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INFLUENCE OF REQUISITE ARCHITECTURAL OPENINGS ON SHEAR WALLS EFFICIENCY

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Executions of the shear walls along the exterior perimeter of slender high rise buildings enhance the efficiency of such buildings to resist the seismic forces. But uncertainties in the locations of shear walls are very high because of the demandable architectural openings (windows – doors) in the exterior views of such buildings. So, this study presents a considerable interest in establishing design guide lines for numerical investigation of seismic response of shear walls taking into account such openings and their locations. Five three dimensional models of different configurations of the openings are chosen and compared to figure out the best installation of openings having more efficiency on the performance of shear walls under earthquake excitation. Computer generated models are analyzed by SAP2000 program[11] and the loading is considered using acceleration time history with a peak ground acceleration 0.25g provided in the new Egyptian code (ECOL2008)[13] for seismic loads on structures and building works. The comparative results showed that the top displacement, base shears and stress distributions around the openings depend on the openings arrangement system. The results of staggered opening system in the shear walls (spatial arrangement) are very much close to those resulted in the shear walls without openings than the other opening arrangement cases.

Finally the staggered arrangement of openings between the stories in shear walls are suggested to be applied in engineering practice since it satisfies both the architectural and seismic requirements.

KEY WORDS: *shear wall - slender high rise building – base shear – SAP2000- Time history analysis – Openings.*

1. INTRODUCTION

In contrast to the worldwide rapid growth of high-rise buildings, no probabilistic assessment procedures have been proposed or developed for seismic risk evaluation of this special building group. Reinforced concrete (RC) buildings often have *vertical plate-like* RC walls called *Shear Walls* in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. Their thickness can be as low as 150mm, or as high as 400mm in high rise buildings. Shear walls are usually provided along *both* length and width of buildings. Shear walls are like *vertically-oriented* wide *beams* that carry earthquake loads downwards to the foundation.

A simplified analytical model is proposed for modeling the nonlinear response of flexural-yielding reinforced concrete walls using standard structural analysis software. The program SAP2000 [13] is used to implement the proposed model for evaluating structural response by means of nonlinear response history analysis. The model is useful for performing practical nonlinear static or nonlinear dynamic procedures.

The walls are modeled using a fine mesh of linear-response shell elements coupled with uniaxial line elements. The use of line elements allows one to invoke the typical nonlinear response parameters available for such elements. (Ji, et all 2007)[5]

In high-rise structures shear wall is widely used to resist earthquake forces. Earthquake forces produce large displacement, vibration and large stresses in building which leads to building an unsafe and causing discomfort to the occupants. The reinforced concrete shear walls are quite stiff in their own plane. Therefore, shear wall frame building of varying no. of storey are considered to understand effect of site. A seismic force in shear wall building is receive lateral forces from diaphragm and transmits them to foundation.

Shear walled frame building is chosen for study purpose because shear wall is an efficient way of stiffening the structure.

The time history analysis of the multi–storey shear wall frame buildings is carried out using SAP2000 software [13]. The time history function obtained from el-centro for Egypt are provided in SAP2000 for time history analysis.

The forces in these walls are predominantly shear forces, though a slender wall will also incur significant bending. Ground motion enters the building and creates inertial forces which move the floor diaphragms. This movement is resisted by the shear walls, and the forces are transmitted back down to the foundation.

If the building is visualized as rotated so that it extends horizontally. It is clear that the shear walls are acting as cantilever girders which support beams represented by the floor diaphragms. However, unlike a normal cantilever supporting gravity forces, the shear wall must resist dynamic forces that are reversing their direction, for as long as the strong motion continues which is dependent on the characteristics of the earthquake.

The size and location of shear walls is extremely critical. Plans can be conceived of as collections of resistant elements with varying orientations to resist translational forces, and placed at varying distances from the centre of rigidity to resist torsion forces.

Properly designed and detailed buildings with shear walls have shown *very good* performance in past earthquakes. The overwhelming success of buildings with shear walls in resisting strong earthquakes is summarized in the quote:

"We cannot afford to build concrete buildings meant to resist severe earthquakes without shear walls." Shear walls are easy to construct, because reinforcement detailing of walls is relatively straight-forward and therefore easily implemented at site. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and nonstructural elements (like glass windows and building contents). Most RC buildings with shear walls also have columns; these columns primarily carry *gravity* loads (*i.e.,* those due to self-weight and contents of building). Shear walls provide large strength and stiffness to buildings in the direction of their orientation, which significantly reduces lateral

sway of the building and thereby reduces damage to structure and its contents (Ji, et all 2007)[5].

Since shear walls carry *large* horizontal earthquake forces, the overturning effects on them are large. Thus, design of their foundations requires special attention. Shear walls should be provided along preferably *both* length and width. However, if they are provided along only one direction, a proper grid of beams and columns in the vertical plane (called a *moment-resistant frame*) must be provided along the other direction to resist strong earthquake effects.

Shear walls in buildings must be symmetrically located in plan to reduce ill-effects of twist in buildings. They could be placed symmetrically along one or both directions in plan. Shear walls are more effective when located along exterior perimeter of the building – such a layout increases resistance of the building to twisting.

Where shear walls are connected by a rigid diaphragm so that they must deflect equally under horizontal load, the proportion of total horizontal load at any story or level carried by a perpendicular shear wall is based on its relative rigidity or stiffness. The rigidity of a shear wall is inversely proportional to its deflection under unit horizontal load. The total deflection of the shear wall can be determined from the sum of the shear and moment deflections.

