Performance of Reinforced Concrete Building with Shear Wall under the Effect of Seismic Loads

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ABSTRACT: *Shear wall was classified as vertical structural element that transmitting gravity loadings to the foundation and resists lateral loadings that developing from wind and seismic. In present study, the performance of reinforced concrete shear walls under the effect of seismic loads is consider with different loading types as static as equivalent static analysis and dynamic as time history analysis that applied on reinforced concrete frame building with and without presences of reinforced concrete shear walls. The models are simulating using finite element method by SAP2000 software. Displacements, drifts, building performance and base shear are evaluating for all cases of loadings. The analysis results indicated that the presences of reinforced concrete shear wall lead to reduce in displacements, drifts, increase in frequency under static seismic load and also reduces in deformation under time history loading and in additional increase the base shear resistance with more stability and increase in overall stiffness of building.*

Keywords: *Reinforced concrete shear wall, Seismic loading, Dynamic analysis, SAP2000, Time history.*

I. INTRODUCTION

Shear wall as vertical structural elements was adopted in many buildings around the world due to its capability of resisting lateral loads, increasing the stiffness and building stability that lead to reduce the structural elements deformations under applied loads. Mode of failure of reinforce shear wall very complex when it is subjected to vertical and in plane shear loads that relies on the aspect ratio and reinforcement ratio in addition to the concrete compressive strength of shear wall [1]. Reinforced concrete shear wall is the main structural elements especially in high rise buildings. Shear walls providing more strength and stiffness to the building that lead to reduces lateral deformations in the direction of their orientation. Shear walls carry large horizontal earthquake forces that lead to reducing the effects of shear forces that developed due to ground motion for all floor levels. Paul Heerema et al, 2017 [2], analyzed the experimental results of reinforced concrete shear wall under the effects of seismic loadings. The experimental works focused on the impact of twist on the reinforced concrete shear wall deformations as displacement and strength demands. Also, the analysis tacked into account the contributions of shear wall within the building to resist or reduce the effects of seismic loadings to the building as structural effects. Analysis results pointed out the energy dissipation increased with increased of building displacement ductility. Makoto Kato et al, 2018 [3], studied the seismic energy dissipation of coupled reinforced concrete shear wall system. Twelve stories reinforced concrete building was analyzed to check out the energy dissipation due to the presence of shear walls. The shear walls placed at the building center that working as core. Analysis results indicated that the presence of shear walls reduced seismic compressive stresses that lead to enhance the overall seismic behavior of the structural building. D.T.W. Looia et al, 2017 [4], studied the effects of axial force on the reinforced concrete shear wall under the influence of seismic loading within tall building. The adapted reinforced concrete shear wall was existing in building without seismic reinforcements details was examined in analysis. Analysis results founded that the magnitude of axial force significant on the performance of reinforced concrete shear wall crack patterns, failure modes and deformability.

Baetu, S., et.al. 2011 [5] simulated reinforced concrete shear wall by adapted nonlinear numerical analysis used finite element approach by ANSYS software. The reinforced concrete shear wall with slit worked and behaved as passive control resulting in damping system. The damping system increases and the whole structural system ductility increases that was happed when the yielding of shear connector. In case of high seismic zones, the slit walls are more adequate due to shear connectors yield point has been achieved. Analysis results compared with walls without slits, structure failed because of plastic hinge was prevented under extreme seismic load because of high ductility provided to the structure after yielding of shear connectors. Manicka Dhanasekar et al., 2019 [6], studied the full performance of reinforced concrete shear wall under the effect of seismic loadings with different rebar's details. The influence of concrete compressive strength of reinforced concrete shear wall, wall thickness and rebar's details such as single and double layers were considered. All models were simulated using finite element approach and analyzed as nonlinear material. Analysis results showed that the single and double rebar's not significantly differ in lateral in-plane load capacity nor in their ductility. Also, the reinforced concrete shear walls with high concrete compressive strength and high tensile rebar strength showed no ductile at failure stage. Double rebar's layers gave more confinements to the reinforced concrete shear wall against applied lateral loadings. Double flanged squat shear wall dominated by shear mode of failure. Hamed Hamidi et. Al. 2018 [7], pointed on the effects of repeated seismic loadings on the behavior and strength of reinforced concrete shear wall. Different structural building levels were considered such as 10, 15 and 20 stories. The analysis results revealed that repeated applied seismic loading due to earthquakes gave attention to increase in seismic requirements of reinforced concrete shear wall but not caused failure of the structure. Also, the presence of the next record reduced the residual structural displacement. The final decision, the effect of repeated applied seismic loadings must be considering in the assessment of the reliability of structures. Energy distribution showed that an increase in the structure height will possibly increase the contribution of mass matrix and decrease the contribution of stiffness matrix of input energy. Guoqiang Li et al., 2016 [8], analyzed non-conventional shear wall by introduced metal to working out as energy dissipation under the effects of seismic loadings. different parameters were adopted in the study such as metal energy-dissipation shear wall that included coupled shear wall in addition to energy-dissipating steel link beams and frame that contained steel plate to prevent buckling-so that it working as restrained to the shear wall. Analysis results showed that the steel coupling beams and the buckling restrained steel plate working as coupling elements. Kalil Erazo et al., 2019 [9], estimated the response and damaged that occurred in reinforced concrete structural building consisted of reinforced concrete shear wall subjected to a strong earthquake. Seismic loadings were applied seriously and increased gradually up to serve damage on the structure occurred. Linear and nonlinear time history analysis are applied in which the analysis and test results such as displacements at each floor levels, accelerations, story drifts, base shear, and overturning moment caused by strong base excitations where adopted. The estimated results were considered to compute damage.

The aim and significant of present study are to assessment the performance of reinforced concrete building with and without reinforced concrete shear walls (RCSWs)that presences within frame building under the effect of seismic loads such as loading types as static and dynamic.

II. Models descriptions

Finite element approach is the approximate solution method to solve differential equation. In finite element method (FEM), the whole problem is divides into a pieces that represents the selected elements in which these elements are connecting by nodes. Linear seismic analysis in cases of static and dynamic apply loadings are considering to analyze the RCSW. The RCSW that adopted in present study consists of concrete material and steel reinforcements as vertical and horizontal that built inside frame typical eight stories building. The finite element software such as SAP2000 [10] that adopted to evaluate the performance of RCSW allow to insert static and dynamic loadings with many options that require in analysis.

Different factors effects on the response of structure subjected to seismic loadings for both static analyses. These factors rely on the location of building with properties of seismic zone. All factors based on the Iraq seismic code [11]. Factors such as S_s and S_1 for the short periods (0.2 sec) and it mapped maximum earthquake parameter at the period of 1 sec respectively with assumed damping ratio 5%. These factors are used to calculate the parameters S_{MS} and S_{M1} as follows:

$$S_{MS} = S_S \ F_a \qquad 1$$

$$S_{M1} = S_1 \ F_v \qquad 2$$

where

F_a= Site coefficient at short period (0.2 sec)

F_v= Site coefficient at 1.0 sec period

The values of as S_s and S_1 is 0.3 and 0.1 for Baghdad city

The F_a and F_v parameters are presented in Tables 2-2/1a and 2-2/2 b [11] Iraq seismic code 2017 respectively, in which

F_a = 0.8 and F_v= 0.8

Design earthquake spectral response acceleration parameters S_{DS} and S_{D1} related to 0.2 and at 1 sec period, respectively computed as follow [37]:

$$S_{DS} = \frac{2}{3} S_{MS} \qquad 3$$

$$S_{D1} = \frac{2}{3} S_{M1} \qquad 4$$

By applied the equations mentioned above, the calculations result lists in Table 1. The seismic factors based on the building types lists in Table 2.

