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# A Parametric Study on the Effects of Shear Wall Locations in a Typical Five-Story Reinforced Concrete Structure Subjected to a Severe Earthquake

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**Abstract**

To minimize earthquake-induced damages in structures, one of the most reliable ways to design and construct earthquake-resistant buildings is to utilize reinforced concrete shear walls because they increase the structural resistance to lateral loads and effectively stiffens and strengthens the structure. This is known as the best seismic-resistant design method that ensures the stability of multi-story buildings against lateral forces when subjected to strong earthquakes. This paper investigates the effects of the shear wall location in a typical low-rise building to improve earthquake resistance. The study initially models a five-story reinforced concrete structure without shear walls and then adds shear walls at different locations in the structure. SAP2000 is used to perform dynamic analysis under the 1994 Northridge earthquake, an example of severe seismic excitation. Response modal nonlinear time-history dynamic analysis is utilized to obtain an accurate representation of the structure's behavior. The response of the building with and without shear walls is analyzed and compared for various locations of the shear walls in the structure. Study results show that shear walls effectively reduce horizontal displacements and story drifts to achieve compliance with seismic design codes. The use of shear walls also significantly reduces shear stresses, bending moments, and displacements of various members of the structure. Numerical values and maximum percent of possible changes in the design parameter are reported in the paper. Various seismic demands of the elastic models (with and without shear walls) have been evaluated and compared. The presented work claims that shear walls effectively reduce shear stresses. It is a fact that increasing the stiffness of the structure in severe seismic zones could simultaneously attract more seismic forces, and if the reinforcement is not detailed appropriately, it could reduce the ductility of the structure. The structural elements, including frame elements and the shear walls are inelastic.

**Keywords:** Modal; Nonlinear; Time history; Dynamic analysis; Northridge; Reinforced concrete structure; Shear walls; SAP2000

**Introduction****Time history**

Dynamic loading caused by earthquakes, wind, traffic, or blasts is most commonly represented by time histories. Time histories can be obtained from earthquake ground motion measurements, structural responses during earthquakes, structural measurements during dynamic tests, or outputs of time history analyses of structures. The most general definition of time history data is data that is time stamped. Some applications require the ground motion precise time with date and hours, including minutes, seconds,

and milliseconds. Universal time can be used to avoid confusing time zone and daylight savings time differences. To pinpoint the epicenter of an earthquake, all individual recordings must use the exact same reference time, otherwise wave travel time computation cannot be carried out correctly and the epicenter cannot be precisely located. When evaluating an individual earthquake acceleration recording or a tri-axial set of recordings, the actual recording time is of minimal importance, although exact timing of the recordings is required to locate the earthquake epicenter and hypo center, compared to a constant time interval between samples.

Early analog recordings of earthquakes are discretized with non-uniform time steps, and special algorithms are devised; modern digital recordings use constant time steps. Synchronization of the time signal is essential for large dynamic tests that usually involve several advanced data acquisition systems. If synchronization is overlooked in the planning stages, then subsequent data analysis can be very challenging [1].

### Time series

Time series analysis analyzes data to extract meaningful statistics and other data characteristics. Because time series data are ordered in time, their analysis is distinct from other common data analysis problems that have no ordering of observations. An example of such unordered data would be the height and weight of students in a class. While this information can be rearranged and ranked, the order in which the students' weights and heights were measured is typically irrelevant for comparison if the measuring occurred within a reasonable time frame [1].

### Single degree of freedom dynamics

**Undamped free vibration:** The simplest dynamic system has only a single mass and stiffness (spring). Mass and stiffness of a simple structure can often be approximated and idealized as a single degree of freedom (SDOF) system. SDOF refers to the motion of mass that can be predicted using formulations presented in this section. If the dynamic system has an energy dissipation mechanism, it can be approximated using viscous damping that accounts for motions of system decay after the removal of excitation [1]. The idealized representation of an undamped SDOF system therefore consists of a spring with stiffness,  $k$ , and a mass,  $m$ . Coordinate  $x$  determines the position of mass  $m$  and is expressed as  $x(t)$  since it varies with time [1]. Predicted vibration of the system continues forever since no energy dissipating mechanism will reduce the motion over time.

**Damped free vibration:** An SDOF with mass  $m_a$ , spring stiffness  $k_a$ , and a damper with a constant value  $c_a$  is shown in Figure 1 (Figure 1).

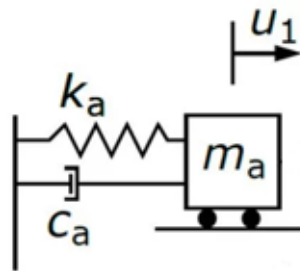


Figure 1: Idealized Damped SDOF System.

Any device is a damper device if it reduces the oscillation amplitude of a system by dissipating energy [1].

**Harmonic excitation:** Harmonic excitation refers to a specific

type of forcing function composed of one or more sinusoidal components [1]. Figure 2 shows a damped SDOF system with an applied force  $f(t)$  that is a function of time.

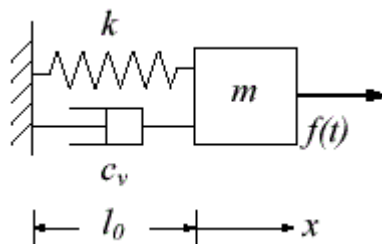


Figure 2: SDOF System with Excitation.

$k$ : spring stiffness

$c_v$ : damping coefficient

$m$ : mass

$l_0$ : undeformed position

$x$ : motion direction

Capturing an SDOF system's maximum displacement response: Depending on the base excitation characteristics and system's natural frequency, the maximum absolute displacement response can occur either during the excitation phase or during the free vibration phase [1].

### Summary of earthquake characteristics

Various earthquake record characteristics should always be computed for a range of angles and, when appropriate, the median geomean value should be used to form the basis of regressions or to judge how well a record meets selected criteria. When processing large numbers of records, individual records and their characteristics must be inspected for abnormalities. To aid in such evaluations, detailed plots of individual record sets are required, allowing a user to verify that no potential manipulations of records adversely affected the time histories. The key is to consistently plot the strong motion records and their characteristics and to examine them carefully before embarking on extensive, costly time history analysis projects for which such records are used as input. Although significant effort is not required to rerun a set of time histories after the original set is rejected or revised, substantial resources are needed to reinterpret, post-process, and document the new results. Thus, the individual carrying out dynamic analysis, not the person who provides the time histories, is responsible for conducting a thorough review of input records before they are used for dynamic analysis. If an individual is unqualified to fully evaluate input motions, then he or she is also generally not qualified to carry

out dynamic analyses without proper technical guidance [1]. In nonlinear dynamic analysis, a series of ground motions to represent seismic demands associated with select hazard levels. A computer model representing nonlinear response characteristics of the structural framing is assembled to simulate dynamic response to the selected earthquake ground motions [2]. The usual application selects two sets of earthquake ground motions, one to represent a Service Level Earthquake (SLE) level and another to represent a Maximum Considered Earthquake (MCE) level [2].

