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Study of the Change in Shear Wall Thickness on High Concrete Structures Under the Influence of Seismic Force

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دراسة التغير في سمك جدار القص في المنشآت الخرسانية العالية تحت تأثير القوة الزلزالية

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Abstract:
Shear walls protect tall buildings from bending or deforming when subjected to horizontal (lateral) forces during high winds, hurricanes, or earthquakes. Shear wall thickness has a significant impact on a building's structural performance. The thicker the thickness, the greater the stiffness and load-bearing capacity, but this can also impact cost, weight, and footprint. Engineers select shear wall thickness based on design requirements, material type, and location. Building codes can provide an indication of the actual performance of an individual concrete element. However, the expected performance of the entire concrete structure cannot be predicted by the code due to the large and variable forces acting on the building. This study compared the structural analysis of a multi-story high-rise building (G+32) under earthquake loads. Five models of the aforementioned high-rise building were studied. The area of each floor was 576 square meters. The first model was a structural building without shear walls, while the second model had constant-thickness central shear walls, the third model had variable-thickness central shear walls, the fourth model had constant-thickness end shear walls, and the fifth model had variable-thickness end shear walls. The analysis and design process were carried out using engineering programs such as ETABS and AUTOCAD, using the American code (UBC97-Uniform Building Code) to determine live and dead loads, as well as earthquake loads. Based on the results of the study obtained from the program, and after comparing the results of the five models under the influence of lateral displacement and floor displacement, it was concluded that the second model, with constant-thickness central shear walls, was the best model compared to the other models in terms of lateral displacement and floor displacement, while the third model, with variable-thickness central shear walls, was the best model compared to the other models in terms of resulting moments.

Keywords: Shear Walls, Earthquake Loads, High Concrete Structures.

الملخص:
تحمي جدران القص المباني العالية من الانحناء أو التشوه عند تعرضه لقوى أفقية (جانبية) أثناء حدوث رياح شديدة أو إعصار أو زلزال. سمك جدار القص له تأثير كبير على الاداء الانشائي للمبني كلما زاد السمك، زادت الصلابة وقدرة التحمل، ولكن قد يؤثر ذلك على التكلفة والوزن والمساحة. ويختار المهندسون سمك جدار القص بناءً على متطلبات التصميم، نوع المواد، والموقع. يمكن لقوانين البناء توفير مؤشر للأداء الفعلي لعنصر خرساني منفرد. ولكن الأداء المتوقع للهيكل الخرساني كامل لا يمكن للكود توقعه بسبب القوي الكبيرة والمتغيرة المسلطة على المبني. في هذه الدراسة تم مقارنة التحليل الإنشائي لمبنى عالي متعدد الطوابق (G+32) تحت تأثير أحمال الزلازل. حيث تم دراسة خمس نماذج للمبنى العالي المذكور أعلاه. وكانت مساحة كل طابق 576 متر مربع. وذلك باعتبار أن النموذج الأول عبارة عن مبنى هيكلي بدون جدران قص، بينما النموذج الثاني يحتوي على جدران قص في المنتصف بسمك ثابت و النموذج الثالث يحتوي على

جدران قص في المنتصف بسمك متغير ، بينما أحتوى النموذج الرابع على جدران قص في الأطراف بسمك ثابت، و النموذج الخامس احتوى على جدران قص في الأطراف بسمك متغير. وتمت عملية التحليل والتصميم بالاعتماد على بعض البرامج الهندسية مثل ETABS و AUTOCAD ، وذلك باستخدام الكود الأمريكي (Uniform Building Code-UBC97) لتحديد الأحمال الحية والميتة وكذلك أحمال الزلازل .من خلال نتائج الدراسة المتحصل عليها من البرنامج ، وبعد ان تم مقارنة تلك النتائج للنماذج الخمسة تحت تأثير الإزاحة الجانبية و الانزياح الطابقي تم الوصول الى ان النموذج الثاني ذو جدران القص في المنتصف بسمك ثابت هو النموذج الأفضل مقارنة بالنماذج الأخرى فيما يخص الإزاحة الجانبية و الانزياح الطابقي, بينما كان النموذج الثالث ذو جدران القص في المنتصف بسمك متغير هو النموذج الأفضل مقارنة بالنماذج الأخرى فيما يخص العزوم الناتجة.

