Energy dissipation of lightweight reinforced concrete shear walls: Nonlinear time history analysis

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Abstract: The energy dissipation performance of lightweight reinforced concrete shear-walls. These shear walls are evaluated for their seismic efficiency when the structure is subjected to seismic stresses, and this efficiency is represented in terms of energy dissipation. -nonlinear time history analysis—was studied in the present research. Twelve models have been analyzed using a finite element approach by SAP 2000 software. These models were created for an eight-story structure that was subjected to a seismic load and an additional gravity load as dead and live. Different parameters were adopted, such as reinforcement ratio, compressive strength, and aspect ratio. The analysis results of the study indicate that there is an improvement in the energy dissipation of those walls, which depends on the approved parameters, as well as that there was no failure in any of the analyzed models.

Keywords: Reinforced Lightweight Concrete, Shear Wall, Seismic Loading, Nonlinear Time History Analysis

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1. Introduction

Reinforced concrete shear walls are the primary structural components, particularly in high-rise structures. Shear walls provide a structure with extra strength and stiffness, which lowers lateral deformations in the direction of their orientation. There are a lot of horizontal earthquake forces that shear walls can carry, which lessens the effects of ground movement on all floors. Despite the fact that several research programs have investigated the performance of lightweight concrete structural elements, there is a limited understanding of the behavior of lightweight shear walls under seismic conditions, so understanding the performance and strength of reinforced lightweight concrete shear walls under seismic loadings is critical. In the case of a seismic event, the fundamental purpose of a shear wall is to resist ground motion and transmit it to all floors of the building. The bulk of modern construction, particularly high-rise buildings, uses RCSW (Reinforce concrete shear wall) to improve the overall stability and stiffness of the structural parts. Lightweight concrete has a low density and may be used to construct structures in low-seismic zones because of its adaptability. Because structural seismic reactions are based on the mass of the building or the dead weight of the structure, it is important to use materials that keep the dead weight of the structure as low as possible [1]. The low density, low thermal conductivity, low shrinkage, and high heat resistance of low-density lightweight concrete make it a good choice for building. It also reduces the dead load, saves money on transportation, and speeds up the building process. The mode of failure of reinforced shear walls is very complex when they are subjected to vertical and in-plane shear loads that rely on the aspect ratio and reinforcement ratio in addition to the concrete compressive strength of the shear wall [2, 3]. In this study, a three dimensional model of lightweight reinforced concrete shear walls, four models of lightweight reinforced concrete shear wall with varying web reinforcements were evaluated and simulated (orthogonal grids or diagonal bars). The nonlinear behavior of lightweight reinforced shear walls subjected to seismic stresses was simulated using finite elements method. Based on the analysis results, the inclined web reinforcement successfully transferred shear forces to the foundation and decreased the shear forces carried by compression [4].They conducted an experimental study that included quasi-static cyclic tests and shake table tests on twenty walls in order to gain an understanding of the effects of lightweight and low-strength concrete on shear strength and displacement associated with different limit states of thin, lightly-reinforced shear walls in different limit states. When comparing normal weight and lightweight concrete, the effects on mechanisms, displacement capacity, initial stiffness of undamaged walls, stiffness deterioration, and energy dissipation were all considered to be significant. Experimentation study results Compared to conventional concrete walls, lightweight concrete walls had higher shear strength and energy dissipation in various boundary states, which indicated that they were more resistant to shear [5]. The effect of seismic loadings on laminated RCSW was studied. The RCSW was assessed based on stiffness degradation, energy dissipation, failure mechanism, and deformability study findings. The models were simulated using ABAQUS using the finite element method, with the RCSW model presented in Figure (2.3) as well as the results of the experimental testing. According to analysis and test findings, the laminated RCSW has good seismic performance [6]. The impacts of soil as well as soil-structure interaction on the performance of RCSW subjected to seismic loadings were investigated. The figure shows different stories of reinforced concrete structures made out of RCSW, such as 3, 6, 10, and 15 stories (2.4).The findings of the analysis revealed that the boundary of the base of the wall had an effect on the behavior and strength of the RCSW when seismic loadings were applied [7]. RCSW and braced concrete frame behavior under earthquake loadings were compared. The comparisons focused on three metrics under the influence of lateral loadings: strength, stiffness, and ductility. Figure (2.5) depicts the study's shear walls and braced frame section. According to the findings of the research, the position of the shear wall and braced frame affects the building's seismic response, with the ideal site being in the middle of the structure. The displacements and drifts were minimized by the braced frame compared to the shear wall [8]. The performance of RCSW when subjected to seismic loads was examined. In the reviewed work, various topics were emphasized, such as boosting the RCSW stiffness, ductility, and energy dissipation by replanting steel sections inside the wall, such as plate of I sections [9]. The scale-down building was made of RCSW and was exposed to seismic dynamic skew dynamic loads. According to analysis and test findings, the elastic and inelastic responses of RCSW were strongly impacted by applied dynamic loadings [10]. RCSW was subjected to nonlinear analysis under the influence of seismic loadings. RCSW was examined in a variety of layouts, including rectangular and T shapes. Closed and the real border as actual was the best technique to represent concrete walls as finite elements, according to numerical and test finding [11]. The effects of seismic loadings on RCSWs with apertures were investigated. The performance of RCSW was investigated using nonlinear finite element modeling and dynamic seismic loadings. Small apertures within a wall showed good displacement response, according to the results [12]. Under the effects of lateral loadings, the effects of wall end configurations and forms, such as rectangular and flanged, as well as boundary element type, were studied (2.6). The vertical and horizontal rebar ratios, as well as the features, were modified. The authors concluded that the test findings matched the CSA-A23.3-14 Canadian code. Flanged and boundary wall sections also have higher ductile capacities than rectangular sections [13]. ANSYS software was used to simulate RCSW using a modified nonlinear numerical analysis and a finite element technique. The RCSW with the slit functioned as a passive control system, resulting in a damping mechanism. When the shear connection yields, the damping system improves and the ductility of the entire structural system improves. Because the yield point of the shear connections has been reached, slit walls are more appropriate in strong seismic zones. When compared to walls without slits, the structure collapsed due to plastic hinge failure, which was averted under extreme seismic stress due to the high ductility offered to the structure when shear connections yielded [14]. Using seismic fragility curves, we were able to predict the behavior of a concrete frame (moment resistant) with a shear wall. It is considered that the damage degree of a structure is determined by probabilistic functions based on seismic intensity (spectral acceleration) (fragility curves). Figure 1 shows a moment-resisting frame and a frame with a wall system (2.8). The damage stages of the two structural systems were estimated using pushover analysis, and the damage states were converted to assess the narrative drift using the values of spectrum acceleration. These values were utilized to generate fragility curves. According to the results of the investigation, the fragility function and probability distribution function might be utilized to define the damage level. Almost all of the researchers listed above are concerned with reinforced concrete shear walls, energy dissipation devices, and methodologies for predicting the behavior of buildings and individual shear walls under the influence of seismic loading. To fill the gap in the literature, the present study employs a finite element approach by SAP2000 to evaluate the performance of reinforced lightweight concrete shear walls (RLCSWs) under seismic loading and determine the energy dissipation while taking into consideration different parameters that impact on the performance of reinforced concrete shear walls and reflect on the overall behavior of structural buildings.

2. Models Descriptions

The finite element approach is an approximate solution method for solving differential equations. In the Finite Element Method (FEM), the whole problem is broken down into parts that represent the finite linked elements, as these elements are to nodes. The nonlinear time history analysis method was adopted for the RCSW analysis. The RCSW used in this study is made of concrete and steel trusses that were built inside a typical construction building's consisting of eight-story structures.

For these walls, they were dealt with separately from the structure of the building account for boundary conditions; a finite element program (sap 2000) was used for evaluation and was based on parameters (compressive strength, reinforcement ratio, and aspect ratio) in order to carry out an evaluation of energy dissipation.

3. Dimensions and Mechanical Properties for Material RlCSW

Table 1 shows RlCSW dimensions and mechanical properties for each material.

Table 1: RlCSW dimensions and mechanical properties for each material

Slab thickness above RCSWs (mm)	200	
Story height (mm), H	3000	H / W
Wall width (mm)	3000	1.00
	4000	0.75
	5000	0.6
	6000	0.5
Wall thickness (mm)	200	
Reinforcement ratio	Vertical ϕ16@150 and 200 mm c/c	
	Horizontal ϕ16@150 and 200 mm c/c	
Concrete compressive strength (fc') (MPa)	17	
	21	
	24	
Poisson's ratio (ν)	Concrete 0.2	
Yielding strength of the steel bars (fy) (MPa)	413	
Unit weight (γ) (kg/m3)	Concrete 1840	
	Reinforcement 7850	

4. Reinforced Lightweight Concrete Separate Shear Walls Models

Different parameters that adopted in present work to evaluate the performance of RCSWs under the effects of seismic loadings. Height to width ratio of wall, concrete compressive strength and rebar's ratio are the main parameters that adoptedthat lists in Table 2.

