International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 13, Issue 5 [May. 2024] PP: 290-300

A Review of Advanced Seismic Isolation Methods for Earthquake Resistant Structures: Role of Shear Walls in Construction

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ABSTRACT: *Earthquakes are natural phenomena that can lead to disasters primarily due to the destruction or collapse of buildings and other man-made structures. It is essential to assess and reinforce existing structures based on evaluation criteria before an earthquake occurs. The extent of earthquake damage is influenced by various factors, including the characteristics of ground motion (intensity, duration, and frequency content), soil properties (topography, geology, and soil conditions), building attributes, and construction quality. Building designs should ensure that structures have sufficient strength, high ductility, and remain structurally intact, even when exposed to significant ground movements. Using a variety of cutting-edge technology and architectural concepts, architects and engineers may construct structures that are earthquake-proof. They consist of moment-resisting frames, shear walls, cross braces, vibration deflection technologies, dampening systems, and flexible foundations. These innovations are crucial for ensuring maximum stability and safety for the occupants of such buildings. Building a structure to withstand seismic waves begins with selecting the right materials with the appropriate properties.*
Overall, this scientific article provides an extensive review of the development of advanced seismic isolation methods for earthquake-resistant structures. The primary objective of this article is to provide a comprehensive review of the latest advanced seismic isolation methods and their effectiveness in enhancing the earthquake resistance of structures. A particular focus of the research is on examining the crucial role of shear walls in a specific 9+1 building.
In conclusion, the development of advanced seismic isolation methods for earthquake-resistant structures is an important area of research in seismic engineering. These methods offer the potential for improved seismic performance, increased seismic resilience, and reduced construction costs. The analytical investigation of these methods is essential for understanding their dynamic response and seismic performance, and for the development of new design methods for earthquake-resistant structures.
KEYWORDS- *Earthquake resistant methods, Base isolation, Resistant materials, Energy Dissipation System, Shear walls.*

Date of Submission: 16-05-2024 Date of acceptance: 31-05-2024

I. INTRODUCTION

1.1. Background on seismic isolation and earthquake-resistant design

Unforeseen events, so-called catastrophes, have always had a negative impact on humanity. In response to such events, efforts have been made to reduce the devastating effects of these disasters.The 1950s saw a surge in construction activity after World War II, which led to the development of the current approach to seismic engineering of buildings. Early attempts to offer earthquake resistance in buildings were hindered by a lack of appropriate analytical tools and seismic records, and were based on very flimsy assumptions about structural behavior. The field of earthquake resistant structural design has been largely shaped by observations of how buildings behave after being subjected to real earthquakes, analytical research, laboratory testing of structural components and subassemblies, and the accumulation of earthquake records over the previous years. .[1]

An earthquake is a sudden shaking of the ground caused by the release of enormous tensile energy stored at the interface of plates.Currently, earthquakes are inevitable and unpredictable, so we have no choice but to design and build earthquake-resistant structures.Attempts in this direction are therefore being made all over the world.Earthquake damage can be most effectively reduced if buildings are designed to be earthquake resistant from the start.[2]

Earthquake-resistant construction involves building structures that can withstand the sudden ground shaking of earthquakes, minimizing structural damage and human casualties. Proper construction methods are crucial to meet earthquake-resistance design objectives, which can vary widely depending on local construction practices and available resources.It's important to distinguish between the design of a building and the construction methods used to build it. Advanced earthquake-resistant designs are effective only if proper construction methods are employed, including site selection, foundation design, structural member fabrication, and connection joints. Ductility, the ability of a building to bend and deform without collapsing, is a key feature of earthquake-resistant designs. This is typically achieved by incorporating steel reinforcement in concrete structures, which allows them to bend and flex during seismic events.[3]

Failures in earthquake-resistant construction are often due to poor construction methods or substandard materials. In less-developed regions, concrete is often not mixed, consolidated, or cured properly, making buildings susceptible to failure during earthquakes. The lack of local building codes, inspection, and quality control exacerbates this issue.Environmental monitoring and early-warning systems are advancing to become highly effective in protecting buildings from seismic threats. However, challenges in deploying 5G technology hinder communication solutions in rural and low-income areas. Hence, constructing earthquake-resistant structures remains crucial.Building resilience to earthquakes starts with the soil. Soft, silty soils are prone to liquefaction during earthquakes, where the soil behaves like a liquid temporarily. Additionally, soft soils can amplify vibrations, putting any structure on them at risk. Therefore, it's ideal to build earthquake-resistant structures on solid ground.For existing structures on less stable ground, techniques like deep mixing and compaction grouting can be used to enhance their seismic resistance. Compaction grouting involves injecting cement-like materials into the soil around footings and pressurizing it. Deep mixing entails inserting diaphragms around the foundation into an impervious layer and then removing any groundwater within the diaphragms.For structural engineers, earthquake engineering presents the greatest challenge. [4]