Table 1: Seismic parameters based on Iraq seismic code [11]

S_s	S_1	F_a	F_v	S_{MS}	S_{M1}	S_{DS}	S_{D1}
0.300	0.100	0.800	0.800	0.240	0.080	0.160	0.053

Table 2: Seismic factors based on Iraq seismic code [11]

Building type	Response modification R	system over strength Ω	Deflection amplification Cd	Importance factorI
Frame building without shear walls	3	3	2.5	1
Frame building with shear walls	4.5	2.5	4	1

To constrict the response spectrum curve for design based on the Iraq seismic code [11] and ASCE 7-16 [12]as

$$S_a = S_{DS} \, (0.4 + 0.6 \frac{T}{T_o}) \qquad 5$$

follows:

equation 5 apply in case of $T < (0.2S_{D1}/S_{DS})$, in case of $T_o \leq T \leq T_S$, but when $T_S \leq T \leq T_L$ (TL= the long-period transition period in sec.), S_a calculate as:

$$S_a = \frac{S_{D1}}{T} \qquad 6$$

when the period $T > T_L$, then:

$$S_a = \frac{S_{D1} T_L}{T^2} \qquad 7$$

in which:

$$T_o = 0.2 \frac{S_{D1}}{S_{DS}} \qquad 8$$

$$T_s = \frac{S_{D1}}{S_{DS}} \qquad 9$$

in which the values of T_o and T_s is 0.0667 and 0.3333 for reinforced concrete building with and without reinforce concrete shear walls respectively.

III. Modal analysis

The first analysis of any structure under the dynamic loading analyzed first as modal analysis. Modal analysis is performed in present study to find out the natural periods and the corresponding mode shapes of each natural frequency. The modal analysis provides the limits of the response of the structural system. Each structural element has an internal frequency (resonant frequency) in which this element naturally vibrates. Also, the frequency in which this object give permission to do the transfer of energy from one form to another with minimal loss, that is mean vibrational to kinetic. If the frequency increases in the direction of the "resonant frequency", the magnitude of response asymptotically increases to infinity. Each structural element described as stiffness matrix that assembled for all structural members and then connects the applied forces with displacements. These obtained frequencies (resonant frequencies) named as natural frequencies and are provided by the eigenvectors of the stiffness matrix. The resonant frequencies rely on mechanical structures that named as mechanical resonance.

Dynamic analyses – Time history linear

El Centro earthquake ground motion that recorded in Imperial Valley in California - 1940 is adopt to evaluate the performance of reinforced concrete buildings with and without RCSW is shown in Figure 1. The peak ground accelerations (PGA) of this earthquake ground acceleration record equals to 0.295 g.

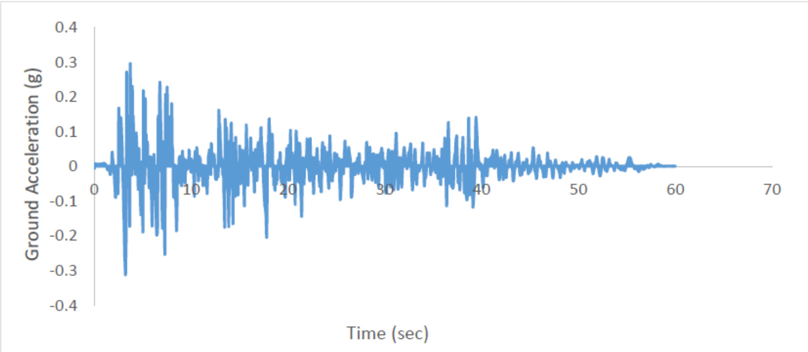


Figure 1: El Centro earthquake ground motion

The dynamic equation that covering the time history analysis based on Newton second low for motion as follow:

$$m\ddot{u}(t)+c\dot{u}(t)+k\,u(t)=f\,(t) \qquad 10$$

where

m: is the mass;*c*: is the damping;*k*: is the stiffness and f(t): is the applied external force as a function of time, while *u¨ (t)*, *u˙(t)* and *u(t)* are the displacement, velocity and acceleration. Equation (3.10) solved in present study by modal solution and can be solving as direct integration method. Equation 10 represent second order differential equation, constant coefficient and nonhomogeneous. Two boundary conditions required to complete the solution of equation (3.10) as follow:

At t = 0, the initial displacement u(t) and initial velocity u.(t) equal to zero.

In case of linear time history LTH analysis, the mode superposition method is used in many structural analysis programs and is an effective way to calculate the dynamic response for the linear dynamic analysis. Accuracy of the whole structural response relies on the natural modes number and on the number of modes. The applied load that consider here change with time with linear time history performance. The accuracy of analysis results relying on the number of modes setting in which the number of modes are consider are 12.

Element types

Different element typesareused to simulates the actual performance of reinforced concrete buildings with and without RCSW as real properties of each material such as frame and area section by SAP2000 software [10]. The beams and columns simulated as FRAME section while slab and RCSW by using SHELL element. Shellelement is considered to model RCEWs and slabs due to the behavior of this type of element in planar and three dimensional structures.

The Shell element have four nodes that formulated so that it takes both membrane and bending behavior. Each Shell element has local coordinate system so that defining the material properties and the applied loads as gravity and uniform loads. The shell stiffness used four-point numerical integration in which all the unknown parameters such as stresses, foresees and moments founded and assessment by adopted the 2x2 Gauss integration points.

Finite element modeling

The structural models that represents the reinforced concrete buildings with and without RCSW are considered and simulated in which the structural elements were designed according to ACI-318-2019 [13] under the effect of gravity loadings. The gravity loads and all kinds of seismic loads are taken into account in the analysis of structural elements.The fixed at the base represent the raft foundation under this type of structural. Gravity applied loadings that is the main loadings to design the structural members of reinforced concrete building based on the ASCE – 07 – 2016 [12]. The superimposed dead load that represents the finish floor, partitions and services loadings equal to 3.25 kN/m^2 in addition to 2 kN/m^2 as live loading.In case of linear static seismic loading, the location of such a building in Baghdad so that all seismic factors from Iraq seismic code adopted in present study. Support condition for all models is assumed to be fixed that represent the foundation type underneath columns and RCSWs is raft foundation.Table 3 lists the dimensions of structural members and mechanical properties for each materials

Table 3: Dimensions of RCSWs and mechanical properties for each materials

Slab thickness (mm)	200
Story height (mm), H	3000
Wall thickness (mm)	200
Concrete compressive strength (f_c') (MPa)	25
Poisson's ratio (ν)	Concrete 0.2
	Reinforcement 0.3
Yielding strength of the steel bars (f_y) (MPa)	410
Unit weight (γ) (kg/m^3)	Concrete 2400
	Reinforcement 7850

Lateral loadings as seismic and wind based on the building location in Baghdad. Wind load assumed that the basic wind speed V_B is 45 m/sec category B.

Proposed structural building

The proposal structural building with plane layout shown in Figure 2 with dimensions of 30x30 m with total height 24 m that include eight levels each 3 m height. The building designed as slab beam system without presences of shear walls under the effects of gravity loads, wind and seismic loading in additions to load combinations. Geometry dimensions for beams and columns are 600x400 m and 400x400 m respectively and the slab thickness is 200 mm for all floor levels.

