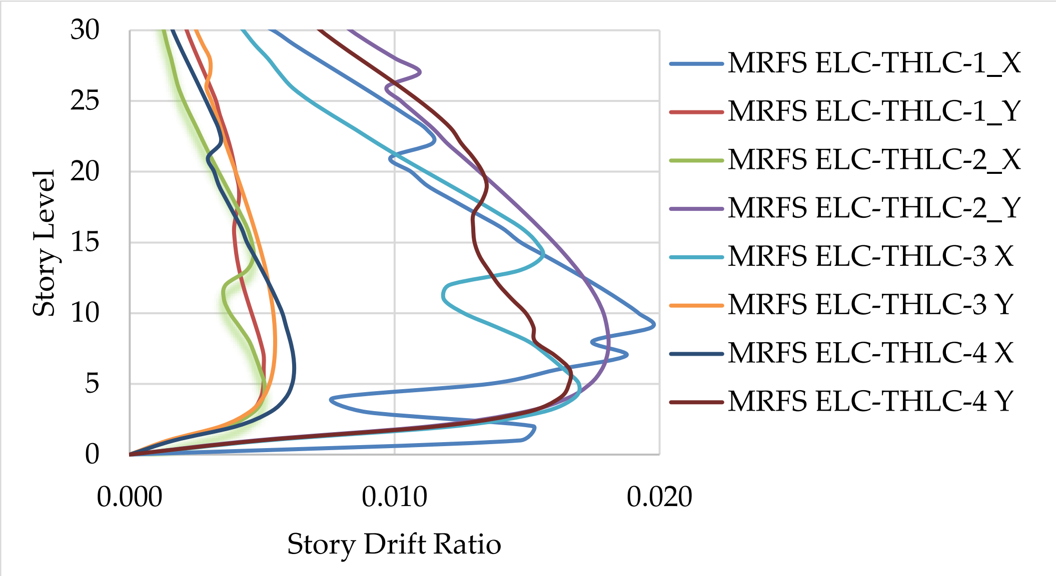


Fig. 4.49: Story drift ratio of El-Centro (MRFS X &Y)

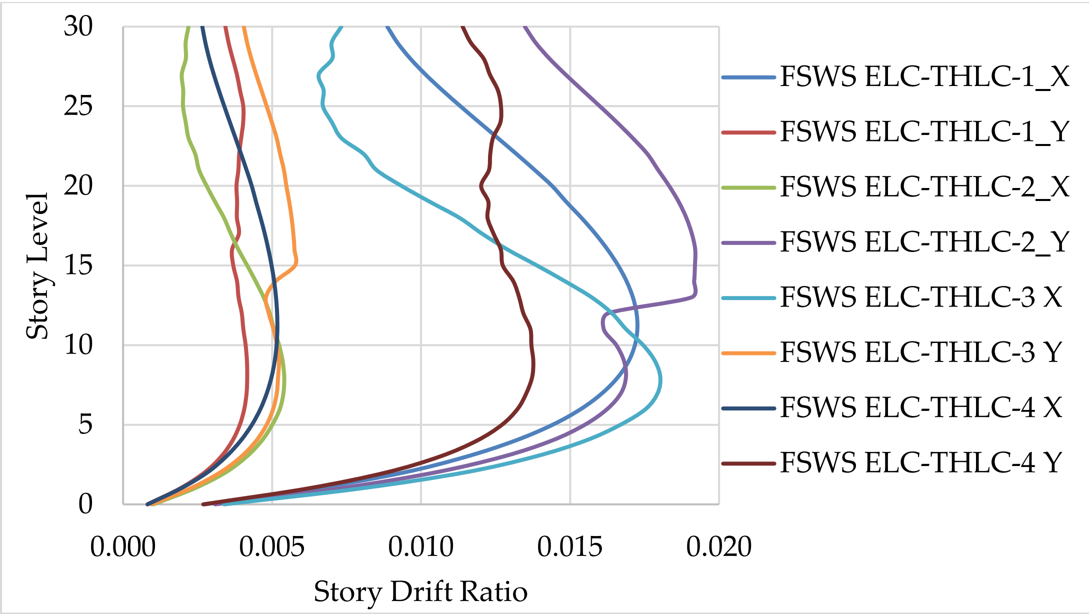


Fig. 4.50: Story drift ratio of El-Centro (FSWS X & Y)

4.5.2 Kobe 1995

The story drift ratio has been compared for two building models with two framing systems in both X and Y directions, shown in Table 4.36 and Table 4.37 Fig. 4.51 and Fig. 4.52, respectively. For Model 1 (MRFS), the maximum story drift ratio is found for time history load case Kobe-U1=THLC-1. Along X and Y directions maximum story drift ratio is 0.018 at the 4th story level and 0.004 at the 2nd story level respectively. For time-history load case Kobe-THLC-2. Along X and Y directions maximum story drift ratio is 0.004 at the 2nd story level and 0.019 at the 5th story level respectively. For time-history load case Kobe-THLC-3. Along X and Y directions maximum story drift ratio is 0.015 at the 4th story level and 0.006 at the 4th story level respectively. For time-history load case Kobe-THLC-4. Along X and Y directions maximum story drift ratio is 0.007 at the 4th story level and 0.014 at the 9th story level respectively. On the other hand, for Model 2 (FSWS), the maximum story drift ratio is found for the time history load case Kobe-THLC-1. Along X and Y directions maximum story drift ratio is 0.019 at the 13th story level and 0.005 at the 6th story level respectively. For time-history load case Kobe-THLC-2 maximum story drift ratio. Along X and Y directions maximum story drift ratio is 0.005 at the 10th story level and 0.017 at the 13th story level respectively. For time-history load case Kobe-THLC-3. Along X and Y directions maximum story drift ratio is 0.016 at the 10th story level and 0.005 at the 5th story level respectively. For time-history load case Kobe-THLC-4. Along X and Y directions maximum story drift ratio is 0.006 at the 12th story level and 0.016 at the 7th story level respectively. Structural behavior maximum bending shifted upward in FSWS compared to MRFS, as the maximum story drift ratio is found at story 9 in MRFS and story 13 in FSWS.

Table 4.36: Story Drift Ratio in X & Y for Kobe THLC-1 & THLC-2

Story	Story Drift Ratio							
	Model 1 (MRFS)				Model 2 (FSWS)			
	Load case Kobe-THLC-1		Load case Kobe-THLC-2		Load case Kobe-THLC-1		Load case Kobe-THLC-2	
	X	Y	X	Y	X	Y	X	Y
30	0.007	0.003	0.002	0.007	0.010	0.005	0.004	0.011
29	0.008	0.003	0.002	0.008	0.011	0.005	0.004	0.012
28	0.008	0.003	0.002	0.008	0.011	0.005	0.004	0.012
27	0.008	0.004	0.003	0.009	0.012	0.006	0.003	0.012
26	0.008	0.004	0.003	0.009	0.013	0.006	0.003	0.013
25	0.008	0.004	0.003	0.009	0.013	0.006	0.003	0.013
24	0.008	0.004	0.004	0.008	0.014	0.006	0.004	0.014
23	0.008	0.005	0.004	0.008	0.015	0.006	0.004	0.014
22	0.007	0.004	0.004	0.008	0.015	0.005	0.004	0.014
21	0.007	0.004	0.005	0.007	0.016	0.002	0.004	0.015
20	0.008	0.003	0.005	0.008	0.017	0.002	0.004	0.015
19	0.008	0.003	0.005	0.008	0.017	0.002	0.004	0.015
18	0.008	0.003	0.004	0.009	0.018	0.002	0.004	0.016
17	0.009	0.003	0.003	0.010	0.018	0.003	0.005	0.016
16	0.010	0.003	0.003	0.011	0.018	0.003	0.005	0.016
15	0.011	0.003	0.003	0.012	0.018	0.003	0.005	0.017
14	0.012	0.004	0.003	0.013	0.019	0.004	0.005	0.017
13	0.013	0.004	0.003	0.014	0.019	0.004	0.005	0.017
12	0.015	0.004	0.004	0.015	0.018	0.004	0.005	0.014
11	0.016	0.004	0.003	0.016	0.018	0.004	0.005	0.014
10	0.016	0.004	0.003	0.017	0.018	0.005	0.005	0.015
9	0.017	0.004	0.004	0.018	0.017	0.005	0.005	0.016
8	0.018	0.004	0.004	0.018	0.017	0.005	0.004	0.016
7	0.018	0.004	0.004	0.019	0.014	0.005	0.004	0.016
6	0.018	0.004	0.004	0.019	0.014	0.005	0.004	0.016
5	0.018	0.004	0.004	0.019	0.013	0.004	0.004	0.016
4	0.018	0.004	0.004	0.018	0.013	0.004	0.003	0.015
3	0.017	0.004	0.004	0.018	0.011	0.004	0.003	0.013
2	0.015	0.004	0.004	0.016	0.010	0.003	0.003	0.011
1	0.012	0.003	0.003	0.012	0.007	0.002	0.002	0.008
0	0.004	0.001	0.001	0.005	0.003	0.001	0.001	0.003

Table 4.37: Story Drift Ratio in X & Y for Kobe THLC-3 & THLC-4

Story	Story Drift Ratio							
	Model 1 (MRFS)				Model 2 (FSWS)			
	Load case Kobe-THLC-3		Load case Kobe-THLC-4		Load case Kobe-THLC-3		Load case Kobe-THLC-4	
	X	Y	X	Y	X	Y	X	Y
30	0.006	0.002	0.001	0.008	0.012	0.003	0.003	0.016
29	0.006	0.002	0.001	0.009	0.013	0.004	0.003	0.016
28	0.008	0.002	0.001	0.011	0.013	0.004	0.003	0.017
27	0.009	0.003	0.001	0.012	0.010	0.004	0.004	0.018
26	0.010	0.003	0.001	0.013	0.011	0.004	0.004	0.019
25	0.011	0.003	0.001	0.014	0.011	0.004	0.004	0.019
24	0.012	0.002	0.001	0.015	0.012	0.004	0.004	0.020
23	0.013	0.002	0.001	0.015	0.012	0.004	0.004	0.020
22	0.014	0.002	0.001	0.015	0.013	0.004	0.005	0.018
21	0.015	0.002	0.002	0.014	0.014	0.004	0.005	0.007
20	0.016	0.002	0.002	0.011	0.014	0.005	0.005	0.006
19	0.016	0.002	0.002	0.010	0.014	0.005	0.005	0.007
18	0.012	0.003	0.002	0.009	0.015	0.005	0.005	0.007
17	0.010	0.003	0.003	0.010	0.015	0.005	0.005	0.008
16	0.010	0.003	0.003	0.010	0.016	0.005	0.005	0.010
15	0.010	0.004	0.004	0.011	0.016	0.005	0.006	0.011
14	0.010	0.004	0.004	0.012	0.016	0.005	0.006	0.012
13	0.011	0.004	0.004	0.012	0.016	0.005	0.006	0.013
12	0.012	0.005	0.005	0.013	0.016	0.005	0.006	0.014
11	0.011	0.005	0.005	0.013	0.016	0.005	0.005	0.015
10	0.011	0.005	0.006	0.014	0.016	0.005	0.005	0.015
9	0.012	0.005	0.006	0.014	0.015	0.005	0.005	0.016
8	0.013	0.006	0.006	0.013	0.015	0.005	0.005	0.016
7	0.014	0.006	0.006	0.013	0.014	0.005	0.004	0.016
6	0.014	0.006	0.007	0.013	0.012	0.005	0.004	0.015
5	0.015	0.006	0.007	0.013	0.012	0.005	0.004	0.014
4	0.015	0.006	0.007	0.013	0.011	0.004	0.004	0.013
3	0.014	0.005	0.006	0.013	0.010	0.004	0.003	0.011
2	0.013	0.005	0.006	0.012	0.009	0.003	0.003	0.009
1	0.010	0.004	0.004	0.009	0.006	0.002	0.002	0.006
0	0.004	0.002	0.002	0.004	0.003	0.001	0.001	0.003

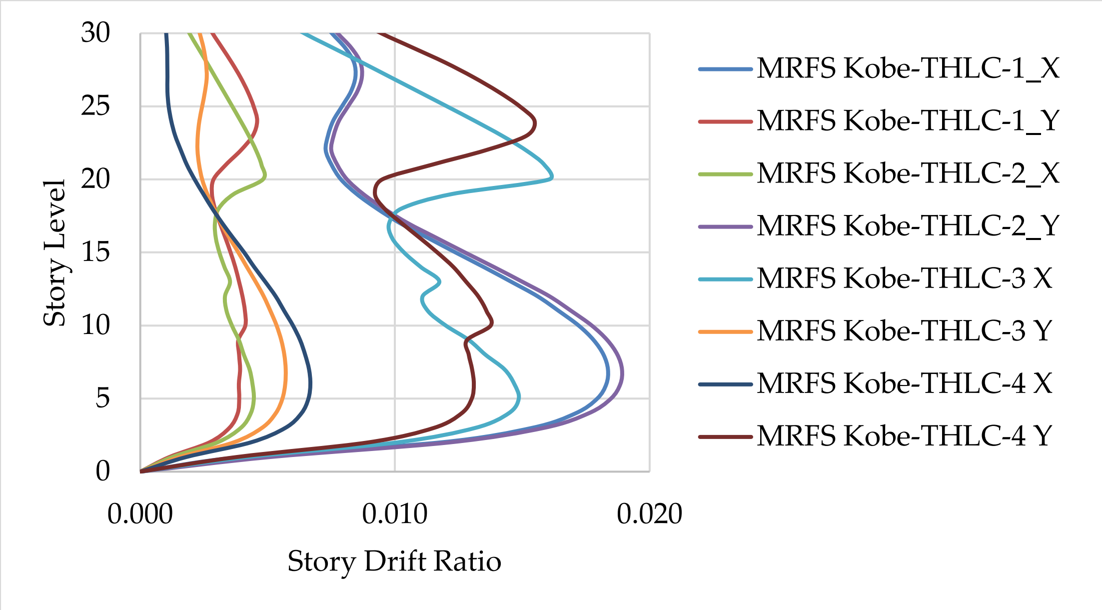


Fig. 4.51: Story drift ratio Kobe (MRFS X &Y)