Table 2: Parameters of LWCSHs models

Model mark	Wall height H (m)	Wall widthW (m)	H/W	Compressive strength f'_c (MPa)	Rebar's spacing c/c (mm)
LW1	3.0	3.0	1.00	17	150
LW2	3.0	4.0	0.75	17	150
LW3	3.0	5.0	0.60	17	150
LW4	3.0	6.0	0.50	17	150
LW5	3.0	3.0	1.00	21	150
LW6	3.0	4.0	0.75	21	150
LW7	3.0	5.0	0.60	21	150
LW8	3.0	6.0	0.50	21	150
LW9	3.0	3.0	1.00	24	150
LW10	3.0	4.0	0.75	24	150
LW11	3.0	5.0	0.60	24	150
LW12	3.0	6.0	0.50	24	150
LW13	3.0	3.0	1.00	17	200
LW14	3.0	4.0	0.75	17	200
LW15	3.0	5.0	0.60	17	200
LW16	3.0	6.0	0.50	17	200
LW17	3.0	3.0	1.00	21	200
LW18	3.0	4.0	0.75	21	200
LW19	3.0	5.0	0.60	21	200
LW20	3.0	6.0	0.50	21	200
LW21	3.0	3.0	1.00	24	200
LW22	3.0	4.0	0.75	24	200
LW23	3.0	5.0	0.60	24	200
LW24	3.0	6.0	0.50	24	200

5. Proposed Structural Building

The proposed structural structure has a plane layout (Figure 1) with dimensions of 30x30 m and a total height of 24 m, with eight floors of 3 m each. The structure was built as a slab beam system. The beam and column geometry dimensions are 600x400 m and 400x400 m, respectively, and the slab thickness is 200 mm at all levels.

The basic load combinations based on ASCE-7-2010 [15] as follows in which the symbols list in Table 3:

1. 1.4D
2. 2. 1.2D + 1.6L
3. 3. 1.2D + 0.5W
4. 4. 1.2D + 1.0W + L
5. 5. 1.2D + 1.0E + L
6. 6. 0.9D + 1.0W
7. 7. 0.9D + 1.0E

Table 3: Load description symbols

Type of load	Description
D	Dead load
E	Earthquake load
L	Live load
W	Wind load

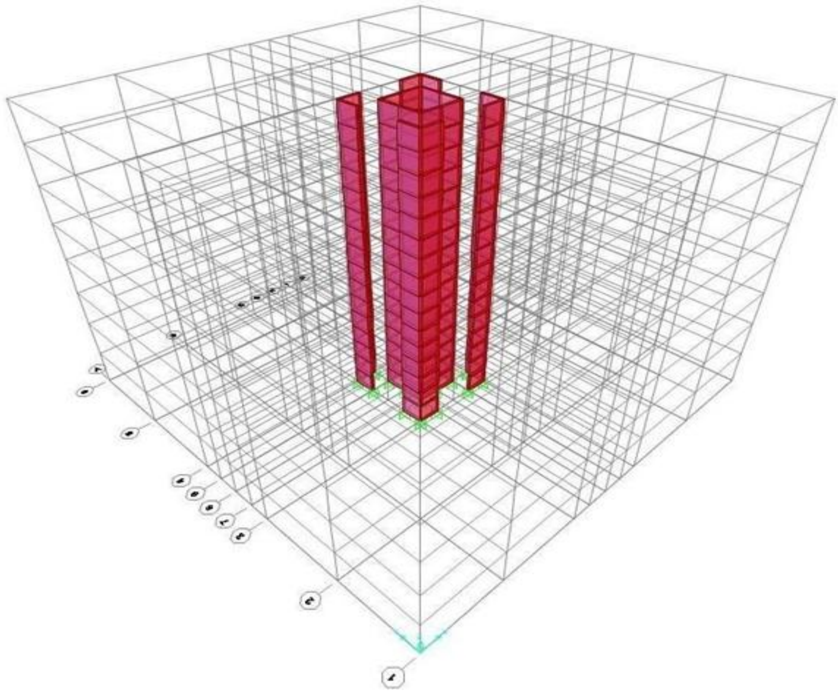


Figure 1: Three dimensional view of the building showing the shear walls and plane layout

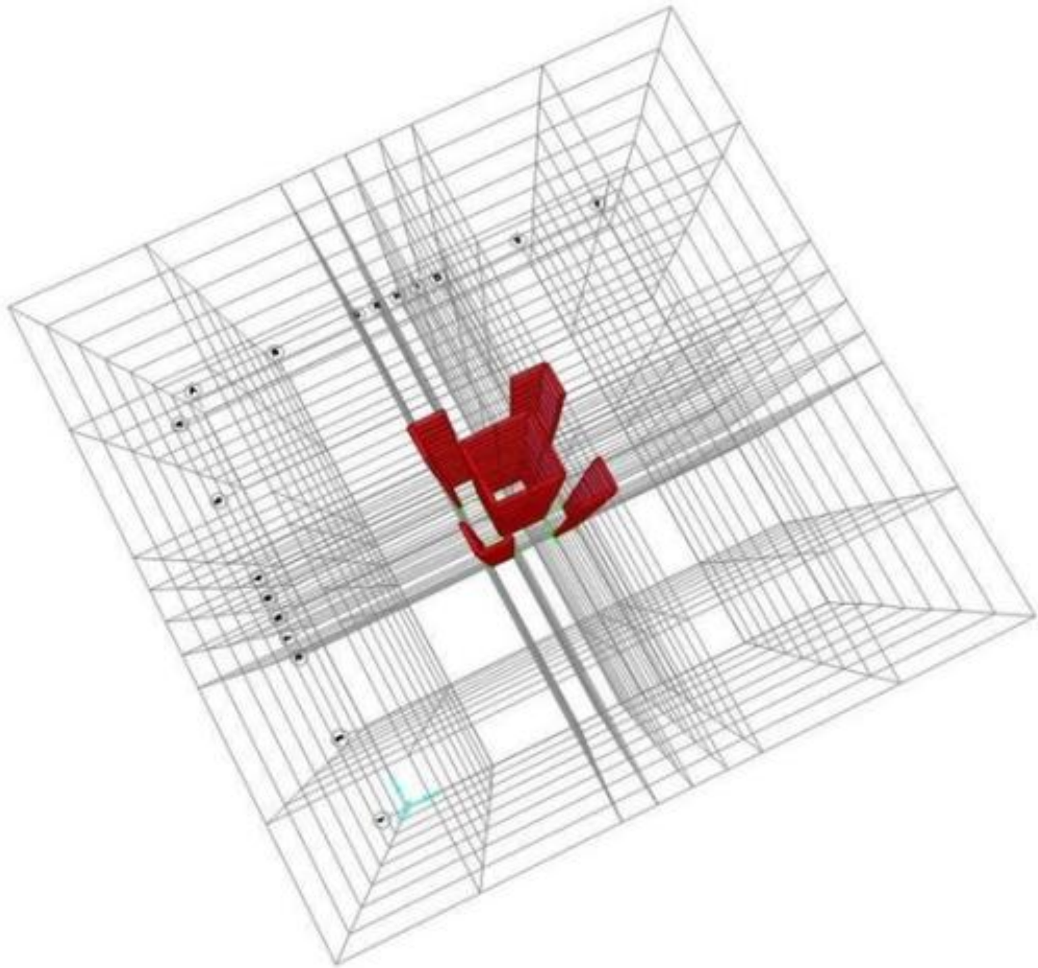


Figure 2: Top view of the building showing the detail of the shear walls.