The basic load combinations based on ASCE-7-2010 [12] as follows:

1. 1.4D

2. 1.2D + 1.6L

3. 1.2D + 0.5W

4. 1.2D + 1.0W + L

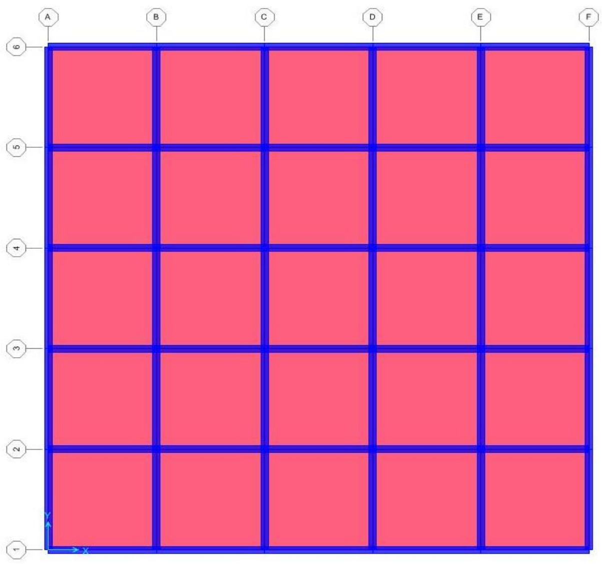
5. 1.2D + 1.0E + L

6. $0.9D + 1.0W$

7. $0.9D + 1.0E$

In which, D is the Dead load, E is the Earthquake load, L is the Live load and W is the Wind load.

Two structural buildings with same dimensions and columns layout but differ in presences of reinforced concrete shear walls. First building BWTSWS represent building without shear walls and second is BWSWS represent building with shear walls.Plane, elevation and three dimension of adopted building of BWTSWS are shown in Figures2 to 4.



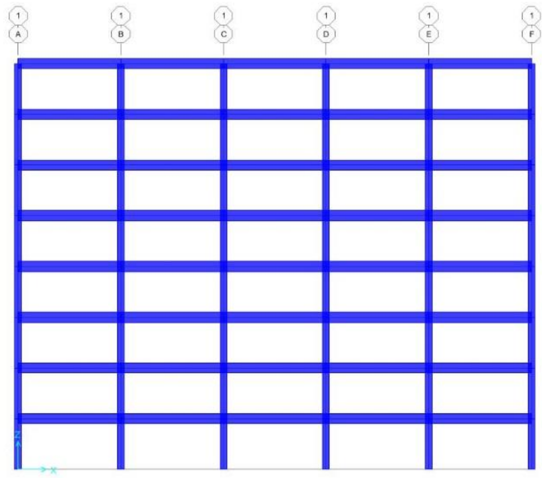


Figure 2: Plane building layout

Figure 3: Building elevation

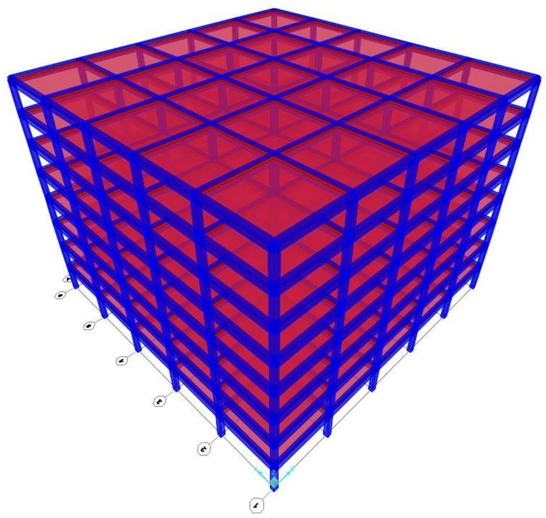
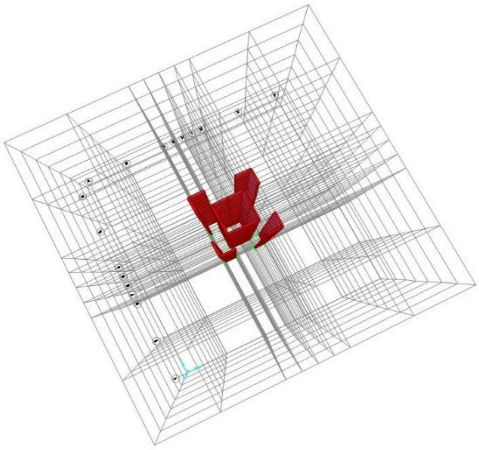


Figure 4: Building three-dimension view

The shear walls layout with full structural building BWSWS are shown in Figures5 to 7.



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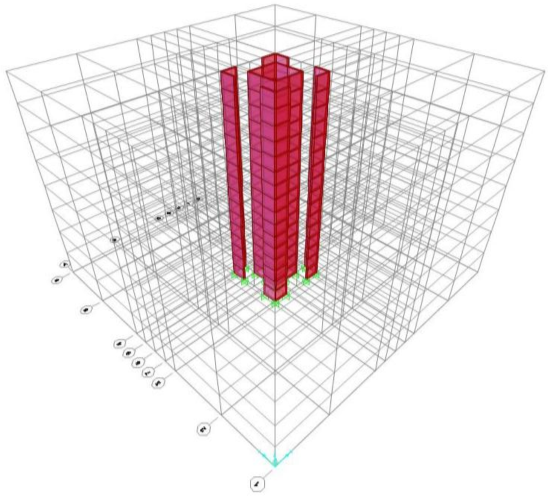


Figure 5: Top view of shear walls

Figure 6: Three dimensional view of shear walls

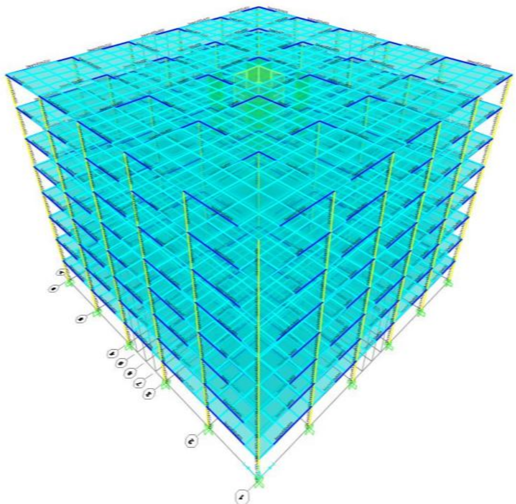


Figure 7: Three dimensional view of BWSWS building

Results and discussions

Modal analysis is performed for all models as full structural; buildings to determine the dynamic properties of such as the natural periods and mode shapes of vibration, which are important for any seismic analysis method. The period time and circular frequency ω_n calculated by:

$$T = \frac{2\pi}{\varpi_n} \quad (11)$$

$$\omega_n = \sqrt{\frac{k}{m}} \quad (12)$$

Frequency f by applied the following relationship:

$$f = \frac{1}{T} \qquad 13$$

The Eigen value (shape mode) as follow:

$$Eigen\,value = (circular \quad frequency)^2 \qquad 14$$

Tables 4 and 5 lists the modal periods and frequencies of BWTSWS and BWSWS respectively

Table 4: Modal periods and frequencies-BWTSWS

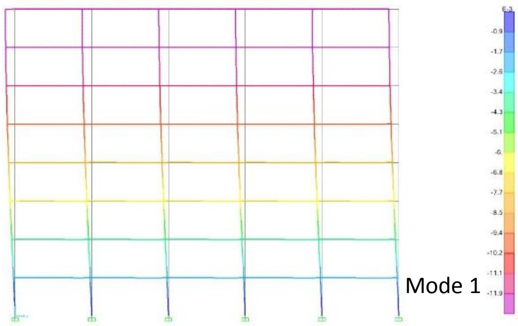
Output Case	Step Type	Step Number	Period (Sec.)	Frequency (Cycle/sec)	Circular Frequency (rad/sec)	Eigen value (rad^2/sec^2)
Modal	Mode	1	1.25719	0.79542279	4.99778884	24.9778932
Modal	Mode	2	1.257193	0.795422798	4.99778884	24.97789329
Modal	Mode	3	1.109036	0.901683962	5.665447419	32.09729446
Modal	Mode	4	0.417958	2.392585572	15.03305851	225.9928482
Modal	Mode	5	0.417958	2.392585572	15.03305851	225.9928482
Modal	Mode	6	0.3689	2.7107652	17.03224008	290.097202
Modal	Mode	7	0.24883	4.018811656	25.25093835	637.6098877
Modal	Mode	8	0.24883	4.018811656	25.25093835	637.6098877
Modal	Mode	9	0.220365	4.53793384	28.51267923	812.9728766
Modal	Mode	10	0.178234	5.610614601	35.25253122	1242.740958
Modal	Mode	11	0.178234	5.610614601	35.25253122	1242.740958
Modal	Mode	12	0.157743	6.339432073	39.83182646	1586.574399