### Shear walls

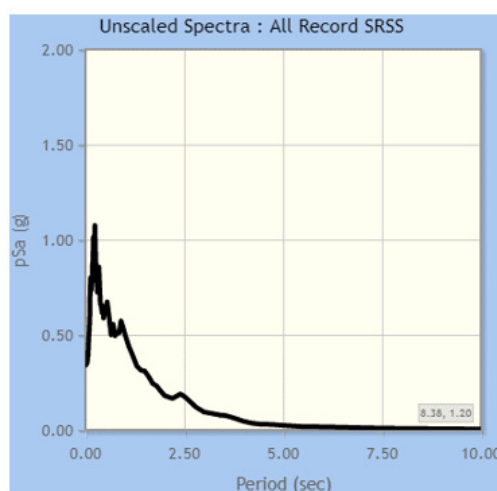
A shear-wall-frame structure, which uses the wall and frame to resist lateral load, is typically used in buildings ranging from 8 to 30 stories [3].

### Literature Review

Chandurkar et al. [4] determined the optimal location for shear walls in a multi-storied building and studied shear wall effectiveness using four models. Kurma et al. [5] conducted pushover analysis on two multi-storied reinforced concrete (RC) frame buildings: one building had 10 stories with five bays in X direction and five bays in Y direction, and the second building contained 15 stories. The shear wall was used to study their resisting lateral forces, and the paper highlighted the effect of a shear wall on the building when a wall was located along the long and short sides of the building. Tidke et al. [6] used five models to study the effect of seismic loading relative to shear wall placement in various locations in a building. Sanjeev et al. [7] considered a spatial configuration of a 20-storied structure with a maximum 70 m height; each story had a height of 3.5 m with a shear wall, with bracing at various locations in the building.

### Numerical Study

Figure 3 shows the unscaled response spectra (Figure 3).

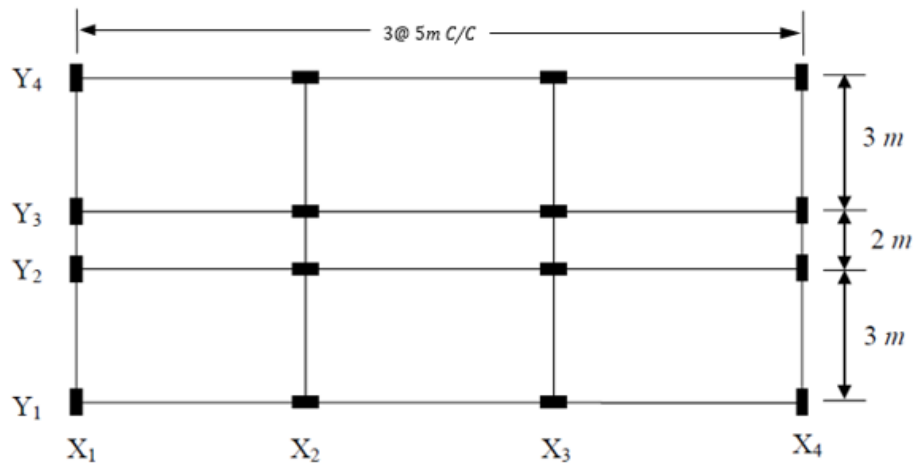


**Figure 3:** Unscaled response spectra.

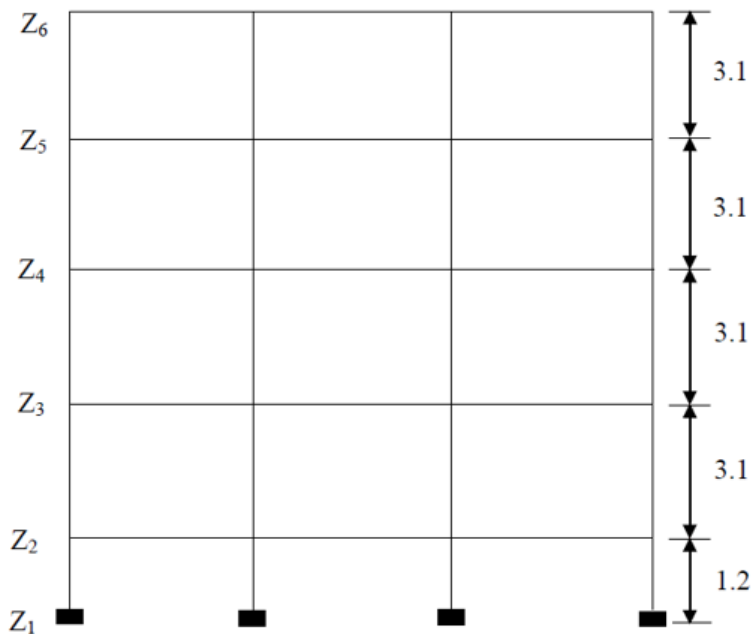
An accelerogram, which measures the peak ground acceleration, duration, and frequency content of an earthquake, can be integrated to obtain time variations of ground velocity and ground displacement [8].

### Building description

The building in this study was a five-storied concrete with and without shear wall building with concrete flat slabs supported by concrete columns. Figures 4 & 5 show the floor plan and elevation of the building model (Figures 4,5).



**Figure 4:** Plan of the building.



**Figure 5:** Elevation of the building.

Building details are as follows:

1. Grade of concrete used is M20 (M20 is 20 MPa strength achieved after 28 days of curing) and grade of steel used is Fe415 (the number 415 indicates that the yield tensile strength of steel is 415 N/mm<sup>2</sup>). These steels are used as rebar in beams, columns and shear walls.