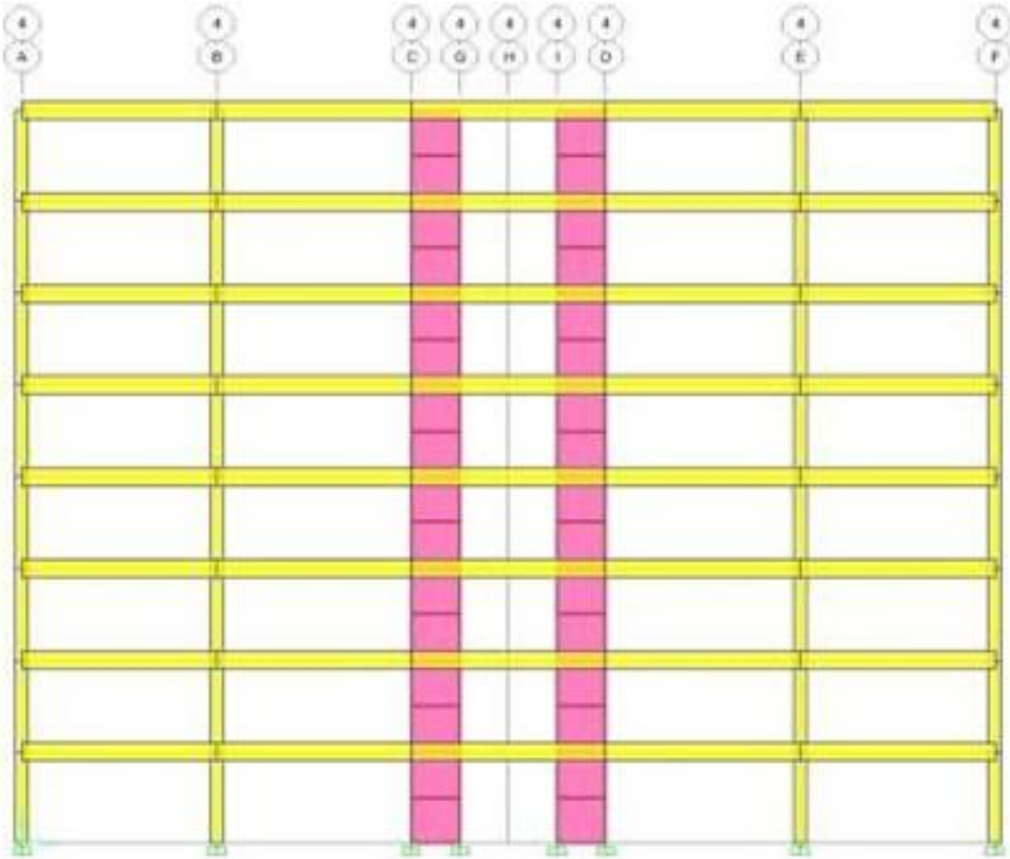


Figure 3: Whole building (Normal weight building with lightweight shear walls) - Elevation

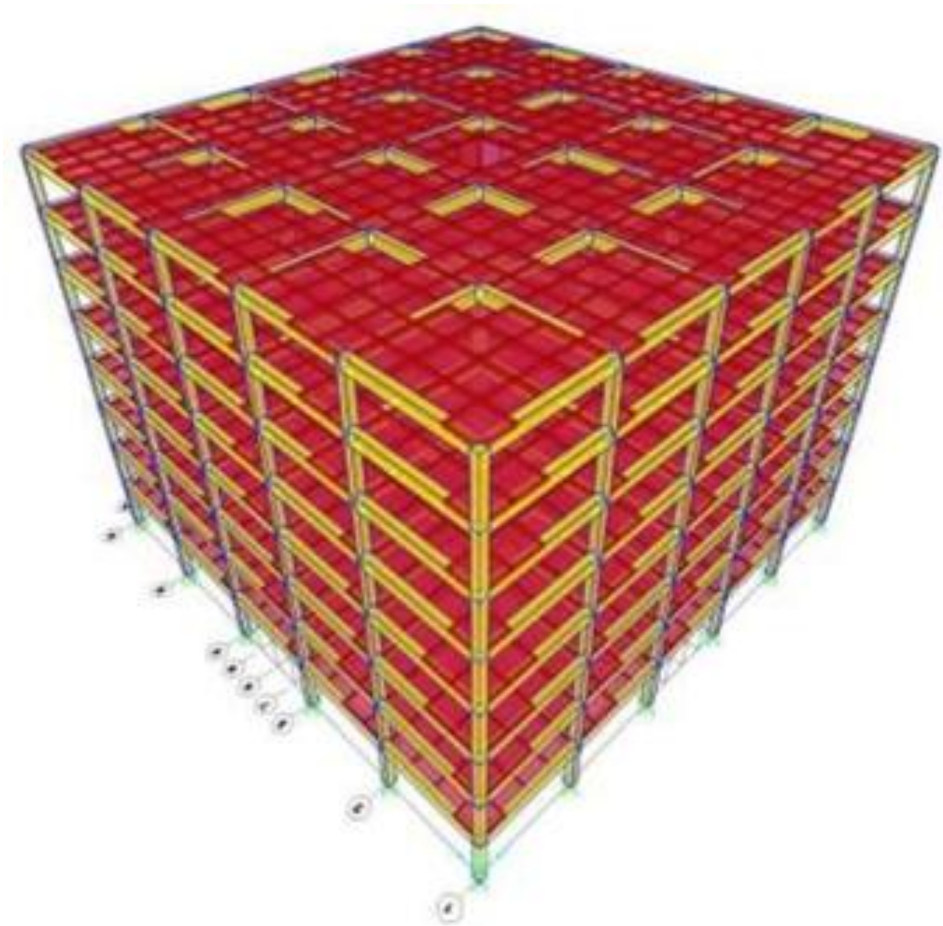


Figure 4: Whole building (Normal weight building with lightweight shear walls) -3D

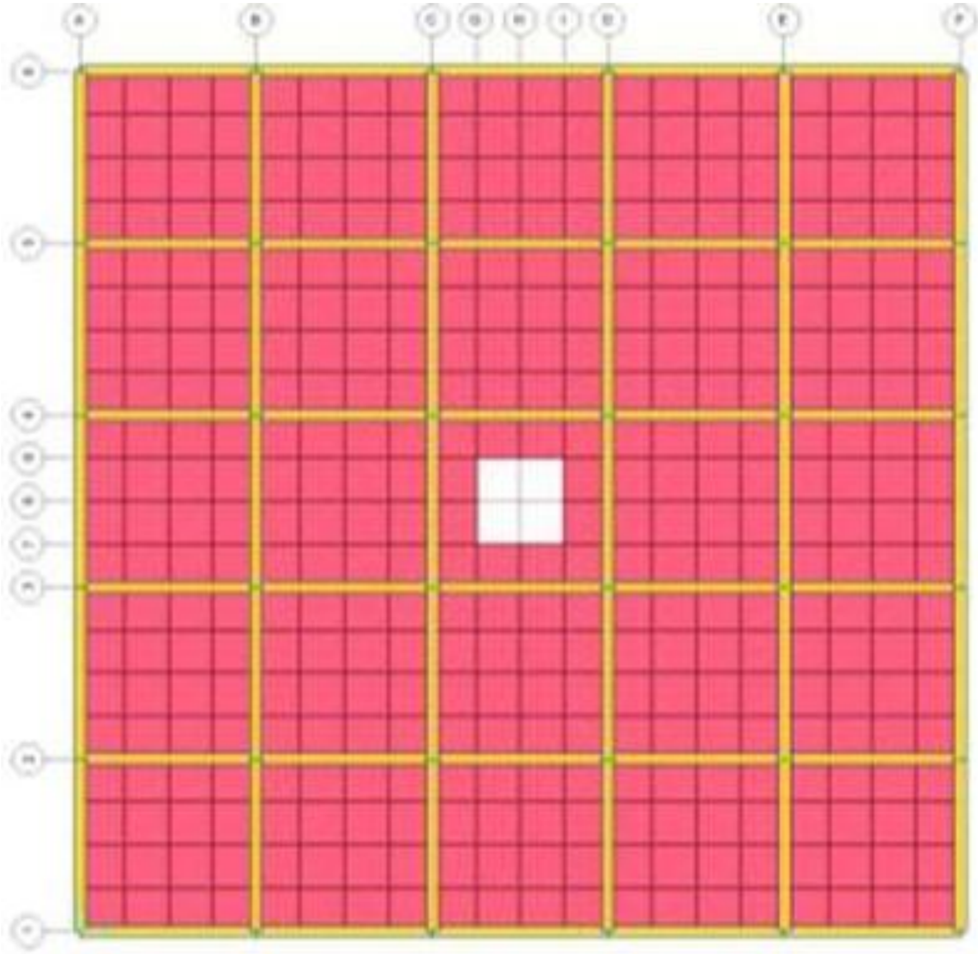


Figure 5: Whole building (normal weight building with lightweight shear walls) -top view

6. Dynamic Analyses–Time History Linear

El Centro earthquake ground motion that recorded in Imperial Valley in California - 1940 is adopted to evaluate the performance of reinforced concrete buildings with RlCSW is shown in Figure 1. The peak ground accelerations (PGA) of this earthquake ground acceleration record equals to 0.295 g. Nonlinear time history analysis by consider El Centro were applied for alladopted models.