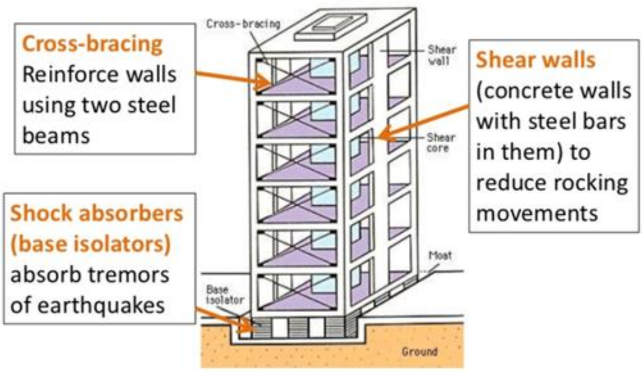

Fig. 1: Earthquake-resistant in a structure. Source(https://expeditieaarde.blogspot.com/2018/03/earthquake-resistant-buildings.html)

II. ISSUES THAT INFLUENCE THE SEISMIC PERFORMANCE OF A BUILDING

Research on the intricate nature of structural pounding has been conducted worldwide. This intricacy could be explained by the multitude of components that contribute to this event. However, in order to develop a logical foundation for strategies to lessen the potentially disastrous effects of pounding, it is crucial to comprehend the physical characteristics of the activity. Numerous articles, studies, and code sections enumerated several elements influencing the phenomenon of pounding. [5]

- Soil condition

Buildings respond differently to varying earthquake loads and exhibit distinct behaviors in different soil types, including soft, medium, and deep soil. Seismic waves can be impacted by various soil qualities as they travel through a layer of soil. The ground moves differently when a structure is exposed to an earthquake excitation because of the interactions it has with the soil and foundation. This indicates that both the kind of soil and the type of structure have an impact on the movement of the entire ground structure system. Seismic waves go up from the earth and change the qualities of the soil, causing the soil to behave differently depending on its specific properties. [6]

- Design errors

In a building project, design is a crucial phase. Mistakes in the design lead to failure both in the project development and construction phases. Parties that do not fully comprehend each other's design concepts might result in design errors, which can lower the quality of construction work and increase project delays and cost overruns. Errors in design can also lead to engineering failures, which can cause mishaps and fatalities. It is essential to take preventive measures to lower the errors. [7]

- Construction Quality

One important consideration is the level of quality provided by local construction methods with regard to adherence to codal provisions and the state of upkeep or look.Following practically all of the recent earthquakes, damage inspections of contemporary buildings have pointed to instances of subpar material quality, inadequate reinforcement detailing, and a lack of capacity design principles. [8]

- Building height

It is determined by a structure's natural frequency, or by its innate mass and stiffness, which determines how a building responds seismically to a ground vibration. These variables change according to the building's height and, thus, its vulnerability. Because of this, building height is limited in severe seismic zones in line with the region-specific seismic hazard estimate. [9]

III. ADVANCED EARTHQUAKE RESISTANT BUILDING TECHNIQUES

- Shear walls

Shear walls are walls installed in a structure that extend from the bottom to the top, at various locations in the plan, preferably along the perimeter. Shear walls are used in structures to withstand earthquakes and wind forces that act laterally on the structure. They are designed to withstand these forces primarily along a plane. Load-bearing wall structures are generally rectangular, dumbbell-shaped, or L-shaped and extend the entire height of the building from the foundation to the top.They are usually made of rebar, steel, or wood. Originally used for high-rise buildings, it is now also used for mid-rise buildings. These walls are large in size and heavy in weight. This additional property allows these walls to easily stabilize moments due to seismic forces within the structure. They are placed in pairs on the building's floor plan to prevent the building from twisting due to external forces. The main role of shear walls is to improve the earthquake resistance of structures.Well-developed design methodologies are available for a variety of standards. Shear walls are used in both new construction and retrofitting purposes.They are introduced to increase the strength, stiffness and energy dissipation capacity of a structure. [3]

Shear walls absorb the stress from weaker building parts, such as external walls, floors, and roofs, and transmit it to the ground foundation when lateral forces, such as strong winds or earthquakes, impose strain on a structure. Buildings cannot swing or topple because of the lateral strength that shear walls offer.In that they both absorb and transport a load's stress and pressure from its source to the ground foundation, shear walls and load-bearing walls fulfill comparable functions. Shear walls prevent a structure from falling sideways by resisting horizontal pressures, as opposed to absorb vertical loads and holding it up like load-bearing walls do. The required shear capacity and the specifications for deflection calculations are two important variables that might affect shear wall design. [10]

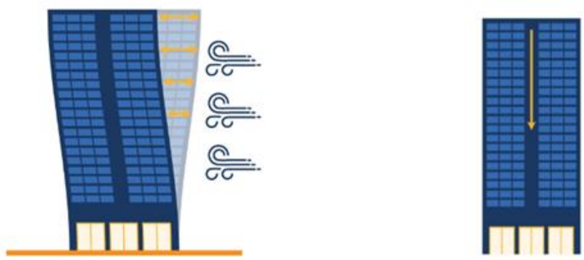

Fig. 2: Work of shear walls. Source(https://www.bigrentz.com/blog/shear-wall)

There are various types of shear walls, including simply rectangular, coupled, rigid frame, column supported, and core type. Barbell walls are rectangular or barbell-shaped walls reinforced horizontally and vertically, resisting shear and allowing vertical flexure. Coupled shear walls are formed when two structural walls are joined by short spandrel beams, increasing stiffness and energy dissipation without structural damage. Rigid frame shear walls are cast monolithically with frames, while column supported shear walls are discontinued at floor level for architectural reasons or for wide space in basements. [11]

Although there are several materials that may be used to create a shear wall, the most popular ones are concrete, steel, and plywood.

