Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

Research article

UDC 691.32

DOI: 10.34910/MCE.134.9

An investigation on the nonlinear dynamic behavior of reinforced concrete shear wall under seismic loading

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Keywords: reinforced concrete, shear wall, nonlinear dynamic analysis, seismic loading, finite element method

Abstract. The current research presents a new approach for nonlinear dynamic analysis of reinforced concrete shear wall under seismic loading in ANSYS Mechanical software via adding APDL commands. By applying lateral load, the behavior of reinforced concrete shear wall as a model was analyzed using the proposed method and the maximum bearing load, maximum displacement and the positions of the occurrence of the cracks were determined. Then, this shear wall was analyzed through Response Spectrum Method (RSM) as a linear dynamic method and the results of nonlinear dynamic method were compared with RSM. The results of nonlinear dynamic analysis showed that the maximum loading and its maximum displacement were 276 kN and 2 cm, respectively. However, the maximum displacement obtained by RSM was more than the corresponding value using the proposed nonlinear method, which this is mainly due to the consideration of safety factor in RSM. In addition, the whole capacity of materials is employed in nonlinear analysis, which this issue is not taken into account in RSM.

Funding: The research was funded by the Ministry of Science and Higher Education of the Russian Federation as the grant Self-Healing Construction Materials (contract No. 075-15-2021-590 dated 04.06.2021)

Citation: Hasanzadeh, A., Hematibahar, M., Vatin, N.I., Kharun, M. An investigation on the nonlinear dynamic behavior of reinforced concrete shear wall under seismic loading. Magazine of Civil Engineering. 2025. 18(2). Article no. 13409. DOI: 10.34910/MCE.134.9

1. Introduction

Reinforced concrete (RC) shear wall is a vertical element utilized to withstand lateral loads such as wind and seismic loads acting on a building structure. Many studies have been performed on the modeling of the behavior of the RC shear wall during earthquakes [1–4]. Modeling techniques have been progressively updated during the last two decades, moving from linear static to nonlinear dynamic, enabling more realistic representation of the behavior of structure. Different models have been developed over time, including macro-models, vertical line element models, finite element (FE) models, and multi-layer models. For example, Epackachi et al. [5] developed a FE model to simulate the nonlinear cyclic response of flexure-critical steel-plate concrete (SC) composite shear walls. Each SC wall was constructed with steel faceplates, infill concrete, steel studs and tie rods, and a steel baseplate that was post-tensioned to a RC foundation. They showed that the FE predictions are in good agreement with the measured values. Rafiei et al. [6] presented the development and validation of FE models to simulate the performance of a composite shear wall system consisting of two skins of profiled steel sheeting and an infill of concrete under in-plane loadings. According to the results, the developed FE models were capable of simulating the behavior of composite walls under in-plane loadings with reasonable degree of accuracy.

Kharun et al. [7] simulated the behavior of shear walls with different material properties (glass fiber, basalt fiber, steel fiber and conventional concrete) under earthquake loading via SAP2000 software. They found that glass fiber and conventional concrete shear walls had higher dissipation energy and showed more suitable responses during earthquake. Rahai and Hatami [8] assessed the behavior of composite steel shear wall (CSSW) under cyclic loadings. They focused on the impact of shear studs spacing variation, middle beam rigidity, and the method of beam to column connection on the CSSW behavior. They reported that the increase of the shear studs spacing can reduce the slope of load–displacement curve and enhance the ductility up to a specific studs' spacing. Najm et al. [9] employed ANSYS software to numerically analyze the behavior of smart composite shear walls under dynamic loading. The results of FE analysis indicated excellent agreement with the experimental test results in terms of the ultimate strength, initial stiffness and ductility. Wang et al. [10] developed FE models to forecast the hysteresis behavior of composite shear walls with stiffened steel plates and in-filled concrete. They found that the web plate contributes between 55 % and 85 % of the total shearing resistance of the wall. Furthermore, the corner of wall mainly resisted the vertical force and the rest of wall resisted the shear force.

Wang et al. [11] studied the seismic performance of shear walls with different coal gangue replacement rates. They found that the stress performance and failure morphology of coal gangue concrete shear walls and conventional concrete shear walls are extremely similar, and the characteristics of the hysteretic and backbone curves are approximately the same. They concluded that with increasing in the coal gangue replacement rate, the stiffness degradation gradually slows. Therefore, it is possible to construct a shear wall using coal gangue concrete instead of conventional concrete. Sijwal et al. [12] used ABAQUS FE software for modeling of the concrete-filled cold-formed steel shear wall (CFCSW) and validated their results with the experimental results. They found that the FE analysis is able to appropriately simulate the overall behavior of CFCSW. In addition, ABAQUS satisfactorily predicted the load carrying capacity of the CFCSW. Liu et al. [13] investigated seismic performance of recycled aggregate concrete (RAC) composite shear walls with different expandable polystyrene (EPS) configurations. They found that the seismic resistance behavior of the EPS module composite performed better than ordinary recycled concrete for shear walls. In addition, shear walls with sandwiched EPS modules had a better seismic performance than those with EPS modules lying outside. Kamgar et al. [14] evaluated the dynamic behavior of steel shear wall (SSW) stiffened with Shape-Memory Alloy (SMA). They indicated that SMA strips are able to limit structural and non-structural damage under earthquakes. Besides, SMA strips can delay the SSW failure. They concluded that their method can be a good retrofitting approach to strengthen existing steel structures against seismic loading.

On the other hand, linear analysis is an analysis, in which there is a linear relationship between applied forces and displacements. Besides, the stresses remain within the linear elastic range. In nonlinear analysis, the applied forces and displacements have non-linear relationship. Nonlinearity effects can be due to geometry (e.g. large deformations), materials (e.g. elasto-plastic materials), or support conditions. A linear analysis mainly requires linear elastic materials and small displacements while a nonlinear analysis considers large displacements and elasto-plastic materials. Thus, the superposition effect cannot be applied. Another important difference is the stiffness matrix. The stiffness matrix remains constant during a linear analysis while it is not constant in the nonlinear analysis. Whenever a material in the model demonstrates a nonlinear stress-strain behavior under the specified loading, nonlinear analysis must be used. ABAQUS is FE software, which is able to simulate linear and nonlinear materials easily, while ANSYS Mechanical is not able to simulate nonlinear material independently. In fact, Advertising Permit and Developer's License (APDL) commands have to be added to ANSYS Mechanical software in order to make it possible to simulate the behavior of nonlinear materials. APDL is a powerful structured scripting language used to interact with the ANSYS Mechanical. The lack of nonlinear definition of the material behavior in ANSYS Mechanical software is a neglected point that makes problems for engineers. Moreover, this software is not able to find cracks on the surface of concrete. To cover these gaps, in this study, the APDL commands have been added to ANSYS Mechanical software for investigation of the nonlinear behavior of reinforced RC shear wall under earthquake loading.

2. Methods

The concrete can not be defined as a nonlinear material in the ANSYS Mechanical. To change the behavior of material to the nonlinear behavior, the APDL commands were applied as a text in this study. The APDL text is based on Drucker–Prager theory. First, the isotropic elastic materials were selected in the ANSYS Mechanical (Fig. 1). Next, a displacement was applied as a loading with symmetries in X, Y and Z axis. Finally, the APDL commands were added to the ANSYS Mechanical (Figs. 2 and 3).

