EVALUATION OF DUCTILITY OF REINFORCED CONCRETE STRUCTURES WITH SHEAR WALLS HAVING DIFFERENT THICKNESSES AND DIFFERENT POSITIONS

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ABSTRACT: Ductility is one of the main criteria in reinforced concrete (RC) structures. ASCE 7-10 seismic design code recognizes the importance of ductility in earthquake-resistant structures. The structures need to be designed to have sufficient strength and ductility for overall safety against earthquake forces. Both the strength and the ductility are mutually associated to enhance structural seismic safety in this study. Previous studies showed that a shear wall gives different performance based on its position in building structures. This paper presents the position of the shear walls and shear wall thicknesses effects on ductility. A total of 96 two-dimensional (2D) models are analyzed for this work using ETABS software. The non-linear static analysis (pushover) method is used to analyze and design these RC building structures with shear walls. It is concluded that an increase in shear wall thickness causes a decrease in ductility values, and a decrease in ductility value will also occur when the shear wall position changes from edge to middle.

ABSTRAK: Kemuluran adalah salah satu kriteria utama dalam struktur konkrit bertulang (RC). Kod reka bentuk ASCE 7-10 seismik dunia menyedari pentingnya kemuluran dalam struktur tahan gempa. Struktur perlu dibina bagi mencapai ketahanan kekuatan dan kemuluran yang mencukupi bagi keselamatan keseluruhan terhadap kekuatan gempa. Kekuatan dan kemuluran dihubungkan bersama bagi meningkatkan keselamatan tahan gempa dalam kajian ini. Kajian sebelumnya menunjukkan bahawa dinding ricih memberikan prestasi yang berbeza berdasarkan kedudukannya dalam struktur bangunan. Kertas ini menunjukkan kedudukan dinding ricih dan ketebalan dinding ricih kesan pada kemuluran. Sebanyak 96 model dua dimensi (2D) dianalisis dalam kajian ini menggunakan perisian ETABS. Kaedah analisis statik bukan linear (pushover) digunakan bagi menganalisis dan merancang struktur bangunan RC ini dengan dinding ricih. Kesimpulannya peningkatan ketebalan dinding ricih menyebabkan penurunan nilai kemuluran, dan penurunan nilai kemuluran juga akan terjadi ketika posisi dinding ricih berubah dari tepi ke tengah.

KEYWORDS: *ductility; non-linear static analysis; earthquake design; pushover curve; shear wall*

1. INTRODUCTION

According to past earthquakes, several reinforced concrete structures have either failed or sustained different degrees of destruction. Overall, knowing the seismic efficiency of structures has been a question for science communities for a long time [1]. One of the most dangerous natural hazards is an earthquake that causes great losses of life and property damage [2].

Earthquake-resistant structural system design depends on standardized seismic requirements to provide secure quality of life during massive earthquakes [3]. It is essential to build analytical modeling to evaluate the seismic behavior of current systems and to modify structural performance properties such as strength, stiffness, and deflection to better-desired performance specifications [4].

The destruction depends not only on the scale of the earthquake but also on the form of the structural system. Of utmost importance here, the dual system includes structural reinforced concrete frames with shear walls (MRFSW). Dual structural frameworks are generally utilized as structural frameworks offering resistance to gravity and lateral forces [5].

In engineering structures, the concept of the formation of structural systems corresponds with the resistance to lateral forces of building structures. Based upon the variety of stresses that may occur throughout the structural elements due to the implementation of forces, the widely utilized structural systems are divided into various groups [6]. The structural system formation is designed to work against longitudinal forces of gravity and lateral loads affected by wind or earthquake actions. Gravity loads and lateral loads are the primary loads that are exposed to building structures [7].

Shear walls are among the most widely applied systems in buildings to withstand lateral loads. Implementing a shear wall is an effective solution to stiffen structural systems under lateral loads. The primary function of a shear wall is to increase the rigidity and strength of the building for lateral resistance [8]. Shear walls are widely utilized as a longitudinal structural component across modern buildings to withstand the lateral loads caused by winds and earthquakes. If a reinforced concrete shear wall is built to become a ductile element, it already conducts forces significantly better. To increase the ductility of shear walls, the shear wall's general geometric measurements, the form and quantity of reinforcement, and the relation against the other components through the building support should be taken into consideration [9]. The location, number and curtailment of shear walls act an important factor for the soft story structures to displace during an earthquake. To minimize the negative influence of twisting in buildings, shear walls should be perfectly symmetrically positioned through plan [10].