According to *The Council of Tall Buildings and Urban Habitat,* the description of ‘Tall building’, equivalent to ‘High-rise building’ used herein, is: “A building whose height creates different conditions in the design, construction, and use than those that exist in common buildings of a certain region and period. A traditional height cutoff between high-rise and low-rise buildings is 35 meters or 12 floors. This distinction is used as 12-floors is generally considered to be the minimum height needed to achieve the physical presence to earn the recognition as a "high-rise". The twelve-floor limit is also seen as a compromise between ambition and manageability for use in classification of buildings in a worldwide database (Ali 2001)[2].

Through advancements in material properties, construction techniques and structural knowledge, more complex but efficient structural form has emerged. They are typically some combination of tube and outrigger system, use either concrete or steel composite systems, and are thereby generally referred to as hybrid systems.

The analysis methods for RC high-rise buildings have special requirements different from low-to-middle rise buildings, especially for the typical structural system that consists of slender members in frames and more RC stocky structural walls.

The complexities of concrete properties, wall-frame interaction and three-dimensional effects need to be accounted for in structural modeling.

No matter what type and size of RC structure is under investigation the finite element method (FEM) is the most accurate and reliable analytical technique for assessing the demands on structure components in both 2D and 3D domains. The earliest application to the analysis of RC structures was by Ngo and Scordelis (1967)[12]. Scordelis et al. (1974)[12] used the same approach to study the behavior of beams in shear. Nilson (1972)[9] introduced nonlinear material properties for concrete and steel and a nonlinear bond-slip relationship into the analysis. Nayak and Zienkiewicz (1972)[7] conducted two-dimensional stress studies that include the tensile cracking and the elasto-plastic behavior of concrete in compression using an initial stress approach. For the analysis of RC beams with material and geometric nonlinearities Rajagopal (1976)[10] developed a layered rectangular plate element with axial and bending stiffness treating concrete as an orthotropic material. RC frame problems have also been treated by many other investigators (Bashur and Darwin (1978)[3]; Adeghe and Collins (1986)[1]; Bergmann and Pantazopoulou (1988)[4]) using similar methods. At the same time the damage and crack simulation have also been studied and generated some representative models, extended by researches like Meyer and Okamura (1985)[6].

1.1. Description of model

The model is a building of 12^{th} stories with height each story 3m, the length of the building plan area is 20x10m which is ration of length and width equals 2. The model consists of frame elements as beam and column, the column dimension is 65x65cm, the beam section is 25x75cm, and the shell element for the description of slab, walls, and foundation. The slab mesh thickness is 14cm and shear wall thickness 20cm constant thickness all over the height of the building. Foundation is a raft foundation with thickness 130cm modeled as shell elements constant thickness. All opening in each case is 2x2.25m to satisfy the requirements of doors or windows.

Figure (1) shows plane of the tested model, it can be recognized the places of the shear walls as along exterior parameter and the tested frame element (shown in circles) as elements from (1) to (6) that the effect of base shear will be study. The places of frame elements (columns) give the variety values of base shear that may be subject to the model from the effect of earthquake. A real earthquake was used to get the real effect of seismic force on the model by using time history function of the el-centro of acceleration 0.25g.

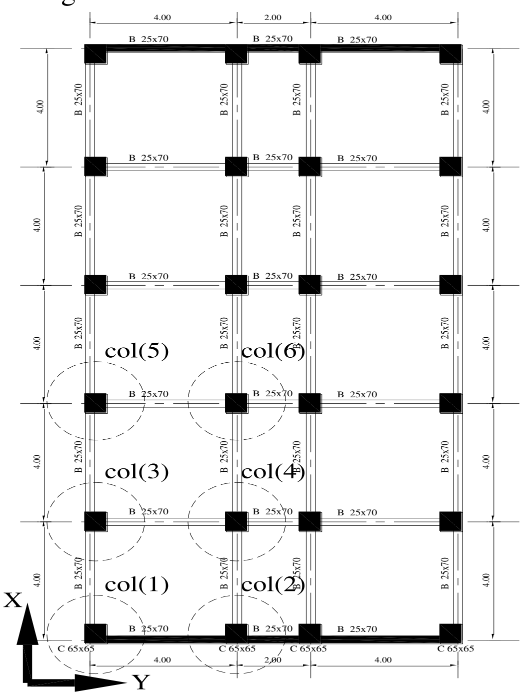


Figure (1): the plane of the model and shear walls arrangement with the tested frame element places

2. CASES OF STUDY

Figure (2) shows the different cases studies and the arrangement of openings on the shear walls. Figure 2-a shows the case that the shear wall without openings with thickness 10, 15, 20, 25, 30, and 35cm these thickness tested to give the different values of base shear and draft of the whole model, the case that using varies thickness (such that at first story shear wall thickness = 35cm, second story thickness=30cm, third story thickness = 25cm, fourth story thickness =20cm, fifth story thickness = 15cm, and from sixth story to twelfth story the thickness of shear wall = 10cm).