Concrete: To increase the lateral strength and rigidity of shear walls, reinforced concrete is utilized in their construction. The majority of the time, medium- to high-rise buildings (those with four to 35 floors) are constructed using these concrete walls.

Steel: Steel and infill plates are used to build steel plate shear walls. Because they are constructed with boundary features that can withstand seismic loads during occurrences like earthquakes, they are most frequently utilized in tall structures for seismic protection.

Plywood: Constructed from wood, plywood shear walls are intended to withstand continuous lateral stresses

from wind loads, such as those caused by hurricanes, tornadoes, and strong winds. [10]
Without a doubt, shear walls can be utilized as the principal or perhaps the only vertical load-bearing element in residential buildings, fulfilling the dual roles of providing space and supporting loads. When it comes to commercial buildings, where having a vast, clear area is essential, an interactive system consisting of sufficient shear walls can offer both space flexibility and rigidity. [11]

- Base Isolation

Seismic isolation, also known as base isolation or base isolation systems, is one of the most common methods of protecting structures from seismic forces.In some cases, applying foundation insulation can significantly improve both the seismic performance and seismic durability of a structure. [12]

In recent years, foundation insulation has become one of the tools that has received the most attention in earthquake-resistant structures.The concept of using foundation insulation to isolate buildings has been invented for a century. Many researchers have worked on basic insulation systems that have been accepted across technology fields.It helps control the energy transferred from the foundation and ground to the upper floors.To achieve this, a flexible insulation layer is installed between the superstructure and the substructure.This changes the fundamental natural period of the structure and ultimately reduces the vibration frequency.This avoids resonance conditions between ground acceleration and structural vibration. [13]

The foundation insulation structure is supported by a series of bearing blocks placed between the building and the foundation. Installing bearings may reduce the rigidity of the building. Three types of bearings or insulators are most commonly used: friction bearings, roller bearings and elastomer bearings. Elastomers are suitable for large buildings with high axial loads, while plain bearings are suitable for small buildings with low loads. Elastomeric bearings and low-friction bearings act as stiffness reducing devices. They are also called seismic isolation devices. All these bearings are made of heavy metal. Foundation insulation is suitable not only for low- or medium-rise buildings and bridges, but also for reinforcing new and old structures in general. [3]

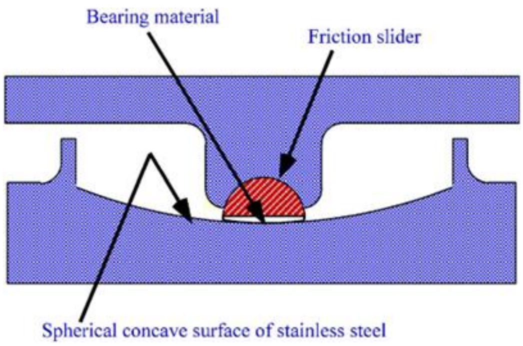

Fig. 3: Friction bearings. Source (Okamura,2007)

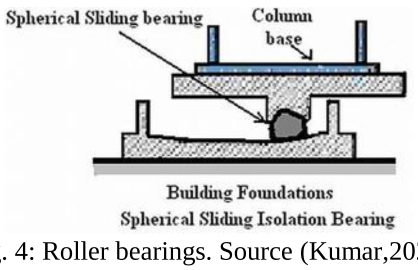

Fig. 4: Roller bearings. Source (Kumar,2020)

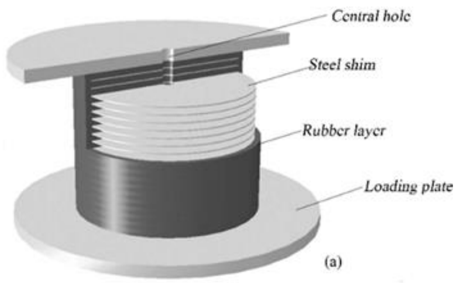

Fig. 5 : Elastomer bearings. Source (Asl,2014)

- Energy Dissipation System

Another option for amplifying earthquakes is the use of energy dissipation devices called dampers.In this construction method, by equipping the structure with an additional device with high damping capacity called a seismic damper, it is possible to significantly reduce the seismic energy that enters the building and minimize damage to the building. They are generally made of heavy metals to accommodate specific loads.There are many types of energy dissipation devices on the market, and the choice of a specific type depends on the type of construction.These devices limit the deformation of structural elements and reduce damage.Their effectiveness depends on their structural properties. This system consists of primary and secondary structures.During an earthquake, damage occurs only to the secondary support system and can be repaired with minimal cost and time.The main structure remains intact. [3]

Systems with structural damping disperse a certain portion of the generated energy, thus reducing the demand for generated energy on critical frame components and reducing the possibility of structural damage. The general dynamic behavior of buildings during large earthquakes is mitigated by vibration control systems based on dynamic energy dissipation mechanisms caused by lateral displacements of the building structure. [14]