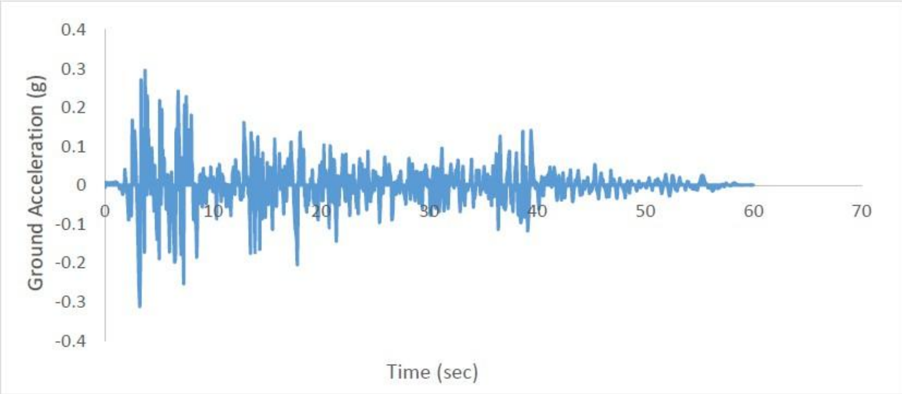


Figure 6: El Centro earthquake ground motion [16]

Mű(t) + C ū(t) + K u(t) =F (t) (1)

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, where ű (t), ū (t), and u. (t) are the displacement, velocity, and acceleration, respectively. Equation (3.10) solved in the present study by modal solution and can be solved by the direct integration method. Equation 10 represents a second order differential equation with a constant coefficient and is non-homogeneous. As follows, two boundary conditions are required to complete the solution of equation (1):

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

In the 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. The accuracy of the whole structural response relies on the natural mode number and the number of modes. The applied load that is considered here changes with time with linear time history performance. The accuracy of analysis results relies on the number of modes set in which the number of modes considered is 12.

7. Energy Dissipation

Energy dissipation defined as the area under the base shear-displacement curve. Figure 7 shows the performance hysterias of all adopted models under the effect of nonlinear time history (seismic loading). Figure 8 shows the energy dissipation that represents the half (area under the hysteric’s curve of base shear-displacement). The energy dissipation varied with time that represent the period in which the seismic load remains in shear wall. The energy dissipation showed increase up to time rounded to 12 second and then become constant for most of the models. This means the effective time is 12 second and then after this period the wall will dissipated the energy. The energy dissipation for all models lists in Table 4 in which these energy dissipations represent the half area under the curve of base shear- displacement so that the total energy dissipations is twice of these values.

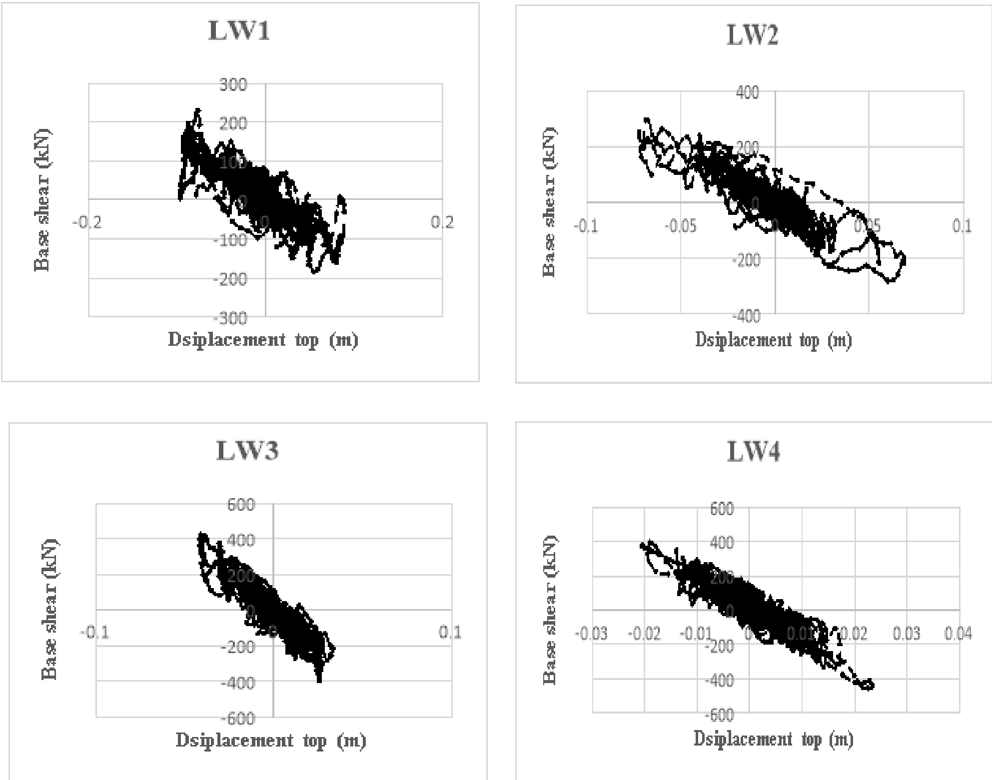


Figure 7: Base shear-displacement variation for all models (24 models) (to be continued)

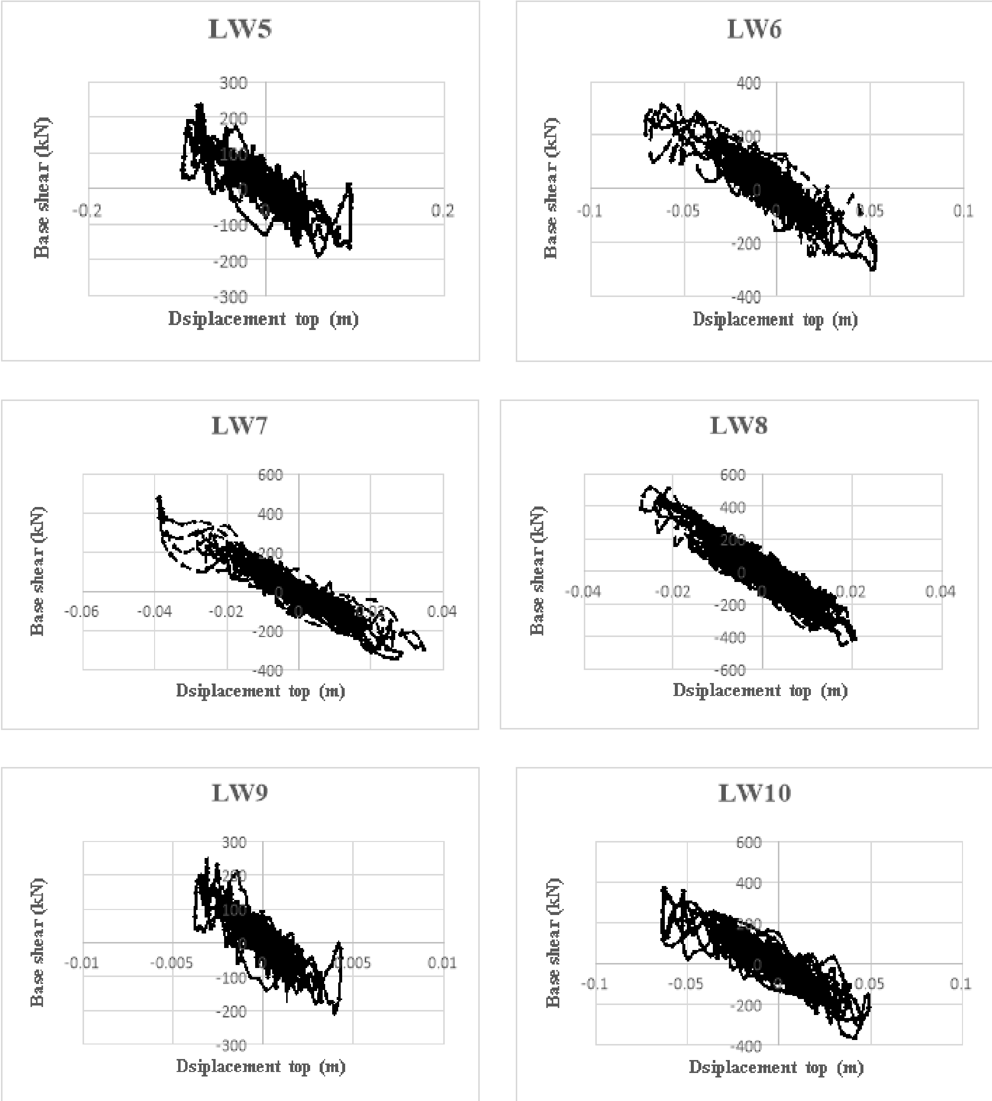


Figure 7: Base shear-displacement variation for all models (24 models) (continue; to be continued)