Figure 2-b shows case(1) of openings arrangements that the shear wall with an interior similar openings with wall thickness 10, 15, 20, 25, 30, and 35cm these thickness tested to give the different values of base shear and draft of the whole model, the case that using varies thickness (such that at first story shear wall thickness = 35cm, second story thickness=30cm, third story thickness = 25cm, fourth story thickness =20cm, fifth story thickness = 15cm, and from sixth story to twelfth story the thickness of shear wall = 10cm)

Figure 2-c shows case(2) of openings arrangements that the shear wall with staggered openings with wall thickness 10, 15, 20, 25, 30, and 35cm these thickness tested to give the different values of base shear and draft of the whole model, the case that using varies thickness (such that at first story shear wall thickness = 35cm, second story thickness=30cm, third story thickness = 25cm, fourth story thickness =20cm, fifth story thickness = 15cm, and from sixth story to twelfth story the thickness of shear wall = 10cm)

Figure 2-d shows case of openings arrangements that the shear wall with exterior similar openings with wall thickness 10, 15, 20, 25, 30, and 35cm these thickness tested to give the different values of base shear and draft of the whole model, the case that using varies thickness (such that at first story shear wall thickness = 35cm, second story thickness=30cm, third story thickness = 25cm, fourth story thickness =20cm, fifth story thickness = 15cm, and from sixth story to twelfth story the thickness of shear wall = 10cm)

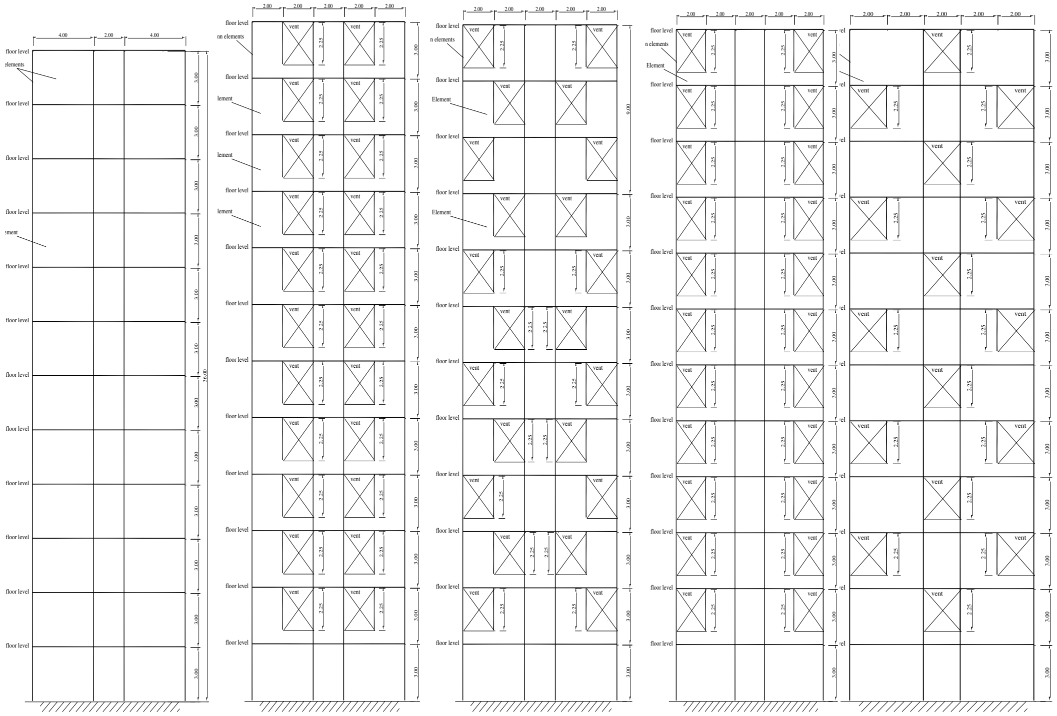
Figure 2-e shows case of openings arrangements that the shear wall with one middle and two exterior openings with wall thickness 10, 15, 20, 25, 30, and 35cm these thickness tested to give the different values of base shear and draft of the whole model, the case that using varies thickness (such that at first story shear wall thickness = 35cm, second story thickness=30cm, third story thickness = 25cm, fourth story thickness =20cm, fifth story thickness = 15cm, and from sixth story to twelfth story the thickness of shear wall = 10cm)

The comparison between the different cases of shear wall openings will do with respect to the original case of shear wall without openings.

3. RESULTS AND DISCUSSION

The cases of openings of the well known architected requirements will be studied to achieve the ideal case that will serve as seismic and architectural requirements. The 3-D model of each case with variable thickness is studied with a commercial finite element program SAP2000.

Figure (3) shows the effect of different cases of openings on the displacements of the top point of the model. The dashed line illustrate the displacement of top point of shear wall without openings (the original case), case (1) shows the maximum values of displacement then case (3) then the next case (2) with respect to the no opening case and in case (4), recorded values the nearest displacements to the shear wall without openings.