Though there are other types of energy dissipation systems, such as visco-elastic, electro-inductive, and friction damping, the most popular ones are viscous (force related to the velocity of deformation) and hysteretic (force proportional to displacement). [15]

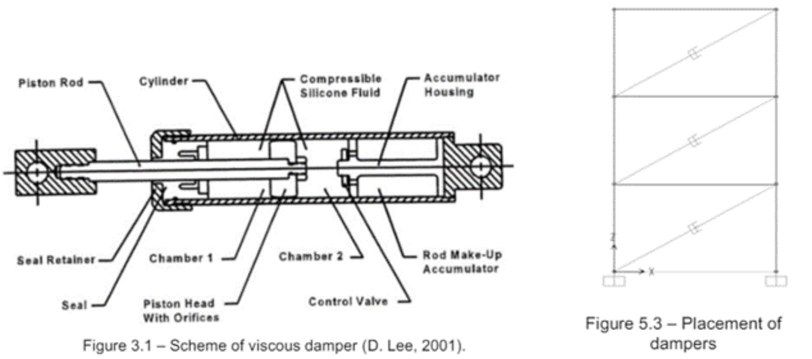

Fig. 6 : a) Scheme of viscous damper. b) Placement of dampers Source (Monteiro,2011)

- Earthquake resistant materials

Earthquake-resistant materials are essential in construction to mitigate damage and ensure the safety of structures and inhabitants during seismic events. Here are some materials commonly used for this purpose:

Shape-memory alloys: It exhibits excellent properties that are desirable for earthquake-resistant buildings.Generally, shape memory alloys are made from metal mixtures of nickel-titanium, copper-aluminum-nickel, and copper-zinc-aluminum-nickel.They have the ability to dissipate significant energy without causing permanent deformation or significant destruction.This is suitable for large scale applications. [16]

Cross-Laminated Timber (CLT): CLT is a type of engineered wood product made by stacking layers of wood at right angles and bonding them together with adhesives. CLT structures can perform well during earthquakes due to wood's inherent ability to flex and absorb energy. [17]

Fiber-Reinforced Polymers (FRP): FRP materials, such as carbon fiber or fiberglass, are lightweight and have high strength-to-weight ratios. They can be used to strengthen concrete structures and improve their seismic performance. [18]

Composite Materials: Composite materials, combining different materials like concrete, steel, and fibers, can be engineered to provide optimal seismic resistance while also reducing construction weight and cost.

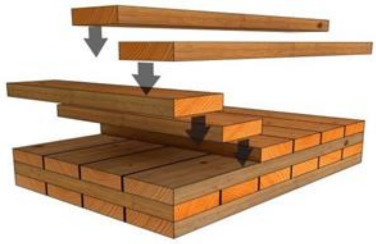

Fig.7: Cross-Laminated Timber.Source (https://www.linkwdin.com/pulse/cross-laminated-tiber-market-size-estimmated-grow-cagr-138-n4w7f/)

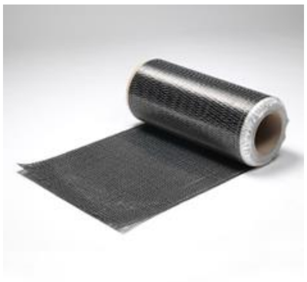

Fig.8 Fiber-Reinforced Polymers. Source (https://mcheminfratec.com/english/products/civil-engineering-materials_05/)

Each of these materials offers different advantages and may be suitable for different types of structures and seismic zones. A combination of these materials and seismic design principles is often used to create earthquake-resistant buildings and infrastructure.

IV. METODOLOGY

The methodology employed in this research follows a systematic approach, leveraging the advanced capabilities of the ETABS software.To analyze the provided building, which is a 9-story structure with a footprint area of 440 m2, ground floor height of 4.5m, typical floor height of 3.24m, foundation slab thickness of 110 cm, columns measuring 40x80cm, and featuring monolithic slabs (20cm) with beams (30 cm), constructed using concrete of grade C25/30 and steel of grade S500, a methodology is employed encompassing several steps to assess its performance and resistance to earthquakes.