The capacity of members or structural components that show displacement is generally indicated by the required ductility ratios, μ, in earthquake-resistant design. [11]. The ratio of maximum displacement identifies ductility proportion (Δm) to the related displacement at the beginning of yield (Δy) [12].

Pushover analysis is a static non-linear technique that progressively raises the amount of the horizontal loads, preserving a specified distribution sequence throughout the height of the structure. Pushover analysis, considering the maximum load and the peak inelastic deformation, will define a building's performance. Influences of nonlinear static analysis can be modified once a mechanism of collapse has been formed. The primary benefit of pushover analysis is to obtain an over-strength estimation and provide a sense of the system's general ability to sustain inelastic displacement ductility [13]. Nonlinear pushover analysis offers sufficient knowledge regarding the building's durability, deformation capability, the discovery of the yield displacement, and the ultimate displacement, which are all used to compute the building structure's ductility from dividing the maximum displacement by the displacement of the yield [14]. The pushover analysis assesses the structural system's predicted quality by measuring the structural system's strength and deflection. This approach computes the building's base shear capability and the performance stages of each building component against various degrees of earthquake force [15].

2. OBJECTIVE OF THE STUDY

This present work aims to assess the RC structural buildings' ductility using various parameters with different thicknesses and different positions of shear walls. The research study evaluates the seismic assessment and the ductility of the 2D models of dual systems (MRFSW) using the pushover method. Moreover, to evaluate the degree of impact on ductility value, different parameters such as span length, compressive strengths of concrete, number of stories, various thicknesses of the shear wall, and different positions of the shear wall are chosen.

3. LITERATURE REVIEW

The effect of shear walls upon RC building structures' seismic efficiency is presented in this study. An estimate was made to assess losses in building structures, including suitable concrete and reinforced materials and shear walls besides beams and columns. These research findings will help select appropriate materials for structural buildings and shear walls in order to avoid destruction [16].

The impact of shear wall position in seismic resistance is defined [17]. The usage of the shear wall will efficiently decrease the displacement of the structure and story drifting. The shear walls' positioning in the centre of structures evenly provides an excellent performance that decreases the displacement and story-drift. Shinde and Raut [18] studied the varying shear wall thicknesses throughout similar buildings at various levels, preserving the places around similar positions and their impact upon multi-storied buildings' deformation. It is discovered, according to the findings, that the thickness already raises the rigidity, and by increasing the height and thickness, the deformation of shear walls decreases. The suitability of pushover analysis has been discussed for seismic evaluation of mid-rise to high-rise shear wall building structures and showed that pushover analysis understates the inner story drifts, especially those located on the top floors of building structures, and magnifies inelastic maximum roof displacement [19].

Carrillo et al. [20] studied ductility for earthquake design of RC walls for low-rise houses. The study contrasts and explains RC walls' ductility value generally utilized in one-floor and two-floor houses. Ductility capabilities in this research will be utilized to estimate the power modification and displacement amplification factors. The purpose of ductility throughout structural buildings is to guarantee that they have a specific amount of energy dispersion and deformation to prevent brittle destruction throughout the event of an earthquake [21].

Considering the reaction of a structural framework to seismic behavior may be managed by limiting lateral displacements, the ductile approach should be designed [22]. The major energy absorbing component utilized by the current design technique to produce a ductile performance throughout a seismic loading cycle was plastic hinges. As per seismic design rules in current building codes, structures shall withstand minor to severe earthquakes without harm, at most without major damage or collapse [23]. Throughout a large seism, the structure should get a low-cost resistance. Plastic energy might be employed during the design by ground shaking a structure for efficiency assessment. The appropriate amount of ductility is crucial for RC structure collapse prevention [24].

Venkatesh et al. [25] investigated the structural performance of RC moment-resisting frames with and without shear walls at various places to withstand seismic loads, as used in modern building techniques. In the condition of shear walls, the outcomes show higher resistance to horizontal loads. The impact of shear walls on the vulnerability of structures is

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demonstrated in [26]. Shear walls were examined for a G+8 story structure with and without shear walls. Once compared to the models without the shear wall, the shear wall model showed a significant decline in horizontal displacement. Because the structure's stiffness had increased, the displacement of the story had decreased.