2. Floor heights are 3.1 m.

3. Parapet heights are 1.5 m.

4. Slab Thicknesses are 150 mm.

5. External wall thicknesses are 230 mm and internal wall thicknesses are 150 mm.

6. Sizes of columns are 300 mm × 450 mm and sizes of beams are 300 mm × 450 mm.

7. Live loads on floors are 3 KN/m<sup>2</sup> and live loads on roof are 1.5 KN/m<sup>2</sup>.

8. Floor finishes are 1 KN/m<sup>2</sup> and roof treatments are 1.5 KN/m<sup>2</sup>.

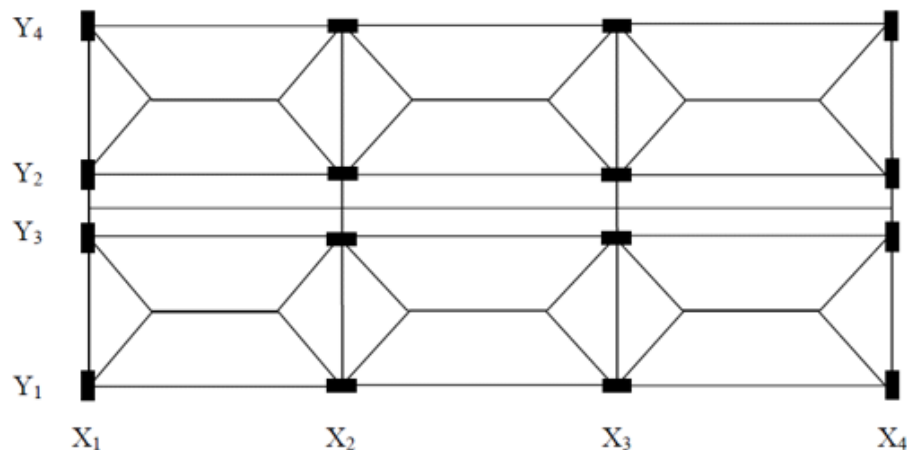
9. Building frame type is Special Moment Resisting Frame (SMRF).

10. Density of concrete is 25 KN/m<sup>3</sup> and density of masonry wall is 20 KN/m<sup>3</sup>.

The shear walls were shell-thin members, and 304.8 mm thick.

### Slab load distribution

Slab loads are transferred to adjacent beams and rigid diaphragms are assigned to simulate the in-plane slab rigidity. Yield line pattern for slab load is shown in Figure 6 (Figure 6).

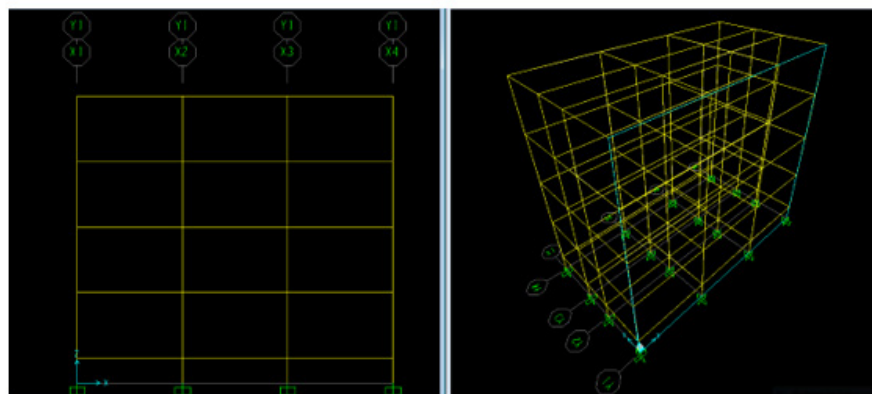


**Figure 6:** Yield line pattern for slab load.

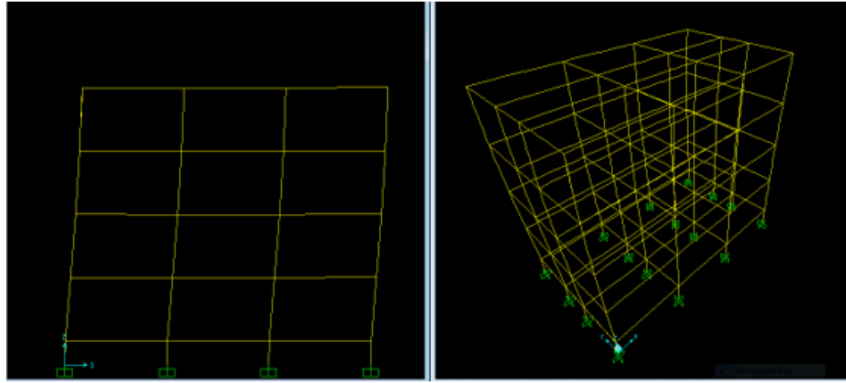
This research's main objective is to determine the optimum shear wall locations under three dimensions of earthquake excitation using SAP2000. SAP2000 automatically utilizes conventional meshing to mesh any areas drawn with more than four joints. Therefore, three models of shear wall locations have been used in this research and were compared to the base model without shear walls (Case1). In Case 2, the shear walls are located on the perimeter of the structure at the left of each of the four building

faces. In Case 3, the shear walls are also located at the perimeter of the structure but at the center of each face. In Case 4, the shear walls are located at the core of the structure. These different cases are described in detail in the following sections.

**Without shear walls - Case 1:** Figure 7 depicts the isometric (3-D) and the two-dimensional (2-D) views of the structure without shear walls, and Figure 8 shows the corresponding deformed shape typically obtained in this study for such a case (Figures 7,8).



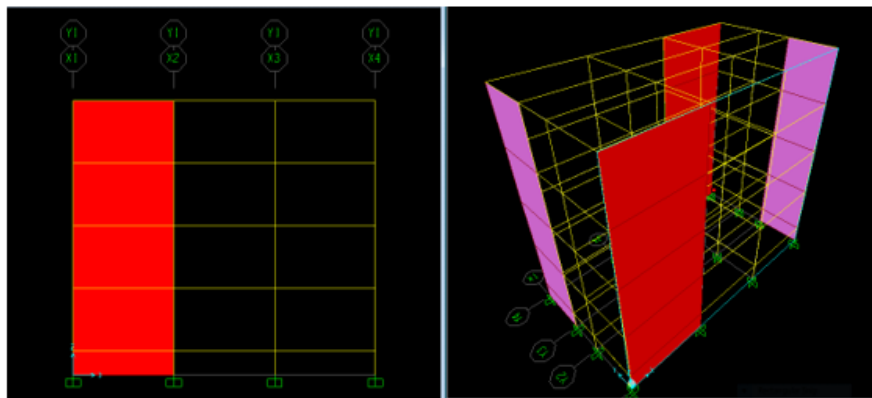
**Figure 7:** 3-D and 2-D views without shear walls.