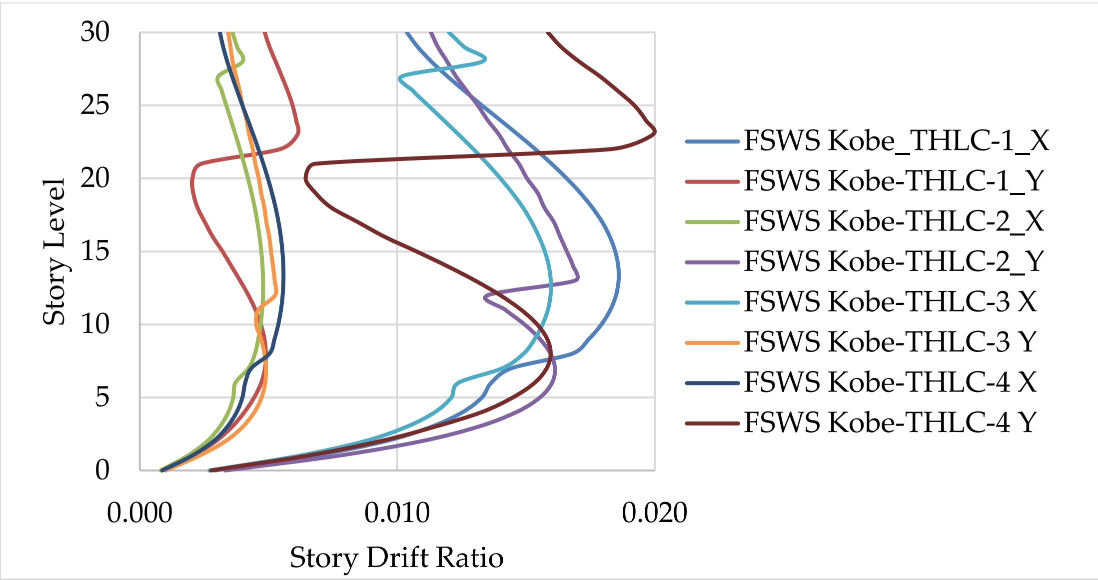


Fig. 4.52: Story drift ratio Kobe (FSWS X &Y)

4.5.3 Northridge 1994

The story drift ratio has been compared for two building models with two framing systems in both X and Y directions, shown in Table 4.38 and Table 4.39 Fig. 4.53 and Fig. 4.54, respectively. For Model 1 (MRFS), the maximum story drift ratio is found for time history load case Northridge-THLC-1. Along X and Y directions maximum story drift ratio is 0.018 at the 10th story level and

0.006 at the 4th story level respectively. For time-history load case Northridge-THLC-2. Along X and Y directions maximum story drift ratio is 0.006 at the 4th story level and 0.018 at the 17th story level respectively. For time-history load case Northridge-THLC-3. Along X and Y directions maximum story drift ratio is 0.019 at the 4th story level and 0.005 at the 6th story level respectively. For time-history load case Northridge-THLC-4. Along X and Y directions maximum story drift ratio is 0.005 at the 3rd story level and 0.019 at the 4th story level respectively. On the other hand, for Model 2 (FSWS), the maximum story drift ratio is found for time history load case Northridge-THLC-1. Along X and Y directions maximum story drift ratio is 0.018 at the 6th story level and 0.005 at the 13th story level respectively. For time-history load case Northridge-THLC-2 maximum story drift ratio. Along X and Y directions maximum story drift ratio is 0.005 at the 7th story level and 0.017 at the 7th story level respectively. For time-history load case Northridge-THLC-3 maximum story drift ratio. Along X and Y directions maximum story drift ratio is 0.017 at the 11th story level and 0.005 at the 5th story level respectively. For time-history load case Northridge-THLC-4 maximum story drift ratio. Along X and Y directions, the maximum story drift ratio is 0.005 at the 5th story level and 0.016 at the 14th story level respectively. Structural behavior maximum bending shifted upward in MRFS compared to FSWS at the Y direction, as the maximum story drift ratio is found at story 4 in MRFS and story 6 in FSWS.

Table 4.38: Story Drift Ratio in X & Y for Northridge THLC-1 & THLC-2

Story	Story Drift Ratio							
	Model 1 (MRFS)				Model 2 (FSWS)			
	Load case Northridge 1994-THLC-1		Load case Northridge1994-THLC-2		Load case Northridge1994-THLC-1		Load case Northridge-THLC-2	
	X	Y	X	Y	X	Y	X	Y
30	0.007	0.002	0.001	0.010	0.011	0.004	0.003	0.013
29	0.008	0.002	0.002	0.011	0.012	0.004	0.003	0.013
28	0.009	0.002	0.002	0.012	0.012	0.004	0.003	0.014
27	0.011	0.002	0.002	0.013	0.012	0.004	0.003	0.014

26	0.012	0.003	0.002	0.014	0.013	0.004	0.004	0.015
25	0.013	0.003	0.002	0.015	0.013	0.004	0.004	0.015
24	0.015	0.003	0.002	0.015	0.014	0.004	0.004	0.014
23	0.016	0.003	0.002	0.016	0.014	0.004	0.004	0.014
22	0.017	0.003	0.002	0.016	0.014	0.005	0.004	0.014
21	0.017	0.003	0.002	0.016	0.015	0.005	0.005	0.014
20	0.017	0.003	0.002	0.016	0.016	0.005	0.005	0.014
19	0.017	0.004	0.002	0.017	0.016	0.005	0.005	0.015
18	0.016	0.004	0.002	0.017	0.016	0.005	0.005	0.015
17	0.016	0.004	0.003	0.018	0.017	0.005	0.005	0.015
16	0.016	0.004	0.003	0.016	0.013	0.005	0.005	0.016
15	0.017	0.004	0.003	0.015	0.014	0.005	0.005	0.016
14	0.017	0.004	0.003	0.015	0.015	0.005	0.005	0.016
13	0.017	0.004	0.004	0.015	0.015	0.005	0.005	0.017
12	0.017	0.004	0.004	0.015	0.016	0.004	0.005	0.017
11	0.018	0.004	0.004	0.015	0.017	0.004	0.005	0.017
10	0.018	0.005	0.005	0.015	0.017	0.004	0.005	0.017
9	0.017	0.005	0.005	0.015	0.018	0.004	0.005	0.017
8	0.016	0.005	0.005	0.015	0.018	0.004	0.005	0.017
7	0.016	0.005	0.005	0.015	0.018	0.004	0.005	0.017
6	0.016	0.005	0.005	0.015	0.018	0.004	0.004	0.016
5	0.016	0.006	0.006	0.015	0.017	0.004	0.004	0.015
4	0.016	0.006	0.006	0.015	0.016	0.004	0.004	0.014
3	0.016	0.005	0.005	0.014	0.015	0.003	0.003	0.012
2	0.014	0.005	0.005	0.013	0.012	0.003	0.003	0.010
1	0.011	0.004	0.004	0.010	0.009	0.002	0.002	0.007
0	0.005	0.002	0.002	0.004	0.004	0.001	0.001	0.003

Table 4.39: Story Drift Ratio in X & Y for Northridge THLC-3 & THLC-4

Story	Story Drift Ratio							
	Model 1 (MRFS)				Model 2 (FSWS)			
	Load case Northridge 1994-THLC-3		Load case Northridge1994-THLC-4		Load case Northridge1994-THLC-3		Load case Northridge-THLC-4	
	X	Y	X	Y	X	Y	X	Y
30	0.005	0.003	0.002	0.006	0.010	0.004	0.003	0.012
29	0.005	0.003	0.002	0.007	0.010	0.004	0.003	0.012
28	0.006	0.004	0.003	0.007	0.011	0.004	0.004	0.013
27	0.007	0.004	0.003	0.008	0.011	0.004	0.004	0.013
26	0.007	0.004	0.004	0.008	0.012	0.004	0.004	0.013
25	0.007	0.005	0.004	0.009	0.013	0.004	0.004	0.014
24	0.007	0.005	0.004	0.010	0.013	0.004	0.004	0.014

23	0.007	0.005	0.005	0.010	0.014	0.004	0.004	0.014
22	0.007	0.005	0.005	0.010	0.014	0.004	0.004	0.015
21	0.007	0.005	0.005	0.011	0.015	0.004	0.005	0.015
20	0.007	0.005	0.005	0.011	0.016	0.004	0.005	0.015
19	0.007	0.005	0.005	0.012	0.016	0.004	0.005	0.015
18	0.008	0.005	0.005	0.012	0.016	0.005	0.005	0.016
17	0.008	0.005	0.005	0.013	0.017	0.005	0.005	0.016
16	0.009	0.005	0.005	0.013	0.017	0.005	0.004	0.016
15	0.010	0.004	0.005	0.014	0.017	0.005	0.004	0.016
14	0.011	0.004	0.005	0.012	0.017	0.005	0.004	0.016
13	0.012	0.005	0.005	0.013	0.017	0.005	0.005	0.013
12	0.013	0.005	0.005	0.014	0.017	0.005	0.005	0.012
11	0.014	0.005	0.005	0.015	0.017	0.005	0.005	0.013
10	0.015	0.005	0.005	0.016	0.016	0.005	0.005	0.013
9	0.016	0.005	0.005	0.016	0.016	0.005	0.005	0.014
8	0.017	0.005	0.005	0.017	0.016	0.005	0.005	0.014
7	0.017	0.005	0.005	0.018	0.015	0.005	0.005	0.014
6	0.018	0.005	0.005	0.018	0.014	0.005	0.005	0.014
5	0.019	0.004	0.005	0.018	0.014	0.005	0.005	0.013
4	0.019	0.004	0.005	0.019	0.012	0.004	0.005	0.012
3	0.018	0.004	0.005	0.018	0.011	0.004	0.004	0.011
2	0.017	0.004	0.004	0.017	0.009	0.003	0.004	0.009
1	0.013	0.003	0.003	0.013	0.006	0.002	0.003	0.006
0	0.005	0.001	0.001	0.005	0.003	0.001	0.001	0.003

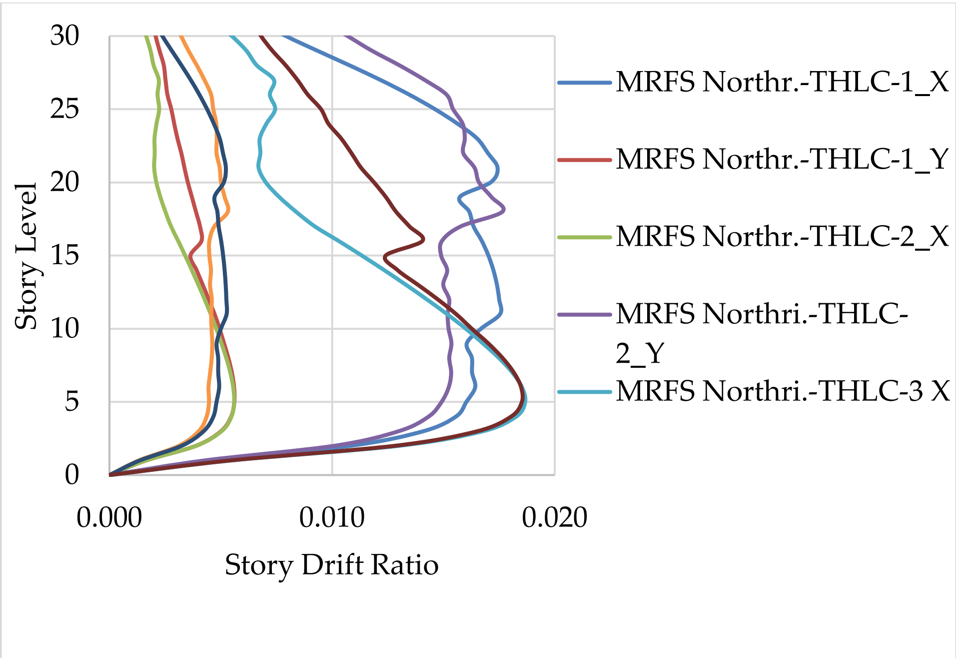


Fig. 4.53: Story drift ratio Northridge (MRFS X & Y)

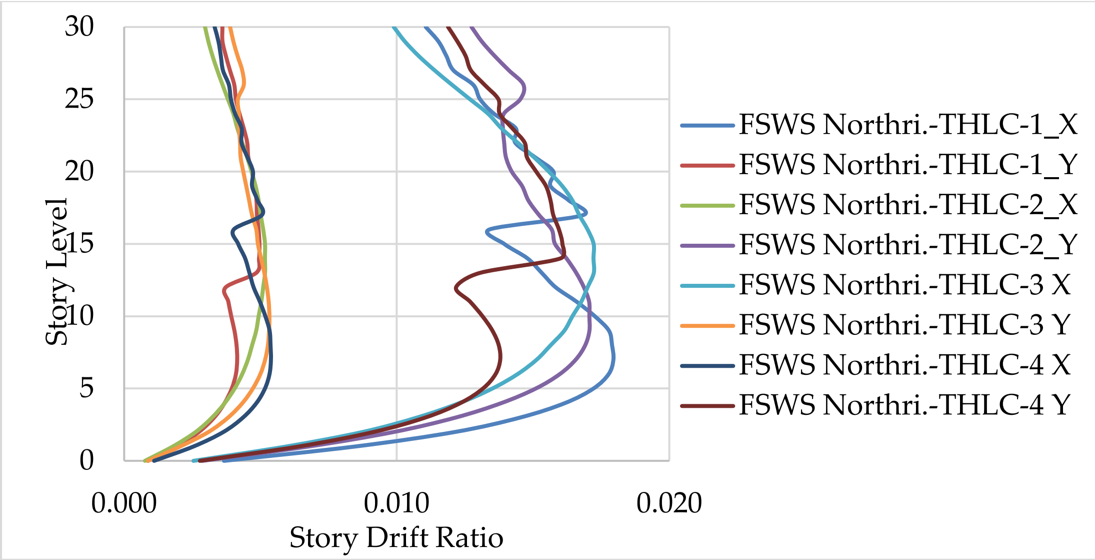


Fig. 4.54: Story drift ratio Northridge (FSWS X & Y)

Table 4.40: Summary of maximum Story Drift Ratio

THA Load Case	Model 1 (MRFS)				Model 2 (FSWS)			
	X	Story	Y	Story	X	Story	Y	Story
El-Centro 1940-THLC-1	0.020	8th	0.005	2nd	0.017	8th	0.004	4th
El-Centro 1940-THLC-2	0.005	2nd	0.018	5th	0.005	4th	0.019	13th
El-Centro 1940-THLC-3	0.017	3rd	0.005	2nd	0.018	6th	0.006	15th
El-Centro 1940-THLC-4	0.006	3rd	0.017	4th	0.005	6th	0.014	7th
Kobe 1995_THLC-1	0.018	4th	0.004	2nd	0.019	13th	0.005	6th
Kobe 1995_THLC-2	0.004	2nd	0.019	5th	0.005	10th	0.017	13th
Kobe 1995_THLC-3	0.015	4th	0.006	4th	0.016	10th	0.005	5th
Kobe 1995_THLC-4	0.007	4th	0.014	9th	0.006	12th	0.016	7th
Northridge 1994-THLC-1	0.018	10th	0.006	4th	0.018	6th	0.005	13th
Northridge 1994-THLC-2	0.006	4th	0.018	17th	0.005	7th	0.017	7th
Northridge 1994-THLC-3	0.019	4th	0.005	6th	0.017	11th	0.005	5th
Northridge 1994-THLC-4	0.005	3rd	0.019	4th	0.005	5th	0.016	14th

The maximum story drift ratio summary is observed that each time history load case for X direction is greater model 1 (MRFS) than model 2 (FSWS). Maximum story drift ratio summary is observed that each time history load case for Y direction is equal between model 1 (MRFS) and model 2 (FSWS).