(a)No openings (b) Case (1) (c) Case (2) (d) Case (3) (e) Case (4)

Figure (2): Openings-arrangement cases

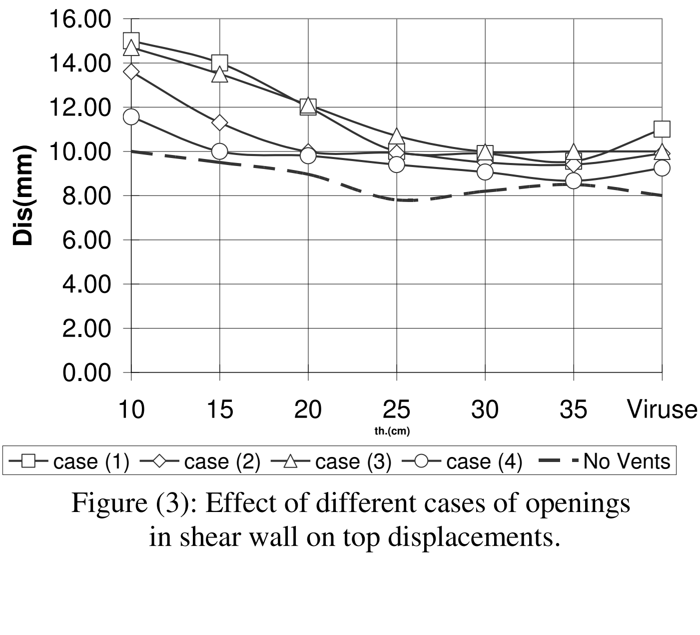


Figure (3): Effect of different cases of openings in shear wall on top displacements.

Figure (4) shows the effect of openings on base shear of different frame elements of the model. Figure 4-a shows the base shear of column (1) with varies cases of openings and shear wall thickness. Figure 4-a shows that case (3) record the maximum value, follow by case (2), the case (4) nearly identical with no opening case but case (1) record a minimum values of base shear nearly half values of no opening case. Thickness of shear walls varying from 10 to 35 cm and varies thickness the big thickness the small values of base shear and vice versa.

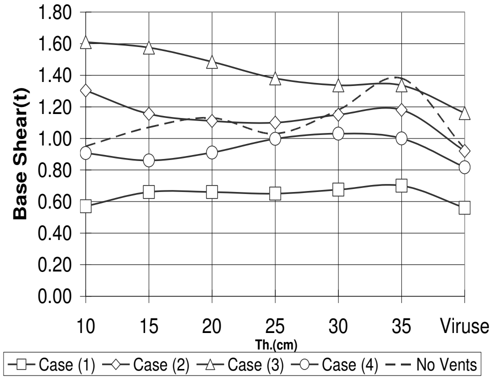
Figure 4-b shows the base shear of column (2) with varies cases of openings and shear wall thickness. Figure 4-b shows that case (1) record the maximum value, follow by case (4), the case (2) nearly identical with no opening case but case (3) record a minimum values of base shear nearly half values of no opening case. Thickness of shear walls varying from 10 to 35 cm and varies thickness case, the big thickness the small values of base shear and vice versa.

Figure 4-c shows the base shear of column (3) with varies cases of openings and shear wall thickness. Figure 4-c shows that case (4) records the maximum value; follow by case (1) and case (3) but case (2) record minimum values of base shear nearly half values of no opening case. Thickness of shear walls varying from 10 to 35 cm and varies thickness case, the big thickness (35cm) records the maximum values of the base shear in different cases on and nearly closed with the varies thickness case on contrary the small thickness that record the small values of base shear in different cases.

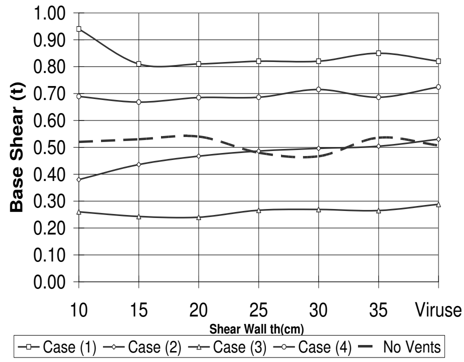
Figure 4-d shows the base shear of column (4) with varies cases of openings and shear wall thickness. Figure 4-d shows that case (4) record the maximum value, follow by case (2), the case (3) nearly and case (1) record a minimum values of base shear nearly half values of no opening case. Thickness of shear walls varying from 10 to 35 cm and varies thickness case, the big thickness the small values of base shear and vice versa and varies thickness case nearly identical with the thickness 10cm.

Figure 4-e shows the base shear of column (5) with varies cases of openings and shear wall thickness. Figure 4-e shows that case (4) record the maximum value, but cases (1), (2), and (3) record minimum values of base shear nearly half values of no opening case. Thickness of shear walls varying from 10 to 35 cm and varies thickness case, the big thickness (35cm) shows a big values of base shear with respect to small values (10:25cm), and the varies thickness records high base shear values with respect to the no opening case.

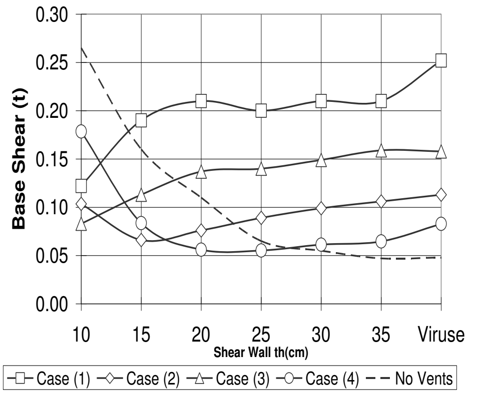
Figure 4-f shows the base shear of column (6) with varies cases of openings and shear wall thickness. Figure 4-f shows that case (1) record the maximum value, follow by case (3), and case (4) the case (2) nearly equal 0.75 of base shear values in no opening case. Thickness of shear walls varying from 10 to 35 cm and varies thickness case, the big thickness the small values of base shear and vice versa, and the different thickness case records the minimum values of base shear with respect to other thickness.