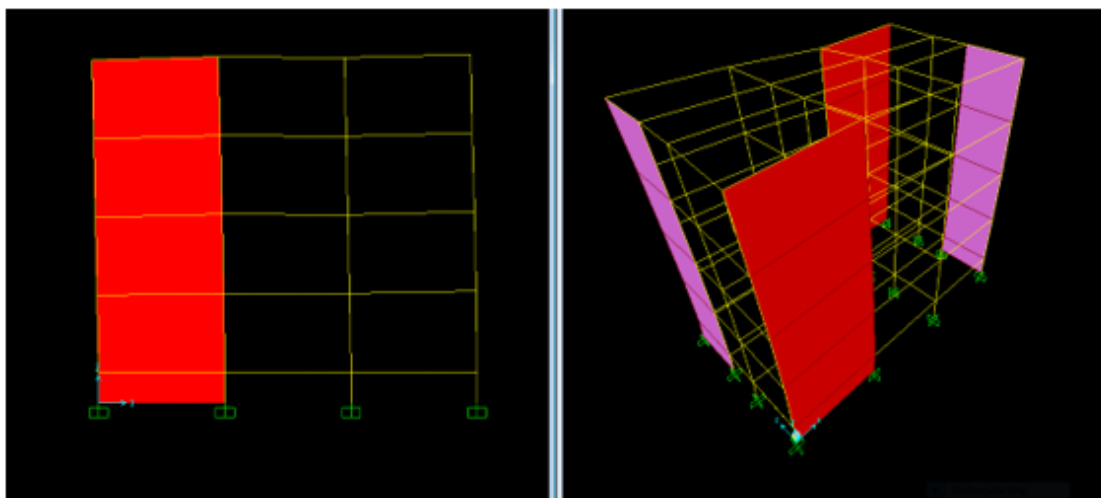
**Figure 8:** Deformed Shape of Building without Shear Walls.

**With shear walls - Case 2:** Figure 9 depicts the isometric (3-D) and the two-dimensional (2-D) views of the structure with shear walls located at the left edge of the structure faces, and Figure 10

shows the corresponding deformed shape typically obtained in this study for such a case (Figures 9,10).



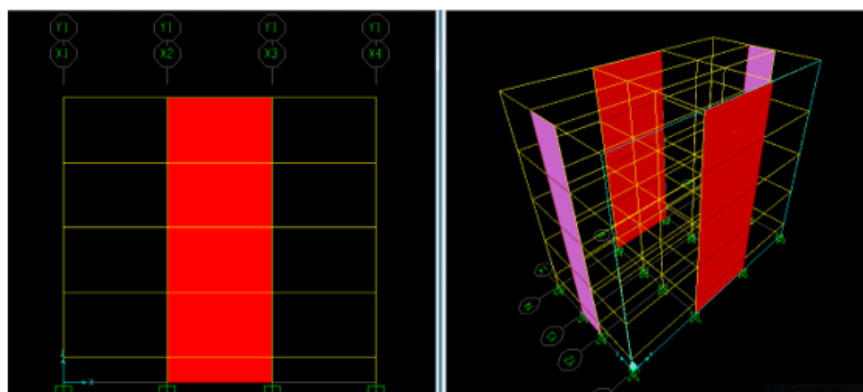
**Figure 9:** 3-D and 2-D views with shear walls (Case 2).



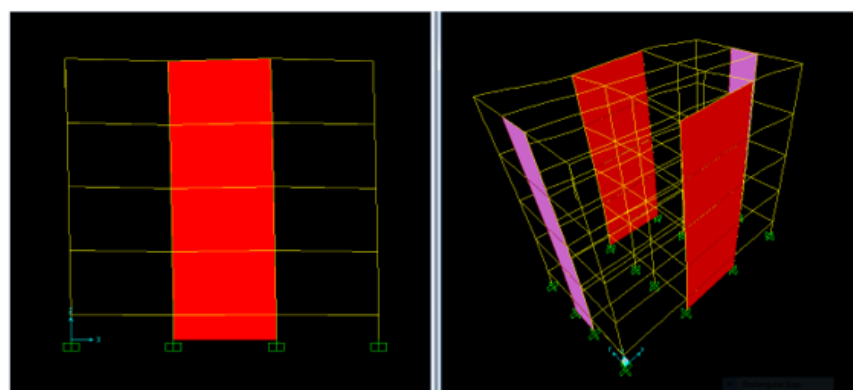
**Figure 10:** Deformed Shape of Building with Shear Walls (Case 2).

**With shear walls - Case 3:** Figure 11 depicts the isometric (3-D) and the two-dimensional (2-D) views of the structure with shear walls located on the perimeter of the structure at the center

of each of the four faces, and Figure 12 shows the corresponding deformed shape typically obtained in this study for such a case (Figures 11,12).



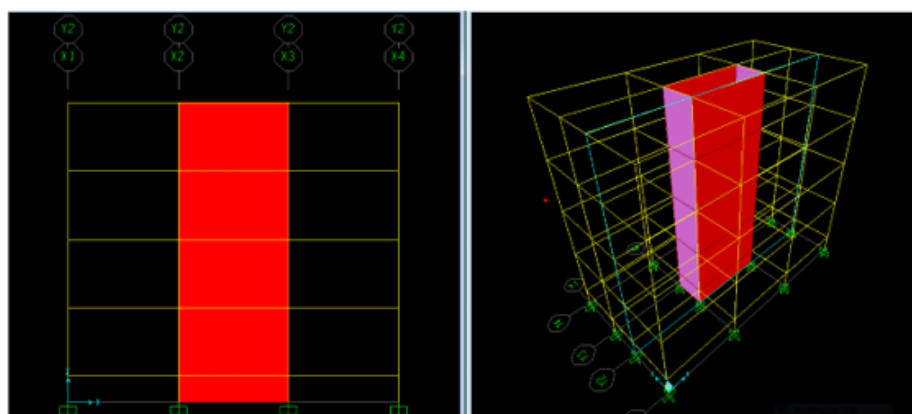
**Figure 11:** 3-D and 2-D views with shear walls (Case 3).



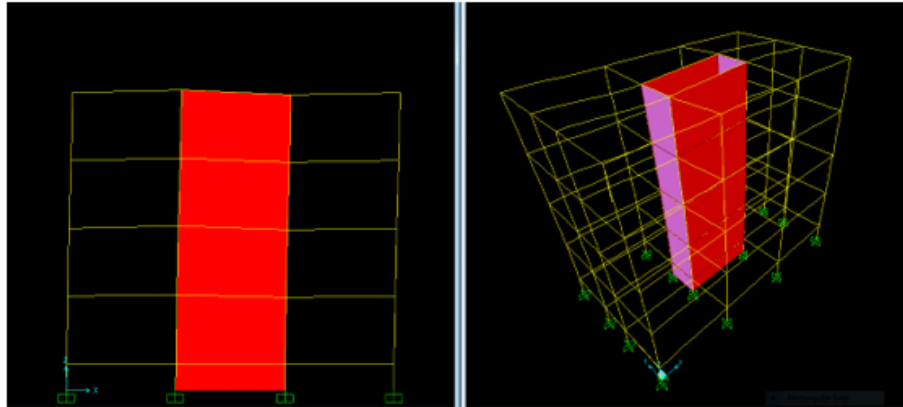
**Figure 12:** Deformed Shape of Building with Shear Walls (Case 3).