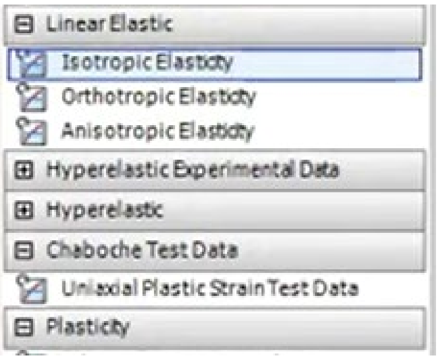


Figure 1. Selection of the material type.

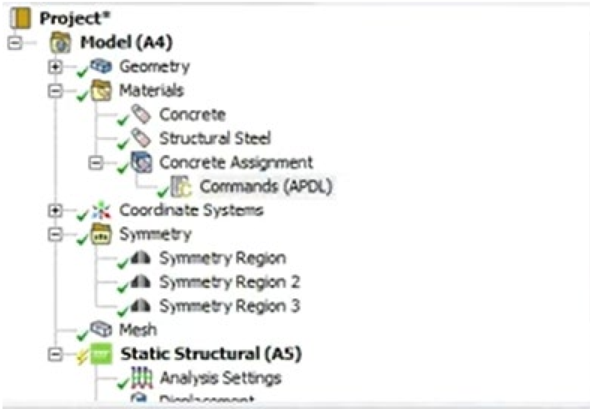


Figure 2. Settings of ANSYS Mechanical.

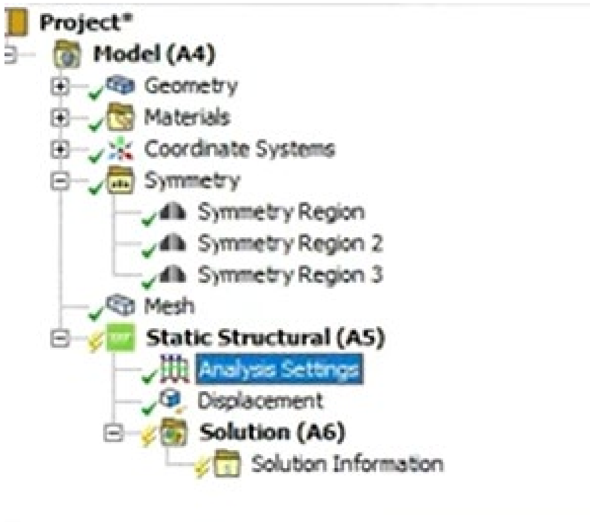


Figure 3. The addition of the APDL commands to the ANSYS Mechanical.

In the APDL command, compressive and tensile strength of concrete, tension cap hardening, compressive hardening constant, compression cap ratio constant, compressive, tensile damage threshold, and the number of quadratic elements were coded. The purpose of adding of these properties is simulating the compressive stress-strain curve of concrete in the ANSYS Mechanical. In fact, ANSYS Mechanical is not able to simulate the hardening and softening parts of stress-strain curve. In this term, the APDL commands help to find a new way to simulate this curve.

The research methodology has three steps, which have been shown in Fig. 4. At the first step, the compressive strength of cubic concrete sample (as a nonlinear material), and its compressive stress-strain curve were assessed using ANSYS Mechanical FE software via adding APDL commands to check the reliability of this software. It should be noted that the APDL commands were added to ANSYS Mechanical to change the behavior of concrete to a nonlinear behavior using the mentioned command. In fact, the first step is the basis for the the second and third steps to find the reliability of the proposed method. At the second step, the lateral load was applied to RC shear wall constructed by reinforced high-performance concrete (as a nonlinear material) and its maximum dispalcement and failure load were determined using

ANSYS Mechanical and APDL. At the third step, the behavior of RC shear wall was investigated by the Response Spectrum Method (RSM) as a linear dynamic analysis method. Finally, the results obtained by the second and third steps were compared with each other.

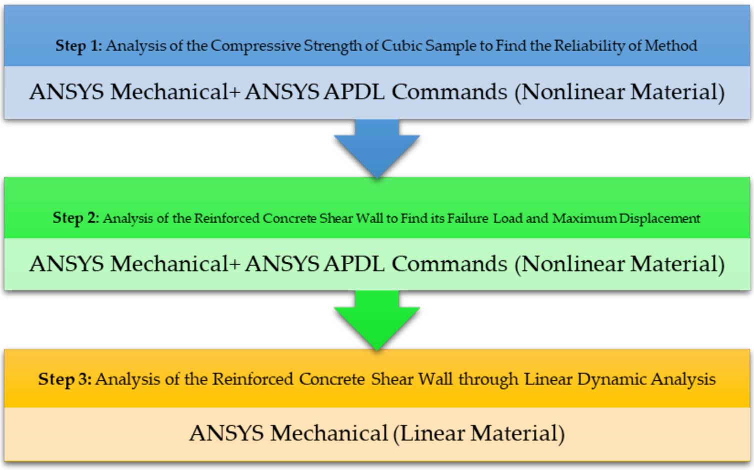


Figure 4. The research methodology.

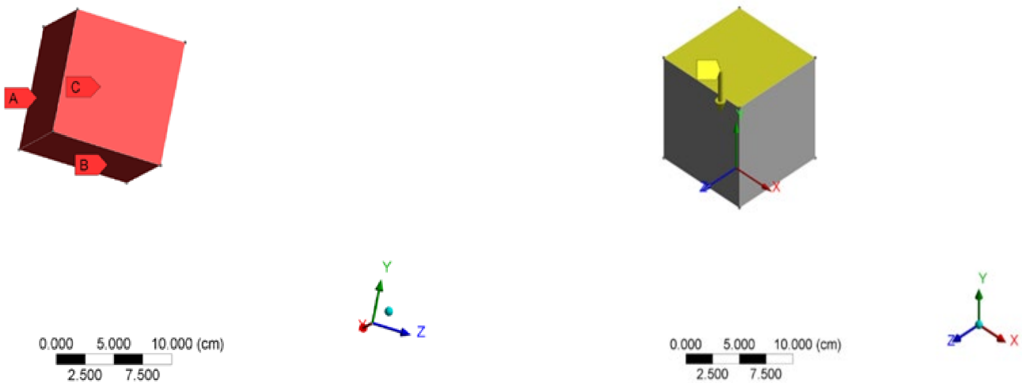
2.1. Model Reliability

In this study, high-performance concrete with 1.2 % basalt fibers (HPC-12) was selected as the concrete material for the shear wall. Table 1 shows the properties of this concrete. To control the model reliability, the compressive strength and compressive stress-strain curve of a cubic HPC-12 sample were investigated through ANSYS Mechanical via adding the APDL commands. To simulate the cubic concrete sample, the Micro-Plane method was applied. This method has been employed by several researchers [15–18].

Table 1. Mechanical properties of HPC-12 [19].

Concrete type	Compressive Strength (MPa)	Tensile Strength (MPa)	Young Modulus (GPa)	Density (kg/m^3)
HPC-12	94.5	14	33.8	3475

To find the compressive stress-strain curve, three symmetric sides in the cube (A, B, and C) were applied to the opposite sides of each natural coordinate axis (Fig. 5, a). Moreover, the material behavior was defined nonlinear in the software via APDL commands. The loading of 5 kN/mm^2 was applied at the Y- direction (Fig. 5, b).



a) **b)**

Figure 5. Concrete cubic simulation: a) the symmetric sides; b) application of load.

As seen in Table 2, the difference between experimental and numerical values of compressive strength is 0.6 MPa. Moreover, the compressive stress-strain curve was estimated via ANSYS software (Fig. 6). The comparison of the experimental and numerical results shows that the modeling has been performed with high accuracy. The results of the current study show the reliability of coding and APDL commands.