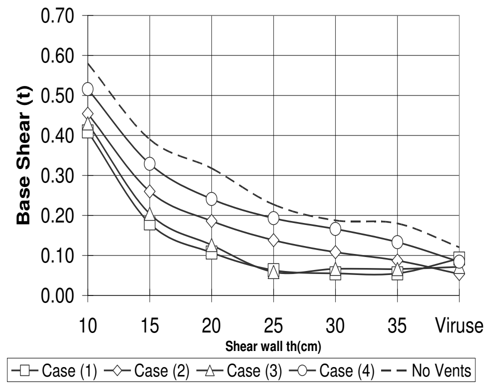
(a) Effect of openings on base shear of column (1)



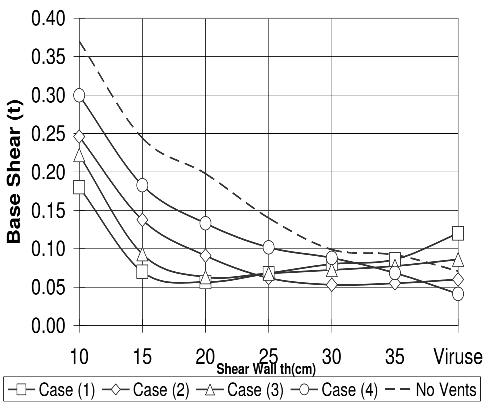
(b) Effect of openings on base shear of column (2)



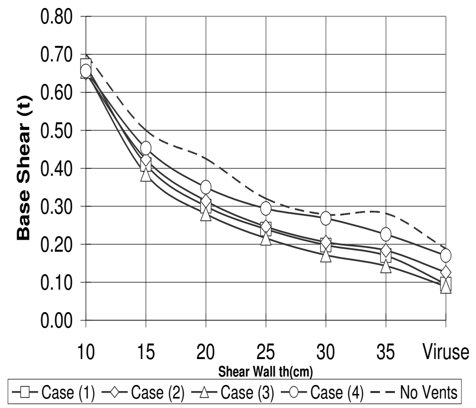
(c) Effect of openings on base shear of column (3)



(d) Effect of openings on base shear of column (4)



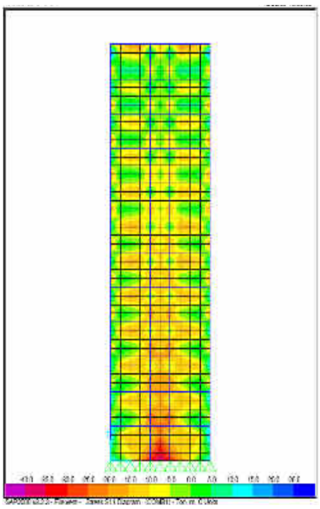
(e) Effect of openings on base shear of column (5



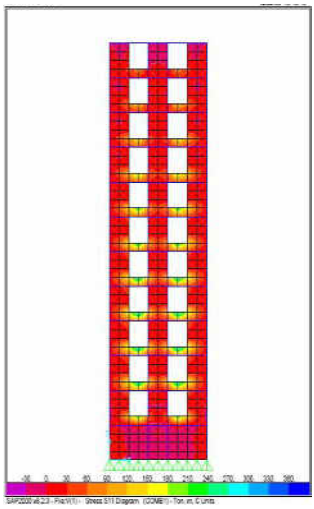
(f) Effect of openings on base shear of column (6)

Figure (4): Effect of different cases of openings in shear wall on base shear in different frame members of the model

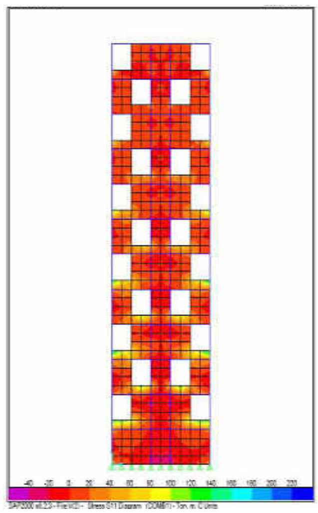
Figure (5) shows the distribution of stress (S11) in X-direction on the different cases of openings. The thickness of walls takes as 20cm for whole shear walls. Figure (5-a) shows the distribution of stress on end shear wall without openings, the stress distribution look symmetrical at the sides of the shear wall and have a negative bigger value at the first floor and be decreased by increasing the height. Figures (5-b) to (5-e) show the distribution of stress on shear wall with a series distribution of openings that can serve as architectural requirements. The concentration of stress around the openings in each case of openings in the shear wall record a high values between second and third floors. The values of stress (S11) are very high with respect to the case of no openings in the shear wall. Figure (5-e) shows the distribution of stress on shear wall in case (4), the distribution look like the lowest stress that the other cases.