4. METHODOLOGY

4.1 Introduction

The analyzed RC dual system (MRFSW) is designed in accordance with ASCE 7-10 seismic design code. Shear walls can minimize the lateral displacement of the building structures during the impact of earthquakes. The implementation of shear walls is a functionally effective solution for stiffening structures.

The pushover analysis method is used to verify the yield displacement, maximum displacement, maximum base shear, and ductility ratio for 96 models with several thicknesses and positions of shear walls including various parameters such as span length, number of stories and compressive strengths of concrete. The location of the models is assumed to be in Washington DC, United States of America.

4.2 Material Properties and Details of Models

The material properties and details of the models are given below in Table 1 and Table 2, respectively.

Table 1: Material properties of models

Material	Value
Compressive strength($f'c$)	250, 300 kgf/cm^2
Fy of reinforcement steel	420 N/mm^2.
Steel modulus of elasticity	200,000 N/mm^2
Concrete modulus of elasticity	23500 and 25743 N/mm^2
Unit weight of concrete	24 kN/m^3
Live load	2 kN/m^2
Super dead load	1.5 kN/m^2
Masonry load	14 kN/m
Shear modulus, G	99847.2, 109377 kgf/cm^2

Table 2: Details of 2D models

Parameters	Value
Number of stories (S)	Low (4), mid (8), and high-rise building (12)
Number of spans(N)	5 spans
Height of stories(h)	Typical story height (3.2m) and ground floor height (4m)
Span length(L)	5m, 5.5m, 6m, and 7m.
Positions of the shear wall.	Middle and edge
Thicknesses of shear wall	250mm and 300mm
Location of buildings	Washington DC, USA
Column section size for 4,8 and 12 stories	400mm*400mm, 400mm*650mm, and 400mm*800mm
Beam section sizes for 4,8 and 12 stories	350mm*400mm, 350mm*450mm, and 400mm*500mm

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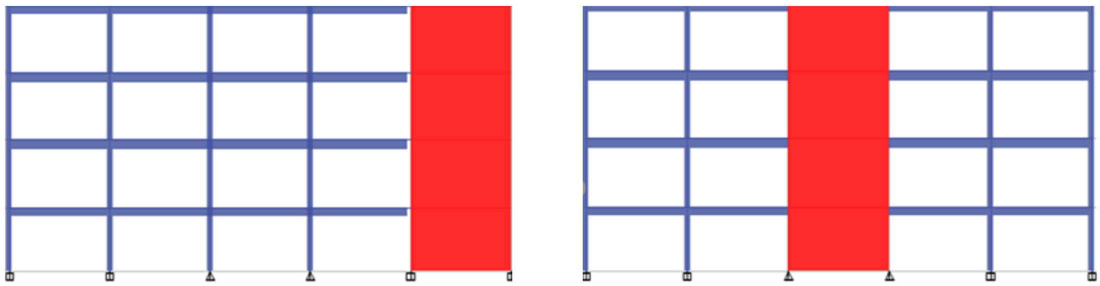

(a) edge (b) middle

Fig. 1: Different positions of the shear wall.

4.3 Seismic Analysis Methods

Every structure must be designed in a way to resist lateral forces including earthquakes [27]. In order to determine the performance and the maximum response of the structures, instead of the use of complicated nonlinear dynamic analysis, a nonlinear static analysis was employed, which is a simpler and quicker method for the estimation of the structural response.