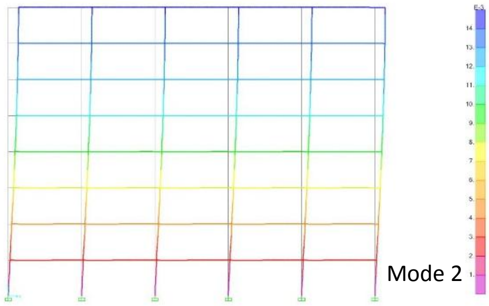
Table 5: Modal periods and frequencies-BWSWS

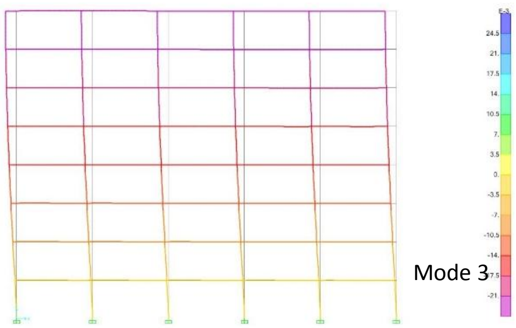
Output Case	Step Type	Step Number	Period (Sec)	Frequency (Cycle/sec)	Circular Frequency (rad/sec)	Eigen value (rad^2/sec^2)
Modal	Mode	1	0.97781	1.022693974	6.42577575	41.290594
Modal	Mode	2	0.757083	1.320859059	8.299202233	68.8767577
Modal	Mode	3	0.757083	1.320859059	8.299202233	68.8767577
Modal	Mode	4	0.324788	3.07893142	19.34549666	374.248241

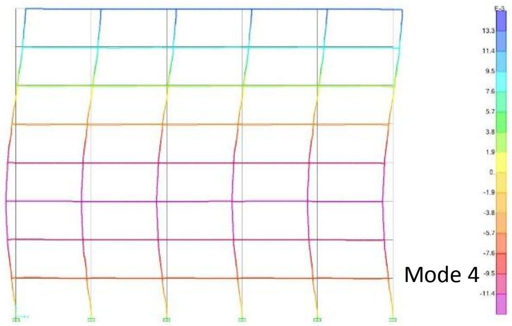
Modal	Mode	5	0.219692	4.551829627	28.59998903	817.9593726
Modal	Mode	6	0.219692	4.551829627	28.59998903	817.9593726
Modal	Mode	7	0.19366	5.163683668	32.44438136	1052.637882
Modal	Mode	8	0.140447	7.120110809	44.73697562	2001.396988
Modal	Mode	9	0.13838	7.226491498	45.4053852	2061.649005
Modal	Mode	10	0.137743	7.259888997	45.61522788	2080.749014
Modal	Mode	11	0.137743	7.259888997	45.61522788	2080.749014
Modal	Mode	12	0.133607	7.484625125	47.02728661	2211.565686

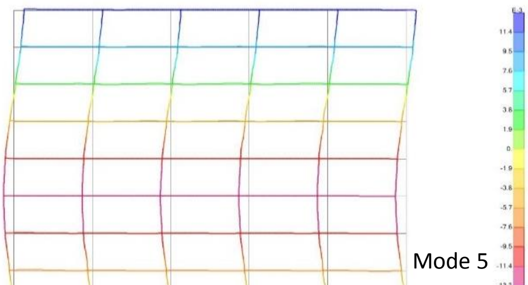
Figures 8 and 9 shows the mode shape of BWTSWS and BWSWS