**With shear walls - Case 4:** Figure 13 depicts the isometric (3-D) and the two-dimensional (2-D) views of the structure with shear walls located at the core of the structure, and Figure 14 shows the

corresponding deformed shape typically obtained in this study for such a case (Figures 13,14).



**Figure 13:** 3-D and 2-D views with shear walls (Case 4).

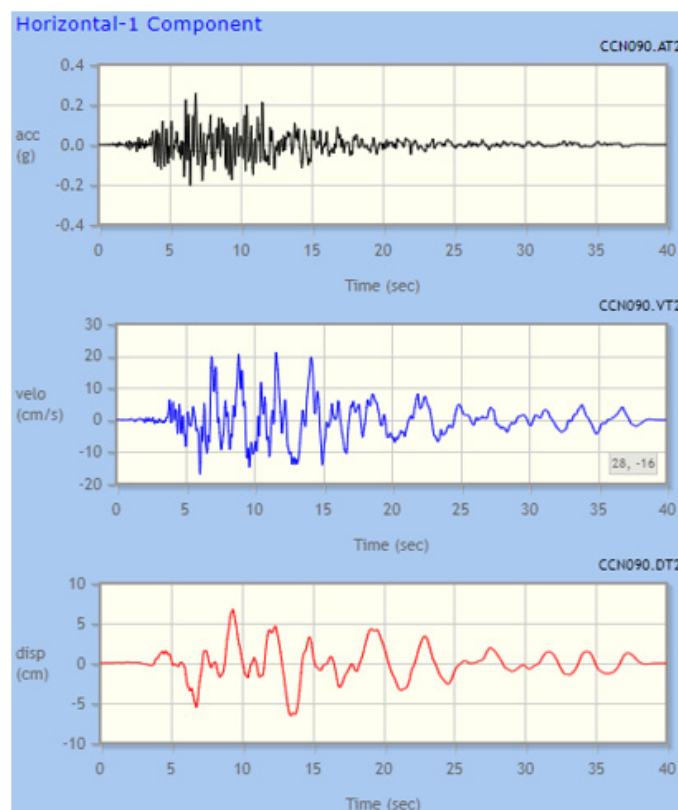


**Figure 14:** Deformed Shape of Building with Shear Walls (Case 4).

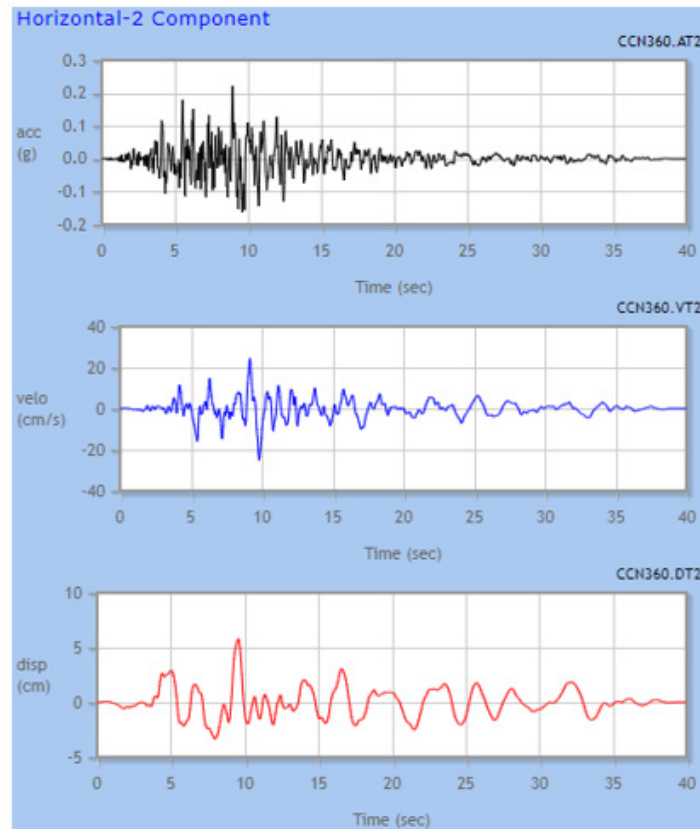
### Numerical Comparison

The presented results are the seismic demands obtained from an individual earthquake (1994 Northridge). The 1994 Northridge earthquake was used in this study as the source of dynamic excitation. Figure 15 shows the unscaled time series of the earthquake record Horizontal-1 Component, while Figure 16

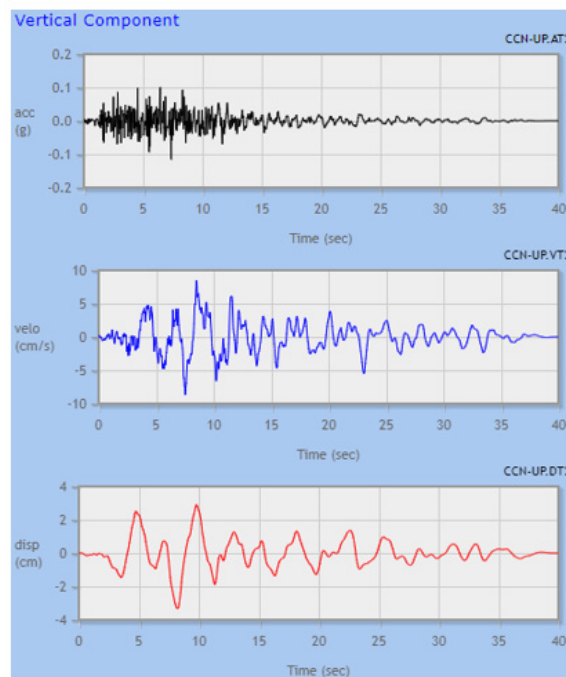
shows the unscaled time series of its Horizontal-2 Component. Figure 17 shows the unscaled time series of the earthquake record Vertical Component. In the current research, the dynamic analysis was carried out using two different records of load time histories. Figures 18 & 19 depict the two records of the load time history (LACC\_NOR-1.TH) and (LACC\_NOR-2.TH), respectively (function graphs in the X and Y direction) (Figures 15-19).