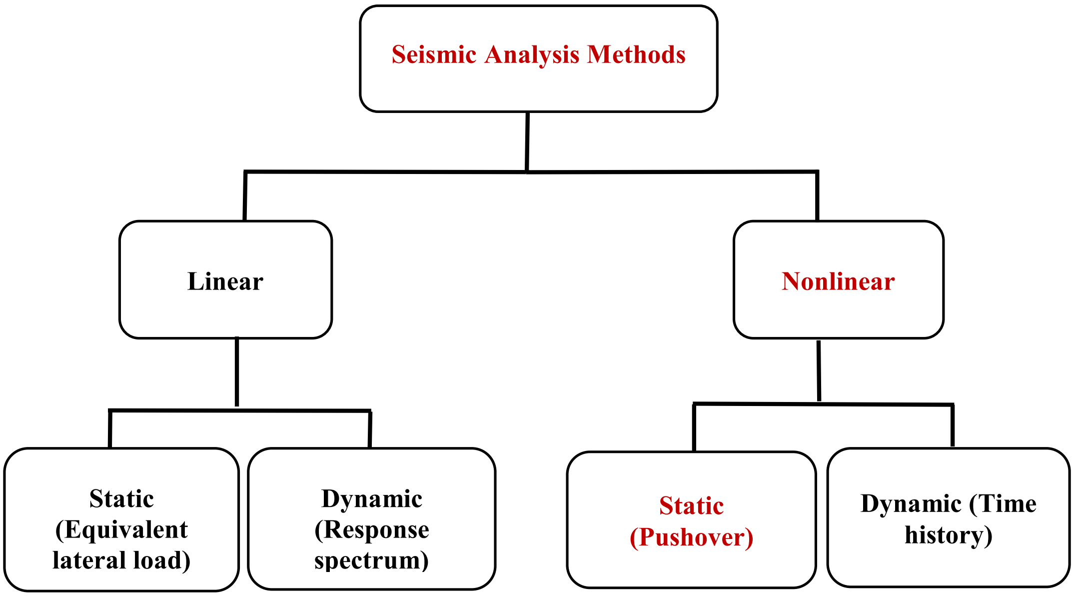

Fig. 2: Seismic analysis methods.

4.4 Bilinear Curve of Pushover Curve

The request for a straightforward approach to estimate the non-linear analysis of a structure against earthquake loading is widely recognized as the pushover study. Pushover Curves illustrate the structure's nonlinear nature and a base shear deformed curve against the construction's lateral floor displacement. This method is dependent upon the principles of FEMA356, assuming equal regions underneath the primary curve and bilinear curves. A bilinear pushover curve has been constructed for every design building method and reflects various earthquake designs and building efficiency stages. So, each curve has been defined via 2 points: yields of capability and ultimate capacity. The maximal capacity was achieved after the general structural framework was developed as a total approach. A 15 percent reduction in strength occurred by failing specific components to reach the deformation capability. Consequently, the strength referring to the optimum capacity does not always correlate with the actual highest power reported through the study. Furthermore, the yield capability is not the building's power while the member's initial yield occurs.

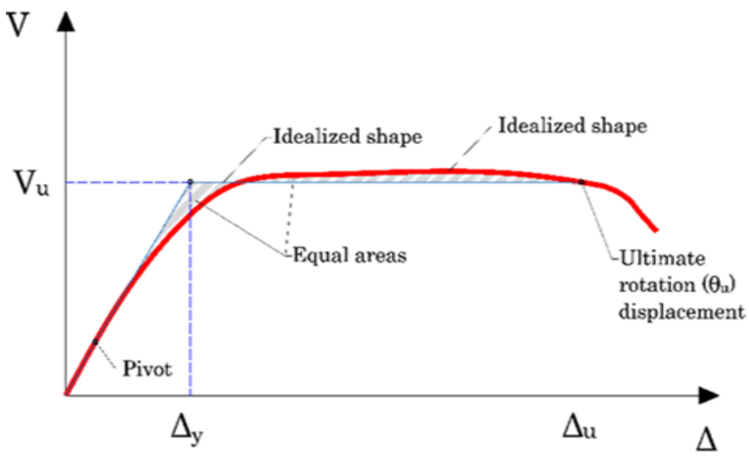

Fig. 3: The bilinear curve of pushover curve [11].

4.5 Sample of the Bilinear Curve of Capacity Curve

The ratio between the maximum displacement and linear displacement in a bilinear capacity curve is defined as the ductility factor. In order to estimate a bilinear curve from the capacity curve, the area under both curves must be identical. To determine the global yield point, the capacity curve is usually simplified as a bilinear curve that has the same area with respect to the axis of spectral displacement, which is referred to as the equal energy rule. The main intent for this procedure is to find the area under the pushover curve, which corresponds to the dissipated energy during earthquake, and it should be equal to the area under the bilinear curve. That area calculation is carried out using AutoCAD, which is a commercial computer-aided design and drafting software application. These areas above the capacity curve and below the bilinear curve are shown in Fig. 4.