الكلمات المفتاحية: جدران القص، أحمال الزلازل، المنشاءات الخرسانية العالية.

Introduction

A simple structure cannot resist lateral loads on its own because the stiffness to resist lateral loads is insufficient. This type of structure is usually equipped with reinforcing, core, or shear walls. One of the most common systems for resisting lateral loads in buildings is shear wall systems [3]. Shear walls are very effective in seismic loads and resist reinforced concrete from medium to high-rise buildings. Shear walls have very high strength and stiffness and can be used to simultaneously resist large horizontal loads and support gravity loads, making them useful in the seismic performance of buildings. Various factors such as span, wall density, and slenderness ratio influence the effect of these factors. They are typically used for buildings ranging in height from 10 to 50 floors. In most cases, a shear wall may be part of an elevator or staircase. Shear wall construction exhibits a dramatic increase in stiffness and strength in both the horizontal plane of the building and has good weight distribution [8].

Despite the severity of the 2010 Haiti earthquake on a 12-story building, the Digicel building performed well from a structural engineering perspective, sustaining minimal damage. A pilot project was conducted, consisting of visual assessments to describe the damage, and audiovisual interpretation software was implemented to identify the building's main dynamic properties (natural vibration frequencies, mode shapes, and damping ratios). Damping ratios are an effect resulting from external changes. ETABS was used to generate finite element models before and after audio-visual testing to evaluate the capabilities of common modeling assumptions in predicting the dynamic behavior of the structure. AVT resulted in identifying the first six vibration modes and corresponding damping ratios for the building structure in its damaged state, confirming the efficiency and accuracy of the AVT method in determining the structural dynamic properties. It was found that the backfill walls have a major specialty in influencing the dynamic behavior of the building. The study showed that the FEM is reliable in predicting the dynamic behavior of the structure, but it is very sensitive to the assumptions used during modeling. The FEM can accurately predict vibration frequencies, but it requires an accurate representation of the mode shapes and careful updating of the model [10].

Shear walls are an excellent means of providing earthquake resistance to multi-story reinforced concrete structures. They are commonly provided in high-rise buildings and have been found to be extremely beneficial in avoiding total collapse of the building under seismic forces. It is essential to determine the effective and optimal location of a shear wall. In this study, a 25-floor building in Zone IV was presented, along with some preliminary investigations to reduce the seismic impact of reinforced concrete shear walls on the building. They can be used to improve the seismic response of buildings, as shear walls provide an effective and economical mechanism in the building. Shear walls are easy to construct and effective both in terms of construction costs and their effectiveness in reducing earthquake damage to structural and non-structural elements (such as windows and building contents). This study aims to investigate the effect of adding shear walls in different locations and configurations, as well as with varying shear wall thicknesses. The results are tabulated using an easy-to-use analysis using ETABS v9.7.1 in the form of displacement and floor drift [12].

Building Description

The concrete sections were defined based on the building's structural drawings, and their dimensions and units of measurement are shown in Table 1. Beam B1 represents the external and internal beams. For the columns, C1 was chosen for the largest dimension on the first 15 floors of the building, and C2 for the smallest dimension. Shear walls W1 represent the thickest shear walls and are located on the ground floor and the first 10 floors. W2, with a thickness smaller than W1 and larger than W3, are located from the 12th to the 22nd floors. W3 is smaller than W1 and W2 and is located from the 23rd to the 33rd floors. Finally, a solid slab S was chosen with the thickness shown in Table 1.

Table 1 Dimensions of concrete sections used in the structure under study.