4.6 COMPARISON OF STORY DISPLACEMENT FOR DIFFERENT GROUND MOTION PAIRS

4.6.1 All Models for THLC-1 for all ground motion pairs

The maximum story displacement values for THLC-1 in X directions for building models 1 and 2 (MRFS and FSWS) with THA load case are shown in Table 4.41, Fig. 4.55 & 4.56. For El Centro 1940-THLC-1, maximum story displacement models 1 & 2 are 8.40 in, 2.57 in, and 8.85 in, 2.37 in the X and Y directions respectively. For Kobe 1995-THLC-1, maximum story displacement models 1 & 2 are 7.88 in, 2.40 in, and 9.49 in, 2.60 in the X and Y direction respectively. For Northridge 1994-THLC-1, maximum story displacement models 1 & 2 are 9.79 in, 2.56 in, and 9.51 in, 2.57 in the X and Y direction respectively. Although, the two building models consist of the same plan area, story displacement maximum El Centro 1940 and Northridge 1994 in both model 1 and model 2.

Table 4.41: Maximum story displacement in load case THLC-1 for all Models

Time History Load Case	Maximum Story Displacement			
	Model 1 (MRFS)		Model 2 (FSWS)	
	X (in)	Y (in)	X (in)	Y (in)
El-Centro 1940-THLC-1	8.40	2.57	8.85	2.37
Kobe 1995-THLC-1	7.88	2.40	9.49	2.60
Northridge 1994-THLC-1	9.79	2.56	9.51	2.57

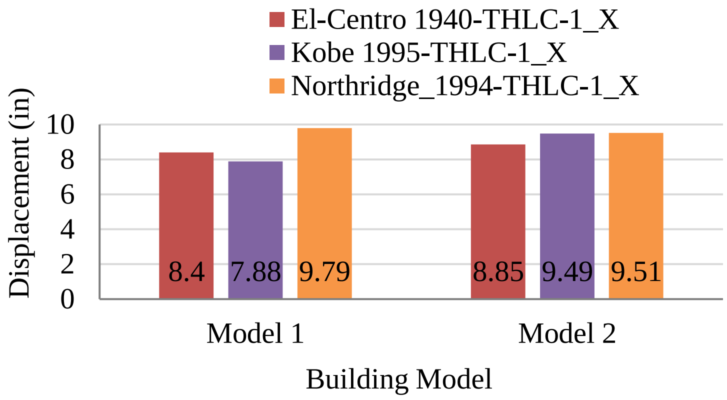


Fig. 4.55: Maximum Story Displacement X direction for THLC-1

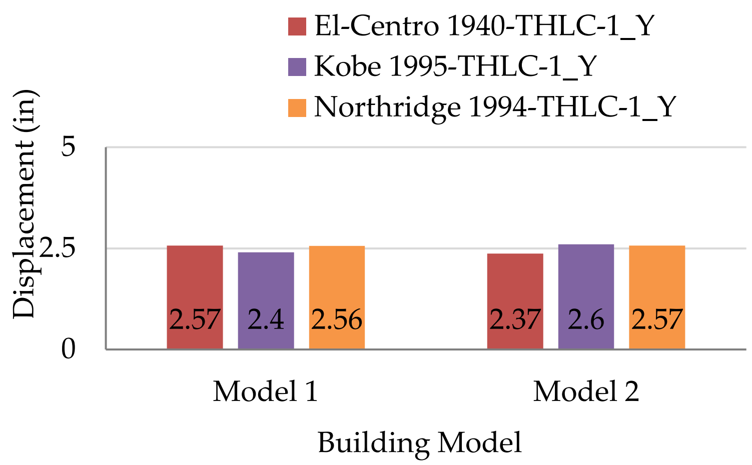


Fig. 4.56: Maximum Story Displacement Y direction for THLC-1

4.6.2 All Models in THLC-2 for all ground motion pairs

The maximum story displacement values in the THLC-2 load case for building models 1 and 2 (MRFS and FSWS) with THA load case are shown in Table 4.42, Fig. 4.57 & 4.58. For El Centro 1940-THLC-2, maximum story displacement models 1 & 2 are 2.23 in, 9.23 in, and 2.32 in, 10.62 in the X and Y direction respectively. For Kobe 1995-THLC-2, the maximum story displacement models 1 & 2 are 2.32 in, 8.11 in, and 2.54 in, 9.36 in the X and Y directions respectively. For Northridge 1994-THLC-2, maximum story displacement models 1 & 2 are 2.22 in, 9.68 in, and 2.73 in, 9.58 in the X & Y directions respectively. Although, the two building models consist of the same plan area, story displacement maximum El Centro1940 and Northridge 1994 in both models 1 and 2.

Table 4.42: Maximum story displacement in load case THLC-2 for all Models

Time History Load Case	Maximum Story Displacement			
	Model 1 (MRFS)		Model 2 (FSWS)	
	X (in)	Y (in)	X (in)	Y (in)
El-Centro 1940-THLC-2	2.23	9.23	2.32	10.62
Kobe 1995-THLC-2	2.32	8.11	2.54	9.36
Northridge 1994-THLC-2	2.22	9.68	2.73	9.58

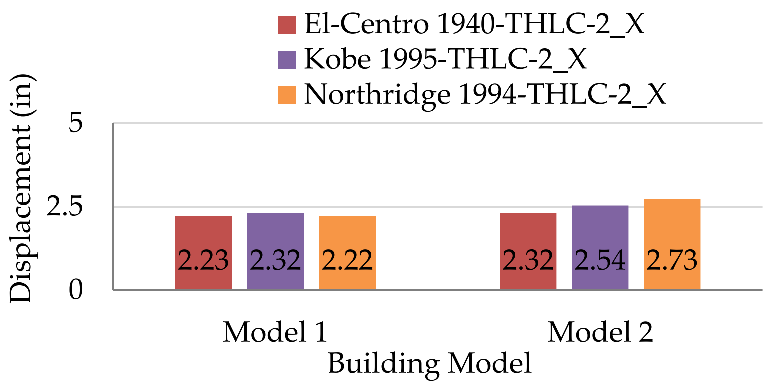


Fig. 4.57: Maximum Story Displacement X direction for THLC-2

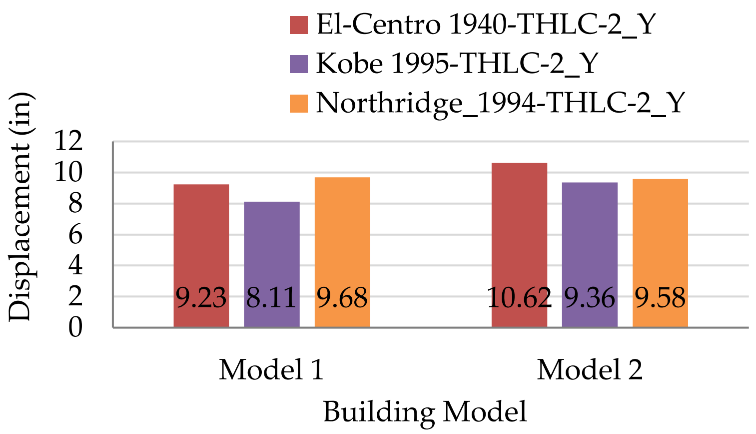


Fig. 4.58: Maximum Story Displacement Y direction for THLC-2

4.6.3 All Models in THLC-3 for all ground motion pairs

The maximum story displacement values in the THLC-3 load case for building models 1 and 2 (MRFS and FSWS) with THA load case are shown in Table 4.43, Fig. 4.59 & 4.60. For El Centro 1940-THLC-3, maximum story displacement models 1 & 2 are 7.44 in, 2.79 in, and 7.74 in, 3.19 in the X and Y direction respectively. For Kobe 1995-THLC-3, the maximum story displacement models 1 & 2 are 7.71 in, 2.42 in, and 8.48 in, 2.88 in the X and Y directions respectively. For Northridge 1994-THLC-3, maximum story displacement models 1 & 2 are 7.39 in, 2.89 in, and 9.10 in, 2.95 in the X & Y directions respectively. Although, the two building models consist of the same plan area, story displacement maximum Kobe 1995 and Northridge 1994 in both models 1 and 2.

Table 4.43: Maximum story displacement in load case THLC-3 for all Models

Time History Load Case	Maximum Story Displacement			
	Model 1 (MRFS)		Model 2 (FSWS)	
	X (in)	Y (in)	X (in)	Y (in)
El-Centro 1940-THLC-3	7.44	2.79	7.74	3.19
Kobe 1995-THLC-3	7.71	2.42	8.48	2.88
Northridge 1994-THLC-3	7.39	2.89	9.10	2.95

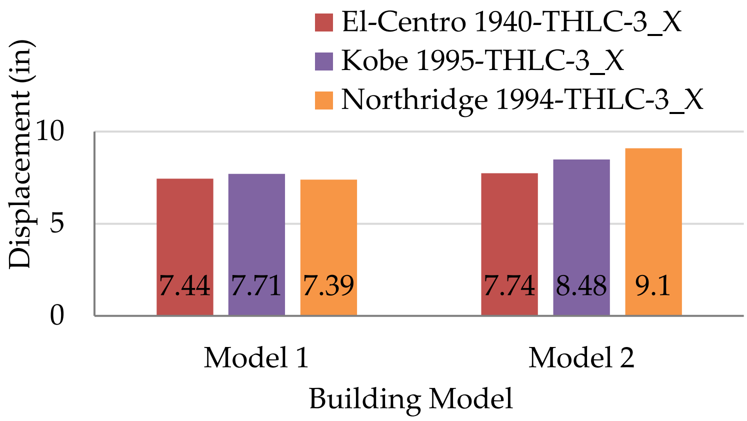


Fig. 4.59: Maximum Story Displacement X direction for THLC-3

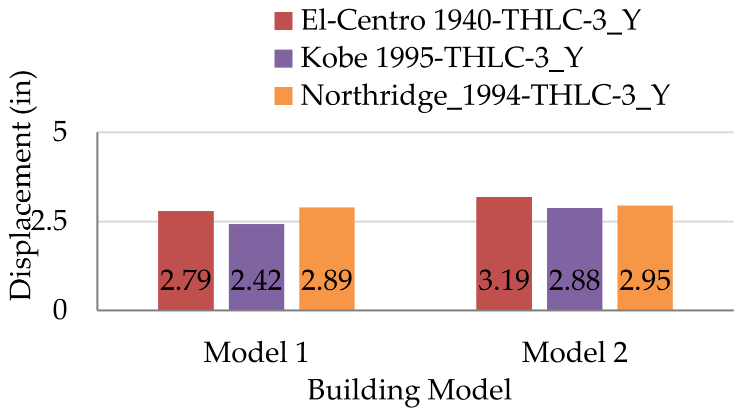


Fig. 4.60: Maximum Story Displacement Y direction for THLC-3

4.6.4 All Models in THLC-4 for all ground motion pairs

The maximum story displacement values in the THLC-4 load case for building models 1 and 2 (MRFS and FSWS) with THA load case are shown in Table 4.44, Fig. 4.61 & 4.62. For El Centro 1940-THLC-4, maximum story displacement models 1 & 2 are 2.66 in, 8.42 in, and 2.65 in, 8.05 in the X and Y direction respectively. For Kobe 1995-THLC-4, the maximum story displacement models 1 & 2 are 2.34 in, 7.99 in, and 2.84 in, 8.87 in the X and Y directions respectively. For Northridge 1994-THLC-4, maximum story displacement models 1 & 2 are 2.94 in, 8.51 in, and 2.85 in, 8.77 in the X & Y directions respectively. Although the two building models consist of the same plan area, story displacement is maximum in both models 1 and 2.

Table 4.44: Maximum story displacement in load case THLC-4 for all Models

Time History Load Case	Maximum Story Displacement			
	Model 1 (MRFS)		Model 2 (FSWS)	
	X (in)	Y (in)	X (in)	Y (in)
El-Centro 1940-THLC-4	2.66	8.42	2.65	8.05
Kobe 1995-THLC-4	2.34	7.99	2.84	8.87
Northridge 1994-THLC-4	2.94	8.51	2.85	8.77

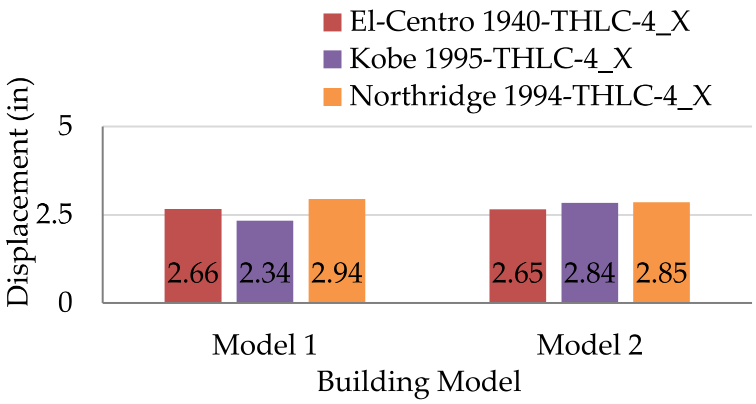


Fig. 4.61: Maximum Story Displacement X direction for THLC-4

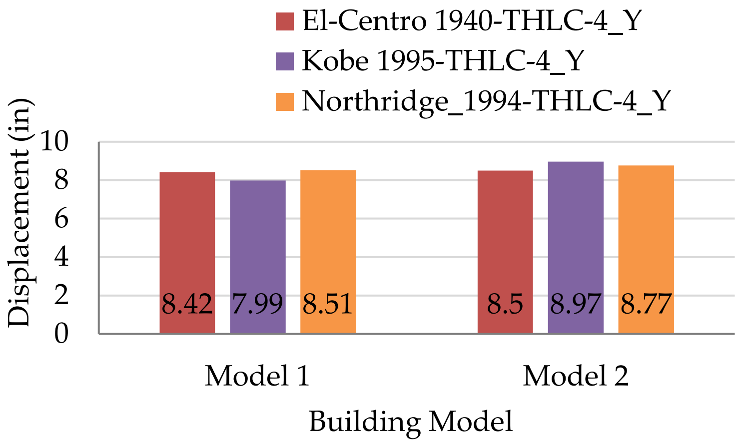


Fig. 4.62: Maximum Story Displacement Y direction for THLC-4

4.7 COMPARISON OF STORY DRIFT RATIO FOR DIFFERENT GROUND MOTION PAIRS

4.7.1 Model 1 (MRFS) for THLC-1 Load Case

The story drift ratio has been compared for building model 1 (MRFS) with THLC-1 load case are shown in Table 4.45, Fig. 4.63 & 4.64. Maximum story drift ratio values are 0.020, 0.018, and 0.018 for the X direction and 0.005, 0.004, and 0.006 for the Y direction of building model 1 with load case El Centro-THLC-1, Kobe-THLC-1, and Northridge-THLC-1 respectively at the different story level. El-Centro 1940 shows the highest story drift ratio values among all other ground motions.