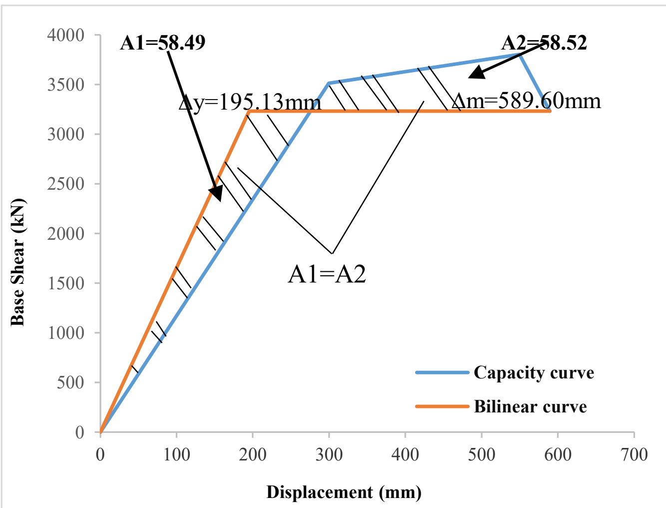

Fig. 4: Bilinear relationship of base shear versus roof displacement.

Thus, the pushover curve is exported from ETABS to Microsoft Excel and is then transferred to AutoCAD. In this stage, a horizontal line is drawn from 85% of the pushover

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curve's maximum base shear. This line intersects the pushover curve and is passes it. Another line is drawn from the coordinate centre and intersects with the drawn horizontal line. After that, the areas below the pushover curve and above the pushover curves are compared with each other, and the position of the second drawn line is changed until both areas are the almost equal.

5. RESULTS AND DISCUSSIONS

5.1 Results

The results of yield displacement, maximum displacement, maximum base shear that were obtained from the pushover curve, and the ductility ratio calculated by dividing Δ_m over Δ_y, as shown in equation (1), are summarized in Table 3, Table 4, and Table 5 with compressive strength ($f'c$), 300 kgf/cm^2 for low-rise, mid-rise, and high-rise buildings, respectively.

The equation for finding ductility ratio:

$$\mu=\frac{\Delta_m}{\Delta_y} \tag{1}$$

Table 3: Results of pushover analysis and ductility values for low-rise (4-story) buildings

No. of models	Span length(m)	Thickness of shear wall (mm)	Position of shear wall	Δ_y (mm)	Δ_m (mm)	μ
1	5	250	Edge	128.30	296.81	2.31
2	5.5	250	Edge	123.23	305.63	2.48
3	6	250	Edge	118.11	319.15	2.70
4	7	250	Edge	106.12	340.23	3.20
5	5	250	Middle	77.61	149.74	1.92
6	5.5	250	Middle	70.42	158.83	2.25
7	6	250	Middle	64.64	163.29	2.53
8	7	250	Middle	54.81	172.37	3.14
9	5	300	Edge	51.01	112.78	2.21
10	5.5	300	Edge	50.21	120.85	2.40
11	6	300	Edge	49.32	129.44	2.62
12	7	300	Edge	47.12	148.23	3.14
13	5	300	Middle	76.24	136.62	1.79
14	5.5	300	Middle	69.12	145.29	2.10
15	6	300	Middle	63.15	152.47	2.41
16	7	300	Middle	55.90	169.22	3.02

5.2 The Effect of Span Length on Ductility Values

Ductility values of various span lengths are shown in Tables 3, 4, and 5, and a comparison of ductility values with different span lengths is shown in Fig. 5. This figure shows an increase in ductility value by 6%, 10%, and 31% caused by increasing the span length with 10%, 20%, and 40%, respectively. On the other hand, once span length increases, a reduction in yield displacement and an increase in maximum displacement can occur.

The parameters used in this section are the shear wall position, which is located in the middle, and the number of stories, i.e., 4-story.