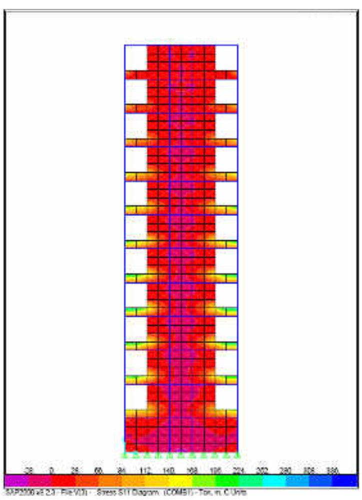
(a) Shear wall without openings



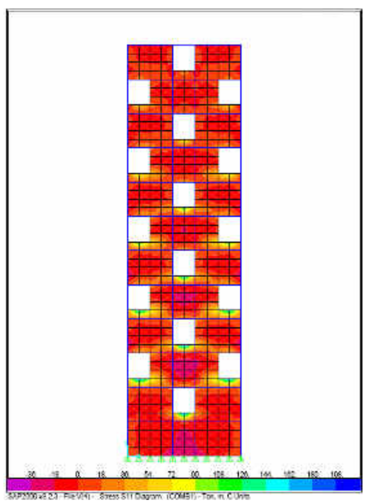
(b) Shear wall case (1)



(c) Shear wall case (2)



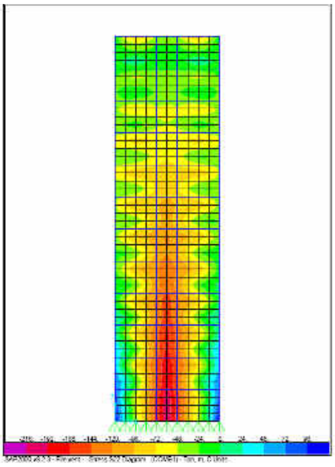
(d) Shear wall case (3)



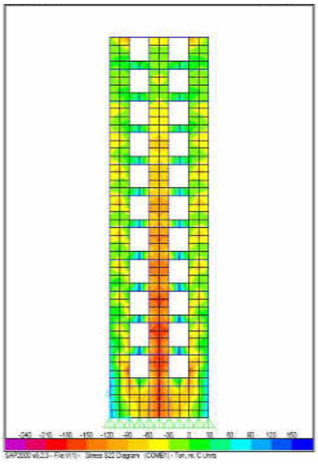
(e) Shear wall case (4)

Figure (5): Stress distribution (S11)

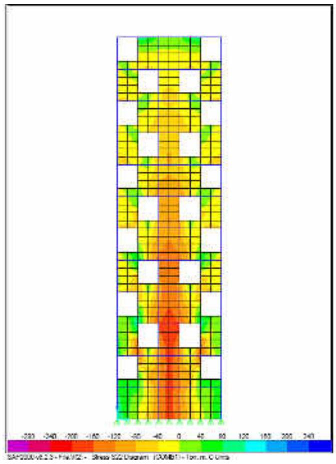
Figure (6) shows the distribution of stress (S22) in Z-direction on the different cases of openings. The thickness of walls takes as 20cm for whole shear walls. Figure (6-a) shows the distribution of stress on end shear wall without openings, the stress distribution look symmetrical at the sides of the shear wall and have a negative bigger value on the middle first to third floors and be decreased by increasing the height. Figures (6-b) to (6-e) show the distribution of stress on shear wall with a series distribution of openings that can serve as architectural solution of distribution of windows and doors at the end of buildings. The concentration of stress around the openings in each case of openings in the shear wall record a high values between second and third floors and decreased with height of the shear wall in cases (1) and (2). The values of stress (S22) are very high with respect to the case of no openings in the shear wall in case (3) at nearly all over the height of the wall. Figure (6-e) shows the distribution of stress on shear wall in case (4), the distribution of stress on the shear wall look like with low values than the case of no openings.



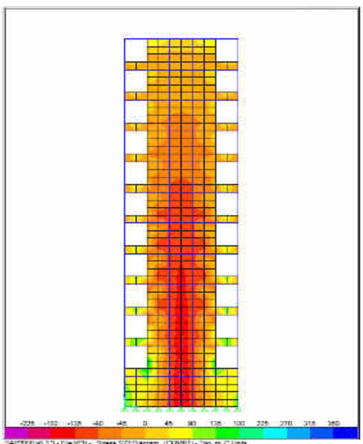
(a) Shear wall without openings



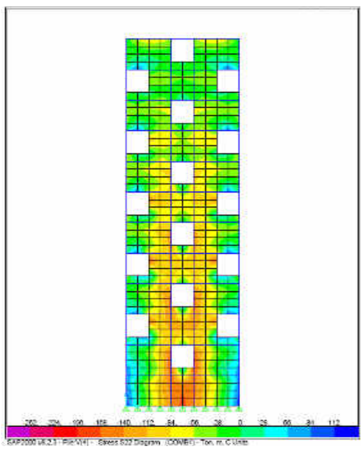
(b) Shear wall case (1)



(c) Shear wall case (2)



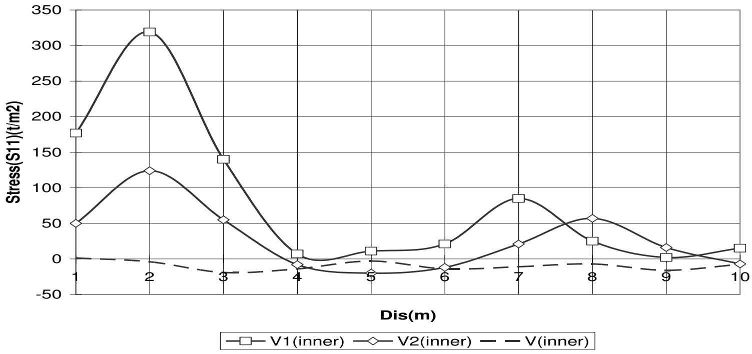
(d) Shear wall case (3)