SN.	Member	Code	Sizes (mm)
1	Beam 1	B1	200*600
2	Column 1	C1	400*1000
3	Column 2	C2	400*600
4	Wall 1	W1	300
5	Wall 2	W2	250
6	Wall 3	W3	200
7	slab	S	175

Drawing the Concrete Frame

Draw the concrete frame of the models from top to bottom, as in the design method. First, draw the slabs and shear walls, then draw the supporting beams, and then draw the columns that transfer these loads to the foundations. After completing these steps, the model is ready for analysis and extraction of results, as shown in Figures 1, 2, and 3.

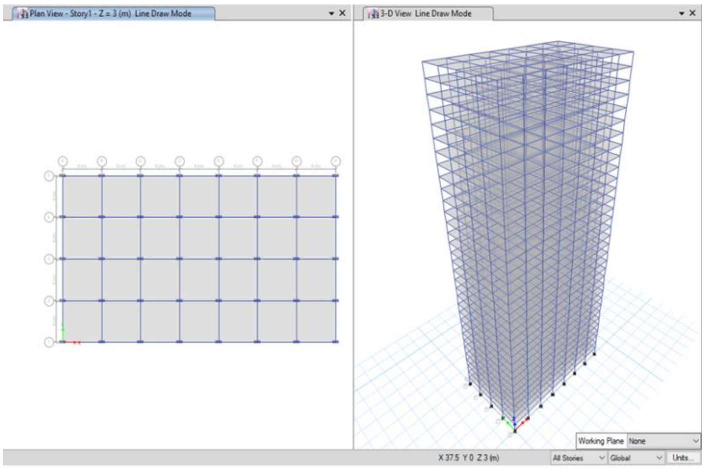

Figure 1: Drawing of the model without shear walls.

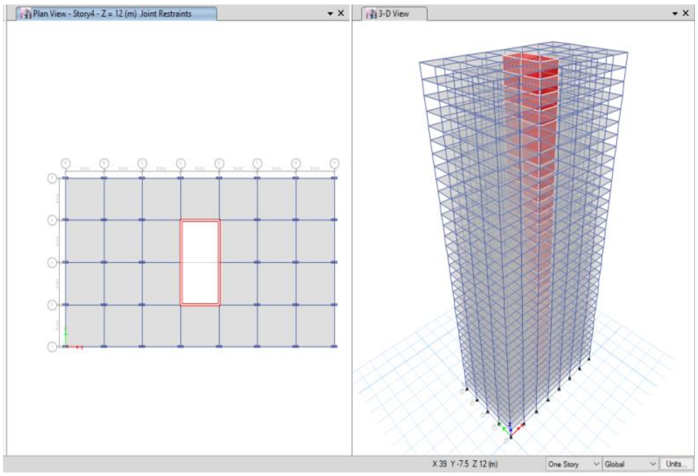

Figure 2: Drawing of the model with shear walls in the middle.

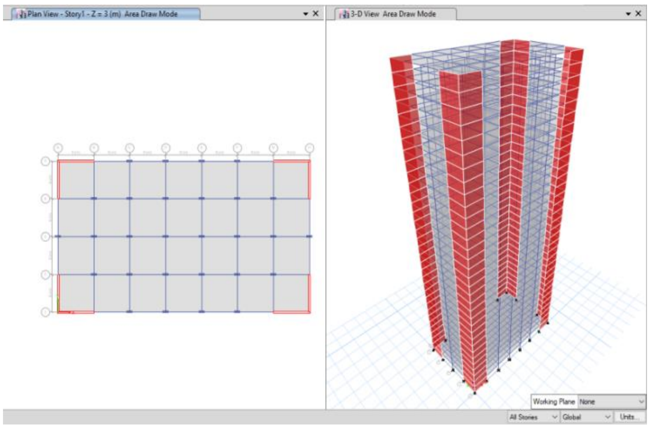

Figure 3: Drawing of the model with shear walls at the ends**.**

Loads

The loads applied to the building, consisting of live loads and dead loads as vertical loads applied to slabs, beams, and columns, and earthquake and wind loads as horizontal loads applied to the entire building, as shown in Figures 4, 5, and 6.