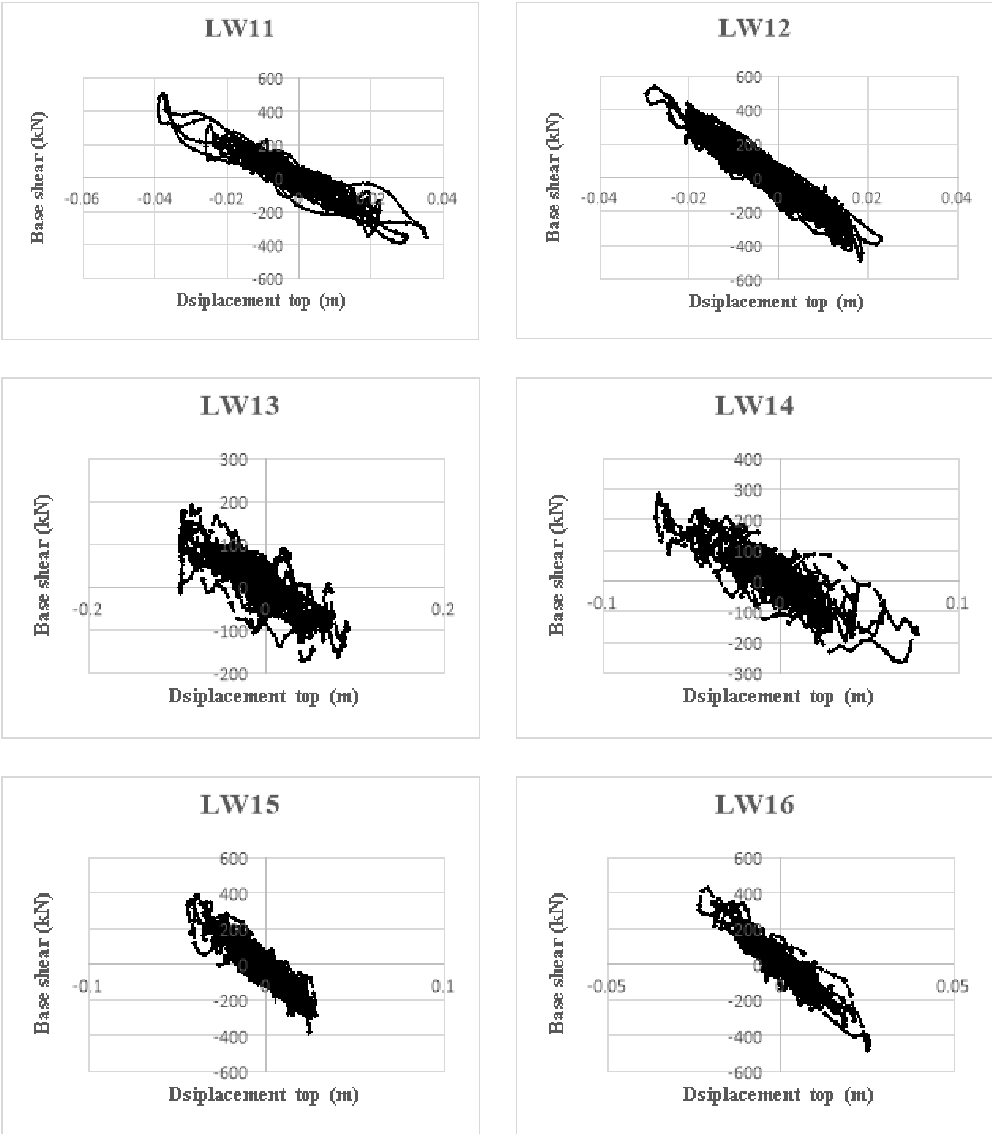


Figure 7: Base shear-displacement variation for all models (24 models) (continue; to be continued)

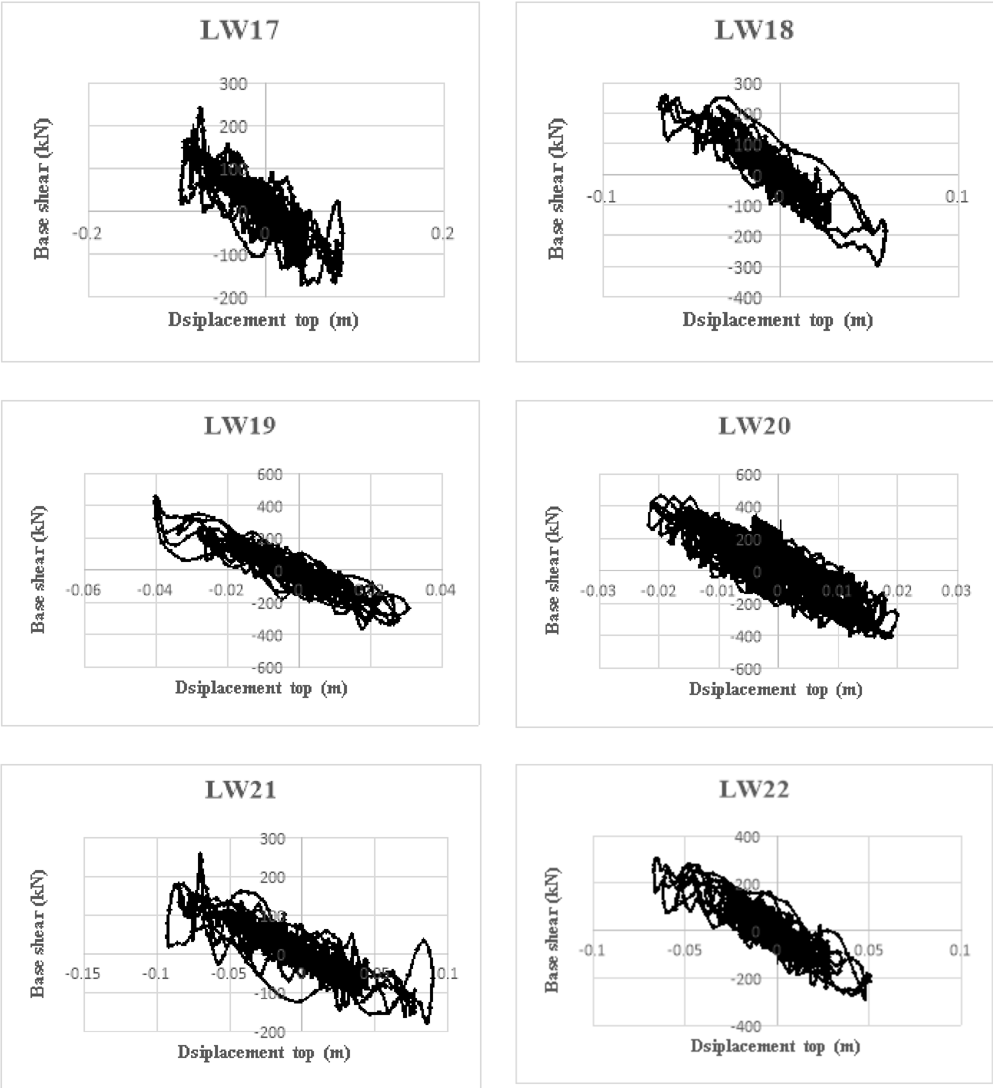


Figure 7: Base shear-displacement variation for all models (24 models) (continue; to be continued)

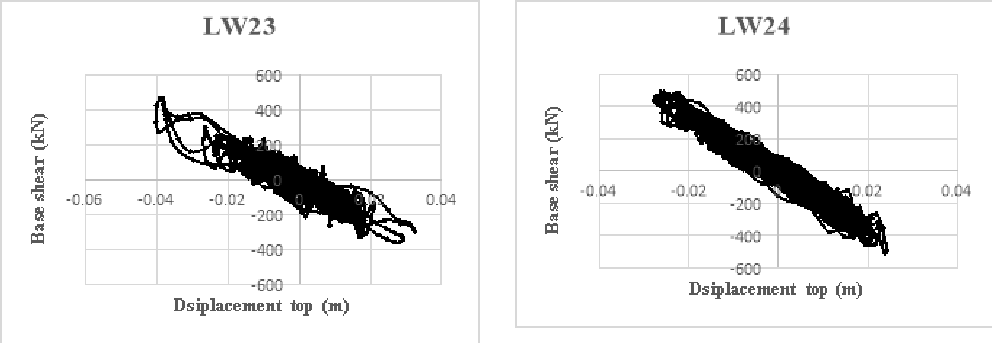


Figure 7: Base shear-displacement variation for all models (24 models) (continue)