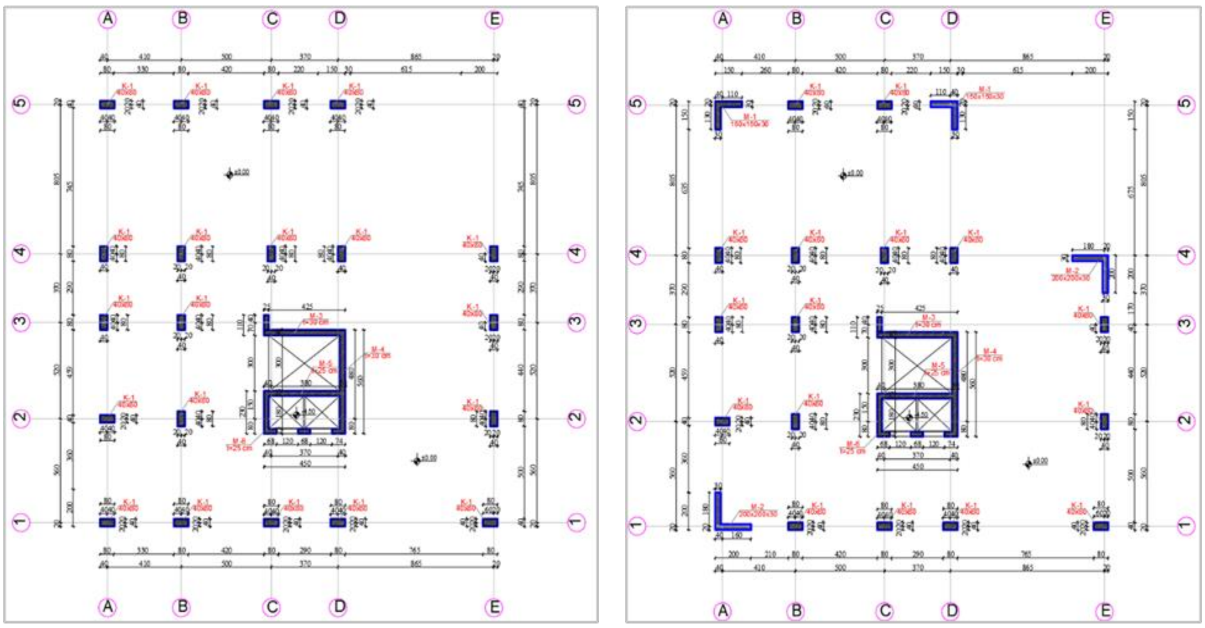

Fig.9 : a) Building plan with columns. b) Building plan with shear walls. Source (Authors, 2024)

Initially, the building model is developed in the ETABS software, incorporating all structural elements such as slabs, columns, walls, and footings, respecting the dimensions and materials used in construction. After creating the model, terrain data and load conditions for the area where the building is located, are utilized to simulate the dimensions and intensity of potential earthquakes. The combinations of dead, live, and earthquake loads, denoted as Ex and Ey, have been considered according to the Eurocodes.

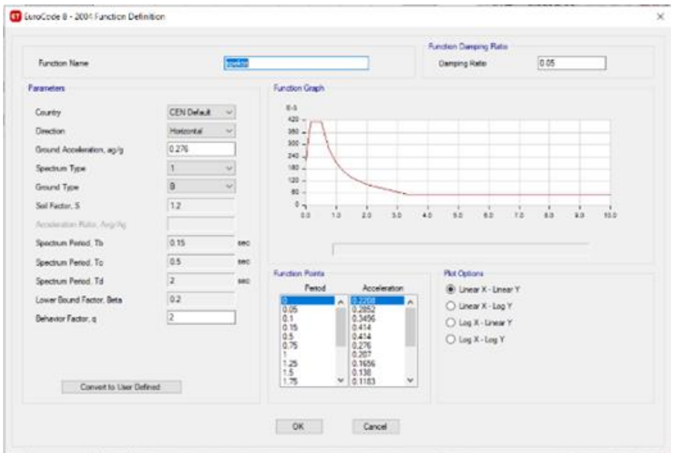

Fig.10 : Eurocode 8-2004 Function Definiton in Durrës,Albania. Source (Authors, 2024)

This process is conducted by including and excluding the shear walls, and assessing their impact on the stability and performance of the building under seismic loads.

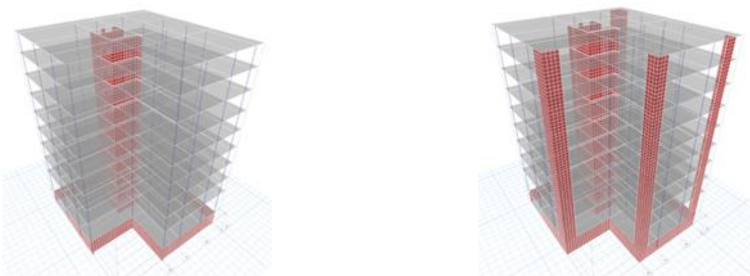

Fig. 11 : Models from Etabs. Source (Authors, 2024)

V. RESULTS

After conducting the analyses, we obtained several results from the ETABS program. First, we noticed that in the case of a structure without shear walls but with a frame system, the first mode of vibration exhibits torsion. This means that the center of mass does not coincide with the center of stiffness, and the rigidity of the structure varies across different zones of the building.

Fig. 12 : Modal behavior of the structure without shear walls. Source (Authors, 2024)

In the next step, by adding reinforced concrete shear walls at the edges of the building, the vibration modes are within the allowed standards, and the structure no longer exhibits torsional issues.

Fig. 13 : Modal behavior of the structure with shear walls. Source (Authors, 2024)

Below are the tables with the results of the Model Participation Mass Ratio for the two cases. We notice that in the case with shear walls, there is a reduction in the vibration periods. Specifically, the addition of the reinforced concrete shear walls at the edges of the building has led to a decrease in the vibration periods compared to the initial frame-only system.