Lateral displacement

The straight path a body travels from one point to another in a constant direction. It is a vector quantity, meaning it has both magnitude and direction. It is measured in centimeters, meters, and kilometers. It can also be defined as the shortest distance from the starting point of a movement to its ending point. It is necessary to calculate the horizontal displacement or translation of structures when required in accordance with code requirements. The maximum displacement resulting from lateral forces must be calculated by applying the design seismic forces [26].

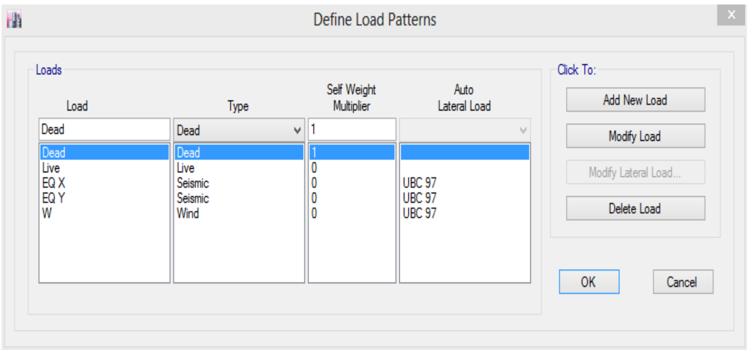

Figure 4: Definition of lateral loads applied to the building.

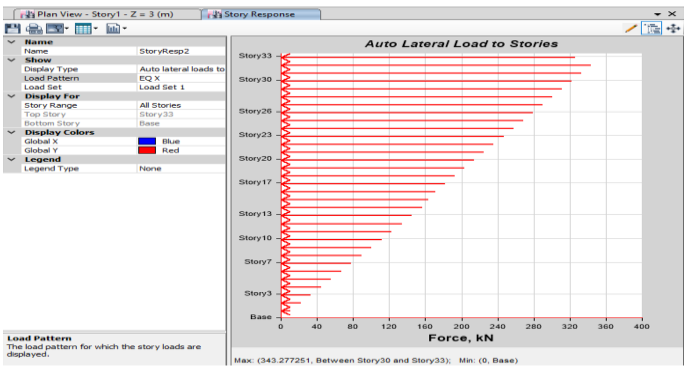

Figure 5: Lateral loads applied to the building Earthquake loads in the X-direction.

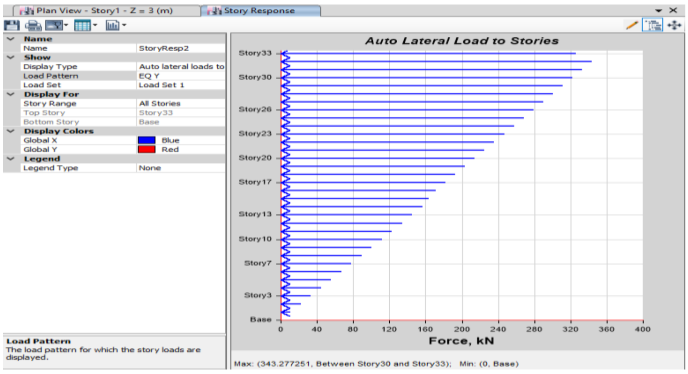

Figure 6: Lateral loads applied to the building Earthquake loads in the Y direction**.**

Results and discussions

Discussion of the Displacement Results in the X-Direction

A comparison was made between the displacement and the number of floors against lateral loads in the X-direction for the following cases:

Case 1: No shear wall in the X-direction, Case 2: Fixed-thickness centered shear wall, Case 3: Variable-thickness centered shear wall, Case 4: Fixed-thickness end-wall, Case 5: Variable-thickness end-wall). Considering that the highest displacement value for each of the aforementioned cases represents the critical condition of the building as a whole, the following displacement values were obtained: (459.681 mm, 279.165 mm, 279.700 mm, 344.665 mm, 341.904 mm) for the previous cases, respectively. It was found that the second case was the best because it yielded the lowest displacement value. This means that this shear wall position is the safest under the influence of the relationship between displacement and the number of floors of the building as a whole against lateral loads. Meanwhile, the first case represents the worst and most critical condition in terms of the displacement resulting from lateral loads on the building's floors.