Table 4.45: Story Drift Ratio for THLC-1 (Model 1)

Story	MRFS Story Drift Ratio (SDR)					
	El-Centro 1940-THLC-1		Kobe 1995-THLC-1		Northridge 1994-THLC-1	
	X	Y	X	Y	X	Y
30	0.004	0.002	0.007	0.003	0.007	0.002
29	0.005	0.002	0.008	0.003	0.008	0.002
28	0.006	0.002	0.008	0.003	0.009	0.002
27	0.007	0.003	0.008	0.004	0.011	0.002
26	0.008	0.003	0.008	0.004	0.012	0.003
25	0.009	0.003	0.008	0.004	0.013	0.003
24	0.010	0.003	0.008	0.004	0.015	0.003
23	0.010	0.003	0.008	0.005	0.016	0.003
22	0.011	0.004	0.007	0.004	0.017	0.003
21	0.011	0.004	0.007	0.004	0.017	0.003
20	0.010	0.004	0.008	0.003	0.017	0.003
19	0.011	0.004	0.008	0.003	0.017	0.004
18	0.011	0.004	0.008	0.003	0.016	0.004
17	0.012	0.004	0.009	0.003	0.016	0.004
16	0.013	0.004	0.010	0.003	0.016	0.004
15	0.014	0.004	0.011	0.003	0.017	0.004
14	0.015	0.004	0.012	0.004	0.017	0.004
13	0.016	0.004	0.013	0.004	0.017	0.004

12	0.017	0.004	0.015	0.004	0.017	0.004
11	0.018	0.004	0.016	0.004	0.018	0.004
10	0.018	0.004	0.016	0.004	0.018	0.005
9	0.019	0.005	0.017	0.004	0.017	0.005
8	0.020	0.005	0.018	0.004	0.016	0.005
7	0.017	0.005	0.018	0.004	0.016	0.005
6	0.019	0.005	0.018	0.004	0.016	0.005
5	0.016	0.005	0.018	0.004	0.016	0.006
4	0.014	0.005	0.018	0.004	0.016	0.006
3	0.008	0.005	0.017	0.004	0.016	0.005
2	0.009	0.005	0.015	0.004	0.014	0.005
1	0.015	0.004	0.012	0.003	0.011	0.004
0	0.015	0.002	0.004	0.001	0.005	0.002

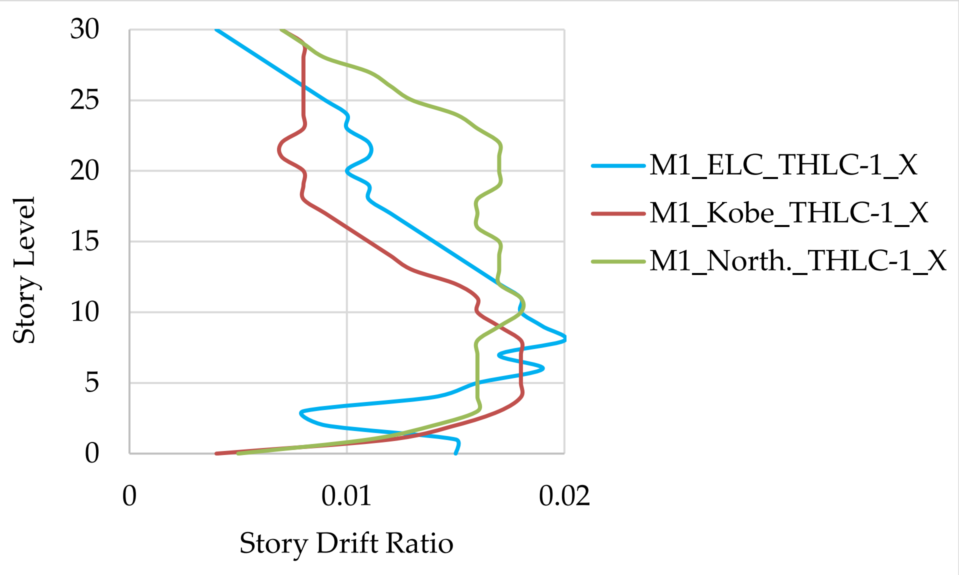


Fig. 4.63: Model 1 Story Drift ratio in X direction for THLC-1

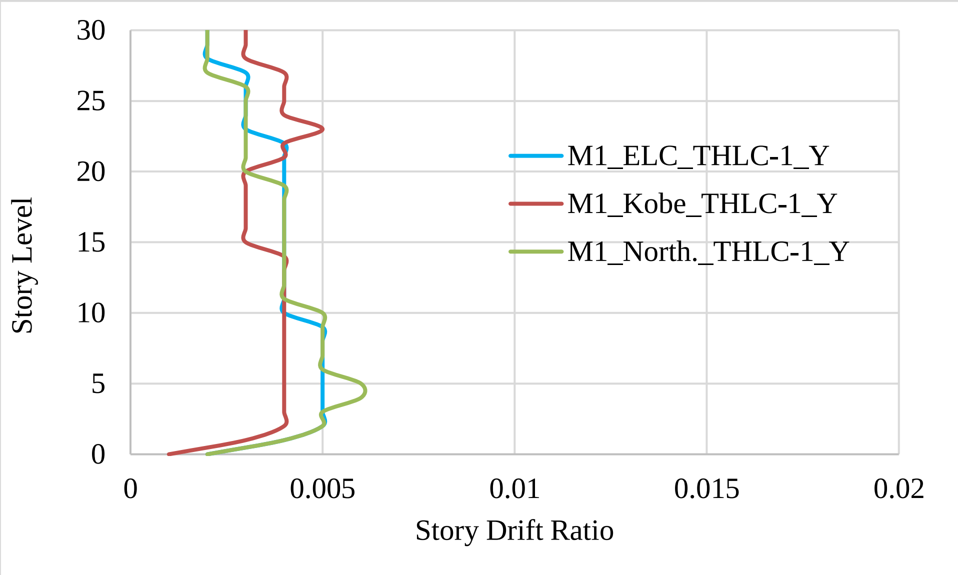


Fig. 4.64: Model 1 Story Drift ratio in Y direction for THLC-1

4.7.2 Model 2 (FSWS) for THLC-1 Load Case

The story drift ratio has been compared for building model 2 (FSWS) with THLC-1 load case are shown in Table 4.46, Fig. 4.65 & 4.66. Maximum story drift ratio 0.017, 0.019, and 0.018 for the X direction and 0.004, 0.005, and 0.005 for the Y direction of building model 2 with El Centro 1940-THLC-1, Kobe 1995-THLC-1, and Northridge 1994-THLC-1 respectively at different story level. Kobe 1995-THLC-1 shows the highest story drift ratio values among all other load cases.

Table 4.46: Story Drift Ratio for THLC-1 (Model 2)

Story	FSWS Story Drift Ratio (SDR)					
	El-Centro 1940-THLC-1		Kobe 1995-THLC-1		Northridge 1994-THLC-1	
	X	Y	X	Y	X	Y
30	0.009	0.003	0.010	0.005	0.011	0.004
29	0.009	0.004	0.011	0.005	0.012	0.004
28	0.010	0.004	0.011	0.005	0.012	0.004
27	0.010	0.004	0.012	0.006	0.012	0.004

26	0.011	0.004	0.013	0.006	0.013	0.004
25	0.011	0.004	0.013	0.006	0.013	0.004
24	0.012	0.004	0.014	0.006	0.014	0.004
23	0.013	0.004	0.015	0.006	0.014	0.004
22	0.013	0.004	0.015	0.005	0.014	0.005
21	0.014	0.004	0.016	0.002	0.015	0.005
20	0.014	0.004	0.017	0.002	0.016	0.005
19	0.015	0.004	0.017	0.002	0.016	0.005
18	0.015	0.004	0.018	0.002	0.016	0.005
17	0.016	0.004	0.018	0.003	0.017	0.005
16	0.016	0.004	0.018	0.003	0.013	0.005
15	0.017	0.004	0.018	0.003	0.014	0.005
14	0.017	0.004	0.019	0.004	0.015	0.005
13	0.017	0.004	0.019	0.004	0.015	0.005
12	0.017	0.004	0.018	0.004	0.016	0.004
11	0.017	0.004	0.018	0.004	0.017	0.004
10	0.017	0.004	0.018	0.005	0.017	0.004
9	0.017	0.004	0.017	0.005	0.018	0.004
8	0.017	0.004	0.017	0.005	0.018	0.004
7	0.016	0.004	0.014	0.005	0.018	0.004
6	0.015	0.004	0.014	0.005	0.018	0.004
5	0.014	0.004	0.013	0.004	0.017	0.004
4	0.013	0.004	0.013	0.004	0.016	0.004
3	0.012	0.003	0.011	0.004	0.015	0.003
2	0.009	0.003	0.010	0.003	0.012	0.003
1	0.006	0.002	0.007	0.002	0.009	0.002
0	0.003	0.001	0.003	0.001	0.004	0.001

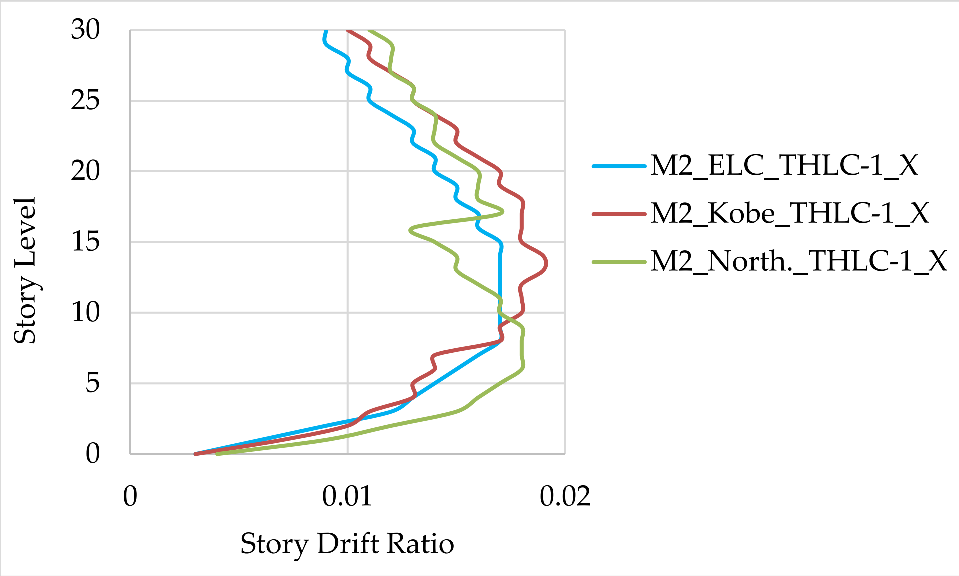


Fig. 4.65: Model 2 Story Drift ratio in X direction for THLC-1

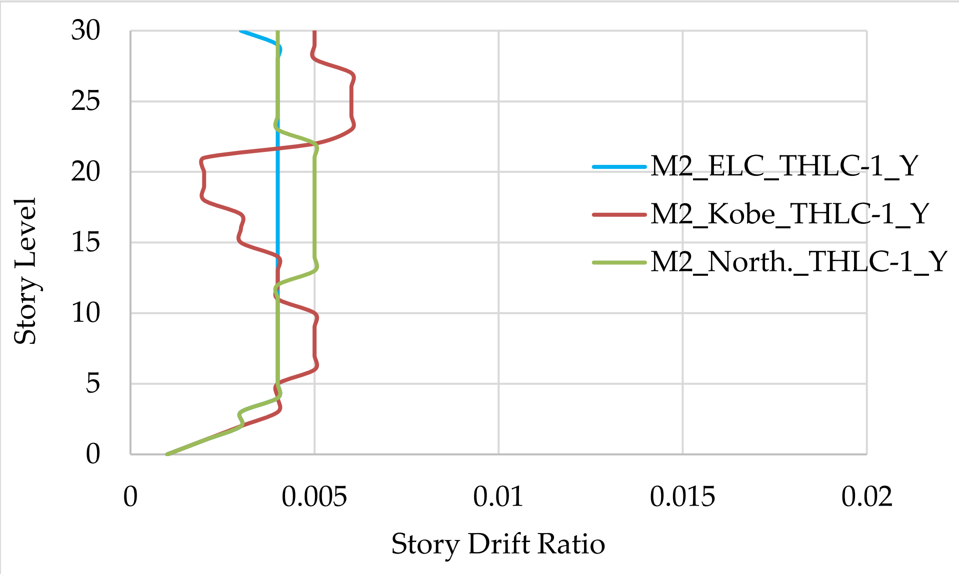


Fig. 4.66: Model 2 Story Drift ratio in Y direction for THLC-1

4.7.3 Model 1 (MRFS) for THLC-2 Load Case

The story drift ratio has been compared for building model 1 (MRFS) with THLC-2 load case are shown in Table 4.47, Fig. 4.67 & 4.68. Maximum story drift ratio values are 0.005, 0.004, and 0.006 for the X direction and 0.018, 0.019, and 0.018 for the Y direction of building model 1 with El Centro 1940-

THLC-2, Kobe 1995-THLC-2, and Northridge 1994-THLC-2 respectively at different story levels. Kobe 1995 shows the highest story drift ratio values among all other load cases.