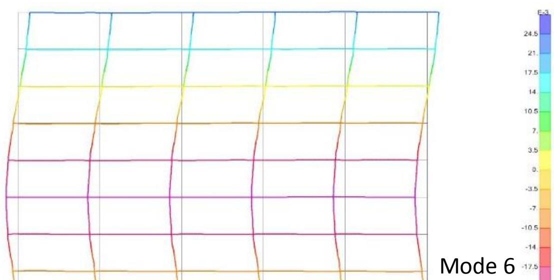












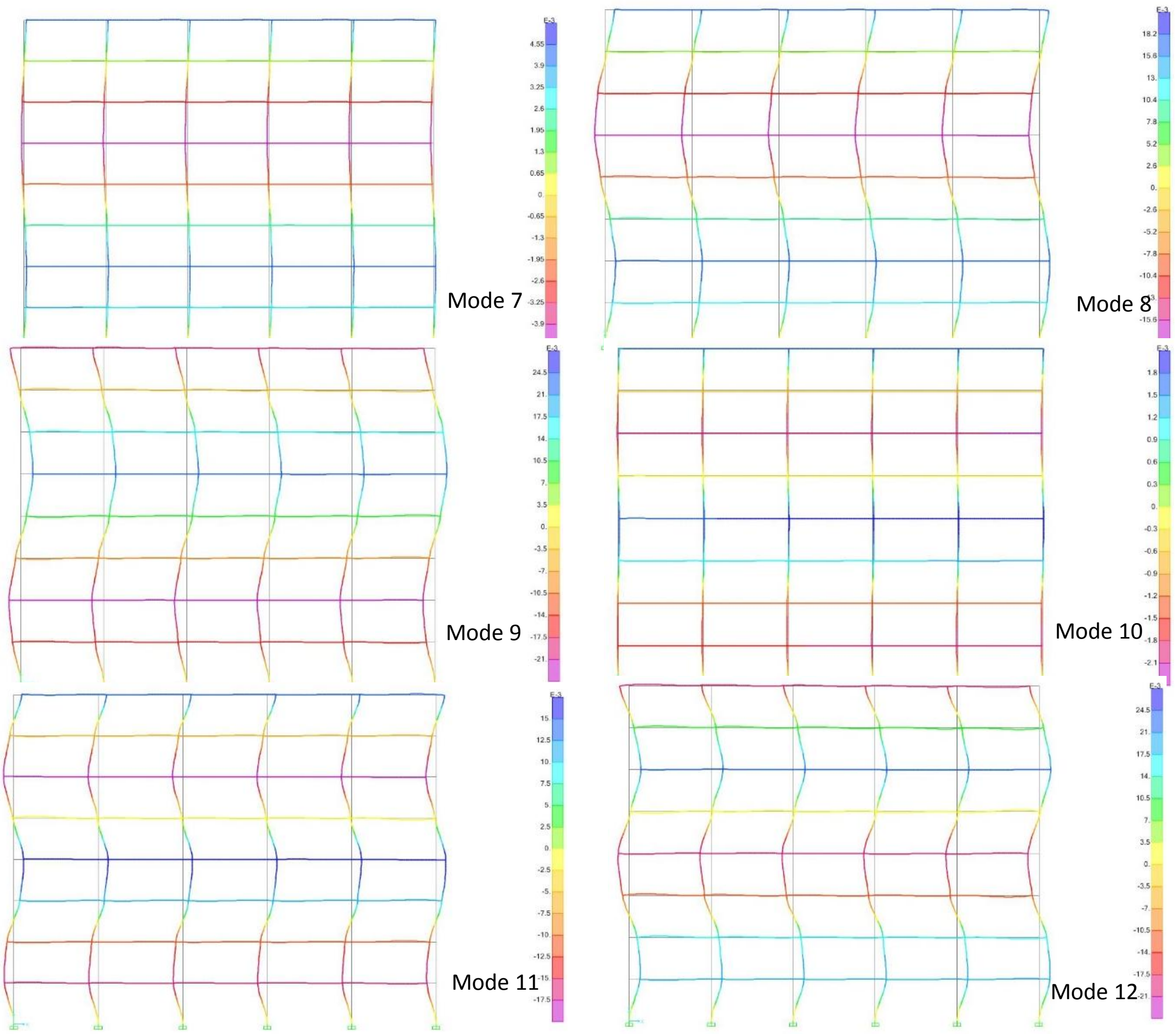
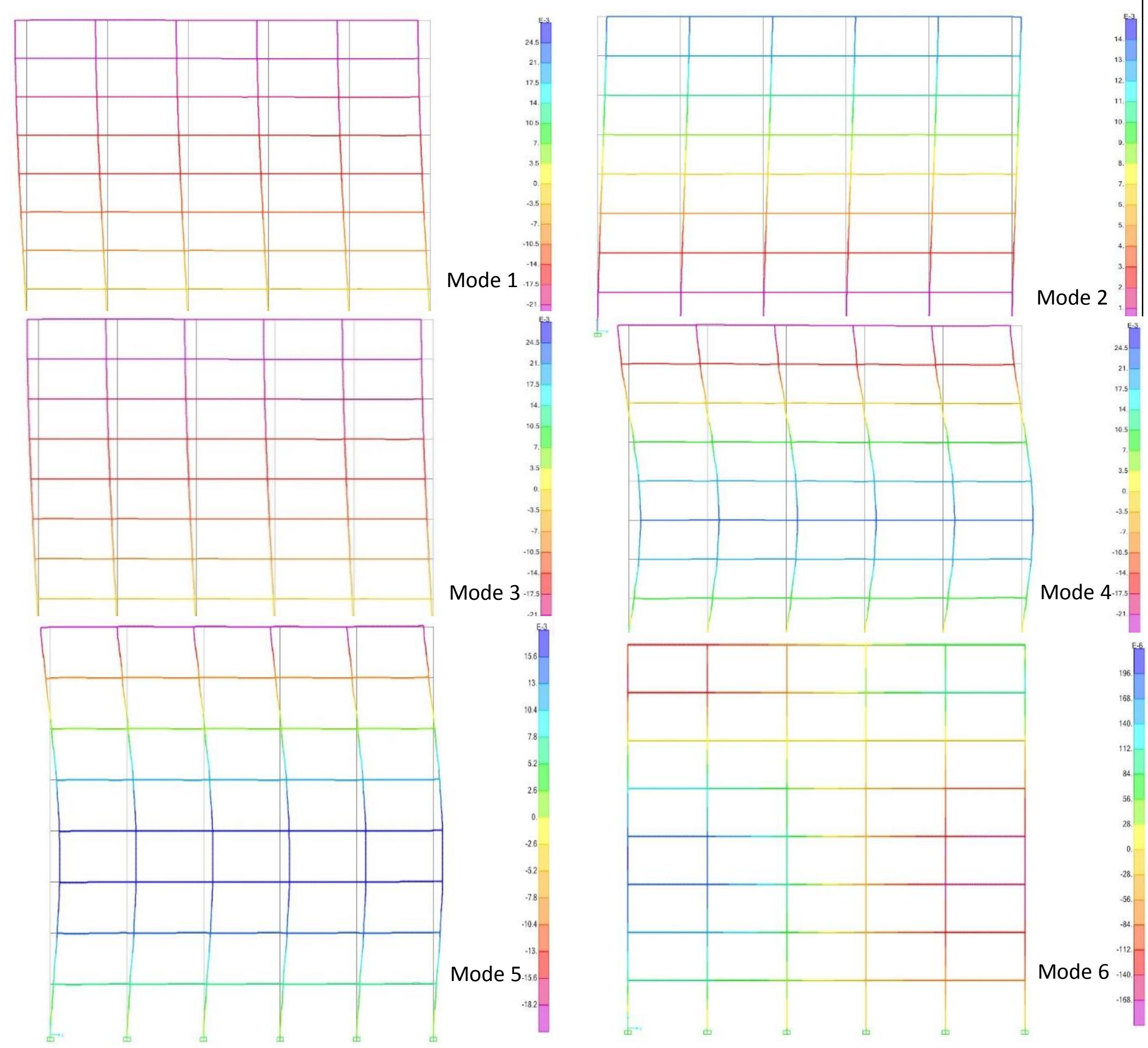


Figure 8: Mode shape of BWTSWS


Mode 1
Mode 2
Mode 3
Mode 4
Mode 5
Mode 6

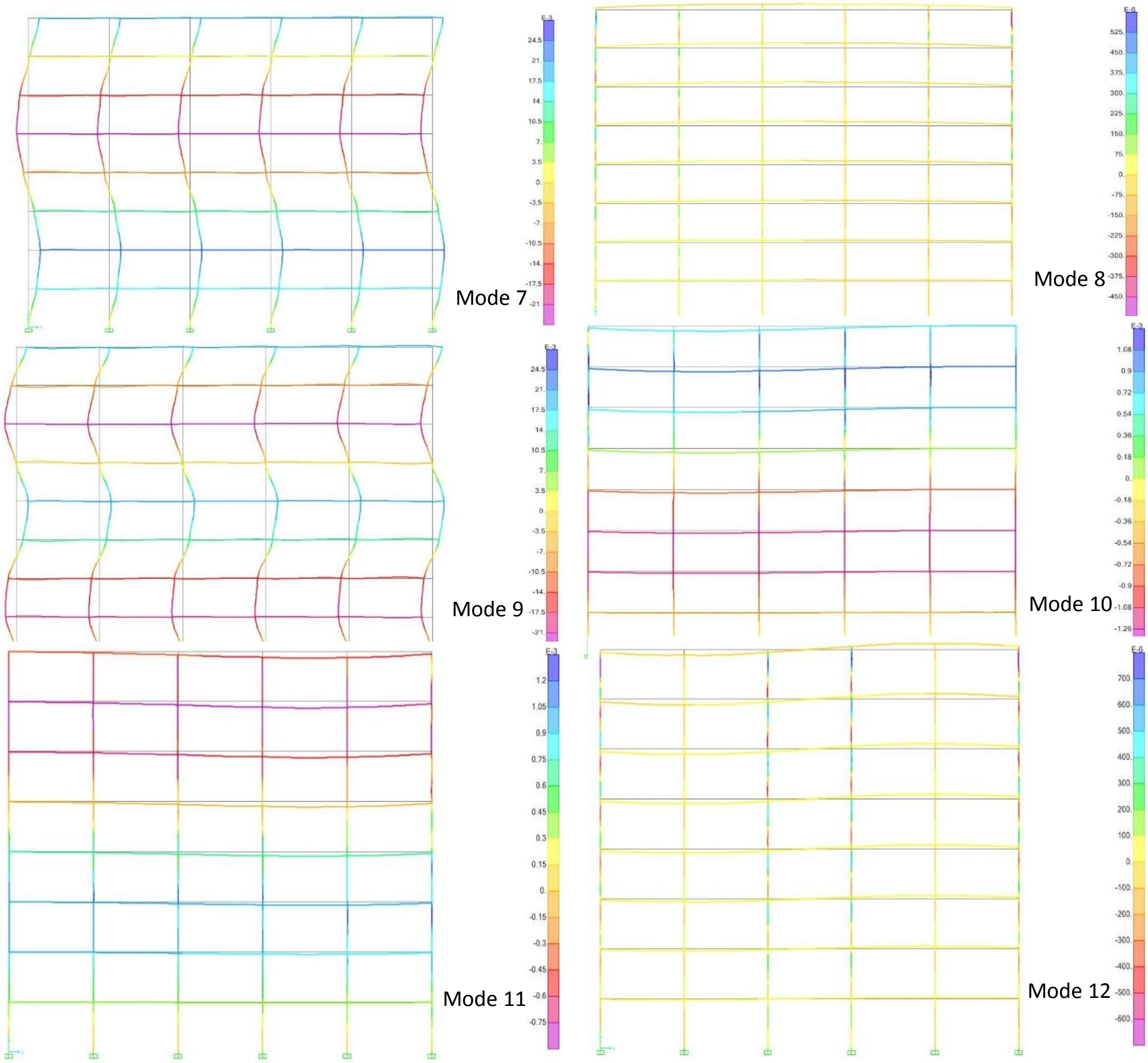
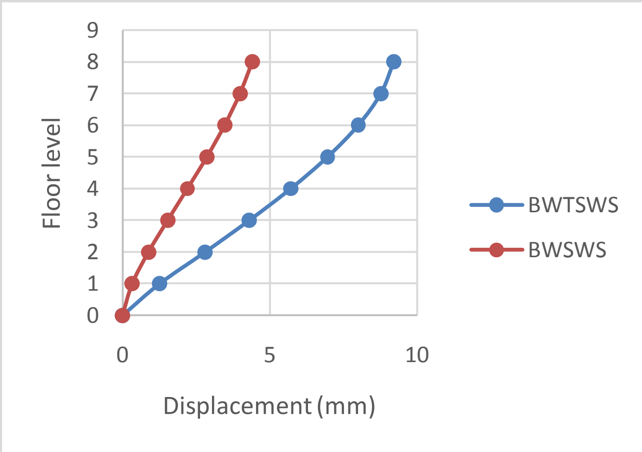