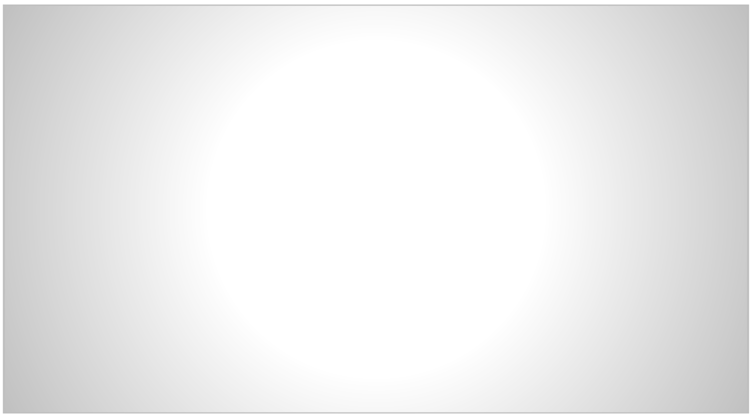

Figure 7: The building floors are affected by displacement resulting from lateral loads in the X-axis direction**.**

Discussion of Y-Direction Displacement Results

A comparison was made between displacement and the number of floors against lateral loads in the Y-direction for the following cases:

(Case 1: No shear wall in the Y direction, Case 2: Fixed-thickness centered shear wall, Case 3: Variable-thickness centered shear wall, Case 4: Fixed-thickness end-to-end shear wall, Case 5: Variable-thick end-to-end shear wall). Considering that the highest displacement value for each of the aforementioned cases represents the critical condition of the building as a whole, the following displacement values were obtained: (718.016 mm, 192.114 mm, 195.037 mm, 416.850 mm, 415.281 mm) for the previous cases, respectively. It was found that the second case was the best because it yielded the lowest displacement value. This means that this shear wall condition is the safest under the influence of the relationship between displacement and the number of floors of the building as a whole against lateral loads. The first case, however, represents the worst and most critical condition due to the displacement resulting from lateral loads.

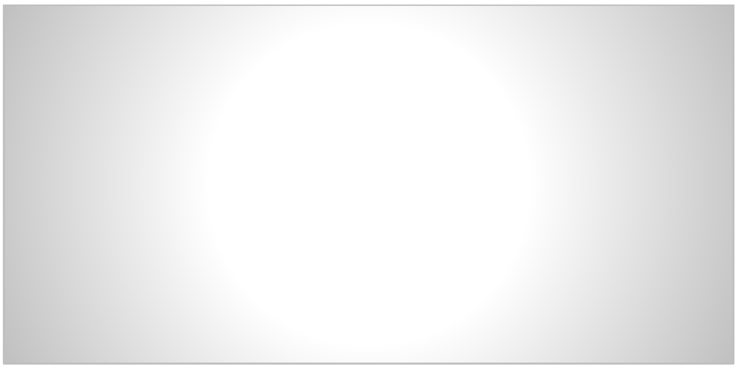

Figure 8: Building floors are affected by displacement resulting from lateral loads in the Y-axis direction.

Relative floor displacement of a 33-story building resulting from wind and earthquake loads

Discussion of the results of relative floor displacement in the X-direction:

A comparison was made between the relative floor displacement and the number of floors against lateral loads in the X-direction for the following cases:

(Case 1: No shear wall in the X-direction, Case 2: Fixed-thickness centered shear wall, Case 3: Variable-thickness centered shear wall, Case 4: Fixed-thickness end shear wall, Case 5: Variable-thick end shear wall). Considering that the highest value of relative floor displacement for each of the aforementioned cases represents the critical condition of the building as a whole, the following relative floor displacement values were obtained for the previous cases: (0.005867 mm, 0.003437 mm, 0.003493 mm, 0.004278 mm, 0.004309 mm) respectively. It was found that the second case was the best because it yielded the lowest value of relative floor displacement. This means that this position of the shear wall is the safest under the influence of the relationship between displacement and the number of floors of the building as a whole against lateral loads, while the first case represents the worst and most critical position for the effect of displacement resulting from lateral loads on the floors of the building.