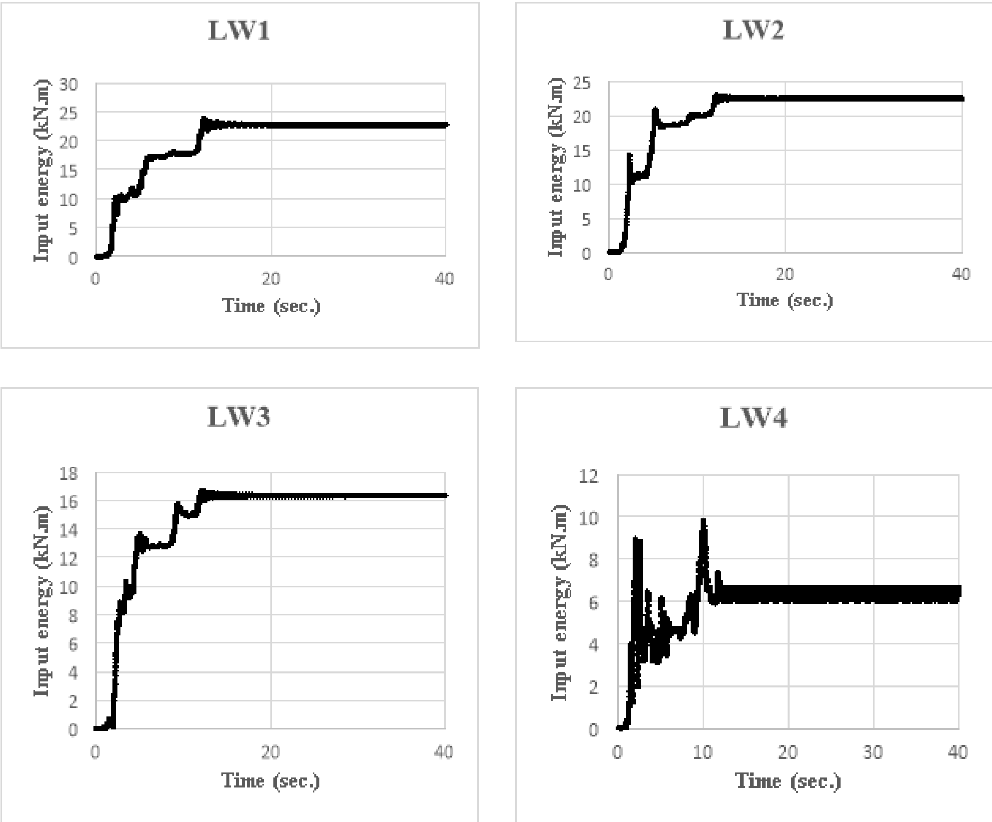


Figure 8: Energy dissipation vs. time performance for all models (half drawing)-(for 24 models) (to be continued)

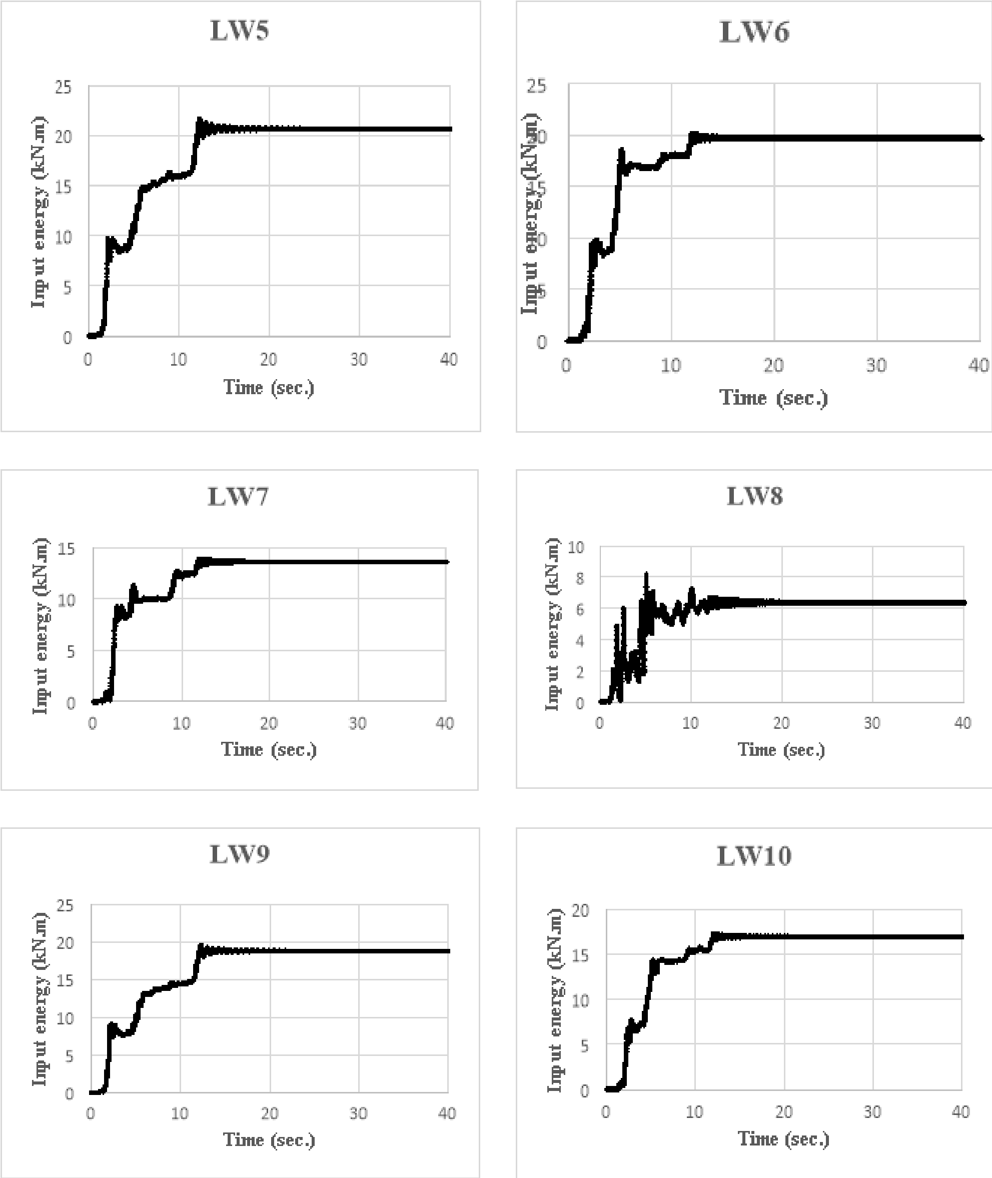


Figure 8: Energy dissipation vs. time performance for all models (half drawing)-(for 24 models) (continue; to be continued)