Figure 9: Mode shape of BWSWS

In tall structures, the frequency value tends to be lower, due to higher flexibility of the structure. A Figure 10 to 15 shows the displacement, drift and mode variations for adopted buildings. Figures 16 to 27 presents the performance of drift-time, strain-time, moment-rotation, displacement-time, base shear-time and base shear-displacement for reinforced concrete building without shear walls and with shear walls respectively.



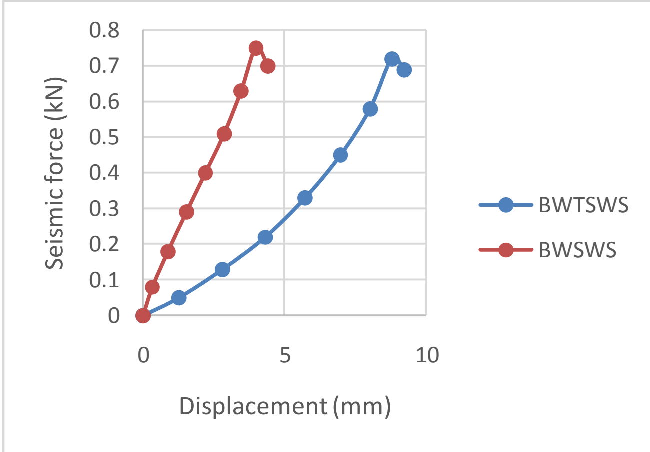
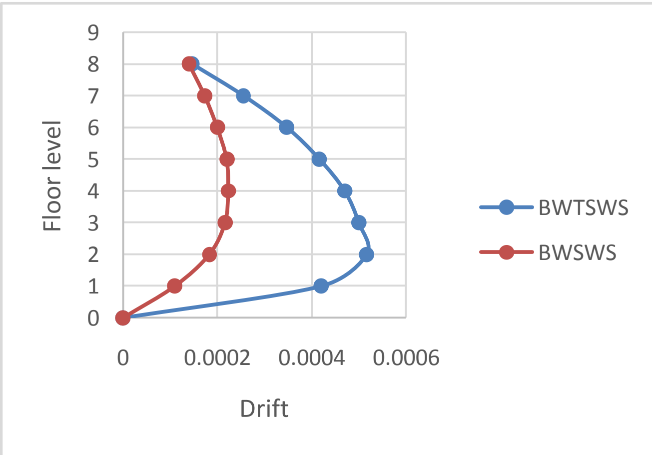


Figure 10: Displacement variations with floor level

Figure11: Seismic force-displacement



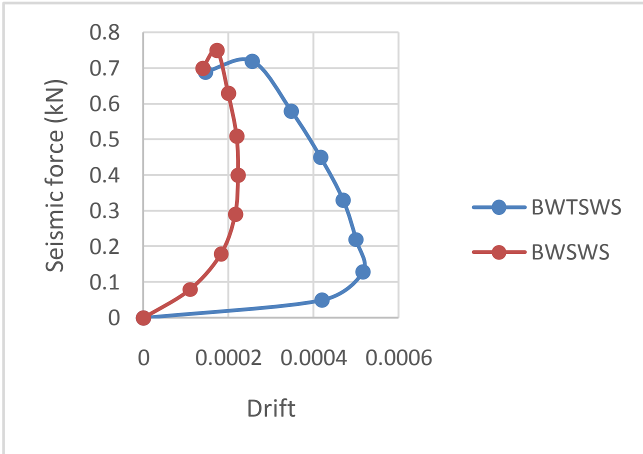
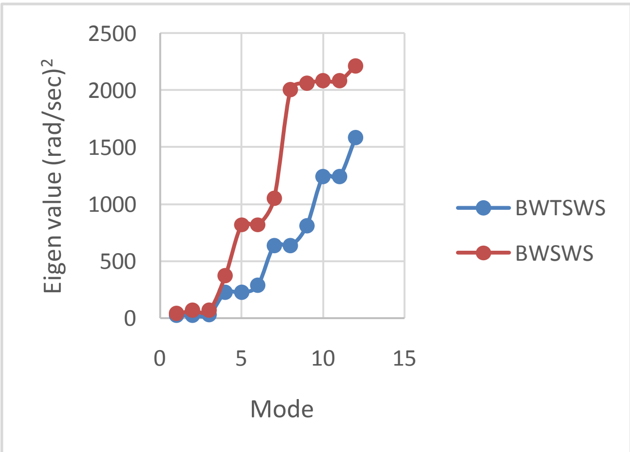