Table 4.47: Story Drift Ratio for THLC-2 (Model 1)

Story	MRFS Story Drift Ratio (SDR)					
	El-Centro 1940-THLC-2		Kobe 1995-THLC-2		Northridge 1994-THLC-2	
	X	Y	X	Y	X	Y
30	0.001	0.008	0.002	0.007	0.001	0.010
29	0.001	0.008	0.002	0.008	0.002	0.011
28	0.001	0.009	0.002	0.008	0.002	0.012
27	0.002	0.010	0.003	0.009	0.002	0.013
26	0.002	0.011	0.003	0.009	0.002	0.014
25	0.002	0.010	0.003	0.009	0.002	0.015
24	0.002	0.010	0.004	0.008	0.002	0.015
23	0.002	0.011	0.004	0.008	0.002	0.016
22	0.003	0.011	0.004	0.008	0.002	0.016
21	0.003	0.012	0.005	0.007	0.002	0.016
20	0.003	0.013	0.005	0.008	0.002	0.016
19	0.003	0.013	0.005	0.008	0.002	0.017
18	0.004	0.014	0.004	0.009	0.002	0.017
17	0.004	0.014	0.003	0.010	0.003	0.018
16	0.004	0.015	0.003	0.011	0.003	0.016
15	0.004	0.015	0.003	0.012	0.003	0.015
14	0.005	0.016	0.003	0.013	0.003	0.015
13	0.005	0.016	0.003	0.014	0.004	0.015
12	0.004	0.017	0.004	0.015	0.004	0.015
11	0.004	0.017	0.003	0.016	0.004	0.015
10	0.004	0.018	0.003	0.017	0.005	0.015
9	0.004	0.018	0.004	0.018	0.005	0.015
8	0.001	0.008	0.004	0.018	0.005	0.015
7	0.001	0.008	0.004	0.019	0.005	0.015
6	0.001	0.009	0.004	0.019	0.005	0.015

5	0.002	0.010	0.004	0.019	0.006	0.015
4	0.002	0.011	0.004	0.018	0.006	0.015
3	0.002	0.010	0.004	0.018	0.005	0.014
2	0.002	0.010	0.004	0.016	0.005	0.013
1	0.002	0.011	0.003	0.012	0.004	0.010
0	0.003	0.011	0.001	0.005	0.002	0.004

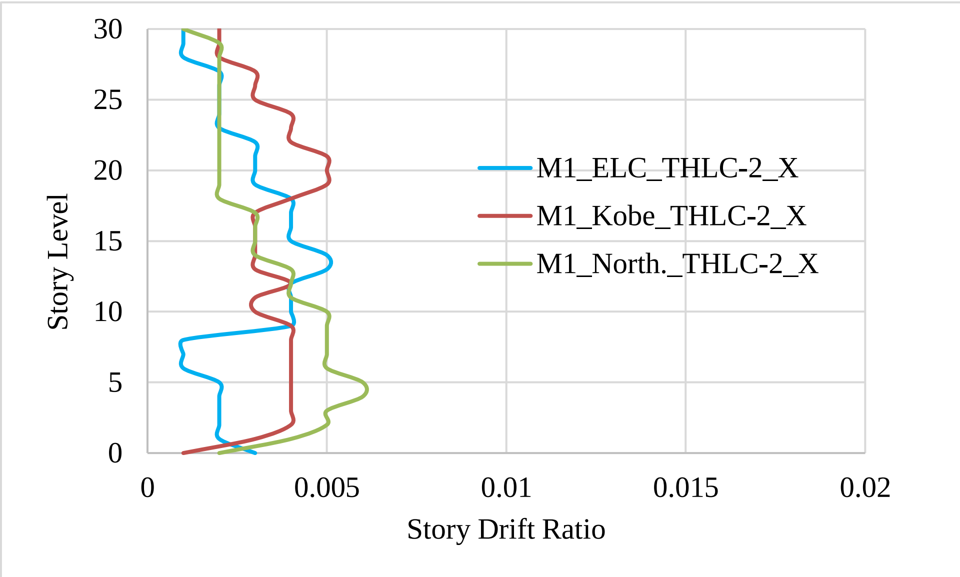


Fig. 4.67: Model 1 Story Drift ratio in X direction for THLC-2

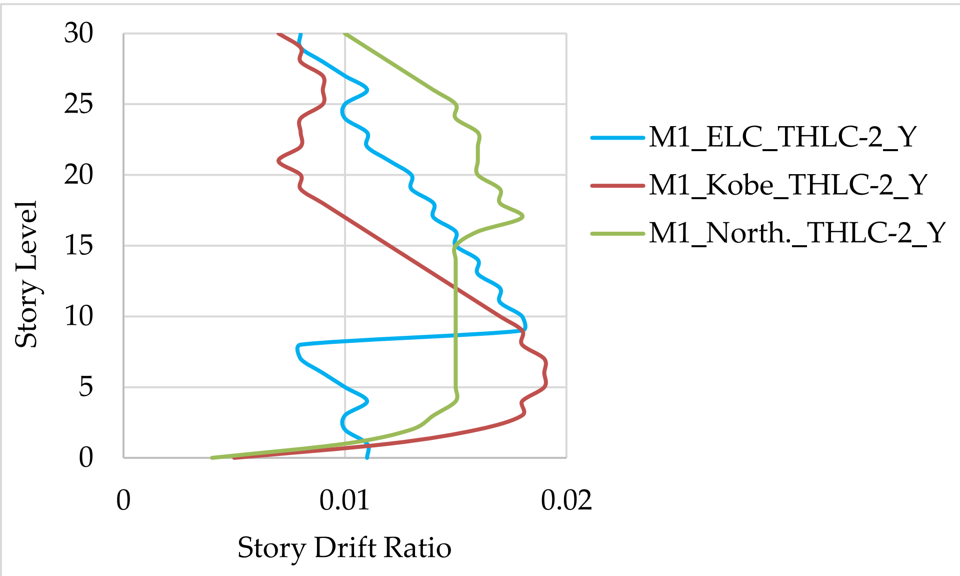


Fig. 4.68: Model 1 Story Drift ratio in Y direction for THLC-2

4.7.4 Model 2 (FSWS) for THLC-2 Load Case

The story drift ratio has been compared for building model 2 (FSWS) with THLC-2 load case are shown in Table 4.48, Fig. 4.69 & 4.70. Maximum story drift ratio values are 0.005, 0.005, and 0.005 for the X direction and 0.019, 0.017, and 0.017 for the Y direction of building model 2 with El Centro 1940-THLC-2, Kobe 1995-THLC-2, and Northridge 1994-THLC-2 respectively at different story levels. El Centro 1940 shows the highest story drift ratio values among all other load cases.

Table 4.48: Story Drift Ratio for THLC-2 (Model 2)

Story	FSWS Story Drift Ratio (SDR)					
	El-Centro 1940-THLC-2		Kobe 1995-THLC-2		Northridge 1994-THLC-2	
	X	Y	X	Y	X	Y
30	0.002	0.013	0.004	0.011	0.003	0.013
29	0.002	0.014	0.004	0.012	0.003	0.013
28	0.002	0.014	0.004	0.012	0.003	0.014
27	0.002	0.015	0.003	0.012	0.003	0.014
26	0.002	0.015	0.003	0.013	0.004	0.015
25	0.002	0.016	0.003	0.013	0.004	0.015
24	0.002	0.017	0.004	0.014	0.004	0.014
23	0.002	0.017	0.004	0.014	0.004	0.014
22	0.002	0.018	0.004	0.014	0.004	0.014
21	0.003	0.018	0.004	0.015	0.005	0.014
20	0.003	0.018	0.004	0.015	0.005	0.014
19	0.003	0.019	0.004	0.015	0.005	0.015
18	0.003	0.019	0.004	0.016	0.005	0.015
17	0.004	0.019	0.005	0.016	0.005	0.015
16	0.004	0.019	0.005	0.016	0.005	0.016
15	0.004	0.019	0.005	0.017	0.005	0.016
14	0.004	0.019	0.005	0.017	0.005	0.016
13	0.005	0.019	0.005	0.017	0.005	0.017
12	0.005	0.016	0.005	0.014	0.005	0.017

11	0.005	0.016	0.005	0.014	0.005	0.017
10	0.005	0.017	0.005	0.015	0.005	0.017
9	0.005	0.017	0.005	0.016	0.005	0.017
8	0.005	0.017	0.004	0.016	0.005	0.017
7	0.005	0.017	0.004	0.016	0.005	0.017
6	0.005	0.016	0.004	0.016	0.004	0.016
5	0.005	0.015	0.004	0.016	0.004	0.015
4	0.005	0.014	0.003	0.015	0.004	0.014
3	0.004	0.013	0.003	0.013	0.003	0.012
2	0.003	0.010	0.003	0.011	0.003	0.010
1	0.002	0.007	0.002	0.008	0.002	0.007
0	0.001	0.003	0.001	0.003	0.001	0.003

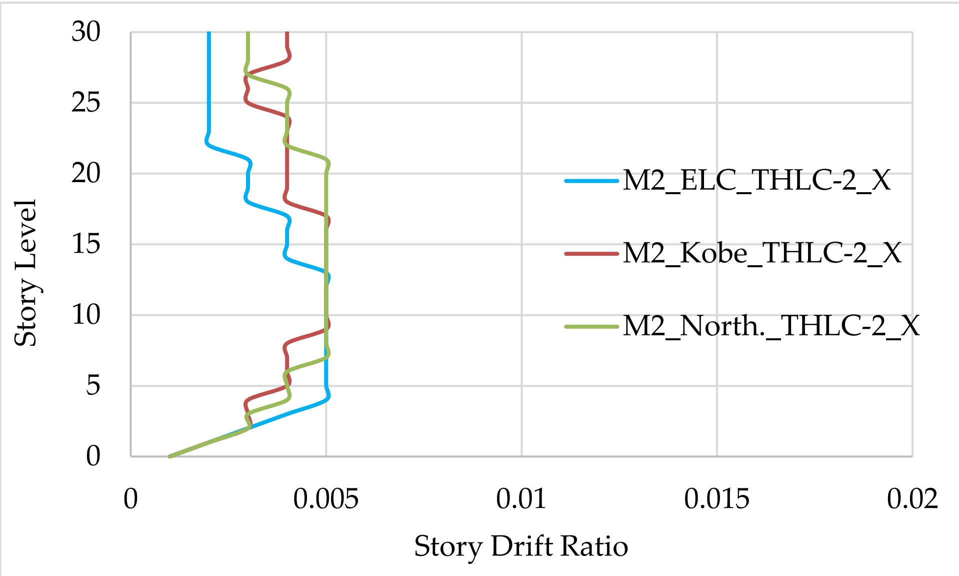


Fig. 4.69: Model 2 Story Drift ratio in X direction for THLC-2

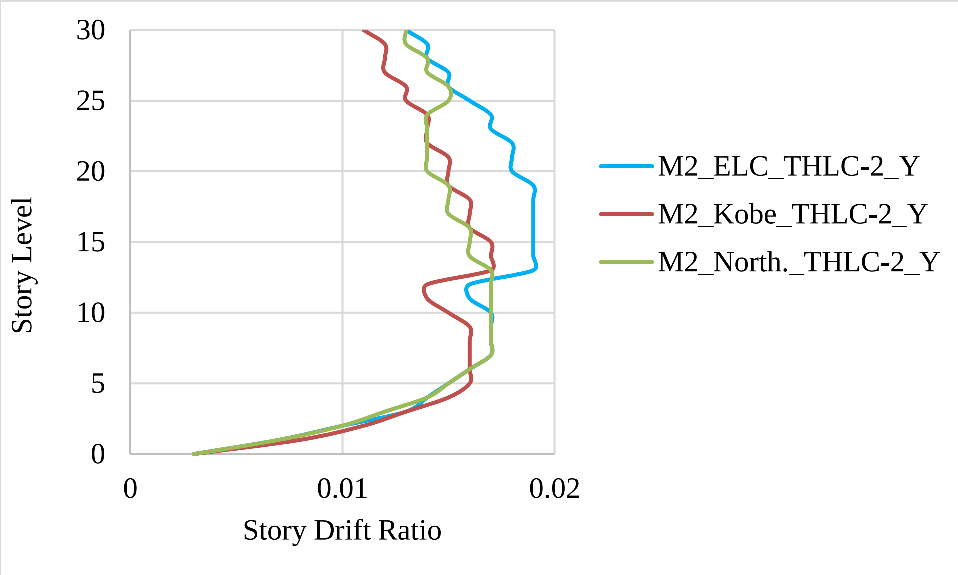


Fig. 4.70: Model 2 Story Drift ratio in Y direction for THLC-2

4.7.5 Model 1 (MRFS) for THLC-3 Load Case

The story drift ratio has been compared for building model 1 (MRFS) with THLC-3 load case are shown in Table 4.49, Fig. 4.71 & 4.72. Maximum story drift ratio values are 0.017, 0.015, and 0.019 for the X direction and 0.005, 0.006, and 0.005 for the Y direction of building model 1 with load case El Centro-THLC-3, Kobe-THLC-3, and Northridge-THLC-3 respectively at the different story level. Northridge 1994 shows the highest story drift ratio values among all other ground motions.

Table 4.49: Story Drift Ratio for THLC-3 (Model 1)

Story	MRFS Story Drift Ratio (SDR)					
	El-Centro 1940-THLC-3		Kobe 1995-THLC-3		Northridge 1994-THLC-3	
	X	Y	X	Y	X	Y
30	0.004	0.002	0.006	0.002	0.005	0.003
29	0.004	0.003	0.006	0.002	0.005	0.003
28	0.005	0.003	0.008	0.002	0.006	0.004
27	0.005	0.003	0.009	0.003	0.007	0.004
26	0.006	0.003	0.010	0.003	0.007	0.004

25	0.006	0.003	0.011	0.003	0.007	0.005
24	0.007	0.003	0.012	0.002	0.007	0.005
23	0.008	0.003	0.013	0.002	0.007	0.005
22	0.009	0.003	0.014	0.002	0.007	0.005
21	0.009	0.004	0.015	0.002	0.007	0.005
20	0.010	0.004	0.016	0.002	0.007	0.005
19	0.011	0.004	0.016	0.002	0.007	0.005
18	0.012	0.004	0.012	0.003	0.008	0.005
17	0.013	0.004	0.010	0.003	0.008	0.005
16	0.014	0.005	0.010	0.003	0.009	0.005
15	0.015	0.005	0.010	0.004	0.010	0.004
14	0.015	0.005	0.010	0.004	0.011	0.004
13	0.016	0.005	0.011	0.004	0.012	0.005
12	0.015	0.005	0.012	0.005	0.013	0.005
11	0.012	0.005	0.011	0.005	0.014	0.005
10	0.012	0.005	0.011	0.005	0.015	0.005
9	0.013	0.005	0.012	0.005	0.016	0.005
8	0.014	0.005	0.013	0.006	0.017	0.005
7	0.015	0.005	0.014	0.006	0.017	0.005
6	0.016	0.005	0.014	0.006	0.018	0.005
5	0.016	0.005	0.015	0.006	0.019	0.004
4	0.017	0.005	0.015	0.006	0.019	0.004
3	0.017	0.005	0.014	0.005	0.018	0.004
2	0.016	0.005	0.013	0.005	0.017	0.004
1	0.012	0.003	0.010	0.004	0.013	0.003
0	0.005	0.001	0.004	0.002	0.005	0.001