Modal Participating Mass Ratios

Units: As Noted

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
Modal	1	1.382	0.0576	0.2265	0	0.0576	0.2265	0	0.1129	0.032	0.3998	0.1129	0.032	0.3998
Modal	2	1.248	0.0009	0.0029	0	0.0585	0.2294	0	0.0003	0.0005	0.0075	0.1132	0.0325	0.4073
Modal	3	1.151	0.5985	0.0137	0	0.657	0.243	0	0.0057	0.304	0.0622	0.1189	0.3365	0.4695
Modal	4	1.044	0.0018	0.424	0	0.6588	0.667	0	0.2109	0.0008	0.2374	0.3298	0.3373	0.707
Modal	5	0.471	0.0003	0.0001	0	0.6591	0.6671	0	0.0002	0.0008	0.0001	0.33	0.3382	0.7071
Modal	6	0.453	6.571E-06	0.0013	0	0.6591	0.6684	0	0.0014	3.14E-06	1.503E-05	0.3314	0.3382	0.7071
Modal	7	0.428	0.0051	0.038	0	0.6642	0.7063	0	0.0695	0.0038	0.0891	0.4009	0.342	0.7963
Modal	8	0.318	0.2672	0.0011	0	0.9314	0.7074	0	0.0016	0.474	0.009	0.4025	0.816	0.8053
Modal	9	0.301	0.0073	0.217	0	0.9388	0.9244	0	0.4133	0.0124	0.0661	0.8157	0.8284	0.8714
Modal	10	0.25	0.005	0.0342	0	0.9438	0.9587	0	0.0535	0.0086	0.0795	0.8693	0.8369	0.9508
Modal	11	0.228	2.23E-06	1.349E-05	0	0.9438	0.9587	0	0.0001	3.927E-06	0.0001	0.8693	0.837	0.9509
Modal	12	0.188	0.0014	0.0066	0	0.9452	0.9652	0	0.0173	0.0029	0.0399	0.8866	0.8399	0.9908

Record 1 of 12

Modal Participating Mass Ratios

Units: As Noted

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
Modal	1	1.25	0.0115	0.0351	0	0.0115	0.0351	0	0.0109	0.0057	0.0024	0.0109	0.0057	0.0024
Modal	2	1.204	0.3428	0.2129	0	0.3544	0.248	0	0.0973	0.1629	0.0986	0.1082	0.1685	0.1009
Modal	3	1.079	0.3173	0.1885	0	0.6717	0.4365	0	0.0722	0.1411	0.2274	0.1803	0.3097	0.3283
Modal	4	1.009	0.0122	0.2593	0	0.6838	0.6958	0	0.1221	0.0041	0.445	0.3025	0.3138	0.7733
Modal	5	0.471	0.0002	6.036E-06	0	0.684	0.6958	0	8.573E-06	0.0006	7.722E-07	0.3025	0.3144	0.7733
Modal	6	0.453	0	0.0008	0	0.684	0.6966	0	0.0009	0	3.702E-05	0.3033	0.3144	0.7734
Modal	7	0.337	0.0113	0.0837	0	0.6953	0.7803	0	0.1917	0.0172	0.0708	0.4951	0.3316	0.8441
Modal	8	0.309	0.2373	0.0052	0	0.9327	0.7855	0	0.0064	0.4811	0.0219	0.5015	0.8127	0.8661
Modal	9	0.293	0.024	0.163	0	0.9566	0.9485	0	0.3526	0.0533	0.0771	0.8541	0.866	0.9432
Modal	10	0.228	2.153E-06	0.0001	0	0.9566	0.9486	0	0.0003	4.049E-06	6.344E-06	0.8544	0.8661	0.9432
Modal	11	0.191	0.0023	0.0342	0	0.959	0.9828	0	0.0775	0.0047	0.04	0.9319	0.8708	0.9832
Modal	12	0.171	0.0001	1.047E-06	0	0.9591	0.9828	0	3.932E-06	0.0003	2.685E-06	0.9319	0.8711	0.9832

Record 1 of 12

Fig. 14 : Modal participating mass ratios of the structure a) without and b) with shear walls . Source (Authors, 2024)

From the analysis of the story response plots, it is clear that the story shear forces and story displacements are considerably reduced in the case where reinforced concrete shear walls are incorporated into the structure