Figure 12: Drift variations with floor level



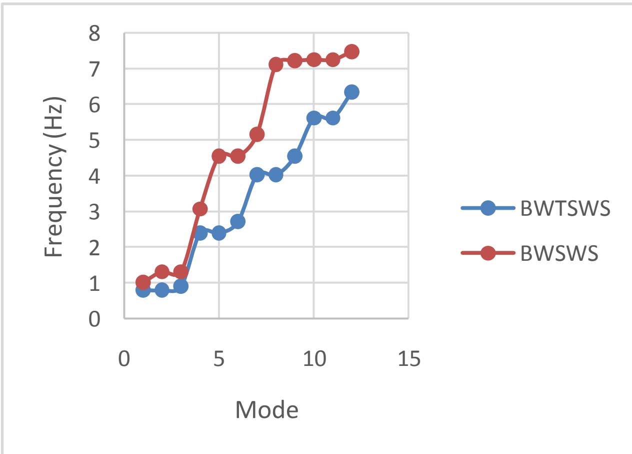


Figure 13: Seismic force-drift

Figure 14: Eigen value variations with floor mode Figure 15: Frequency-mode

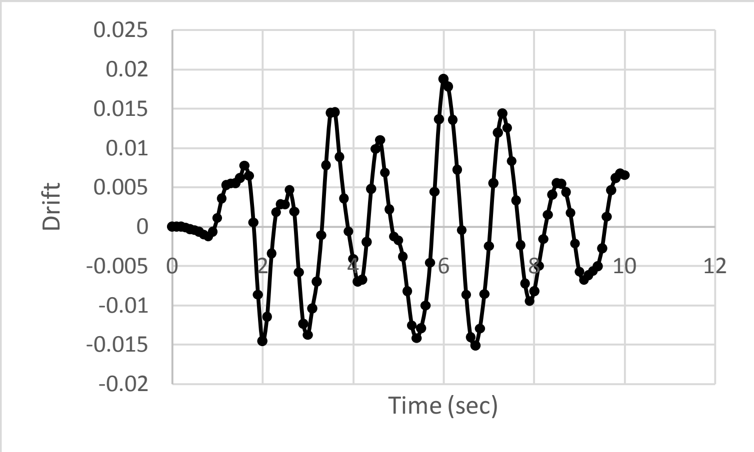


Figure 16: Drift-time performance of BWTSWS

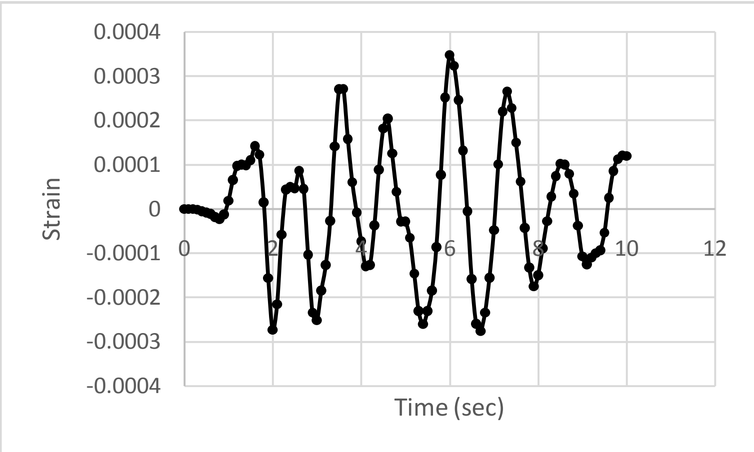


Figure 17: Strain-time performance of BWTSWS

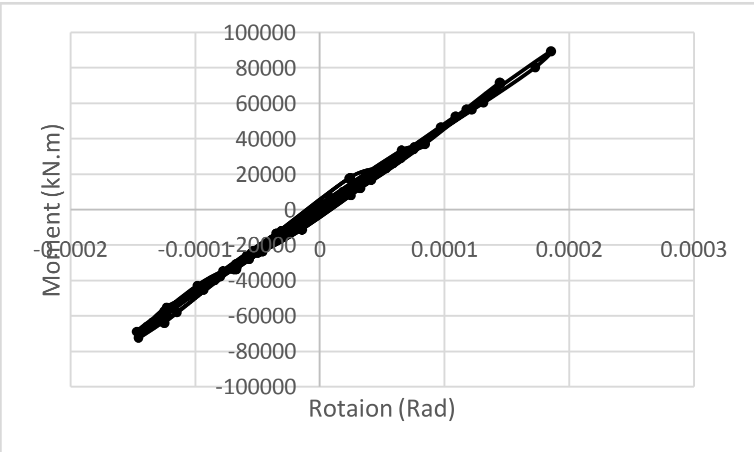


Figure 18: Moment-rotation performance of BWTSWS

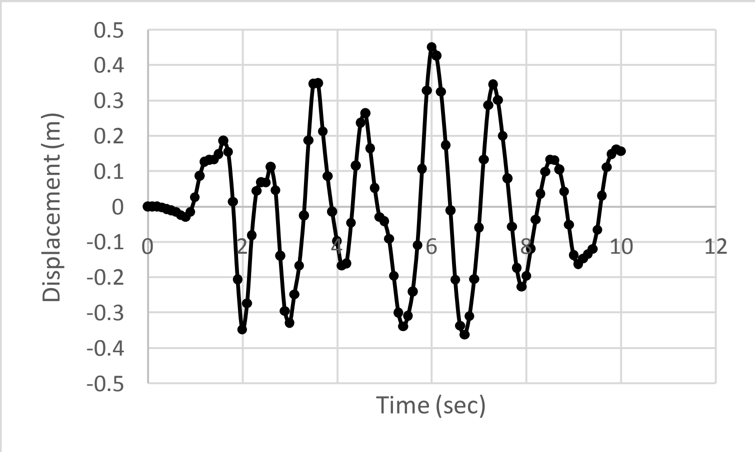


Figure 19: Displacement-time performance of BWTSWS

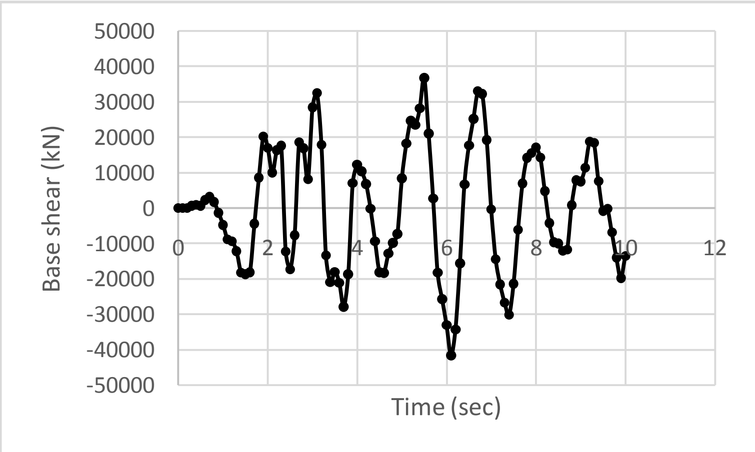


Figure 20: Base shear-time performance of BWTSWS

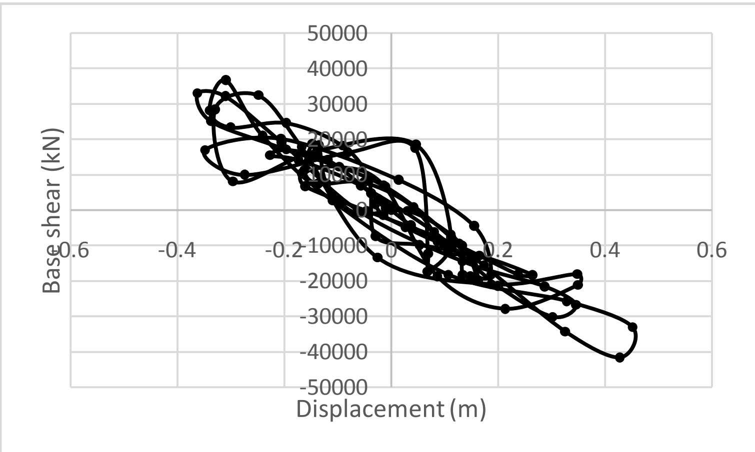


Figure 21: Base shear-displacement performance of BWTSWS

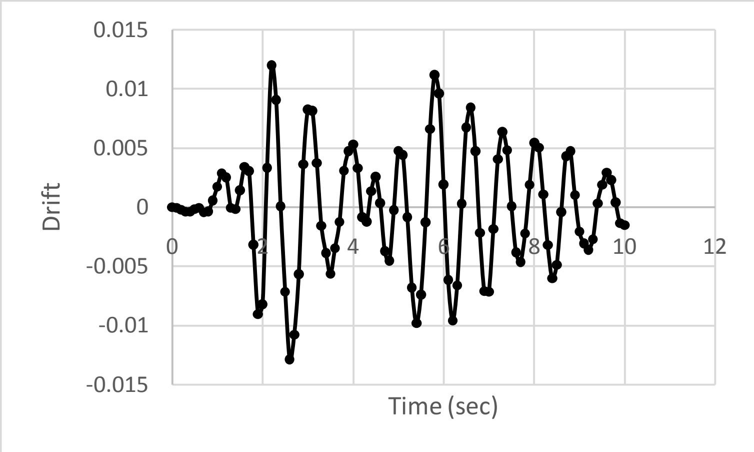


Figure 22: Drift-time performance of BWSWS

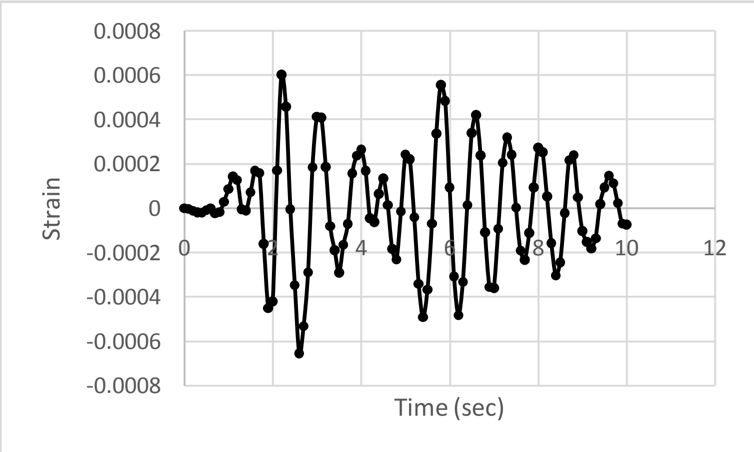


Figure 23: Strain-time performance of BWSWS

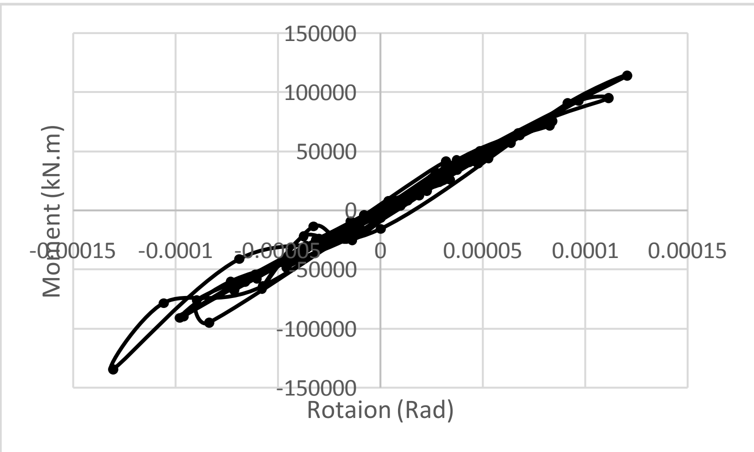


Figure 24: Moment-rotation performance of BWSWS

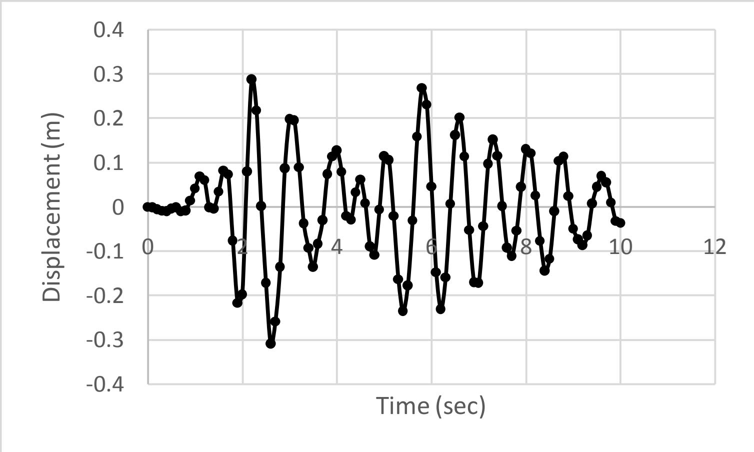


Figure 25: Displacement-time performance of BWSWS

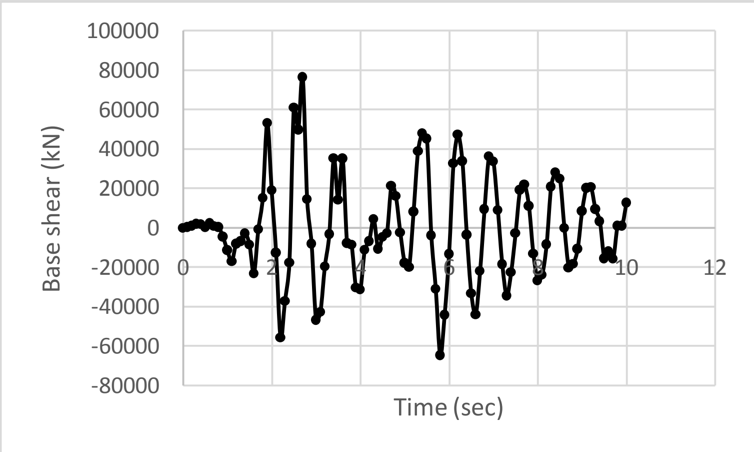


Figure 26: Base shear-time performance of BWSWS

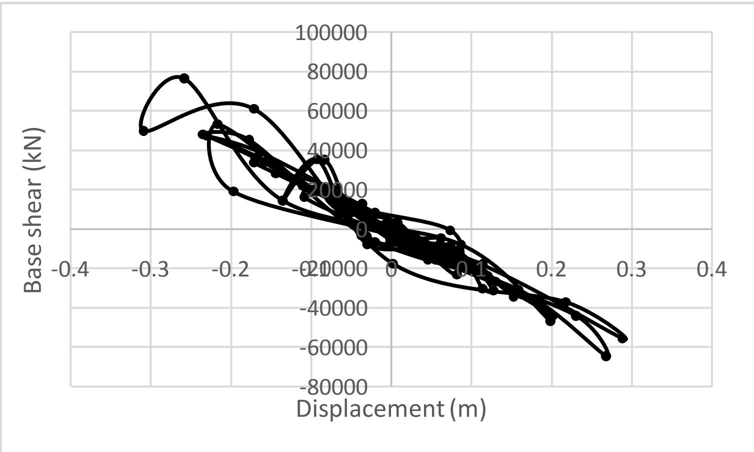


Figure 27: Base shear-displacement performance of BWSWS

IV. Conclusions

Based on the analysis results of RC building without and with RCSWs, following conclusions points are summarized as follows:

1. it is observed that the displacements and drift of BWSWS gave less as compared with the BWTSES

due to the presences of RCSWs that gave more stiffness to the building that reflects on the displacements and drifts for all stories.

2. Frequency of BWSWS gave less as compared with the BWTSES due to the absences of RCSWs so that the time period become more that cause more effects on the structural members that is mean the time period remain within building more.
3. Time history analysis drift and displacements of BWSWS building gave less as compared with the building BWTSWS due to presences of RCSWs that increased the stability of whole building and working as energy dissipation under the effect of seismic loading.
4. Time history analysis, the moment rotation of BWSWS building gave less as compared with the building BWTSWS due to high stability and more stiffness because of presences of RCSWs that reduced the overturning of building.
5. Base shear resistance of BWSWS building higher than BWTSWS due to increase in building mass that gave high stability and more stiffness because of presences of RCSWs that gave more fixity to the building.
6. The hysteresis of BWSWS building higher than BWTSWS and less in displacement due to RCSWs that gave more resistance to the applied time history seismic loadings.
7. No failure that occur due to applied static and dynamic loadings in any structural members and the maximum drift within 0.012h that recommended based on the ASCE-7-2016 [12] that equal to 288 mm.

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