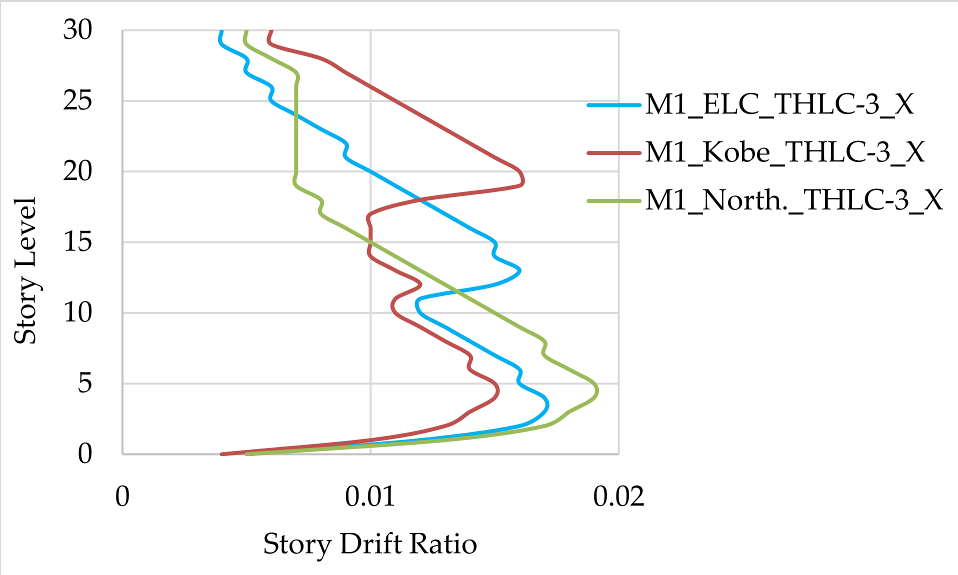


Fig. 4.71: Model 1 Story Drift ratio in X direction for THLC-1

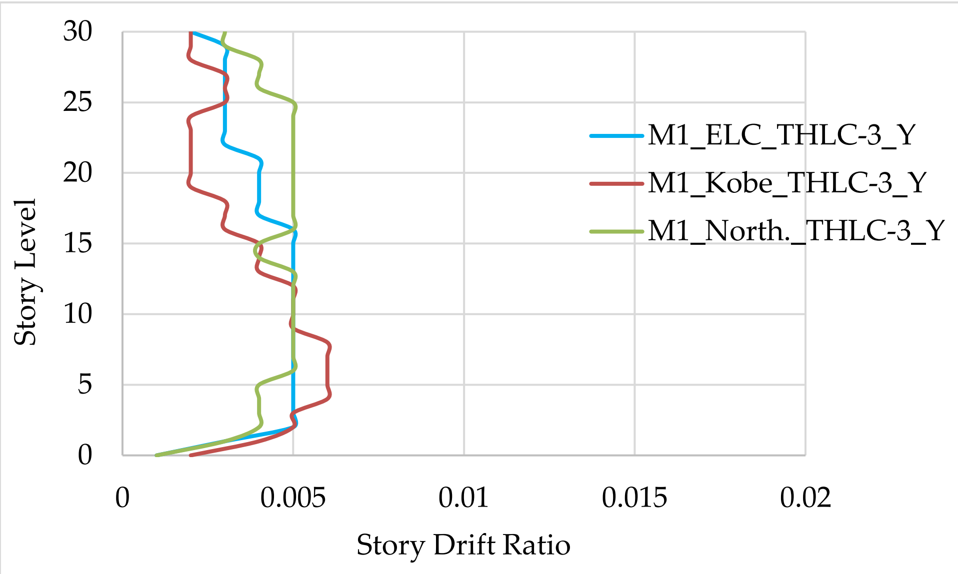


Fig. 4.72: Model 1 Story Drift ratio in Y direction for THLC-1

4.7.6 Model 2 (FSWS) for THLC-3 Load Case

The story drift ratio has been compared for building model 2 (FSWS) with THLC-3 load cases are shown in Table 4.50, Fig. 4.73 & 4.74. Maximum story drift ratio 0.018, 0.016, and 0.017 for the X direction and 0.006, 0.005, and 0.005 for the Y direction of building model 2 with El Centro 1940-THLC-3, Kobe 1995-THLC-3, and Northridge 1994-THLC-3 respectively at different story levels. El Centro 1940-THLC-3 shows the highest story drift ratio values among all other load cases.

Table 4.50: Story Drift Ratio for THLC-3 (Model 2)

Story	FSWS Story Drift Ratio (SDR)					
	El-Centro 1940-THLC-3		Kobe 1995-THLC-3		Northridge 1994-THLC-3	
	X	Y	X	Y	X	Y
30	0.007	0.004	0.012	0.003	0.010	0.004
29	0.007	0.004	0.013	0.004	0.010	0.004
28	0.007	0.004	0.013	0.004	0.011	0.004
27	0.007	0.004	0.010	0.004	0.011	0.004
26	0.007	0.005	0.011	0.004	0.012	0.004
25	0.007	0.005	0.011	0.004	0.013	0.004
24	0.007	0.005	0.012	0.004	0.013	0.004
23	0.007	0.005	0.012	0.004	0.014	0.004
22	0.008	0.005	0.013	0.004	0.014	0.004
21	0.009	0.005	0.014	0.004	0.015	0.004
20	0.009	0.005	0.014	0.005	0.016	0.004
19	0.010	0.006	0.014	0.005	0.016	0.004
18	0.011	0.006	0.015	0.005	0.016	0.005
17	0.012	0.006	0.015	0.005	0.017	0.005
16	0.013	0.006	0.016	0.005	0.017	0.005
15	0.014	0.006	0.016	0.005	0.017	0.005
14	0.015	0.005	0.016	0.005	0.017	0.005
13	0.016	0.005	0.016	0.005	0.017	0.005
12	0.016	0.005	0.016	0.005	0.017	0.005
11	0.017	0.005	0.016	0.005	0.017	0.005
10	0.017	0.005	0.016	0.005	0.016	0.005
9	0.018	0.005	0.015	0.005	0.016	0.005
8	0.018	0.005	0.015	0.005	0.016	0.005
7	0.018	0.005	0.014	0.005	0.015	0.005
6	0.018	0.005	0.012	0.005	0.014	0.005

5	0.017	0.005	0.012	0.005	0.014	0.005
4	0.016	0.004	0.011	0.004	0.012	0.004
3	0.014	0.004	0.010	0.004	0.011	0.004
2	0.011	0.003	0.009	0.003	0.009	0.003
1	0.008	0.002	0.006	0.002	0.006	0.002
0	0.003	0.001	0.003	0.001	0.003	0.001

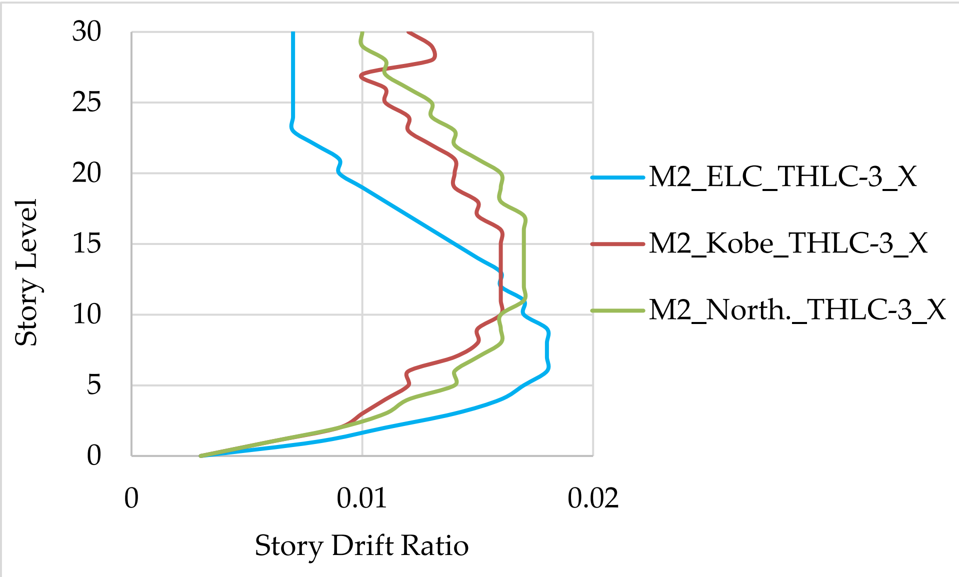


Fig. 4.73: Model 2 Story Drift ratio in X direction for THLC-1

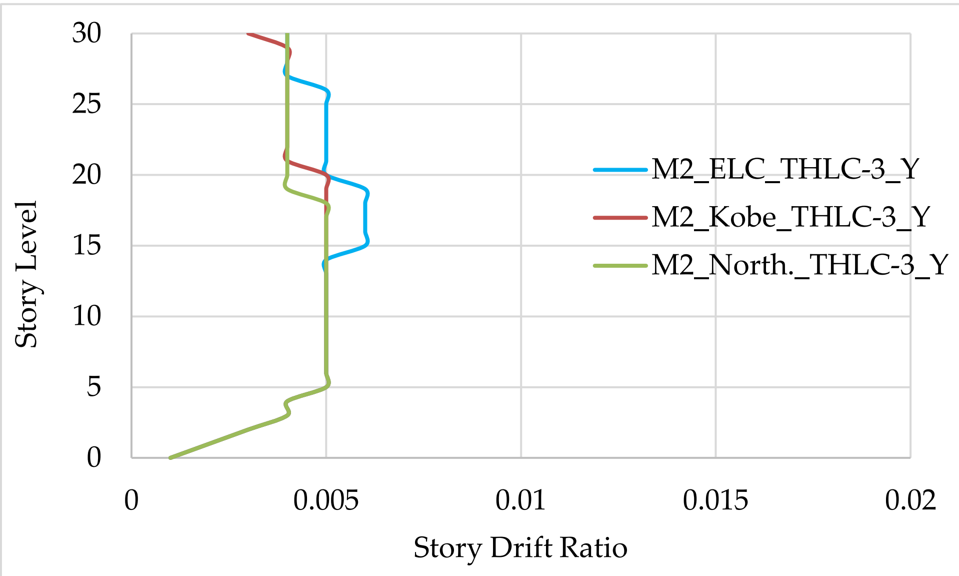


Fig. 4.74: Model 2 Story Drift ratio in Y direction for THLC-1

4.7.7 Model 1 (MRFS) for THLC-4 Load Case

The story drift ratio has been compared for building model 1 (MRFS) with THLC-4 load cases are shown in Table 4.51, Fig. 4.75 & 4.76. Maximum story drift ratio values are 0.006, 0.007, and 0.005 for the X direction and 0.017, 0.014, and 0.019 for the Y direction of building model 1 with El Centro 1940-THLC-4, Kobe 1995-THLC-4, and Northridge 1994-THLC-4 respectively at different story levels. Northridge 1994-THLC-4 the highest story drift ratio values among all other load cases.

Table 4.51: Story Drift Ratio for THLC-4 (Model 1)

Story	MRFS Story Drift Ratio (SDR)					
	El-Centro 1940-THLC-4		Kobe 1995-THLC-4		Northridge 1994-THLC-4	
	X	Y	X	Y	X	Y
30	0.001	0.007	0.001	0.008	0.002	0.006
29	0.002	0.007	0.001	0.009	0.002	0.007
28	0.002	0.008	0.001	0.011	0.003	0.007
27	0.002	0.009	0.001	0.012	0.003	0.008
26	0.002	0.009	0.001	0.013	0.004	0.008
25	0.003	0.010	0.001	0.014	0.004	0.009
24	0.003	0.011	0.001	0.015	0.004	0.010
23	0.003	0.012	0.001	0.015	0.005	0.010
22	0.003	0.012	0.001	0.015	0.005	0.010
21	0.003	0.013	0.002	0.014	0.005	0.011
20	0.003	0.013	0.002	0.011	0.005	0.011
19	0.003	0.013	0.002	0.010	0.005	0.012
18	0.003	0.013	0.002	0.009	0.005	0.012
17	0.004	0.013	0.003	0.010	0.005	0.013
16	0.004	0.013	0.003	0.010	0.005	0.013
15	0.004	0.013	0.004	0.011	0.005	0.014
14	0.004	0.013	0.004	0.012	0.005	0.012
13	0.005	0.013	0.004	0.012	0.005	0.013
12	0.005	0.014	0.005	0.013	0.005	0.014

11	0.005	0.014	0.005	0.013	0.005	0.015
10	0.006	0.014	0.006	0.014	0.005	0.016
9	0.006	0.015	0.006	0.014	0.005	0.016
8	0.006	0.015	0.006	0.013	0.005	0.017
7	0.006	0.015	0.006	0.013	0.005	0.018
6	0.006	0.016	0.007	0.013	0.005	0.018
5	0.006	0.017	0.007	0.013	0.005	0.018
4	0.006	0.017	0.007	0.013	0.005	0.019
3	0.006	0.016	0.006	0.013	0.005	0.018
2	0.005	0.015	0.006	0.012	0.004	0.017
1	0.004	0.012	0.004	0.009	0.003	0.013
0	0.002	0.005	0.002	0.004	0.001	0.005