Table 4: Results of pushover analysis and ductility values for mid-rise (8-story) buildings

No. of models	Span length(m)	Thickness of shear wall (mm)	Position of shear wall	Δ_y (mm)	Δ_m (mm)	μ
1	5	250	Edge	102.07	306.39	3.00
2	5.5	250	Edge	101.25	326.63	3.22
3	6	250	Edge	100.01	340.13	3.40
4	7	250	Edge	85.06	361.68	4.25
5	5	250	Middle	142.05	380.48	2.67
6	5.5	250	Middle	140.19	394.31	2.81
7	6	250	Middle	129.13	407.55	3.15
8	7	250	Middle	112.2	430.00	3.83
9	5	300	Edge	105.49	296.34	2.80
10	5.5	300	Edge	100.30	318.20	3.17
11	6	300	Edge	102.60	332.62	3.24
12	7	300	Edge	89.65	355.00	3.95
13	5	300	Middle	169.44	366.70	2.16
14	5.5	300	Middle	158.41	384.28	2.42
15	6	300	Middle	153.10	399.69	2.61
16	7	300	Middle	134.01	423.80	3.16

Table 5: Results of pushover analysis and ductility values for high-rise (12-story) buildings

No. of models	Span length(m)	Thickness of shear wall (mm)	Positions of shear wall	Δ_y (mm)	Δ_m (mm)	μ
1	5	250	Edge	103.12	521.45	5.05
2	5.5	250	Edge	104.92	545.32	5.19
3	6	250	Edge	106.32	566.45	5.32
4	7	250	Edge	110.87	615.16	5.47
5	5	250	Middle	159.51	639.68	4.01
6	5.5	250	Middle	150.20	663.20	4.41
7	6	250	Middle	152.01	684.15	4.50
8	7	250	Middle	143.25	719.45	5.02
9	5	300	Edge	87.02	399.28	3.95
10	5.5	300	Edge	106.59	426.88	4.00
11	6	300	Edge	100.04	443.96	4.43
12	7	300	Edge	93.12	466.56	5.01
13	5	300	Middle	195.13	589.60	3.02
14	5.5	300	Middle	190.12	605.43	3.18
15	6	300	Middle	185.05	659.45	3.56
16	7	300	Middle	168.64	692.04	4.00

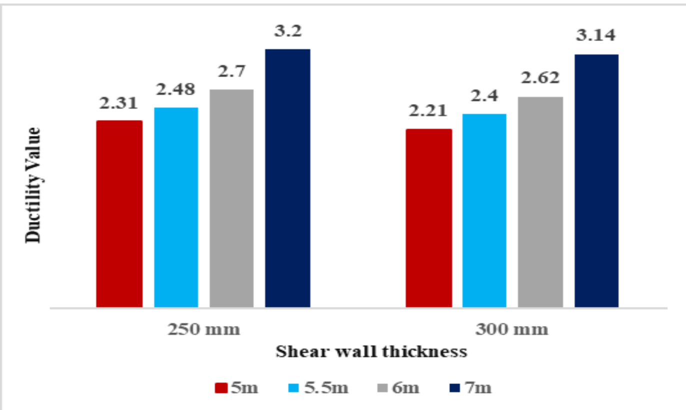

Fig. 5: The Comparison between the ductility values for different span lengths in a 4-story building.

5.3 The Effect of Number of Stories on Ductility Values

In this section, the effect of the number of stories on ductility values is defined. Ductility values of various numbers of stories are shown in Tables 3, 4, and 5. The ductility value is increased by 33% by increasing the number of stories from 4 to 8 and by 71% from 4 to 12. This can be seen in Fig. 6. The increment in the number of stories leads to increased yield displacement and ultimate displacement, which is how ductility value rises.

Parameters used in this section are: shear wall thickness = 300 mm, and shear wall position = middle.