Table 2. The comparison between experimental and numerical values of compressive strength.

Experimental value (MPa)	Numerical value (MPa)	Difference (MPa)
94.5	93.9	0.6

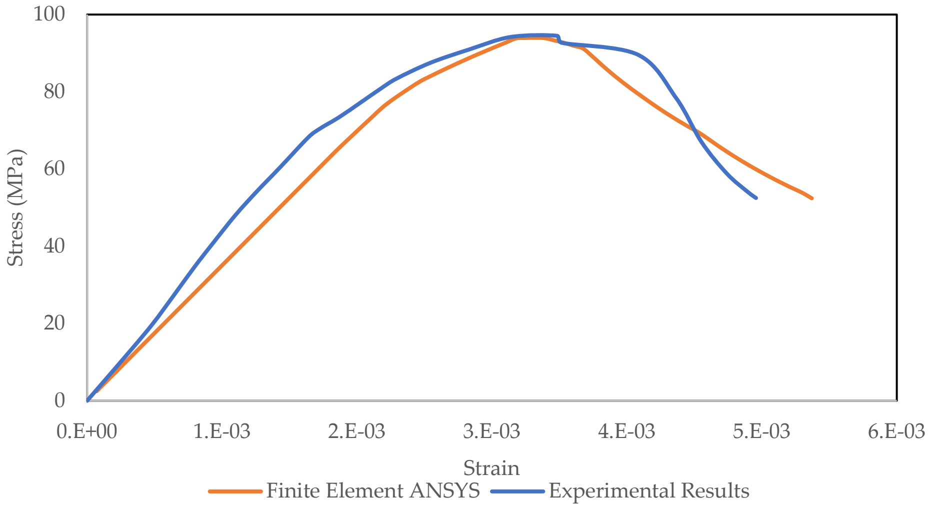


Figure 6. Comparison between stress-strain curves (experimental and numerical).

2.2. Modeling of RC Shear Wall

For the design of RC shear wall, ACI-318 [20] and Iranian Seismic Design Code [21] were used. According to the type and density of concrete, the shear wall thickness was selected. Then, the ratio of height to length of wall and also the horizontal and vertical reinforcement bars were calculated. The dimensions of shear wall are 500×300×30 cm, the horizontal rebars have a diameter of 16 mm used at every 5 cm, and the vertical rebars have a diameter of 16 mm used at every 41 cm. The foundation of RC shear wall was considered rigid. Shear wall model is shown in Fig. 7.

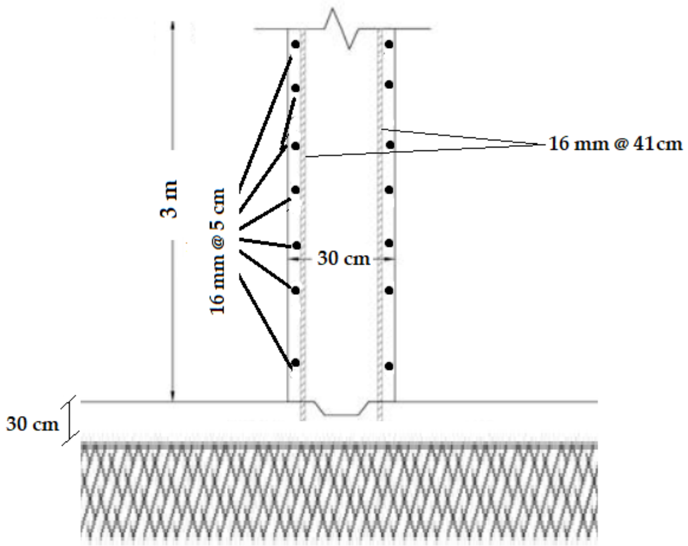


Figure 7. Shear wall section in the current study.

For the nonlinear analysis of the RC shear wall, the material was defined as nonlinear using APDL commands in ANSYS Mechanical software. The quadratic elements were used for meshing. Next, the behavior of materials was changed to nonlinear behavior through adding APDL commands to the ANSYS Mechanical. A lateral load of 10 kN/mm^2 at the X-direction was applied on the top of the RC shear wall (Fig. 8) to find the maximum bearing load and displacement of the shear wall in the lateral direction. Fig. 9 shows the position of rebars in RC shear wall model. The fixed supports were used in the current study.

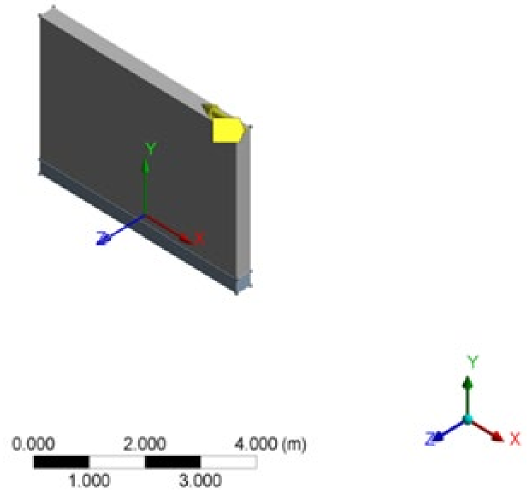


Figure 8. The position of load application to RC shear wall (yellow spot).

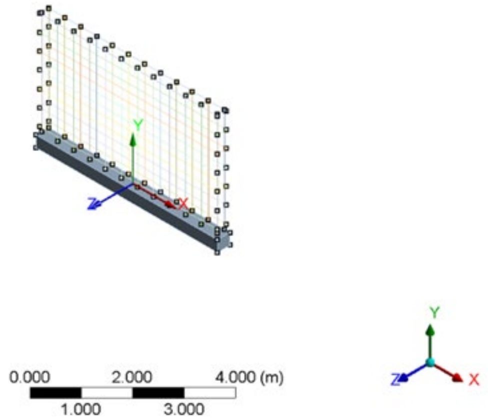


Figure 9. The arrangement of rebars in RC shear wall model.

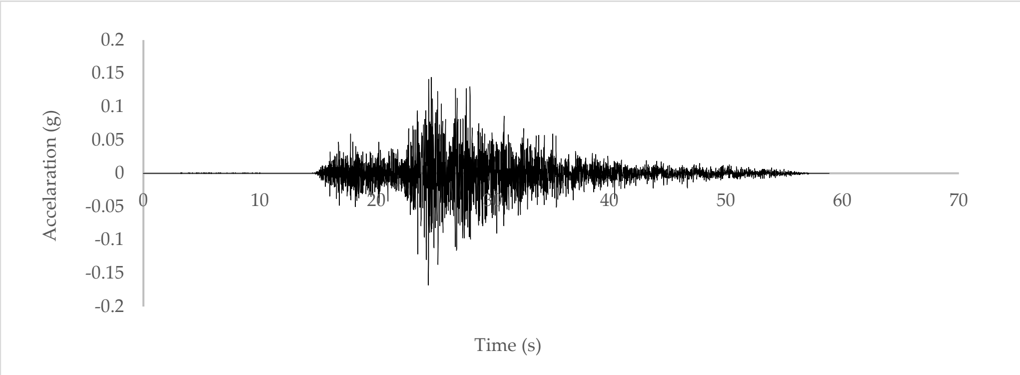
2.3. Response Spectrum Method

In this study, the behavior of RC shear wall under earthquake loading was analyzed using linear dynamic analysis. According to Iranian Seismic Design Code [21], there are two types of linear dynamic methods for analysis of structures under dynamic loads: 1 – RSM; 2 – Time Domain History Method (TDHM). RSM analysis is able to perform a more accurate estimation of the analysis considering the modal effects. TDHM depends on several criteria before applying to the structure while RSM is easier. Thus, in the current study, RSM was used for linear dynamic analysis.