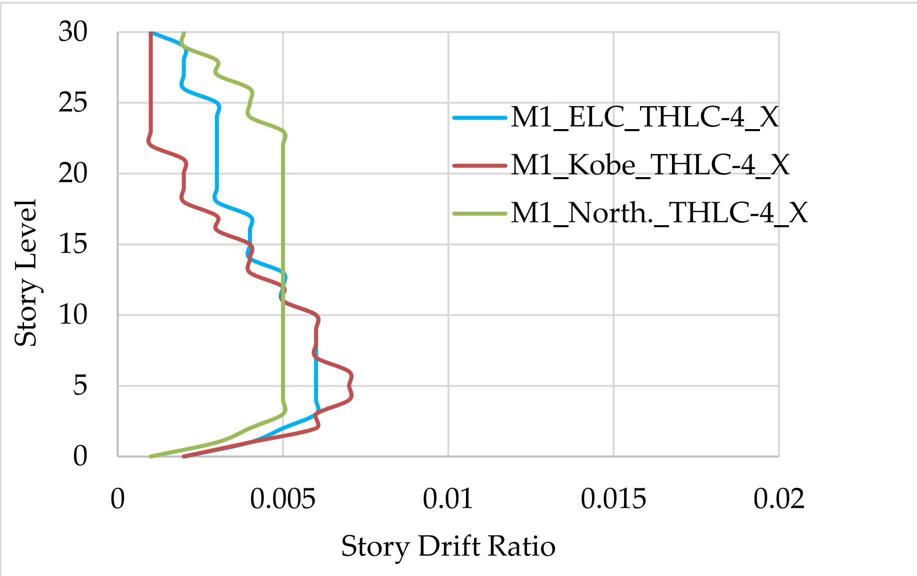


Fig. 4.75: Model 1 Story Drift ratio in X direction for THLC-2

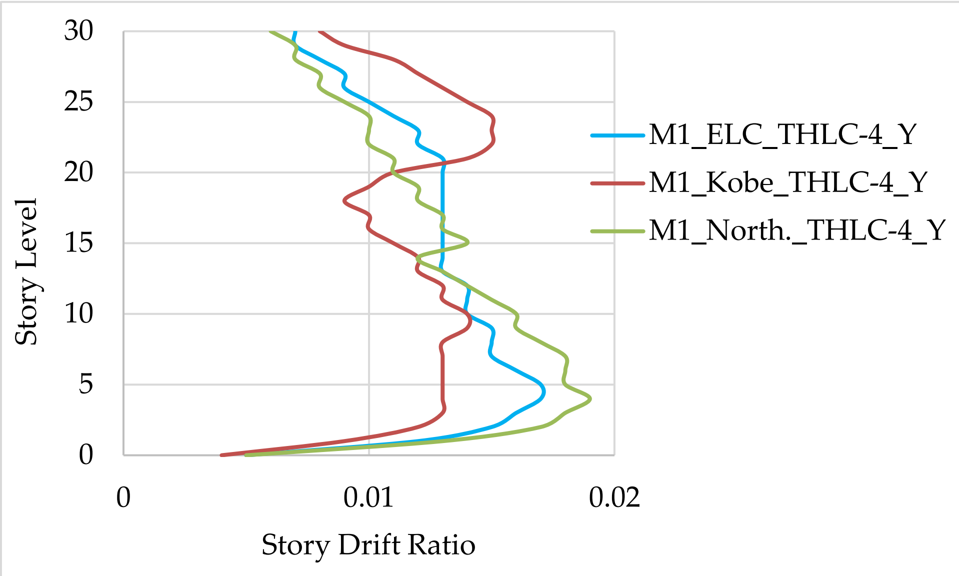


Fig. 4.76: Model 1 Story Drift ratio in Y direction for THLC-2

4.7.8 Model 2 (FSWS) for THLC-4 Load Case

The story drift ratio has been compared for building model 2 (FSWS) with THLC-4 load case are shown in Table 4.52, Fig. 4.77 & 4.78. Maximum story drift ratio values are 0.005, 0.006, and 0.005 for the X direction and 0.014, 0.016, and 0.016 for the Y direction of building model 2 with El Centro 1940-THLC-4, Kobe 1995-THLC-4, and Northridge 1994-THLC-4 respectively at different story levels. Kobe 1995-THLC-4, Northridge 1994-THLC-4 the highest story drift ratio values among all other load cases

Table 4.52: Story Drift Ratio for THLC-4 (Model 2)

Story	FSWS Story Drift Ratio (SDR)					
	El-Centro 1940-THLC-4		Kobe 1995-THLC-4		Northridge 1994-THLC-4	
	X	Y	X	Y	X	Y
30	0.003	0.011	0.003	0.016	0.003	0.012
29	0.003	0.012	0.003	0.016	0.003	0.012
28	0.003	0.012	0.003	0.017	0.004	0.013
27	0.003	0.012	0.004	0.018	0.004	0.013

26	0.003	0.013	0.004	0.019	0.004	0.013
25	0.003	0.013	0.004	0.019	0.004	0.014
24	0.004	0.013	0.004	0.020	0.004	0.014
23	0.004	0.012	0.004	0.020	0.004	0.014
22	0.004	0.012	0.005	0.018	0.004	0.015
21	0.004	0.012	0.005	0.007	0.005	0.015
20	0.004	0.012	0.005	0.006	0.005	0.015
19	0.004	0.012	0.005	0.007	0.005	0.015
18	0.005	0.012	0.005	0.007	0.005	0.016
17	0.005	0.012	0.005	0.008	0.005	0.016
16	0.005	0.013	0.005	0.010	0.004	0.016
15	0.005	0.013	0.006	0.011	0.004	0.016
14	0.005	0.013	0.006	0.012	0.004	0.016
13	0.005	0.013	0.006	0.013	0.005	0.013
12	0.005	0.013	0.006	0.014	0.005	0.012
11	0.005	0.014	0.005	0.015	0.005	0.013
10	0.005	0.014	0.005	0.015	0.005	0.013
9	0.005	0.014	0.005	0.016	0.005	0.014
8	0.005	0.014	0.005	0.016	0.005	0.014
7	0.005	0.014	0.004	0.016	0.005	0.014
6	0.005	0.013	0.004	0.015	0.005	0.014
5	0.004	0.013	0.004	0.014	0.005	0.013
4	0.004	0.012	0.004	0.013	0.005	0.012
3	0.003	0.011	0.003	0.011	0.004	0.011
2	0.003	0.009	0.003	0.009	0.004	0.009
1	0.002	0.006	0.002	0.006	0.003	0.006
0	0.001	0.003	0.001	0.003	0.001	0.003

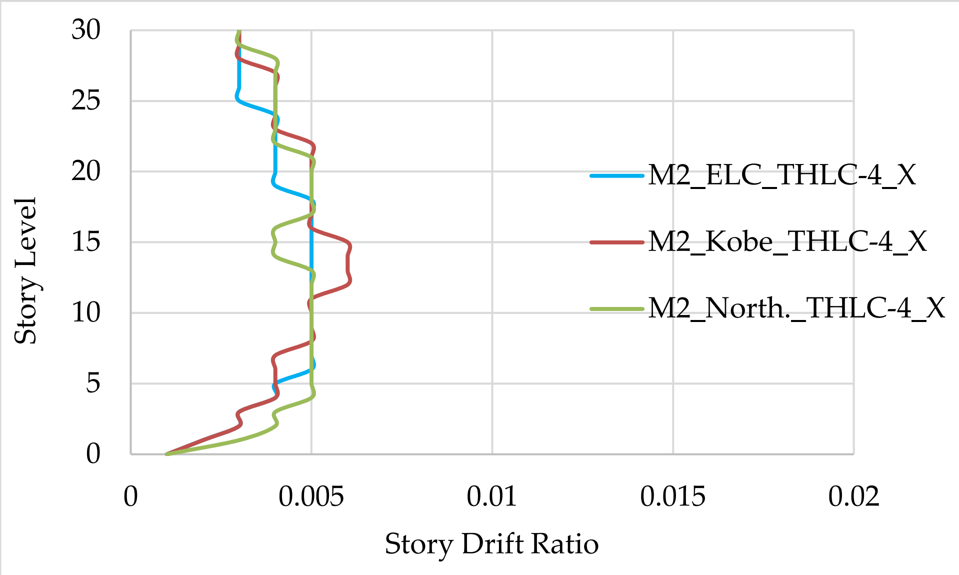


Fig. 4.77: Model 2 Story Drift ratio in X direction for THLC-2

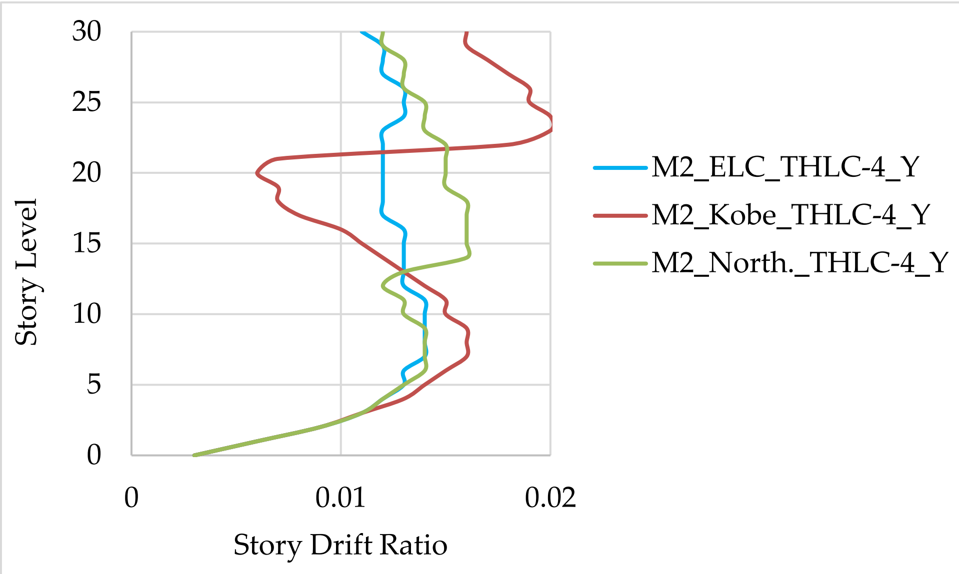


Fig. 4.78: Model 2 Story Drift ratio in Y direction for THLC-2

4.8 COMPARISON OF MAXIMUM STORY DRIFT RATIO FOR MRFS & FSWS (X & Y DIRECTION)

The maximum story drift ratio has been determined for all seismic loads from the time history load cases. Where MRFS and FSWS have been determined for the X and Y directions. The maximum story drift for time history load cases has been determined for the X and Y directions. Here it is found from Table 4.53 and Fig. 4.79 that the story drift ratio is 0.02 for MRFS X direction at the 8th floor and 0.019 for FSWS X direction at the 13th floor. From Table 4.54 & Fig. 4.80 maximum story drift ratio for MRFS Y direction is 0.019 at 4th story and FSWS Y direction 0.02 at 23 story.

Table 4.53: Maximum Story Drift Ratio for THLC_X (Model 1 & 2)

Maximum Story Drift Ratio from all THLC_X		
Story	Max. Story Drift Ratio of MRFS-X	Max. Story Drift Ratio of FSWS-X
30	0.007	0.012
29	0.008	0.013
28	0.009	0.013
27	0.011	0.012
26	0.012	0.013
25	0.013	0.013
24	0.015	0.014
23	0.016	0.015
22	0.017	0.015
21	0.017	0.016
20	0.017	0.017
19	0.017	0.017
18	0.016	0.018
17	0.016	0.018
16	0.016	0.018
15	0.017	0.018
14	0.017	0.019
13	0.017	0.019
12	0.017	0.018
11	0.018	0.018
10	0.018	0.018
9	0.019	0.018
8	0.020	0.018
7	0.018	0.018
6	0.019	0.018
5	0.019	0.017
4	0.019	0.016

3	0.018	0.015
2	0.017	0.012
1	0.015	0.009
0	0.015	0.004

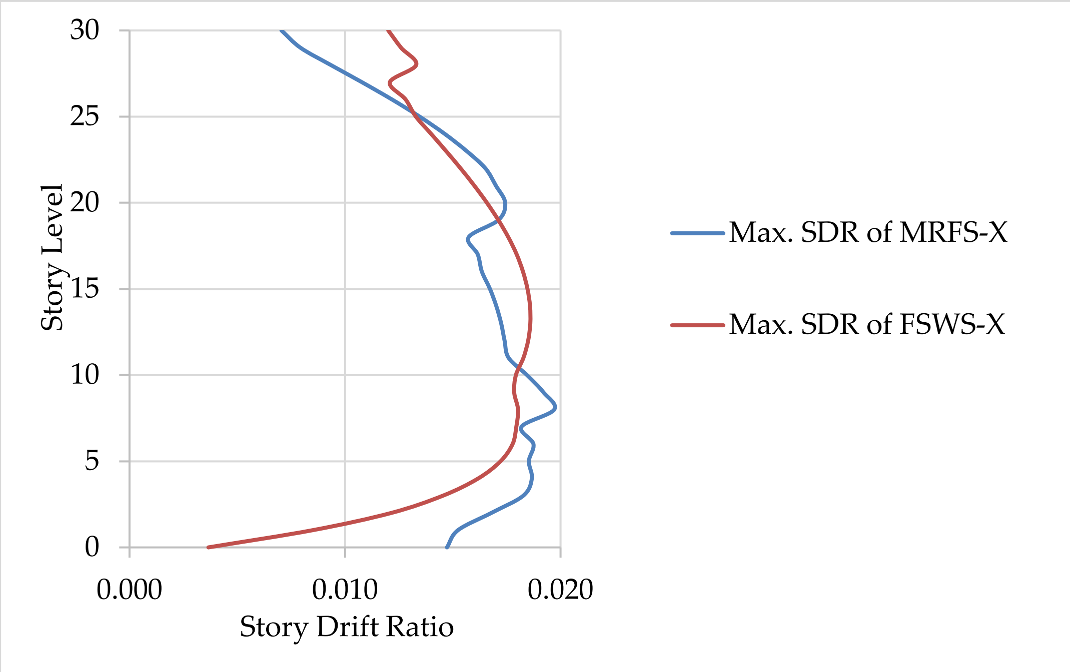


Fig. 4.79: Maximum Story Drift Ratio for THLC_X (Model 1 & 2)

Table 4.54: Maximum Story Drift Ratio for THLC_Y (Model 1 & 2)

Maximum Story Drift Ratio from all THLC_Y		
Story	Max. Story Drift Ratio of MRFS-Y	Max. Story Drift Ratio of FSWS-Y
30	0.010	0.016
29	0.011	0.016
28	0.012	0.017
27	0.013	0.018
26	0.014	0.019
25	0.015	0.019
24	0.015	0.020
23	0.016	0.020
22	0.016	0.018
21	0.016	0.018

20	0.016	0.018
19	0.017	0.019
18	0.017	0.019
17	0.018	0.019
16	0.016	0.019
15	0.015	0.019
14	0.016	0.019
13	0.016	0.019
12	0.017	0.017
11	0.017	0.017
10	0.018	0.017
9	0.018	0.017
8	0.018	0.017
7	0.019	0.017
6	0.019	0.016
5	0.019	0.016
4	0.019	0.015
3	0.018	0.013
2	0.017	0.011
1	0.013	0.008
0	0.005	0.003

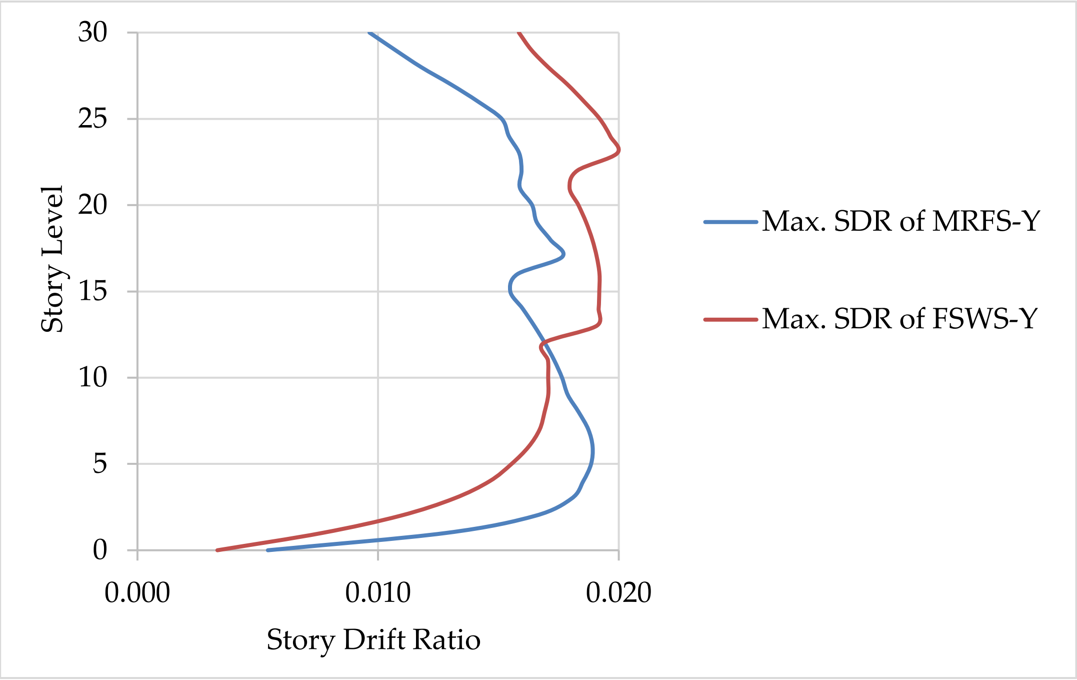


Fig. 4.80: Maximum Story Drift Ratio for THLC_Y (Model 1 & 2)

4.9 COMPARISON OF STORY STIFFNESS FOR MRFS & FSWS

In this study, when comparing the story stiffness between moment resisting frame and the frame shear wall system, it is seen that the story stiffness of the frame shear wall system increases from moment resisting frame in X direction to 23rd floor for X direction shown in Table 4.55 and Fig. 4.81. Again, the stiffness of the frame shear wall system increases from the moment resisting frame in Y direction to 12th floor for Y direction shown in Table 4.55 and Fig. 4.82. Finally, it is seen that the story stiffness of the frame shear wall system is 113% higher than that of the moment resisting frame in X direction at the ground floor and the story stiffness of the frame shear wall system is 77% higher than that of moment resisting frame in Y direction at ground floor.