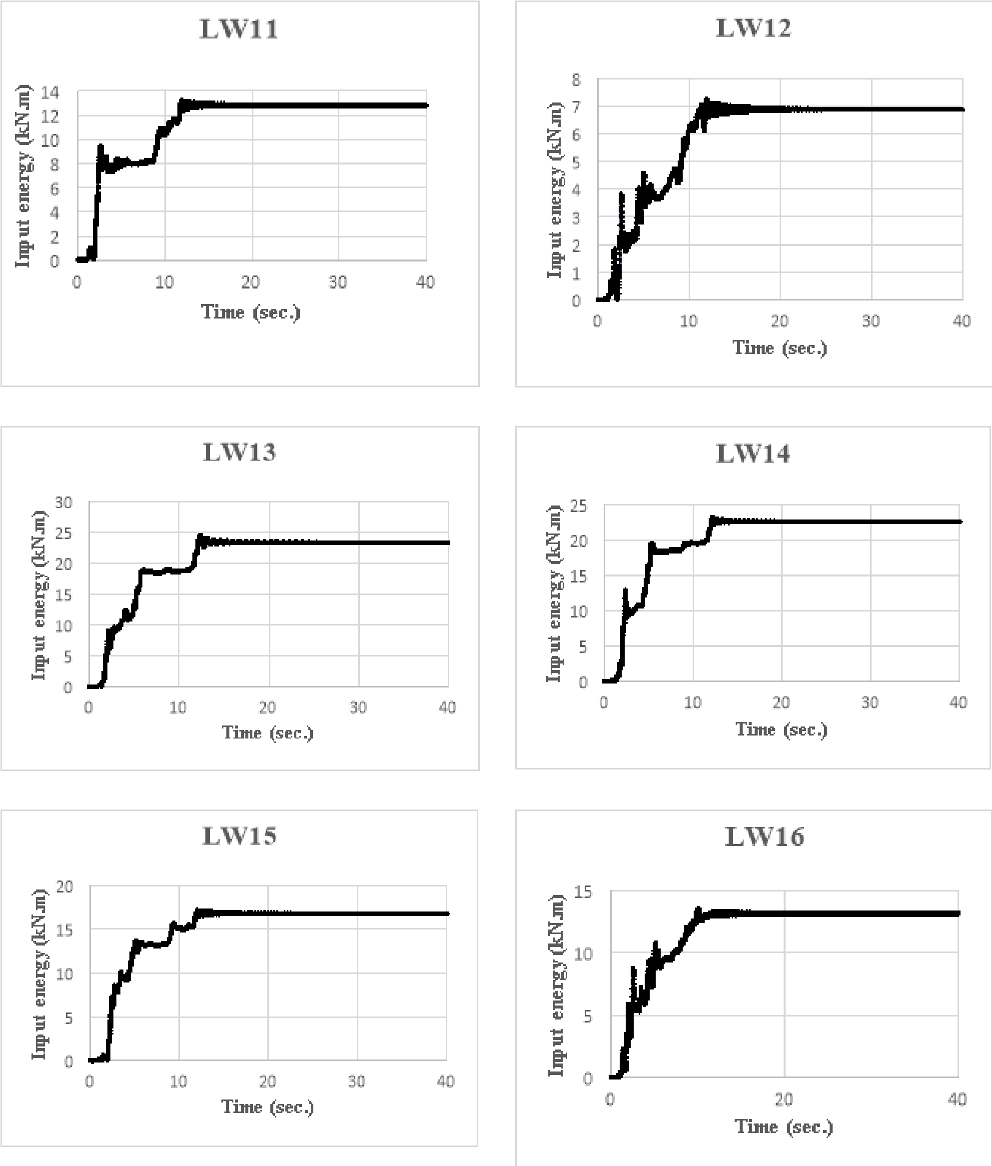


Figure 8: Energy dissipation vs. time performance for all models (half drawing)-(for 24 models) (continue; to be continued)

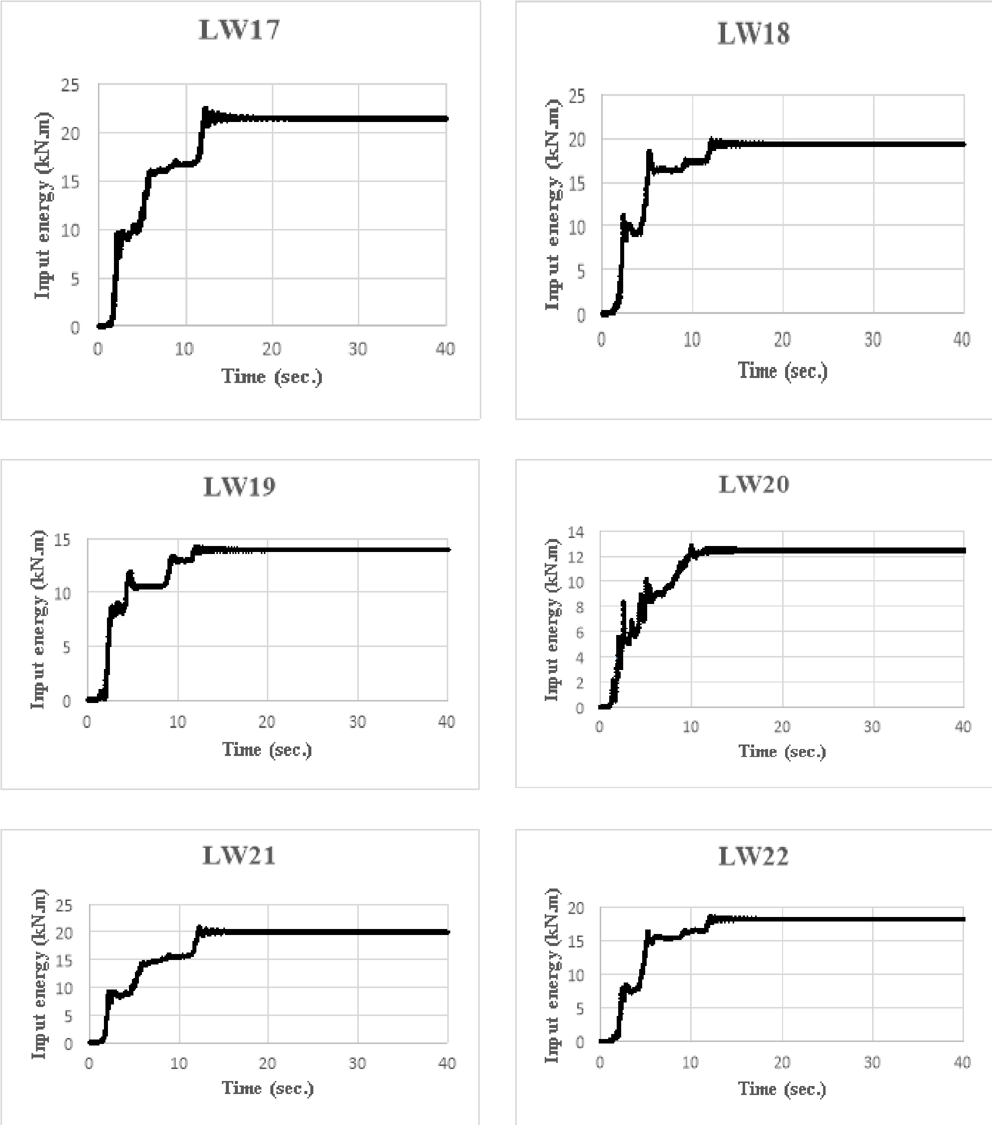
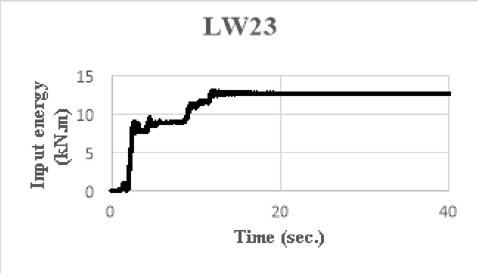


Figure 8: Energy dissipation vs. time performance for all models (half drawing)-(for 24 models) (continue; to be continued)



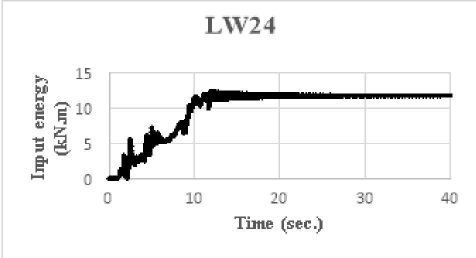


Figure 8: Energy dissipation vs. time performance for all models (half drawing)-(for 24 models) (continue)

Table 4: The highest value Energy dissipations ED for all models obtained through the examination (for 24 models)

Model mark	LW1	LW2	LW3	LW4	LW5	LW6	LW7	LW8
ED (kN.m)	23.86	23.01	16.66	9.54	21.7	20.17	13.92	8.21
Time (sec.)	12.29	12.08	11.98	10.01	12.2	12.09	11.97	5.03
Model mark	LW9	LW10	LW11	LW12	LW13	LW14	LW15	LW16
ED (kN.m)	19.65	17.46	13.23	7.25	24.48	23.21	17.15	13.55
Time (sec.)	12.22	12.03	11.95	11.94	12.36	12.13	12.00	10.01
Model mark	LW17	LW18	LW19	LW20	LW21	LW22	LW23	LW24
ED (kN.m)	22.42	19.77	14.22	12.23	20.85	18.75	13.00	12.39
Time (sec.)	12.27	12.07	11.97	5.05	12.25	12.08	11.96	11.96

As listed in Table (4) and plotted in Figures 9 to 11 that represents the comparisons between the adopted models with parameters considered.
Comparisons between models LW1, LW2, LW3 and LW4 that presented in Figure 9 shows that the energy dissipation become less with decreased of height to width ratio (increase in wall width) that make absorption of energy that lead to decrease in energy dissipation because of increase in wall stiffness and stability.
The effect of compressive strength on the energy dissipation is shown in Figure 10. Increase in compressive strength of lightweight concrete wall improved the ductility index (increase in ductility at service load and decrease the displacement at final stage of applied load) so that increase in energy dissipation so that the failure occurs not at small displacement and the shear wall behaved as large deformation.