Discussion of the Relative Floor Displacement Results in the Y-Direction

A comparison was made between the relative floor displacement and the number of floors against lateral loads in the Y-direction for the following cases:

(Case 1: No shear wall in the Y-direction, Case 2: Fixed-thickness centered shear wall, Case 3: Variable-thickness centered shear wall, Case 4: Fixed-thickness end-wall, Case 5: Variable-thick end-wall). Considering that the highest value of relative floor displacement for each of the aforementioned cases represents the critical condition of the building as a whole, the following relative floor displacement values were obtained for the previous cases: (0.008764 mm, 0.002407 mm, 0.002506 mm, 0.005177 mm, 0.005231 mm) respectively. It was found that the second case was the best because it yielded the lowest value of relative floor displacement. This means that this shear wall position is the safest under the influence of the relationship between displacement and the number of floors of the building as a whole against lateral loads, while the first case represents the worst and most critical situation for the effect of displacement resulting from lateral loads on the building floors.

Conclusions

Through the study and examination of the data and aspects, the following conclusions were reached:

- By changing the location of shear walls in building models with and without shear walls, it was found that changing the location of shear walls affected the values of lateral displacement and relative floor displacement. Furthermore, differences were found in reinforcement values due to the different structural systems of the buildings.
- The results of lateral displacement in both the horizontal and vertical directions revealed that the building without shear walls was negatively affected by lateral loads and was considered the worst choice from an analytical and design perspective, as it yielded the highest displacement value. Meanwhile, the building with a shear wall in the middle of a constant thickness yielded better results, due to its ability to withstand lateral loads better, yielding smaller displacement values compared to the other models.
- It was also shown that the results of relative floor displacement when the shear wall is in the middle of the building and has a constant thickness are the best, as it gave the lowest values for relative floor displacement, while the building that does not contain shear walls gave the

highest values for relative floor displacement, and this is considered the worst and most critical situation for the effect of displacement resulting from lateral loads on the building floors.

- There is a difference between rigid frame systems (moment-resistant) and combined systems. Rigid frame systems are usually used in buildings with no more than 10-15 floors. Combined systems (frames with shear walls) consider the number of floors in service buildings, such as offices, to be between 20 and 35 floors in terms of displacement, floor displacement, and reinforcement. Rigid frame systems (moment-resistant) require increasing column cross-sections from the ground floor to the 32nd floor to achieve minimal reinforcement in column cross-sections. This is due to the poor performance of the building against lateral loads in terms of displacement and relative floor displacement compared to combined systems.

As for combined systems (frames + shear walls), the following was observed:

- The shear wall model in the middle, with a constant thickness and a variable thickness, is considered the best in terms of reinforcement due to the variation in wall thickness. Reinforcement was present in the upper twenty-two floors (from 10 to 32). This is the minimum reinforcement for both of the aforementioned models. The reinforcement increased on the ground floor and up to the ninth floor (G+9) in an uneconomical manner, and it is preferable to increase the cross-section of the shear walls instead.
- In the two shear wall models at the ends, we note that the best displacement is the fixed-thickness shear wall, and the best reinforcement is the variable-thickness shear wall. The reinforcement on the top twenty-two floors (from 10 to 32) was the minimum reinforcement for both of the aforementioned end-shear wall models.

It is necessary to increase the cross-section of the shear walls at the ends with variable and fixed thicknesses, as cross-sectional reinforcement is uneconomical and because the displacement value is large compared to the location of the shear walls in the middle. The shear wall in the middle performs best under the influence of lateral loads. We note that the shear wall in the middle gives the best displacement value because it is close to the building's center of gravity. That is, the best location for shear walls is when they are close to the building's center of gravity.

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