Table 4.55: Story Stiffness for MRFS & FSWS (Model 1 & 2)

Story	Story Stiffness of MRFS (Kip)		Story Stiffness of FSWS (Kip)	
	X	Y	X	Y
30	2178.9	1402.7	1447.7	948.6
29	4634.8	3151.9	3335.8	2210.2
28	6205.2	4447.6	4922.1	3301.9
27	7237.4	5417.4	6226.0	4229.9
26	7956.3	6165.5	7288.0	5015.6
25	8485.5	6760.9	8153.3	5682.5
24	8893.1	7247.9	8862.2	6252.6
23	9218.9	7655.9	9453.4	6744.9
22	9487.3	8005.1	9951.8	7175.5
21	9714.2	8309.8	10378.0	7557.9
20	9910.7	8580.9	10749.8	7903.1
19	10084.6	8826.6	11081.7	8220.6
18	10241.9	9053.4	11385.7	8518.6
17	10387.1	9266.7	11672.2	8804.4
16	10523.8	9470.9	11950.3	9084.6
15	10654.9	9669.9	12222.2	9366.0
14	10783.0	9867.1	12499.4	9655.4
13	10910.2	10065.7	12794.5	9960.2
12	11038.7	10268.9	13118.1	10289.1
11	11170.4	10479.9	13483.3	10652.9

10	11307.3	10701.8	13907.2	11065.5
9	11452.1	10938.5	14419.9	11546.1
8	11608.5	11194.9	15059.6	12122.5
7	11783.0	11478.5	15872.3	12837.0
6	11988.7	11802.6	16941.3	13759.0
5	12255.0	12195.4	18413.5	15009.7
4	12651.9	12723.7	20549.5	16825.4
3	13360.7	13564.1	23969.9	19728.9
2	14926.0	15260.3	30033.2	25119.5
1	19662.6	20162.4	42349.9	35549.9
0	59123.5	60540.6	126340.8	107565.9

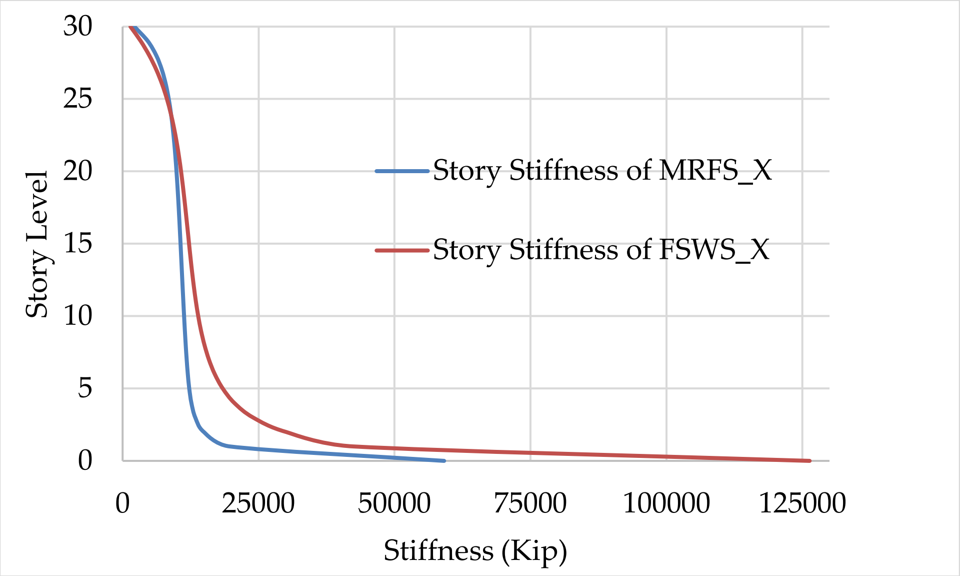


Fig. 4.81: Comparison of Story Stiffness for X Direction

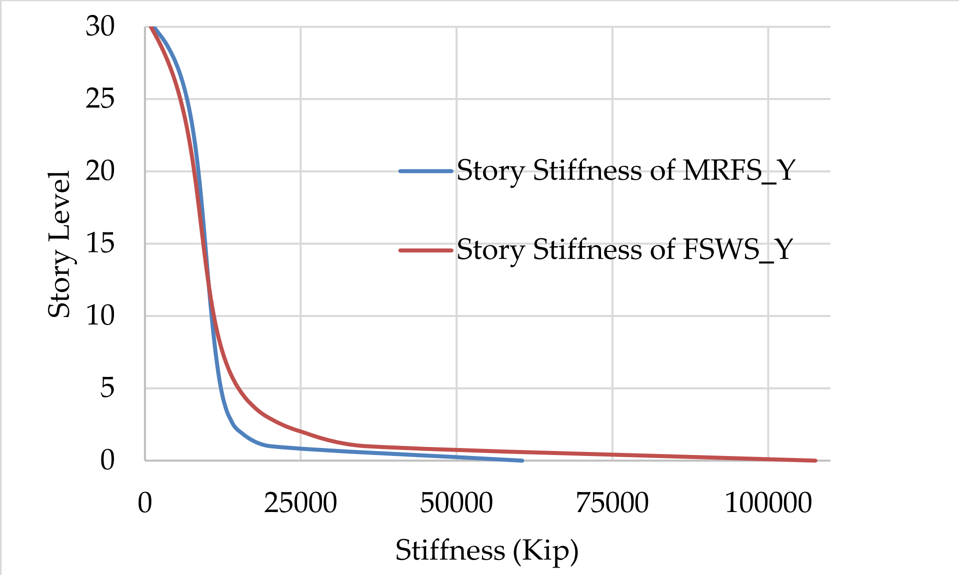


Fig. 4.82: Comparison of Story Stiffness for Y Direction

4.10 CONSUMING CONCRETE VOLUME

Analyzing the two models according to the BNBC and keeping the two models within the allowable drift limit, it is found that the concrete volume of model 1 is higher than that of model 2 for this typical height of the building. Quantities of concrete are shown in Fig. 4.83. The concrete volume calculation is shown in Tables 4.56 and 4.57.

Table 4.56: Concrete volume for Model 1 (MRFS)

Concrete volume for MRFS					
Item Name	Total Length (ft)	Depth (ft)	Width (ft)	Story No./Column No.	Total Volume (cft)
Column	308	3.75	3.75	30	129938
Beam	382	2.92	2.08	30	69603
				Total	199541

Table 4.57: Concrete volume for Model 2 (FSWS)

Concrete volume for FSWS					
Item Name	Total Length (ft)	Depth (ft)	Width (ft)	Story No./Column No.	Total Volume (cft)
Column	308	2.5	2.5	22	42350
Beam	382	2.92	2.08	30	69603
Shear Wall	308	128	1.67	----	65838
				Total	177791

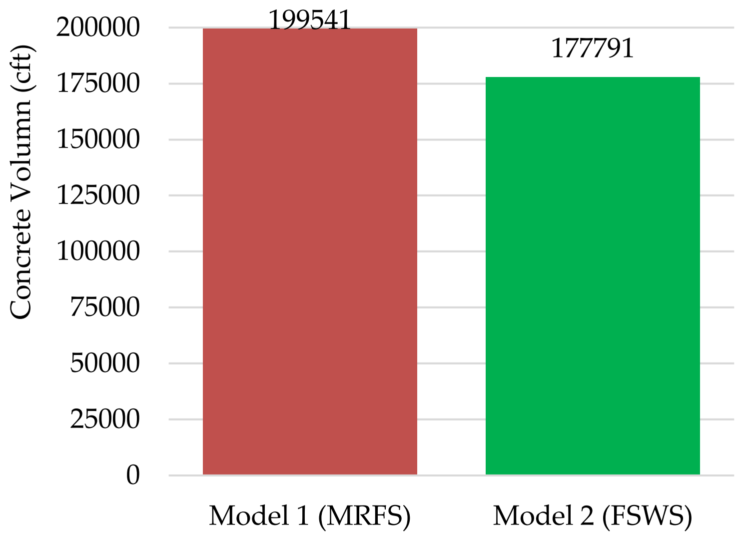


Fig. 4.83: Quantities of Concrete in both Model 1 & 2 (MRFS & FSWS)

4.11 USABLE SPACE AREA

Analyzing the two models according to the BNBC and keeping the two models within the allowable drift limit, it is found that the usable space area of model 2 is much higher than that of model 1 for this typical height of the building. Usable space areas are shown in Fig. 4.84. The total study building dimension is 75 ft x 52 ft. The column size of model 1 (MRFS) is 45 in x 45 in and the column size and shear wall thickness of model 2 (FSWS) are 30 in x 30 in and 20 in respectively. So, the total usable space area is 3900 sft. The model 1 usable space area is (3900 sft – (30 x 3.75 ft x 3.75 ft) = 3478 sft. The model 2 usable space area is (3900 sft – (22 x 2.5 ft x 2.5 ft) – (1.67 ft x 128 ft)) = 3549 sft.

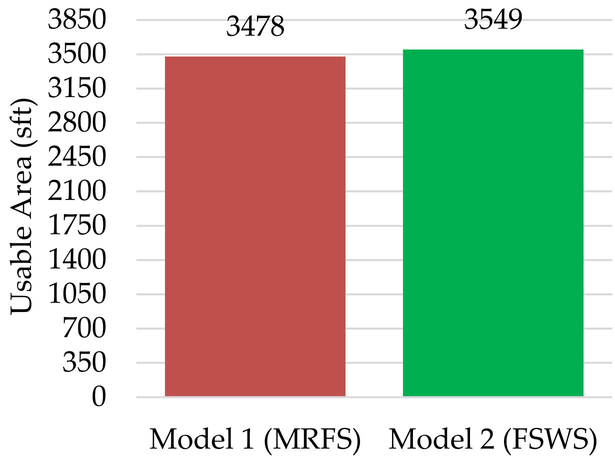


Fig. 4.84: Usable Space Area for both Model 1 & 2 (MRFS & FSWS)

4.12 SYNOPSIS

In this chapter, the Seismic responses of all building models are evaluated in terms of maximum story displacements, story drift ratio, and story stiffness. On the other hand, computed concrete volume and usable space area for all models. Compare the above topics for both models. Moreover, the maximum story drift ratio is governed by the different story levels of all building models in both directions. So, for this study, the location of occurrence of maximum story drift ratio is dependent on both framing systems for all building models concentrating the same seismic weight on similar floors of different models.

Chapter 5: CONCLUSIONS

5.1 GENERAL

Two different building framing systems of 30-storied building models have been considered in the study. Building framing system, one is a moment resisting frame and another one is a frame shear wall system considered for this purpose. These buildings are modelled using the building analysis software, ETABS-2017. Three ground motion pair time histories have been considered for the time history analysis of the building models in accordance with BNBC, 2020. In this regard, El Centro 1940, Kobe 1995, and Northridge 1994 ground motions pair records are selected with BNBC, 2020 guidelines and scaled. Linear time history analysis was conducted using scaled ground motion pair records that were applied separately at the fixed base of all building models in X and Y directions. The seismic responses of building models are evaluated in terms of maximum story displacements and story drift ratio. Compared to the two framing systems of story displacements, story drift ratio, story stiffness, usable space area of the building, and consuming concrete volume.

5.2 SUMMARY

Top displacement, maximum story drift, quantities of concrete, and usable space of the floor are used to compare moment resisting frames with frame shear wall structures. The analysis is done by ETABS software. The separate member sizes of the two building models are selected so that both are within the allowable drift limits, according to BNBC. The following conclusion can be obtained from the study.

- From the table of base shear in both models, it is observed that the base shear of MRFS (Model 1) is greater than FSWS (Model 2) for the time history load case.
- The column steel percentage of MRFS (Model 1) is greater than FSWS (Model 2). The percentage of steel for MRFS is 1.2% and FSWS is 1.0%.
- It is observed that story displacements of the MRFS (Model 1) frame system are less than the FSWS (Model 2) frame system due to the larger sections of the MRFS (Model 1) system.
- The maximum story drift ratio of MRFS (Model 1) is greater than that of FSWS (Model 2) for X direction and the story drift ratio of MRFS (Model 1) is less than the FSWS (Model 2) for Y direction, because the drift limit of both models is kept below the BNBC limit.
- The story stiffness of FSWS (Model 2) is greater than the MRFS (Model 1) at both X and Y directions.
- The FSWS (Model 2) building required 12.3% less quantities of concrete than the MRFS (Model 1) building for the study model.
- The maximum usable space area of the MRFS (Model 1) is 2% less than the FSWS (Model 2).

From all results, it can be said that for buildings with more than 30 stories, the FSWS frame system provides better performance in safety, economy, and usable space area than the MRFS system.

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