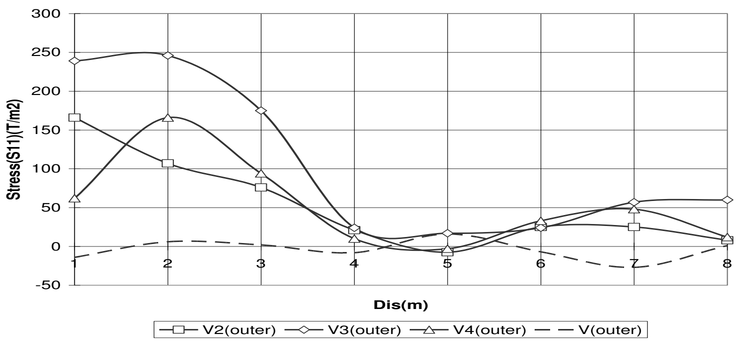
(e) Shear wall case (4)

Figure (6): Stress distribution (S22)

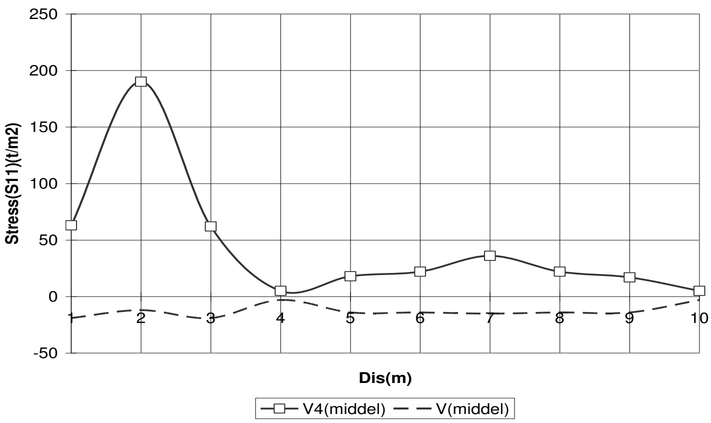
Figure (7) shows the stress (S11) in X-direction distribution around the openings in the different cases of openings. Figure (7-a) shows stress distribution around the inner openings in cases (1, 2) and the no opening case. The points near the corner of the openings record a high stress with respect to the values of stress in the no openings case but the other points nearly with closed values to the no openings case. This phenomenon appears in the other cases of openings when they compared with the no openings case.



(a) Stress distribution around openings case 1,2, and no openings



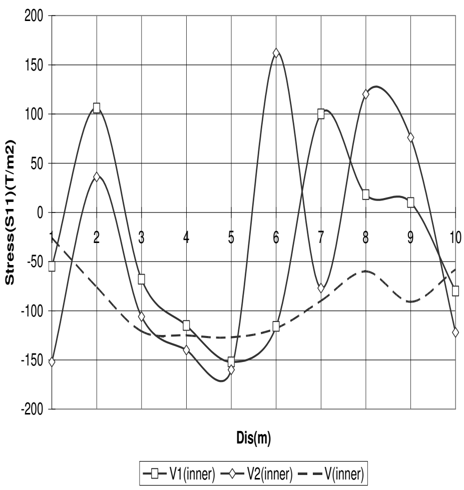
(b) Stress distribution around openings case 2,3,4 and no openings



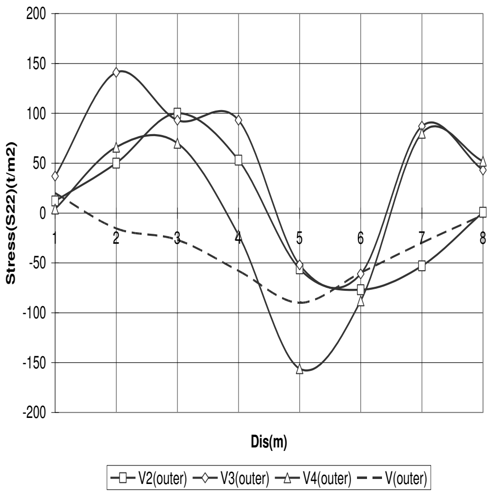
(c) Stress distribution around openings case 4, and no openings

Figure (7): Stress distribution (S11)

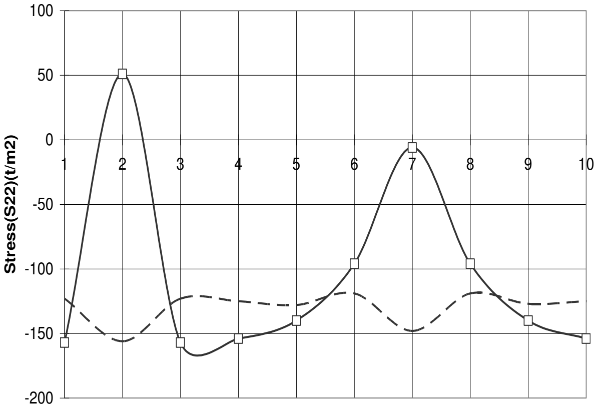
Figure (8) shows the stress (S22) in Z-direction distribution around the openings in the different cases of openings. Figure (8-a) shows stress distribution around the inner openings in cases (1, 2) and the no opening case. The points near the corner of the openings record a high stress with respect to the values of stress in the no openings case but the other points nearly with closed values to the no openings case. This phenomenon appears in the other cases of openings when they compared with the no openings case. Figure (8-b) shows the stress distribution around the openings in case (4) shear wall openings, the nearly closed stress values case, have a big stress values in the corner of the opening with respect to the no openings case. Figure (8-c) shows the stress distribution (S22) around the middle opening for case (4) and with compared with the no openings case the stress nearly equals except in the corners points that the stress convert to a positive small value with respect to a no openings shear wall.