A response spectrum is a plot of the peak or steady-state response (displacement, velocity, or acceleration) of a series of oscillators of varying natural frequencies that are forced into motion by the same base vibration or shock. RSM is a dynamic analysis method, which measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. It can be stated that it is a method to estimate the structural response of short, nondeterministic, and transient dynamic events such as earthquakes and shocks. The response-spectrum analysis provides insight into dynamic behavior by measuring pseudo-spectral acceleration, velocity, or displacement as a function of the structural period for a given time history and level of damping. It is practical to envelope response spectra such that a smooth curve represents the peak response for each realization of the structural period. The RSM is performed in the following four basic steps: 1 – modal analysis of the structure; 2 – calculation of the responses of the structure in each vibration mode; 3 – combining the effects of the modes; 4 – modifying the values of the responses of the structure.

In the modal analysis, the structural responses such as the internal forces of the members, displacement, floor shears, and support reactions are obtained separately for each mode. Due to the fact that the periods of vibration of the modes are different from each other, the maximum responses of the structure for various modes do not occur simultaneously, and for this reason, it is not possible to determine the total response of the structure by summing the response of different modes. In spectral analysis, the final response of the structure is obtained using the superposition of its different modes (within the frequency domain). In fact, the response of the structure is a combination of various mode shapes. For each considered mode, based on the frequency and mass of the mode, the response of that mode is extracted from the design spectrum and then, is combined with the response of other modes to obtain the overall response of the structure. Combination methods include the following: 1 – Square Root Sum of Squares (SRSS); 2 – Complete Quadratic Combination (CQC), which is a modified method of SRSS for close modes. It is well-known that the application of the SRSS in seismic analysis for combining modals can cause significant errors.

The Peak Ground Acceleration (PGA) is computed according to the factored spectral response diagram. Three different earthquake pulses including Bam, Iran (2003), Mount Borrego, USA (1968), and Northern California, USA (1941) were selected to determine the Factorized Response Spectrum (FRS) diagram. FRS is called a spectrum, which is scaled to the standard design spectrum in Code with applying a coefficient factor. Fig. 7 shows the Time-Acceleration graphs of these earthquakes. The applied loads to RC shear wall in RSM are illustrated in Fig. 10.



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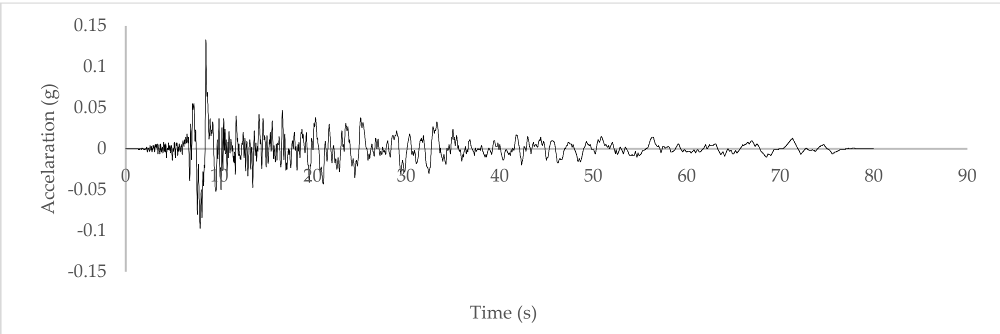

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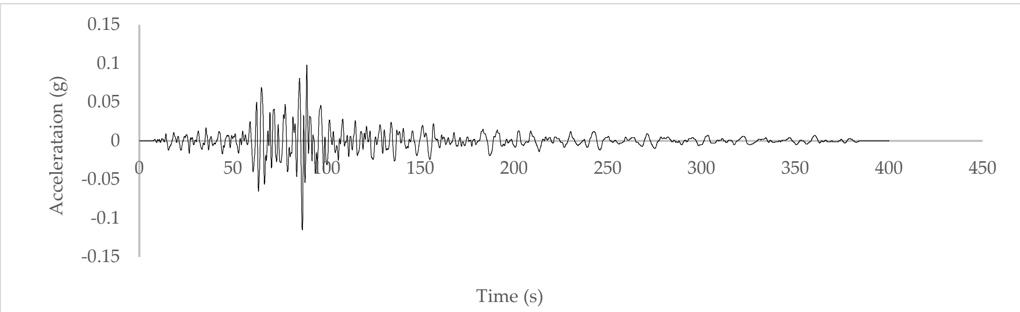


c)

Figure 10. The Time-Acceleration graphs for: a) Bam, Iran (2003); b) Borrego Mountain, USA (1968); c) Northern California, USA (1941).

As seen, Bam and Northern California earthquakes have the highest and lowest frequency content, respectively. Northern California earthquake has the highest period and Bam has the lowest one. Earthquake records with low and high frequency have a greater effect on tall and short structures, respectively, due to the phenomenon of resonance. Moreover, amplitude of the earthquake record is the highest in Bam earthquake. The FRS diagram is shown in Fig. 11. The SRSS and CQC are recommended to plot the FRS diagram. In this research, the SRSS used a damping ratio of 5 % of the structure weight as recommend by Iranian Seismic Design Code [21].

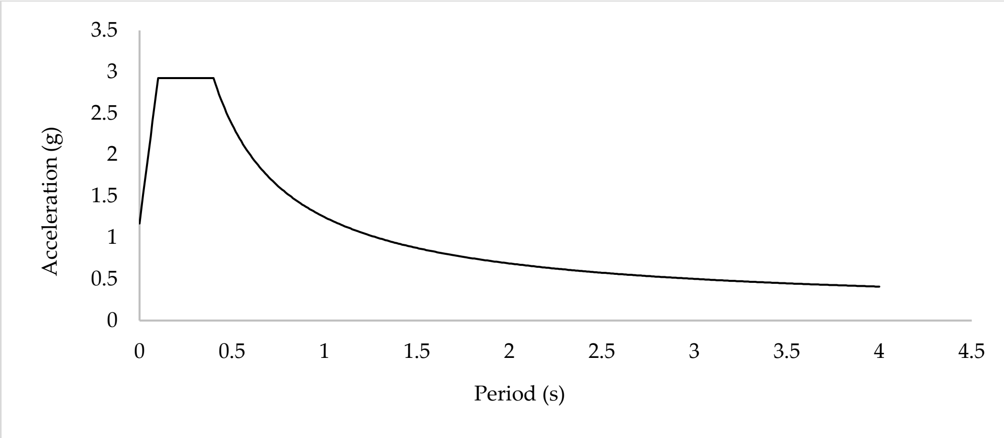


Figure 11. The FRS diagram of three mentioned earthquakes.

3. Results and Discussion

3.1. Results of Nonlinear Analysis

Fig. 12 shows the load–displacement graph of RC shear wall using nonlinear analysis. As seen, the maximum load that RC shear wall can bear and its corresponding displacement are 276 kN and 2 cm, respectively. The shear wall under loading has three phases. The first step is the softening behavior, in which the displacement is lower than 0.39 cm and the loading is less than 118 kN. This section is the linear phase of the shear wall under lateral loading. The second stage is the hardening stage until the maximum bearing loading of 276 kN and displacement of 2 cm. The third stage is the shear wall failure, in which the displacement will be maximum and the load gets near to zero.