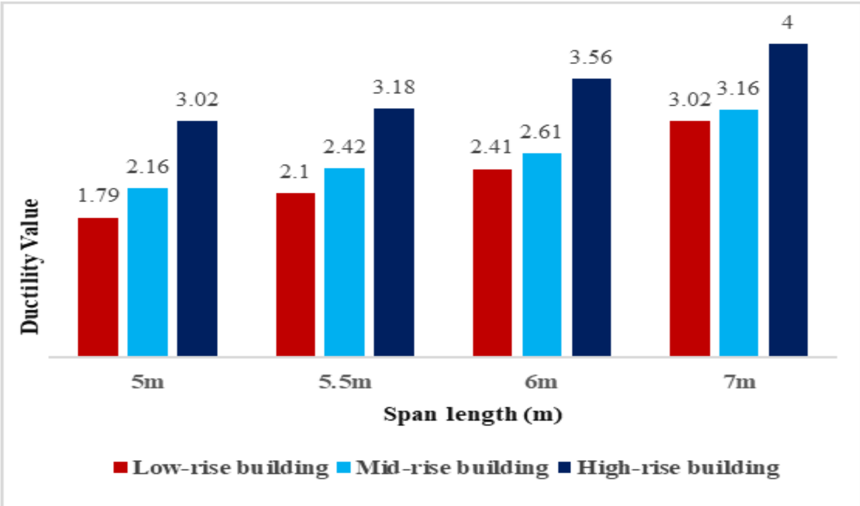

Fig. 6: Comparison of the values of ductility of different number of stories.

5.4 The Effect of Different Thicknesses and Positions of the Shear Wall on Ductility Values and Capacity (Pushover Curve)

The impact of different shear wall thicknesses and positions on ductility ratio is described in this section. Table 3, 4 and 5 illustrate ductility rates with variations in different shear wall thicknesses and positions, respectively. As seen in Fig. 7, as shear wall thickness increases from 250 mm to 300 mm, a decrease in ductility values will occur by 15%. Increasing shear wall thicknesses from 250 mm to 300 mm caused an increment in yield displacement (Δ_y) and a decrease in maximum displacement (Δ_m) will occur that resulted in a reduction in ductility values. Moreover, as shown in Fig. 8, increasing shear wall thickness causes an increase in maximum base shear.

As shown in Fig. 9, when shear wall position changes from edge to middle, it causes a decrease in ductility value of 20 % and causes an increase in both yield displacement (Δ_y), and ultimate displacement (Δ_m). As shown in Fig. 10, a change in shear wall position from edge to middle induces an increase in maximum base shear.

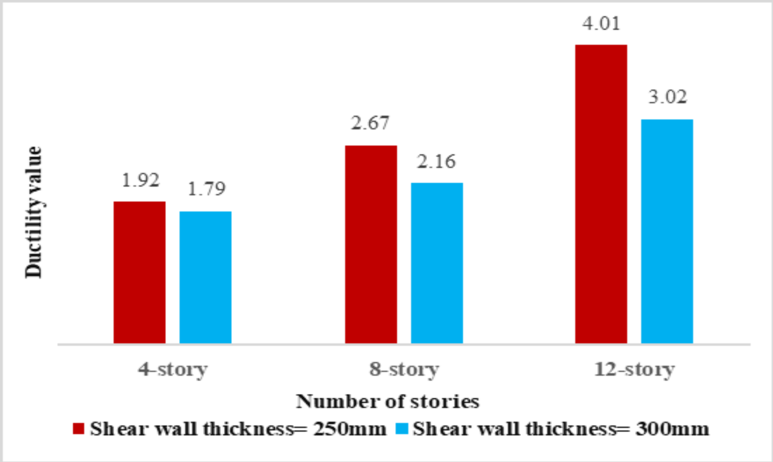

Fig. 7: Comparison between the values of ductility for different thicknesses of shear wall.

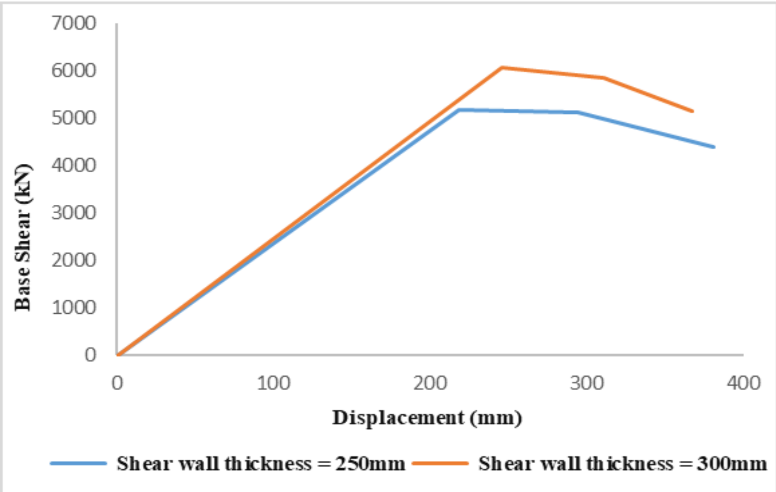

Fig. 8: The impact of the different thicknesses of the shear wall on the capacity (pushover) curve.