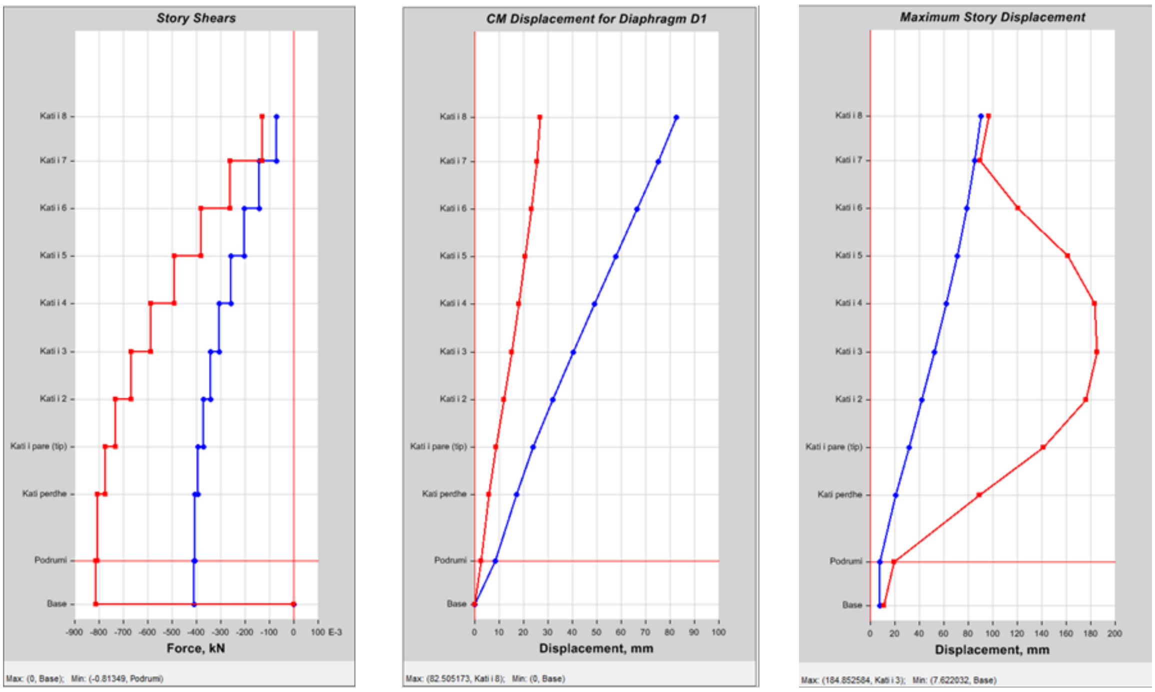

Fig. 15 : Story response plots for the structure without shear walls. a) Story shears, b) CM displacement for diaphragm D1, c) Maximum story displacement. Source (Authors, 2024)

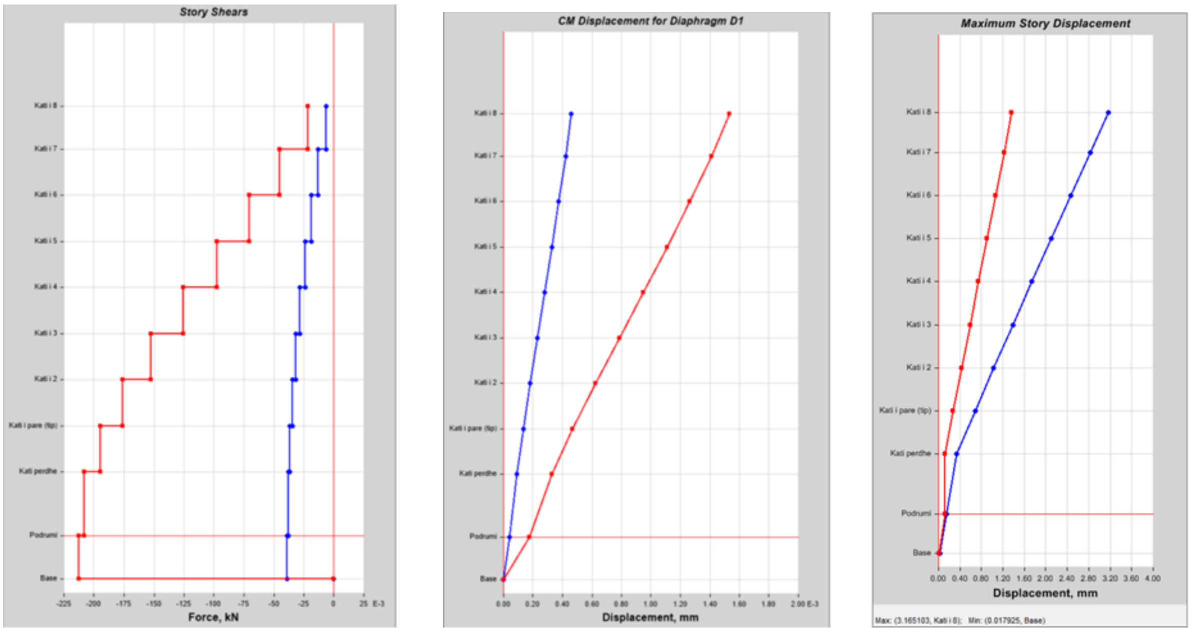

Fig. 16 : Story response plots for the structure with shear walls. a) Story shears, b) CM displacement for diaphragm D1, c) Maximum story displacement. Source (Authors, 2024)

To provide a clearer view of the differences between the two study cases, the diagrams of the maximum displacements along the three directions are presented next. This will allow for a more comprehensive understanding of the impact of incorporating the reinforced concrete shear walls into the structure.