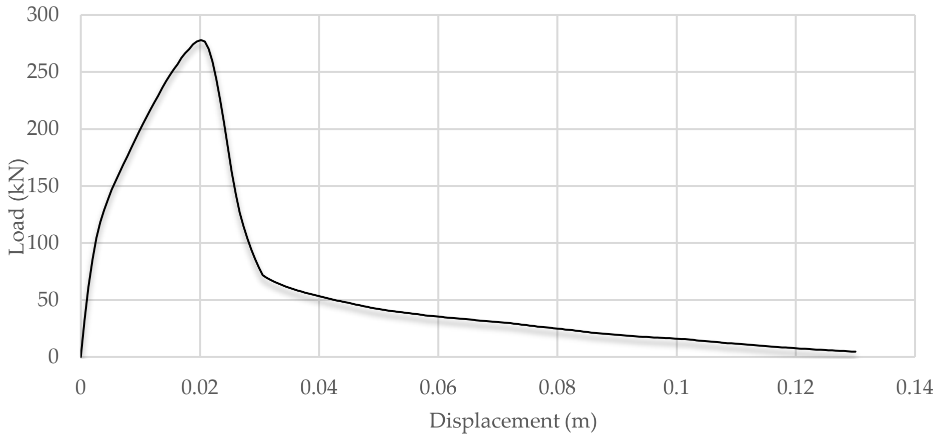


Figure 12. Load–displacement graph of RC shear wall.

Figs. 13 and 14 illustrate the values of displacements in RC shear wall on the concrete and rebar parts, respectively. As seen, the maximum displacement of RC shear wall occurs on its top. Table 3 presents the values of maximum bearing load, maximum linear load, and displacement at the maximum load.

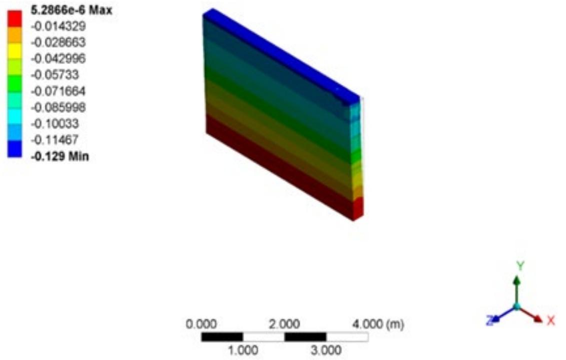


Figure 13. The displacement values in the RC shear wall.

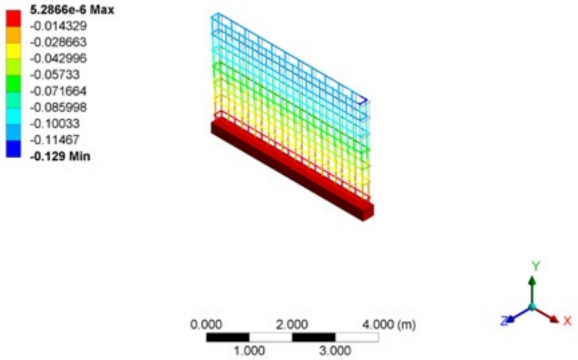


Figure 14. The displacement values in the rebars of RC shear wall.

Table 3. The comparison of the results.

Maximum load (kN)	Maximum linear load (kN)	Displacement at the maximum load (m)
276	118	0.0206

According to the results of the analysis, the joint of the shear wall with the foundation corners and also the middle of shear wall are critical zones in which cracks were occurred (Fig. 15). The maximum shear force likely occurs at these positions due to the stress concentration. Therefore, cracks have been generated near the edges of the shear wall and on its middle. ANSYS Mechanical is not able to show the cracks while the addition of APDL commands has made it possible to reveal the crack zones.

Figure 15. The cracks on the RC shear wall found by nonlinear analysis.

3.2. Results of Linear Dynamic Modal Analysis

The lateral behavior of any building can be written by a linear combination of the vibration modes of that building. Oscillating modes of every building are different forms of vibrations that can be formed at the structure height. Some modes of the structure are easily excited, in other words, with the lowest level of energy entering the building, those modes can be excited in the building. These modes have the highest vibration period. The highest vibration period and the lowest frequency in a building are related to the first vibration mode of that building. Due to the high excitability of the first mode, the largest displacement contribution for a specific vibration is related to this mode. By moving towards higher vibration modes, more energy will be required to excite the modes and the vibrational period of the modes will be decreased. Sometimes, the stimulation of higher modes is difficult (requires high energy) that the Codes assume them as non-sense modes and do not include them in the calculations because the contribution of these modes in the lateral behavior of the structure is insignificant. For the simplicity of modal calculations, it is possible to assume an equivalent single degree of freedom structure for each of the vibration modes of the building, and the jump of that single degree of freedom structure is equal to the vibration jump of the investigated mode in the building.

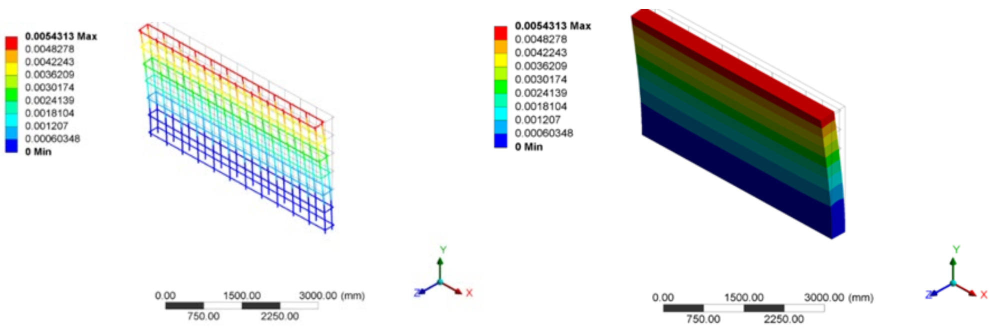
The linear dynamic analysis is investigated by dynamic section of ANSYS Mechanical. In order to analyze RC shear wall through RSM, six natural modals were evaluated by ANSYS Mechanical. According to Iranian Seismic Design Code [21], the cumulative mass up to the modes must be larger than 80 ~ 90 % of the total mass. Moreover, in each of the two orthogonal extensions of the building, all oscillation modes that their total effective masses are more than 90 % of the total mass of the structure should be considered. Thus, six modes were taken into account in this study. Table 4 illustrates the six natural modal data such as natural frequencies, mass participation factor, and effective mass.

Table 4. The modal analysis results.

Modal No.	Frequency [Hz]	Mass participation factor X-direction	Effective mass X-direction (g)
1	25.233	1.40E–12	1.97E–24
2	43.621	9.42E–13	8.88E–25
3	91.126	2.68E–12	7.18E–24
4	151.83	2.85E–11	8.13E–22
5	170.28	9.61E–11	9.37E–20
6	173.15	4.34E–10	1.89E–19

As expected, with the increase in the vibration modes of the structure, the vibration frequency increases. Therefore, the first mode has the lowest frequency and highest period while the sixth mode has the highest frequency and lowest period. Mass participation factors are scalars that measure the interaction between the modes and the directional excitation in a given reference frame. Larger values of mass participation factors indicate a stronger contribution to the dynamic response. Hence, the sixth mode has the highest contribution. The effective mass factors associated with each mode represents the amount of system mass participating in that mode in a given excitation direction. This value is given as a percentage of the total system mass. Therefore, a mode with a large effective mass will be a significant contributor to the system response in the given excitation direction. A common rule of thumb for linear dynamic analysis is that a mode should be included if it contributes more than 1–2 % of the total effective mass. As expected, the sixth mode has the maximum value in effective mass.