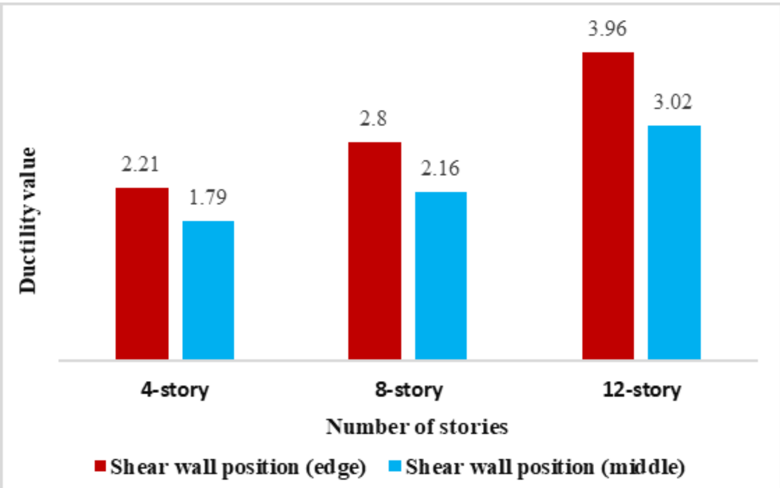

Fig. 9: Comparison of the ductility values of different positions of shear wall.

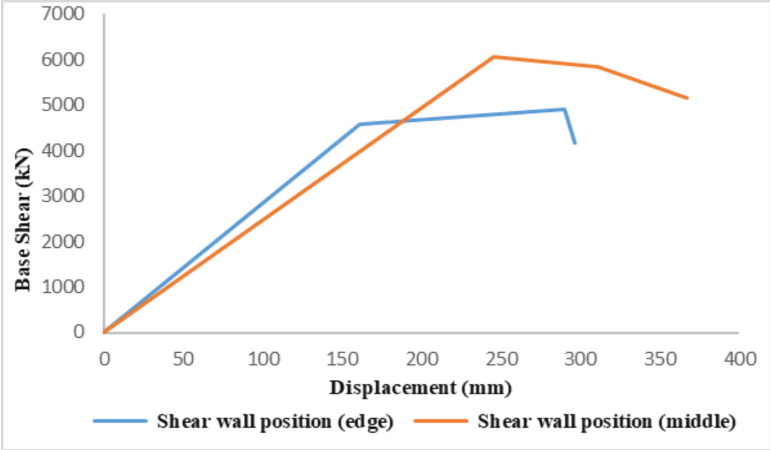

Fig. 10: The impact of the different positions of the shear wall on the capacity (pushover) curve.

6. CONCLUSIONS

In this paper, the two-dimensional dual system (MRFSW) has been studied. The models are designed with different thicknesses and shear wall positions to evaluate the ductility, maximum displacement, yield displacement, and maximum base shear. The summarized outcomes of this study are as follows:

- Increasing span length causes an increase in ductility value in low, mid, and high-rise buildings. It has also been observed that by increasing the span length, there will be an increase in the yield displacement and maximum displacement.
- By increasing the span length, it has been observed that the maximum base shear force decreases in all building models.
- Increasing the number of stories causes an increase in ductility value because the stiffness of the building will decrease by adding more floors.
- When the shear wall thickness was increased from 250 mm to 300 mm, it was observed that there was a decrease in ductility values.
- It has been observed that increasing shear wall thickness causes an increase in maximum base shear force.
- The ductility rate is noticed to decrease by increasing the shear wall thickness.
- When the shear wall position changes from edge to middle, it causes a reduction in ductility value.
- By changing the shear wall position from the edge to the middle, an increase in both the yield displacement and the ultimate displacement has been found.
- Changing the shear wall position from edge to middle causes an increase in maximum base shear force for all story buildings.

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