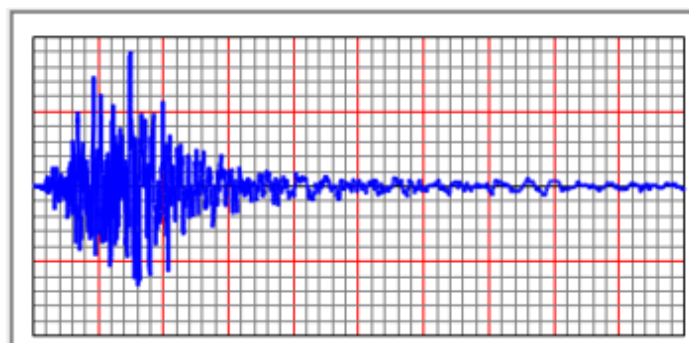
**Figure 15:** Acceleration–time, velocity–time, and displacement–time graphs of processed “LA - Century City CC North” record of 17 January 1994, Northridge earthquake (Horizontal-1 Component).



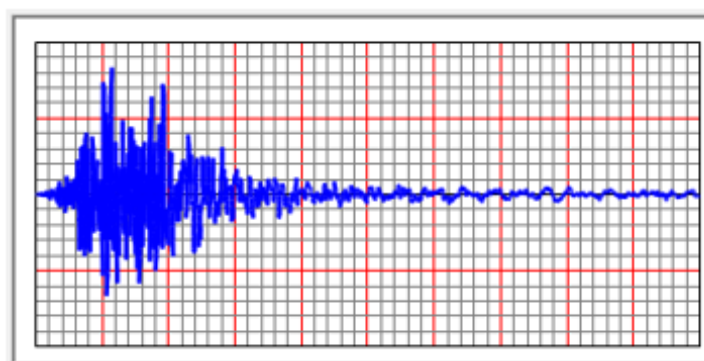
**Figure 16:** Acceleration–time, velocity–time, and displacement–time graphs of processed “LA - Century City CC North” record of 17 January 1994, Northridge earthquake (Horizontal-2 Component).



**Figure 17:** Acceleration–time, velocity–time, and displacement–time graphs of processed “LA - Century City CC North” record of 17 January 1994, Northridge earthquake (Vertical Component).



**Figure 18:** Time-history function graph, X direction.



**Figure 19:** Time-history function graph, Y direction.

## Results

analysis of the structure without shear walls as well as data analysis of the structures with shear walls in different locations (Tables 1-4).

The tables below show results of the nonlinear time history

**Table 1:** Structural time period for nonlinear time history analysis without and with shear walls in different locations.

	Without Shear Walls (Case 1)	With Shear Walls (Case 2)		With Shear Walls (Case 3)		With Shear Walls (Case 4)	
Mode 1	0.8511 s	0.404 s	52.53% decrease	0.5199 s	38.91% decrease	0.3588 s	57.84% decrease
Mode 2	0.7917 s	0.2585 s	67.34% decrease	0.2776 s	64.93% decrease	0.302 s	61.85% decrease
Mode 3	0.7469 s	0.2546 s	65.9% decrease	0.2485 s	66.72% decrease	0.2025 s	72.88% decrease
Mode 4	0.2837 s	0.0906 s	68.07% decrease	0.1237 s	56.37% decrease	0.1018 s	64.1% decrease
Mode 5	0.2497 s	0.08333 s	66.62% decrease	0.08157 s	67.33% decrease	0.08622 s	65.47% decrease

**Table 2:** Structural frequency for nonlinear time history analysis without and with shear walls in different locations.

	Without Shear Walls (Case 1)	With Shear Walls (Case 2)		With Shear Walls (Case 3)		With Shear Walls (Case 4)	
Mode 1	1.174 Hz	2.474 Hz	110.66% increase	1.923 Hz	63.7% increase	2.787 Hz	137.23% increase
Mode 2	1.263 Hz	3.868 Hz	206.26% increase	3.601 Hz	185.17% increase	3.311 Hz	162.15% increase

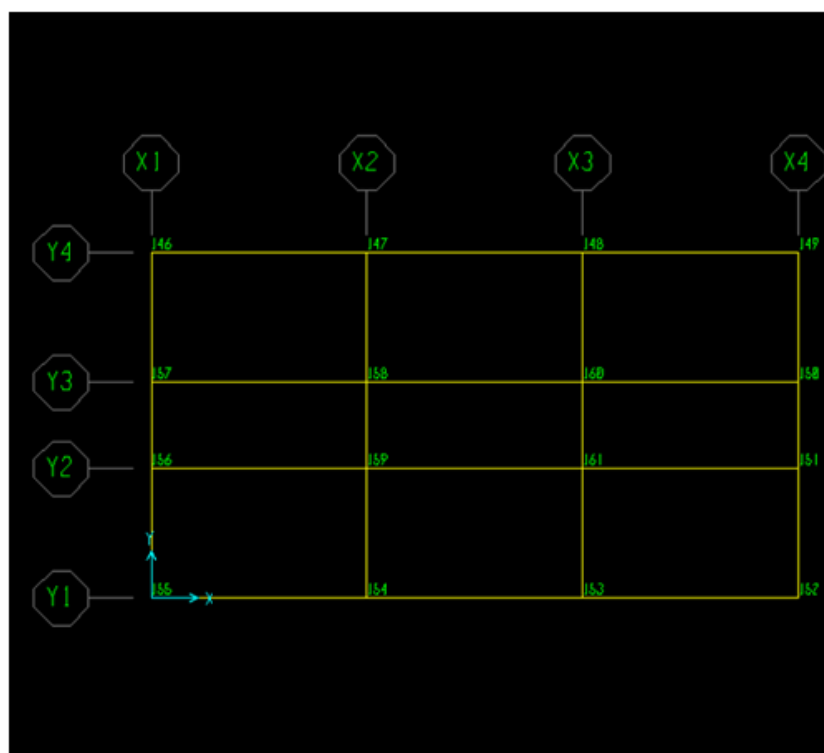
Mode 3	1.338 Hz	3.926 Hz	193.29% increase	4.023 Hz	200.5% increase	4.936 Hz	268.73% increase
Mode 4	3.523 Hz	11.03 Hz	213.2% increase	8.078 Hz	129.23% increase	9.816 Hz	178.56% increase
Mode 5	4.0046 Hz	12 Hz	199.65% increase	12.25 Hz	206.09% increase	11.59 Hz	189.61% increase

**Table 3:** Design base shear for nonlinear time history analysis without and with shear walls in different locations.

	Without Shear Walls (Case 1)	With Shear Walls (Case 2)		With Shear Walls (Case 3)		With Shear Walls (Case 4)	
in X direction	-5860 KN	-13603 KN	132.11% increase	9202 KN	57.02% increase	-9736 KN	66.13% increase
in Y direction	7094 KN	-16701 KN	135.42% increase	-14001 KN	97.35% increase	11201 KN	57.89% increase

**Table 4:** Base moment for nonlinear time history analysis without and with shear walls.

	Without Shear Walls (Case 1)	With Shear Walls (Case 2)		With Shear Walls (Case 3)		With Shear Walls (Case 4)	
in X direction	76991 KN-m	159605 KN-m	107.3% increase	137100 KN-m	78.07% increase	114824 KN-m	49.13% increase
in Y direction	30909 KN-m	63100 KN-m	104.14% increase	-121895 KN-m	294.35% increase	-129646 KN-m	319.43% increase



**Figure 20:** Location of node 158 on the fifth-floor plan.

**Table 5:** Maximum displacements for nonlinear time history analysis without and with shear walls in different locations.