Fig. 16 illustrates six modal shapes of the RC shear wall. As seen, if the structure vibrates in a lower mode, it needs less energy while in higher modes, more energy is required. At the sixth mode, the RC shear wall has the most intricate deformity among others modes. Moreover, displacements are high at the top of the shear wall. It can be said that the first mode has the simplest oscillation and moves along the z-axis. As the mode goes higher, the probability of fluctuation in this mode decreases. In the second mode, the shear wall oscillates in the direction perpendicular to the first mode and in the direction of the x-axis. In the third mode, the oscillation bends in-plane around the z-axis at the corner of the wall. In the fourth mode, oscillation moves towards the z-axis. In the fifth mode, the oscillation is around the z-axis and the maximum bending is in the middle of the shear wall. Finally, the sixth mode has the lowest probability of occurrence and represents a kind of twisting deformation.



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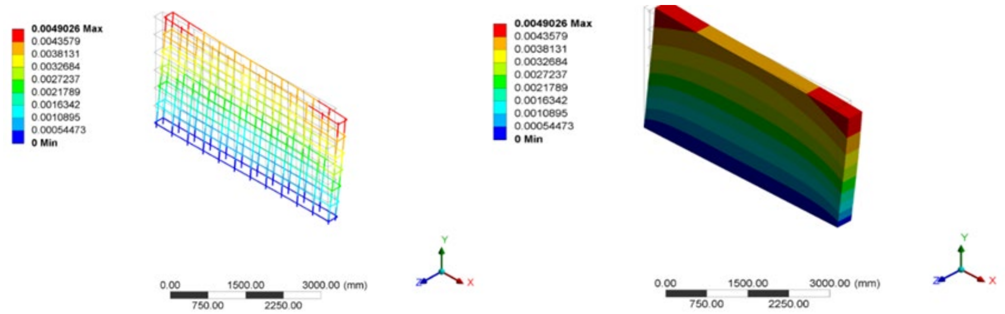

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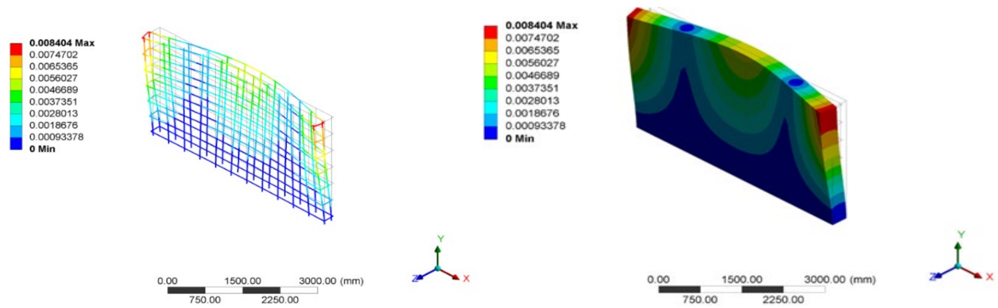

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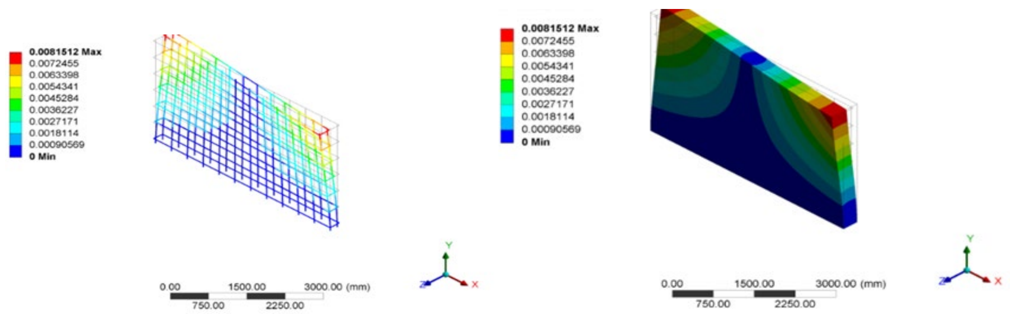

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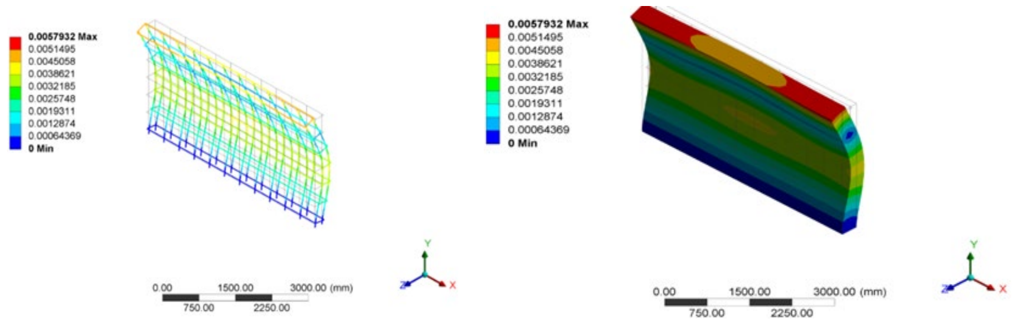

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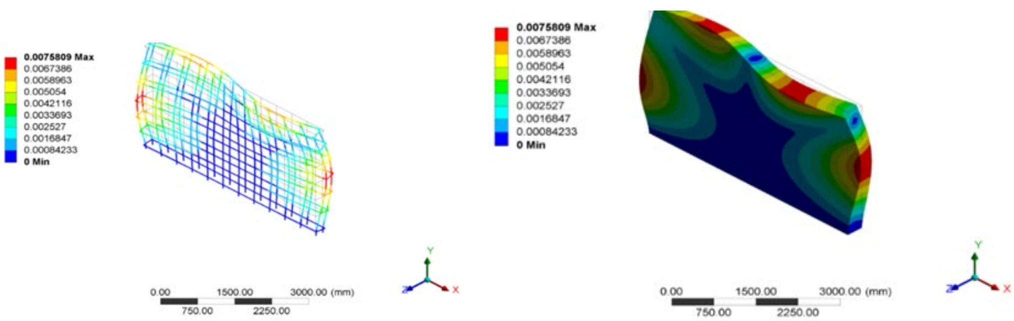


f)

Figure 16. The natural modal analysis for rebar, and shear wall: a) First Mode; b) Second Mode; c) Third Mode; d) Fourth Mode; e) Fifth Mode; f) Sixth Mode.

Fig. 17 shows variation of displacement with period in RC shear wall via RSM. As seen, the maximum displacement of RC shear wall is more than 5 cm while the RC shear wall displacement was 2 cm in non-linear analysis. In fact, due to application of the safety factor to the structure, the maximum displacement obtained via RSM is greater than the maximum displacement found through nonlinear dynamic analysis. Table 5 shows the comparison of displacements. The results of nonlinear analysis are more acceptable than linear analysis. This is related to the usage of the whole capacity of material properties in nonlinear analysis.