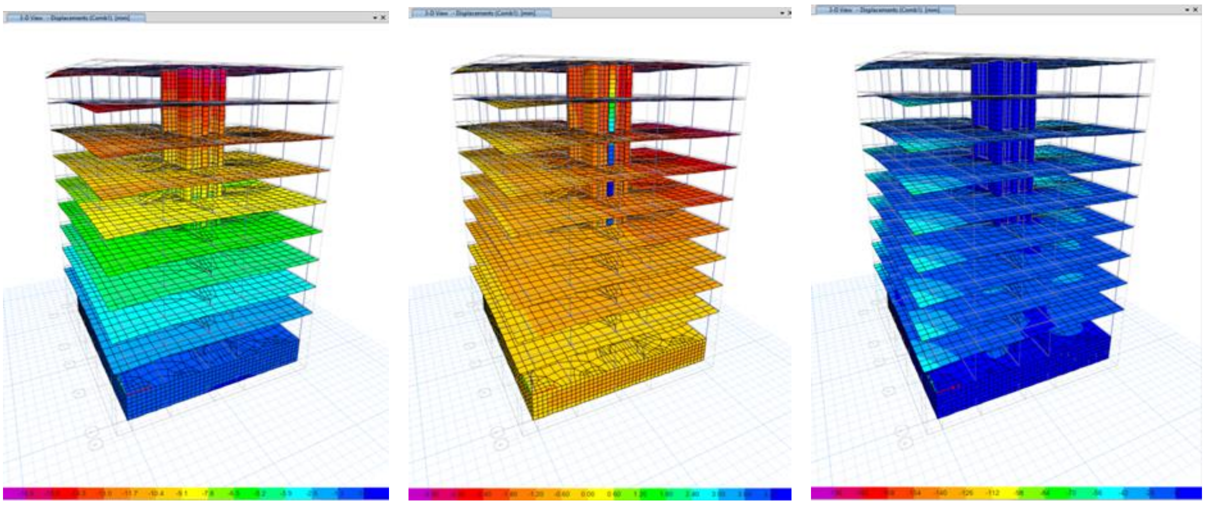

Fig. 17 : Maximum displacements diagram of the structure without shear walls according to a) X, b) Y, c) Z. Source (Authors, 2024)

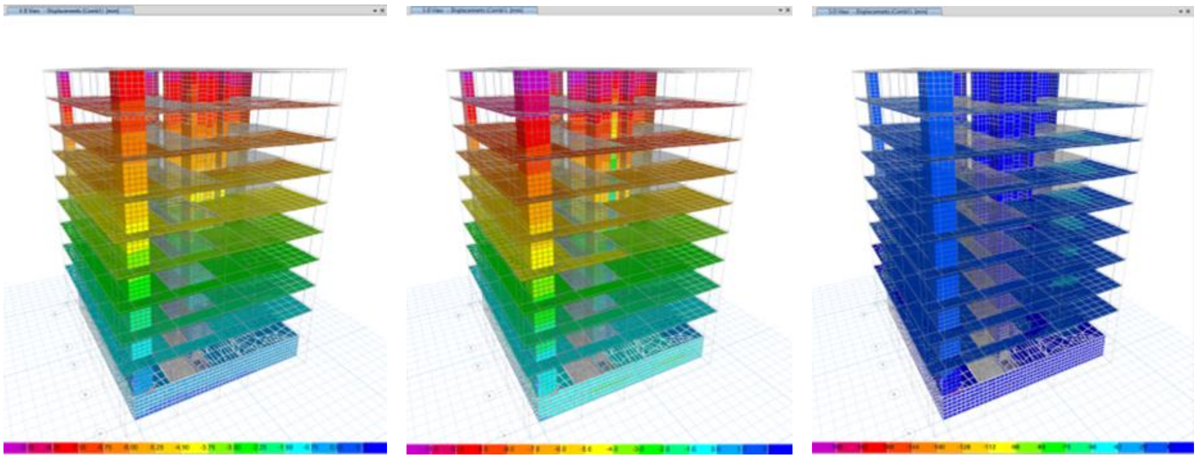

Fig.18 : Maximum displacements diagram of the structure with shear walls according to a) X, b) Y, c) Z. Source (Authors, 2024)

VI. CONCLUSIONS

Every seismic resistance method uses a different approach and set of principles to withstand wind loads and earthquakes. These methods can be applied singly or in conjunction with one or more other methods. In summary, the likelihood of structural damage or failure during an earthquake can be minimized by utilizing appropriate seismic-resistant materials and construction methods. Shear walls, sophisticated construction processes, and modern composite materials can be used to make structures seismically resistant, outperforming traditional procedures.The field of seismic engineering is complex and dynamic. Seismic structural evaluation is an effective technique in earthquake engineering that assesses a building's earthquake resistance bycombining detailed structural modeling with structural analysis. Better designs or materials must be used to update ancient structures just as much as new construction must be started from scratch. The ultimate goal of earthquake civil engineering is to save lives by keeping structures from falling and enabling people to evacuate in a timely manner. As a result, engineers are required to adhere to these guidelines in order to improve their understanding and design ofstructures, particularly those that are located in earthquake-prone locations. The above analysis indicates that models without shear walls have greater displacement compared to those with these elements at different locations. Moreover, the maximum deflection is significantly reduced after the incorporation of shear walls , both in the X and Z directions.

Additionally, the introduction of shear walls effectively decreases story shear at various locations.The implementation of b/a shear walls in a structure increases its resistance to earthquakes.

- Shear walls provide additional strength and rigidity to the building.
- Shear walls help limit lateral movements and sway of the building during earthquakes, keeping it within acceptable limits.

- They help distribute seismic forces throughout the structure, preventing local damage to individual elements.
- Proper placement of shear walls makes the building more stable and less prone to the risks of collapse or destruction during seismic shaking.

Therefore, the proper use of shear walls becomes an essential element in the seismic design of buildings, contributing to their durability and safety in the event of an earthquake.

Moving forward, continued research and innovation in seismic isolation technologies are essential to address emerging challenges and enhance the seismic resilience of structures worldwide.

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