	Without Shear Walls (Case 1)	With Shear Walls (Case 2)		With Shear Walls (Case 3)		With Shear Walls (Case 4)	
Max UX for Joint 104	-96.41 mm	-90.65 mm	5.97% decrease	-91.054 mm	5.56% decrease	-90.994 mm	5.62% decrease
Max UY for Joint 104	-79.089 mm	57.304 mm	27.54% decrease	56.75 mm	28.23% decrease	57.84 mm	26.86% decrease

Max UX for Joint 105	-135.6 mm	-90.7707 mm	33.1% decrease	-93.809 mm	30.86% decrease	-92.905 mm	31.53% decrease
Max UY for Joint 105	-125.4 mm	-90.513 mm	27.86% decrease	-90.0429 mm	28.24% decrease	-85.53 mm	31.83% decrease
Max UX for Joint 106	-174.4 mm	-90.976 mm	47.84% decrease	-98.19 mm	43.7% decrease	-95.76 mm	45.09% decrease
Max UY for Joint 106	-178.5 mm	-108.2 mm	39.38% decrease	-115.5 mm	35.3% decrease	-92.52 mm	48.18% decrease
Max UX for Joint 107	-208.4 mm	-91.16 mm	56.26% decrease	-103.3 mm	50.41% decrease	-98.97 mm	52.51% decrease
Max UY for Joint 107	-226.5 mm	-130.28 mm	42.49% decrease	-141.9 mm	37.36% decrease	-100.12 mm	55.8% decrease
Max UX for Joint 158	-227.5 mm	-91.42 mm	59.82% decrease	-108.5 mm	52.29% decrease	-102.07 mm	55.14% decrease
Max UY for Joint 158	-260.9 mm	-153.9 mm	41% decrease	-166.6 mm	36.14% decrease	-108.1 mm	58.57% decrease

Tables 5 through 7 show maximum horizontal displacements and story drifts at specific nodes (joints) of the structural numerical model. These nodes are shown in Figure 20. Nodes 104, 105, 106, 107, and 158 are located on the X2-Y3 axis for Node 158 as shown in the figure. It is worth noting that in Cases 2 and 3, these nodes are far from the shear walls, while in Case 4, these nodes are inside the shear walls (Figure 20) (Tables 5-7).

**Table 6:** Drifts for nonlinear time history analysis without and with shear walls in different locations.

	Without Shear Walls (Case 1)	With Shear Walls (Case 2)		With Shear Walls (Case 3)		With Shear Walls (Case 4)	
1 <sup>st</sup> Floor - X direction	0.08034 mm	0.07554 mm	5.97% decrease	0.07587 mm	5.56% decrease	0.07582 mm	5.62% decrease
1 <sup>st</sup> Floor - Y direction	0.0659 mm	0.04775 mm	27.54% decrease	0.04729 mm	28.23% decrease	0.0482 mm	26.85% decrease
2 <sup>nd</sup> Floor - X direction	0.01267 mm	0.00003 mm	100.31% decrease	0.0008 mm	93.68% decrease	0.00061 mm	95.18% decrease
2 <sup>nd</sup> Floor - Y direction	0.01496 mm	0.00342 mm	77.13% decrease	0.00341 mm	77.2% decrease	0.00161 mm	89.23% decrease
3 <sup>rd</sup> Floor - X direction	0.01249 mm	0.00006 mm	99.51% decrease	0.00141 mm	88.71% decrease	0.00092 mm	92.63% decrease
3 <sup>rd</sup> Floor - Y direction	0.01712 mm	0.00571 mm	66.64% decrease	0.00822 mm	51.098% decrease	0.00225 mm	86.85% decrease
4 <sup>th</sup> Floor - X direction	0.01097 mm	0.00006 mm	99.45% decrease	0.00166 mm	84.86% decrease	0.00103 mm	90.61% decrease
4 <sup>th</sup> Floor - Y direction	0.01548 mm	0.0071 mm	54.13% decrease	0.00851 mm	45.02% decrease	0.00245 mm	84.17% decrease
5 <sup>th</sup> Floor - X direction	0.00617 mm	0.00008 mm	98.7% decrease	0.00168 mm	72.77% decrease	0.00099 mm	83.95% decrease
5 <sup>th</sup> Floor - Y direction	0.01109 mm	0.00764 mm	31.1% decrease	0.00798 mm	28.04% decrease	0.00257 mm	76.82% decrease
Total drift - X direction	0.01673 mm	0.00672 mm	59.83% decrease	0.00798 mm	52.3% decrease	0.0075 mm	55.17% decrease
Total drift- Y direction	0.01918 mm	0.01132 mm	40.98% decrease	0.01225 mm	36.13% decrease	0.00794 mm	58.6% decrease

**Table 7:** Total weight of building for nonlinear time history analysis without and with shear walls in different.

	Without Shear Walls (Case 1)	With Shear Walls (Case 2)		With Shear Walls (Case 3)		With Shear Walls (Case 4)	
Total weight of building	2297 KN	3859 KN	54.97% increase	3664 KN	59.52% increase	3664 KN	59.52% increase

Table 7 shows that in terms of the total weight of the building, cases 3 and 4 have the same effects (about 60% heavier than Case 1). Case 2 is slightly lighter than Cases 3 and 4 (but still about 55% heavier than Case 1).

## Interpretation of the Results

Tables 8 & 9 show the best behaviors of the structural time periods and frequency, respectively, in the five different modes among all cases with shear walls (Cases 2,3, and 4) and their

comparison to the results the structure without shear walls (Case 1). For example, periods and frequencies of mode 1 were compared for Cases 2, 3, and 4; then, the best value (behavior) was selected and compared to Case 1 (values and corresponding percentage change) (Tables 8,9).