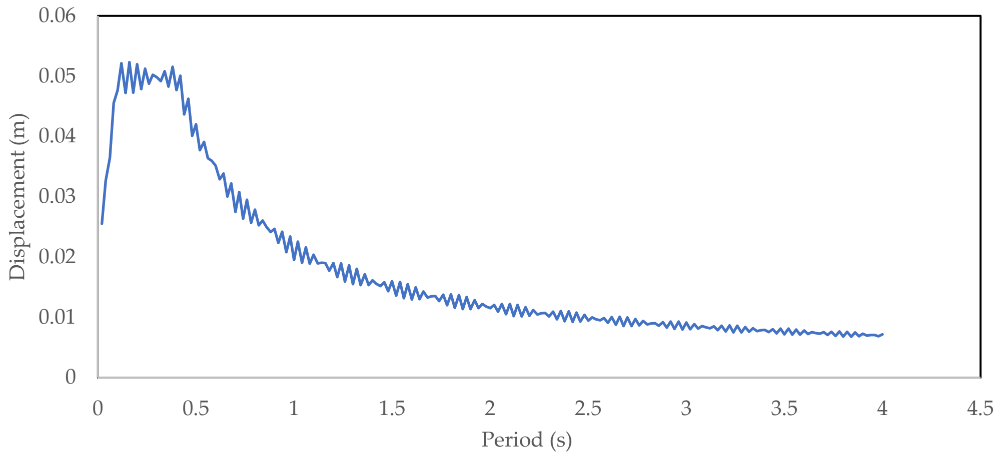


Figure 17. Variation of displacement with period in RC shear wall.

Table 5. Comparison of displacements.

Maximum displacement obtained via RSM (cm)	Maximum displacement obtained via nonlinear analysis (cm)
5.23	2

Based on the von-Mises (VM) failure theory, when principal stress is less than VM stress, the structure tends to fail. In another words, in this theory, a material will fail if the VM or effective stress of the material under load is equal to or greater than the yield strength of the same material under a simple uniaxial tensile test [22, 23]. In fact, when principal stress values increase more than VM stress, the RC shear wall starts cracking. Fig. 18 shows VM theory definition, where σ_1 and σ_2 are the principal stresses.

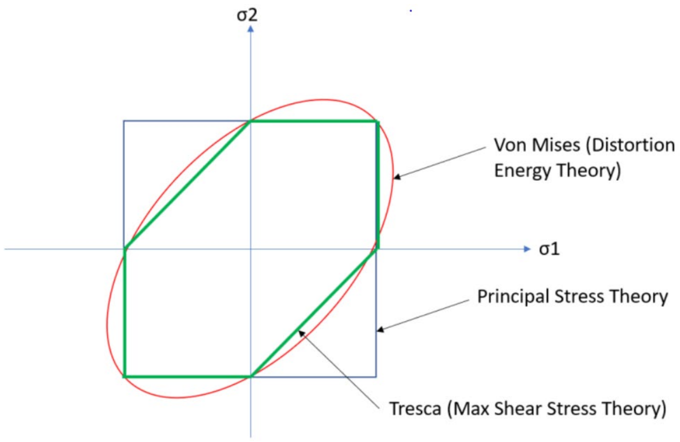
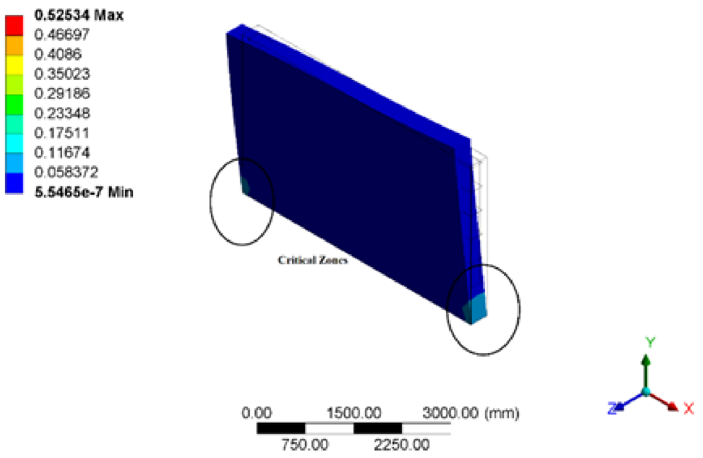
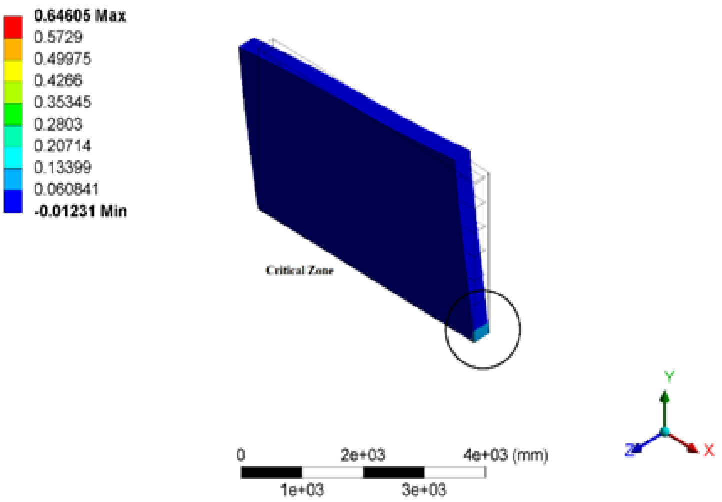


Figure 18. Von-Mises theory definition.

In the present study, the cracks, which occurred based on VM theory, were called “critical crack zones”, which were illustrated by the circle in Fig. 19. As observed, the VM stress is less than principal stress at the fixed supports. Therefore, according to the VM theory, these zones will be possibly cracked. Fig. 20 shows the position of critical zones and probability of cracking on the concrete part of the RC shear wall. As seen, the small cracks have been continued to the middle of RC shear wall. The critical crack zones have been formed in these positions with the angle of about 30° to 45° with respect to the horizontal axis, which is mainly due to the existence of diagonal tension as a result of shear stress. Fig. 21 depicts the VM and principal stresses for rebar part of RC shear wall. As seen, rebars play as the tensile elements and do not allow the total failure of the shear wall.



a)



b)

Figure 19. The concrete part of RC shear wall: a) VM Stress; b) Principal Stress.

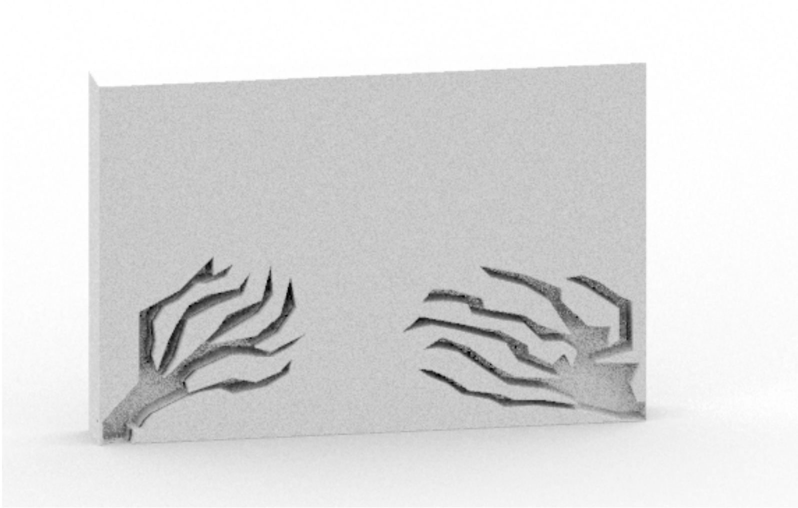
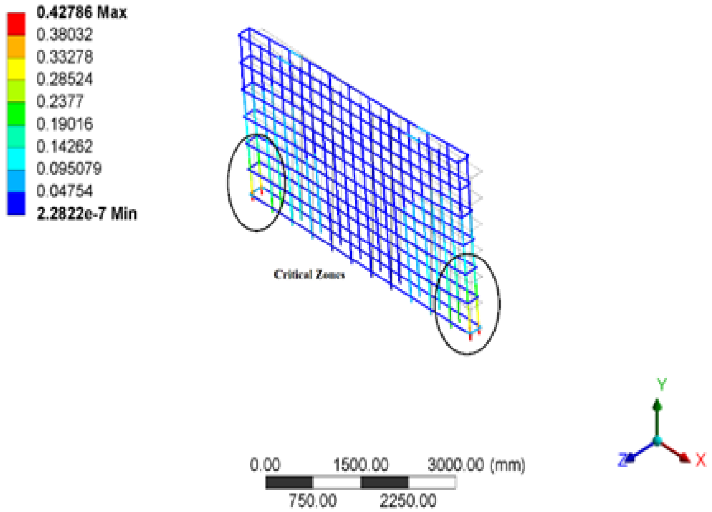
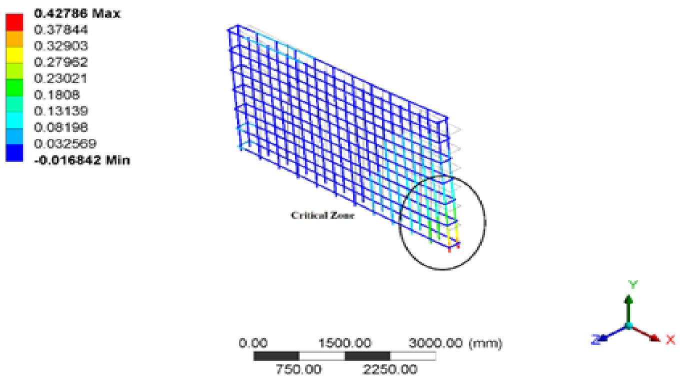