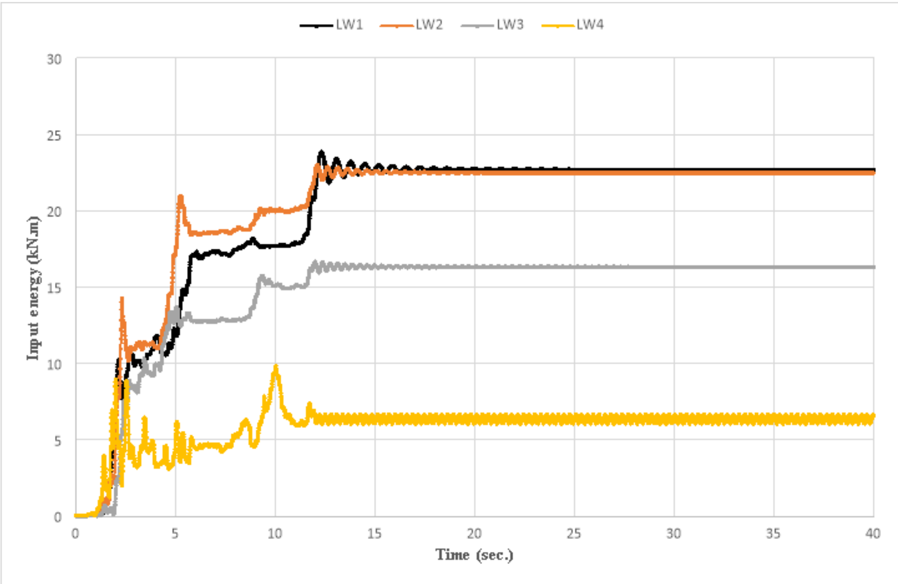


Figure 9: Effect of wall width on energy dissipation

In case of increase in the amounts of reinforcements as horizontal and vertical by make the center to center distance 150 mm rather than 200 mm. The ductility of lightweight concrete shear walls increased at service load and at the end of applied load with increase in displacement higher than other models so that the energy dissipation become more, Figure 11.

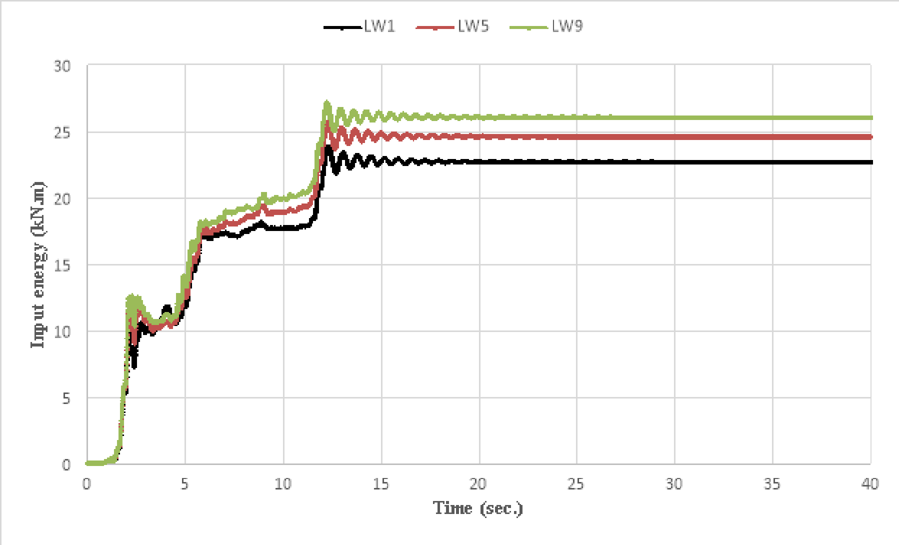


Figure 10: Effect of compressive strength on energy dissipation

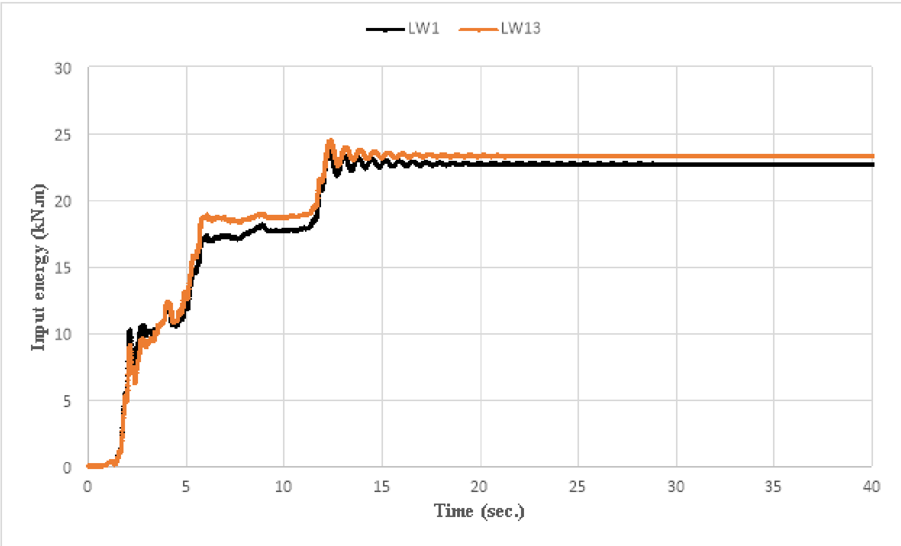


Figure 11: Effect of reinforcement amount on the energy dissipation

8. Discussions

Analysis results of separated lightweight concrete shear walls (LWCSWs), The parameters have an effect on the energy dissipation when the area under the curve of shear-displacement increases due to an increase in shear resistance. Increases in wall widths lead to making the LWCSWs stable due to an increase in wall stiffness so that high energy dissipation.

There is enhancement in LWCSWs energy dissipation when the width of the wall increases because of the increase in moment of inertia, which leads to the stiffness (EI) of the wall increasing, so the displacement is reduced and the base shear resistance is increased.

The LWCSWs energy dissipation is enhanced when the concrete compressive strength is increased. That leads to an increase in the concrete modulus of elasticity. Therefore, the stiffness of the LWCSWs becomes greater. An increase in reinforcement ratio makes the RCSWs more ductile and reduces the energy dissipation.

9. Conclusions

According to the results of the analysis the detached lightweight concrete shear walls; the following are the main points that have been concluded:

1. With increasing shear resistance and decreasing displacement, the energy dissipation of lightweight concrete shear walls (LWCSWs) decreases.
2. As shear resistance and concrete compressive strength rise, the energy dissipation of lightweight concrete shear walls (LWCSWs) decreases.
3. As shear resistance and reinforcing ratios rise, the energy dissipation of lightweight concrete shear walls (LWCSWs) decreases.
4. Global wall behavior is influenced by the wall aspect ratio (height to width ratio).
5. The technique for modeling LWCSWs using a multilayer shell element, as well as the application of the LWCSWs element's nonlinear behavior to concrete and steel constitutive relations
6. The displacement value is an important index for estimating damage levels for LWCSWs within a structure.

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تبديد الطاقة لجدران القص الخرسانية المسلحة خفيفة الوزن: تحليل تاريخ الوقت اللاخطي

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المستخلص: :- أداء تبديد الطاقة لجدران القص الخرسانية المسلحة خفيفة الوزن. يتم تقييم جدران القص هذه لكفاءتها الزلزالية عندما يتعرض الهيكل لضغوط زلزالية ، ويتم تمثيل هذه الكفاءة من حيث تبديد الطاقة. - تحليل التاريخ الزمني غير الخطي - تمت دراسته في البحث الحالي. تم تحليل اثني عشر نموذجًا باستخدام نهج العناصر المحدودة بواسطة تم إنشاء هذه النماذج لهيكل من ثمانية طوابق تعرض لحمل زلزالي وحمل جاذبية إضافي للاحمال الميتة والحية. بستخدام برنامج SAP 2000 . تم اعتماد معايير مختلفة ، مثل نسبة حديد التسليح ، وقوة الضغط ، ونسبة العرض إلى الارتفاع. وتشير نتائج الدراسة إلى أن هناك تحسناً في تبديد الطاقة لهذه الجدران ، والذي يعتمد على المعايير المعتمدة ، فضلاً عن عدم وجود فشل في أي من النماذج التي تم تحليلها.

الكلمات المفتاحية: تبديد الطاقة. جدار القص الخرساني المسلح خفيف الوزن ، التحميل الزلزالي ، تحليل تاريخ الوقت غير الخطي

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