**Table 8:** Structural time period comparison for nonlinear time history analysis by adding the shear walls in different locations.

Best Behavior in	Case Number	Value	Effect of Shear Walls
Period in mode 1	4	0.3588 s	57.84% decrease
Period in mode 2	2	0.2585 s	67.34% decrease
Period in mode 3	4	0.2025 s	72.88% decrease
Period in mode 4	2	0.0906 s	68.07% decrease
Period in mode 5	3	0.08157 s	67.33% decrease

It can be observed from Table 8 that adding shear walls to the structure in different locations leads to a decrease of the structural time period ranging between nearly 57.84% and 72.88%. Also, it can be concluded from Table 9 that adding shear walls to the structure in different locations leads results in an increase of the structural frequency ranging between nearly 137.23% and 213.2%. Table

10 shows the best behaviors of the structural design base shear in the X and Y directions for Case 2 (case of maximum absolute base shear value); This indicates that adding shear walls to the structure at these corresponding locations results in an increase of the structural design base shear in X and Y directions. Such increases will lead to a safer and more conservative design (Table 10).

**Table 9:** Structural frequency comparison for nonlinear time history analysis by adding the shear walls in different locations.

Best Behavior in	Case Number	Value	Effect of Shear Walls
Frequency in mode 1	4	2.78 Hz	137.23% increase
Frequency in mode 2	2	3.868 Hz	206.26% increase
Frequency in mode 3	4	4.936 Hz	200.5% increase
Frequency in mode 4	2	11.03 Hz	213.2% increase
Frequency in mode 5	3	12.25 Hz	206.09% increase

**Table 10:** Design base shear comparison for nonlinear time history analysis by adding the shear walls in different locations.

Best Behavior in	Case Number	Value	Effect of Shear Walls
Design base shear in X direction	2	-13603 KN	132.11% increase
Design base shear in Y direction	2	-16701 KN	135.42% increase

Table 11 shows the maximum absolute value of structural base moment in X and Y directions (Cases 2 and 4); This indicates that adding shear walls to the structure at these corresponding locations provides an increase of the structural base moment in X and Y directions. Such increases will also lead to a safer and more

conservative design. The increased base moment has resulted in increased deformation capacity (Table 11).

Table 12 shows the maximum absolute horizontal displacements in X and Y directions and their corresponding shear wall case (location) (Table 12).

**Table 11:** Base moment comparison for nonlinear time history analysis by adding the shear walls in different locations.

Best Behavior in	Case Number	Value	Effect of Shear Walls
Base moment in X direction	2	159605 KN-m	107.3% increase
Base moment in Y direction	4	-129646 KN-m	319.43% increase

**Table 12:** Maximum displacements comparison for nonlinear time history analysis by adding the shear walls in different locations.

Best Behavior in	Case Number	Value	Effect of Shear Walls
Max UX for Joint 104	2	-90.653 mm	5.97% decrease
Max UY for Joint 104	3	56.75 mm	28.23% decrease
Max UX for Joint 105	2	-90.7707 mm	33.1% decrease
Max UY for Joint 105	4	-85.53 mm	31.83% decrease

Max UX for Joint 106	2	-90.976 mm	47.84% decrease
Max UY for Joint 106	4	-92.52 mm	48.18% decrease
Max UX for Joint 107	2	-91.16 mm	56.26% decrease
Max UY for Joint 107	4	-100.127 mm	55.8% decrease
Max UX for Joint 158	2	-91.42 mm	59.82% decrease
Max UY for Joint 158	4	-108.108 mm	58.57% decrease

As it can be seen in Table 12, the horizontal displacements are significantly decreased when the shear walls are added at the different locations. The addition of the shear walls causes a decrease in the joints maximum horizontal displacement in the X direction that ranges between 5.97% and 59.82%, and a decrease in joint maximum horizontal displacement in the Y direction ranging from

28.23% to 58.57%. These are considered significant improvements to the structure performance during such a powerful earthquake. Table 13 shows the maximum absolute structural drift in X and Y directions and their corresponding shear wall case (location) (Table 13).

**Table 13:** Drifts comparison for nonlinear time history analysis by adding the shear walls in different locations.

Best Behavior in	Case Number	Value	Effect of Shear Walls
1 <sup>st</sup> Floor - X direction	2	0.07554 mm	5.97% decrease
1 <sup>st</sup> Floor - Y direction	3	0.04729 mm	28.23% decrease
2 <sup>nd</sup> Floor - X direction	2	0.00003 mm	99.76% decrease
2 <sup>nd</sup> Floor - Y direction	4	0.00161 mm	89.23% decrease
3 <sup>rd</sup> Floor - X direction	2	0.00006 mm	99.51% decrease
3 <sup>rd</sup> Floor - Y direction	4	0.00225 mm	86.85% decrease
4 <sup>th</sup> Floor - X direction	2	0.00006 mm	99.45% decrease
4 <sup>th</sup> Floor - Y direction	4	0.00245 mm	84.17% decrease
5 <sup>th</sup> Floor - X direction	2	0.00008 mm	98.7% decrease
5 <sup>th</sup> Floor - Y direction	4	0.00257 mm	76.82% decrease

As shown in Table 13, the decrease in floor drifts of the structure in the X direction ranges from 5.97% to 99.76%, and in the Y direction from 28.23% to 89.23%. These are considered significant improvements to the structure performance during such a powerful earthquake. When referring to Table 7, it is clear from the above results that the improvements in the structure seismic resistance and performance are quite beneficial in exchange for the increase in the building weight (59.52% when the shear walls are added (about 55% for Case 2, and 60% for Cases 3 and 4).

## Conclusion

This study analyzed a structure with and without shear walls to determine the effects of shear walls and shear wall locations on a building's response to a severe earthquake event (the 1994 Northridge earthquake was selected). Nonlinear modal time history analysis is also called Fast Nonlinear Analysis (FNA), which is more meticulous and effective than direct integration time history analysis. Response modal nonlinear time history analysis is conducted because it most accurately depicts the correct structural behavior. Structural frequency for various modes, design base shear, base moment, and total building weight increased with shear walls, while structural time periods for various modes, maximum story displacements, and story drifts decreased significantly with shear walls. Numerical values and maximum percentage of increase

and decrease have been reported in the paper. Study results also showed that shear walls are required to resist lateral loads in a structure, and shear walls significantly affect individual framing members and lead to an increase in column base shear force (up to 135%) and column base moments (up to 320%), as well as a decrease horizontal displacement (up to 60%) and story drifts (up to 100%). It should be noted that maximum story drifts often govern the design according to most building codes.

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## Conflict of Interest

No conflict of interest.

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