Figure 20. The critical crack zones in RC shear wall via RSM.



a)



b)

Figure 21. The rebar part of RC shear wall: a) VM Stress; b) Principal Stress.

3.3. Discussion

The present approach for evaluating the displacement of the shear wall needs to be compared with other results obtained in other related papers. The comparison of the results is a way to ensure the reliability of the proposed method in this study. Greifenhagen and Lestuzzi [24] studied the strength and deformation capacity of lightly RC shear walls under cyclic loading. The test series included four lightly RC shear walls in 1:3 scale, for which the horizontal reinforcement, axial force ratio, and concrete compressive strength are varied. For these four samples and under different shear forces, the maximum displacement values were reported. The maximum loading values were 140, 156, 134, and 101 kN, and the maximum displacements were 1.88, 2.88, 3.2, and 2.8 mm, respectively. In this paper, the maximum load bearing of the RC shear wall was 276 kN, and the maximum displacement of the shear wall was 2 cm in the lateral direction. The results showed that the current RC shear wall was able to bear more loads. This difference can be related to the fact that they used light materials that is far from high performance concrete material in this study. Another point is that they applied cyclic loading but in the present paper, nonlinear and RSM analyses were carried out.

Kharun et al. [7] investigated nonlinear behavior of shear walls against seismic wave by using conventional and fiber RC in SAP 2000. They studied the behavior of different sets of fiber RCs such as glass fiber RC, basalt RC, and steel fiber RC. Their research and the present paper both try to estimate displacement value for the shear wall via nonlinear analysis. SAP 2000 is not able to find the crack and also the nonlinear behavior of material can not be defined in this software. However, the nonlinear behavior of materials can be defined in ANSYS through APDL commands. In fact, the ANSYS APDL is able to cover the gap of the material nonlinearity through adding commands.

Al Agha and Umamaheswari [25] studied irregular RC building with shear wall and dual framed-shear wall system by using equivalent static and RSMs. For all nine modes, they reported top story displacement through RSM as 4, 3, 5.5, 6.5, 2, 7, 4, 2.5, and 4.5 cm. In the present paper, RSM analysis for all six modes showed the maximum displacement was 5, 4, 8, 8, 5, and 7 cm. They used the ETABS FE software while the ANSYS Mechanical was used in this study. Obviously, the current analysis method by ANSYS had better results than ETABS. Softwares such as ETABS and SAP2000 do not focus on the determinants and are not able to define the non-linearity of concrete and steel. In the current study, the APDL commands and ANSYS Mechanical have solved this problem in the material definition of ETABS and SAP2000.

Kisa et al [26] explored the effect of hysteric behavior of concrete shear walls with steel sheets. They applied the lateral loads to the shear wall to find the maximum load and displacement. Their results showed that maximum bearing load and displacement was 200 kN and 40 mm, respectively. Zhang et al. [27] examined the seismic behavior of steel fiber-reinforced high-strength concrete shear wall with steel bracing. They found that the maximum displacement and loading was 2 cm and 450 kN, respectively. The reason for the less bearing load in this study (276 kN) is due to the lack of steel bracing. The types of cracks in their study were similar to the results of nonlinear analysis in this research. Zhang et al. [28] assessed the seismic performance of RAC shear wall. They applied the horizontal cyclic load to RC shear wall to find the maximum displacement and loading. Their results depicted that the maximum loading and displacement was 250 kN and 20 mm, respectively. The comparison of the obtained results in this study with the experimental results (Fig. 22) show that the results of this study are similar to them. In addition, the shear wall in this study has been able to bear more load than Kisa et al. [26] and Zhang et al. [28].

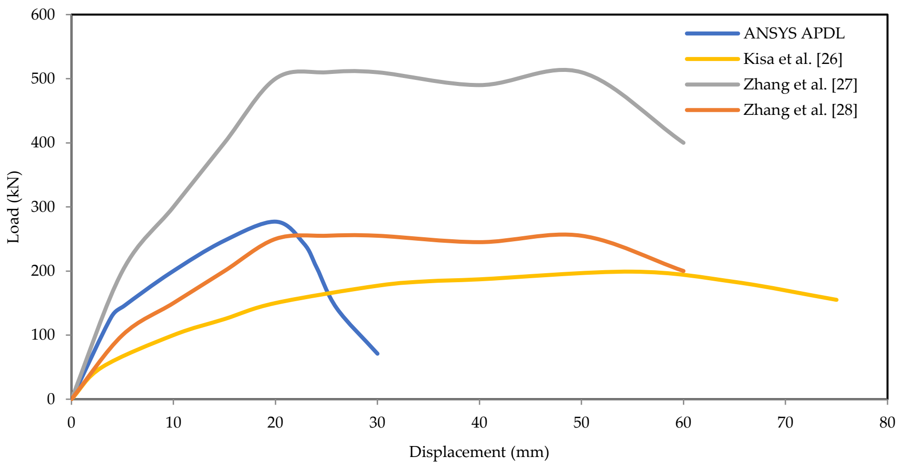


Figure 22. Comparison of the obtained results in this investigation with other studies.

4. Conclusions

The weakness of ANSYS Mechanical software in performing dynamic analysis has led us to use a new approach for this purpose. The present method covers this gap in ANSYS Mechanical by adding APDL commands. The following results can be achieved from this study:

1. ANSYS Mechanical is not able to show the crack while the addition of APDL commands has made it possible to reveal the crack zones.
2. Due to the consideration of safety factor in RSM, the maximum displacement was more than 5 cm, which was higher than the nonlinear dynamic analysis result (2 cm).
3. The current study presented a new method to analyze nonlinear behavior of RC shear wall using ANSYS Mechanical via adding APDL commands. It can be concluded that the nonlinear analysis in this study is able to find the maximum load bearing and displacement similar to the experimental results.

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Received 28.08.2023. Approved after reviewing 15.01.2025. Accepted 18.01.2025.