(a) Stress distribution around openings case 1,2, and no openings



(b) Stress distribution around openings case 2,3,4 and no openings



(c) Stress distribution around openings case 4, and no openings

Figure (8): Stress distribution (S22)

4. CONCLUSIONS

A better understanding with regard to the performance of shear walls with different arrangements of openings in the slender high buildings under seismic excitation is confirmed in this study. Such understanding will benefit construction industry and put such design buildings on rational foot.

The following conclusion can be extracted from the present investigation:

- The results revealed that installation of openings in the shear walls can affect on the top displacements of the buildings and it is related with openings arrangement system of openings. The staggered arrangement and away distance openings gives the top displacement which agreed quit well with that induced in shear walls without openings.
- Position of openings in relation to the columns location has a pronounced effect on the base shear distributions in the columns. The adjacent columns to the openings possess base shears bigger than those deduced in the columns away from openings.
- Opening arrangement system has a remarkable change in the occurring base shear. The staggered arrangements system of openings has slight effect on the resulting base shears in the shear walls compared with that induced in the shear walls without openings.
- The results showed high values of the stresses around the openings regardless of the arrangement system of openings. However, the accompanying increase of stresses in the staggered system of openings is small related to the corresponding in the other configurations of openings.
- The staggered arrangement system of openings between the stories proved to be highly advantageous to use in the shear walls of such kind of buildings.
- The designer must conduct a numerical analysis of such buildings subjected to permanent and seismic loads taking into account the staggered arrangement of opening in the shear walls to choose the suitable dimensions and reinforcement in the different structural elements and the necessary reinforcement around the openings.

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تأثير الفتحات المعمارية المستلزمه على كفاءة حوائط القص

تنفيذ حوائط القص على المحيط الخارجى للمبانى النحيفة ذات الارتفاعات العالية يرفع من كفاءة حوائط القص لمقاومة القوى الزلزالية لتلك المباني و لكن الشكوك و عدم التثّبُت فى تنفيذ حوائط القص على الحدود الخارجية للمبنى يرجع الى الفتحات المعمارية المستلزمه (ابواب و شبابيك). لهذا السبب يقدم هذا البحث اهمية كبيرة فى توطيد و ترسيخ الدلائل و الارشادات التصميمية للمهندس المدنى فى حالة وجود مثل هذه الفتحات الضرورية فى حوائط القص. و فى هذا البحث تم اجراء الدراسة العددية على المبانى النحيفة العالية التى لها انظمة مزدوجة من حوائط القص بانظمة مختلفة للفتحات لتحديد النظام الامثل لهذه الفتحات بالاضافة الى الاطر المقاومة للعزم باستخدام الحاسب الالى مستخدما طريقة السجل الزمنى الديناميكى لعجلة زلزالية قصوى 0.25 من قيمة عجلة الجاذبية الارضية و المقدمة من الكود المصرى لحساب الاحمال و القوى فى الاعمال الانشائية و المبانى. و يمكن تلخيص النتائج التى تم الحصول عليها كالتالى:

- الفتحات فى حوائط القص يؤثر على ازاحة الذروة (العلوية) لتلك المبانى و التى تعتمد على نظام ترتيب الفتحات و ان نظام الفتحات المتبادل القطرى بين الطوابق يعطى ازاحة علوية تتفق تماما مع نظيرتها فى حوائط القص بدون فتحات.
- موضع الفتحات له تاثير واضح و صريح على توزيعات قوى القص المتولدة على الاعمدة. الاعمدة القريبة من الفتحات تنال قوى قص اكبر من المتولدة فى الاعمدة البعيدة عن الفتحات.
- نظام ترتيب الفتحات له تاثير لافت على توزيعات قوى القص المتولدة فى الاعمدة و حوائط القص و لكن نظام الفتحات المتبادل القطرى بين الطوابق له تاثير طفيف على قوى القص بالمقارنة بحوائط القص بدون فتحات.
- الفتحات عموما لها تاثير عالى على الاجهادات المتولدة حول الفتحات و لكن هذه الزيادة فى الاجهادات فى النظام المتبادل القطرى للفتحات صغيرة مقارنة بحوائط القص بدون فتحات.
- النظام المتبادل القطرى للفتحات بين الطوابق اثبت مميزاته للاستخدام فى حوائط القص لتلك المبانى و على المهندس المصمم اجراء تحليل عددى لهذه المنشات تحت تاثير الاحمال الدائمة و الاحمال الزلزالية أخذاً فى الاعتبار التبادل القطرى للفتحات فى حوائط القص و الوقوف على الابعاد و التسليح المناسب لمختلف قطاعات العناصر الانشائية للمبنى و التسليح حول الفتحات.