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# Comparative Study for Different Types of Shear Walls in Buildings Subjected to Earthquake Loading

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## Abstract

Shear walls are effective structural elements used mainly in multi-story buildings to provide resistance against lateral loadings such as earthquake and wind loadings. There are several types and shapes of shear walls depending mainly on geometry and height of the building. Both type and shape of the shear wall affect the efficiency of resisting lateral loadings. In this study, fifty six building models have been analyzed using the finite element method by using the SAP2000 V14 computer program. Each model have ten stories, subjected to earthquake loadings, with various numbers of bays, and with three types of shear walls, namely: side shear walls, middle shear core, and double shear cores, provided that each type of the shear walls (or cores) has the same material volume. The analysis outputs have been investigated to select the appropriate type and location of the shear walls (or cores) for the multi-story buildings subjected to earthquake loadings. Specified conclusions have been presented to obtain the optimum behavior for the multi-story buildings under the effects of earthquake loadings.

**Keywords:** Earthquake, optimum shear walls, response spectrum.

## 1. Introduction

Shear walls are effective structural elements used mainly in multi-story buildings to provide adequate resistance against the lateral loadings such as earthquake and wind loadings. Each building is significantly influenced by the shape and position of shear walls [1]. There are two main arrangements of shear walls; the first one is placed at the edges of the building which could be in either plane or flanged shape. The second arrangement is placed inside the building in the shape of core walls or channel sections [2]. This study will consider the sidewall (edge walls) arrangement, middle core walls, and double core walls arrangements at different positions as shown in figure (1).

Regarding methods used for earthquake analysis, there are several main approaches for this analysis, namely: the equivalent static analysis, response spectrum analysis, time history analysis, nonlinear static analysis, and nonlinear dynamic analysis .The present work will adopt the response spectrum analysis method since it is the most popular method used for analysis due to the fact that it provides a simple and logical way to define the earthquake loadings and economical computational efforts. The response spectrum analysis is considered as a dynamic linear analysis.

The study of the effects of shear walls locations and types in buildings subjected to earthquake loadings are presented in different approaches [2-4]. In this study, a new approach is presented to obtain the optimum behavior of buildings subjected to earthquake loading with different types of shear walls and different locations.

## 2. Description of Models

Ten - story reinforced concrete framed buildings are assumed in this study. There are nine different buildings which have been considered and categorized according to the number of bays in the X-direction (the longitudinal direction) where, the first building has two bays in the X-direction (2B), the second building has three bays in the X-direction (3B), the third building has four bays in the X-direction (4B) and so on. All these buildings have two bays in the Y-direction and all bays (in both X and Y-direction) are of (5 m) span with story height of (3 m).

For each building type, three different arrangements of shear walls are studied: sidewall system (SW), figure (1-b), middle-core system (MC), figure (1-c), double-core at different symmetric locations system (C1, C2, C3,.. etc.) depending on the building width, figure (1-d,e,f). Also a free-wall frame system (F) with no shear walls has been studied, figure (1-a). Each shear wall arrangement built using the same material volume. The total number of models is fifty six. The details of the column and beam sections, and the dimensions of the three arrangements of shear walls are shown in figure (2).

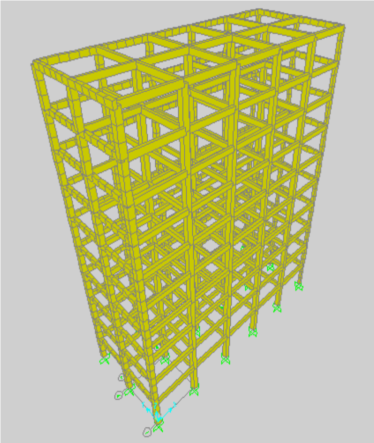


**Figure (1-a):**
Free-wall arrangement.

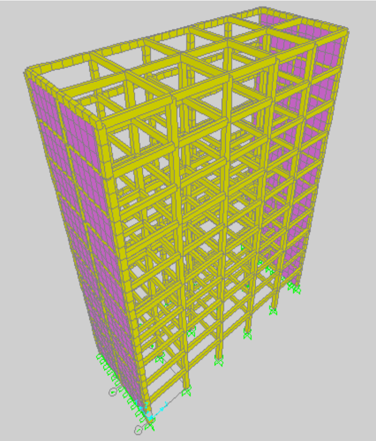


**Figure (1-b):**
Sidewall arrangement.

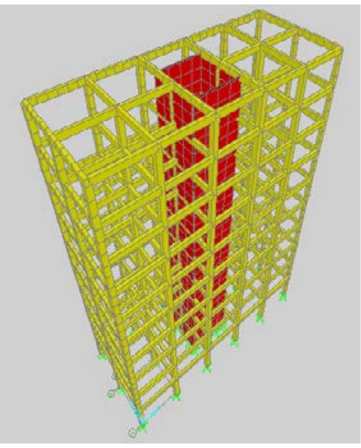


**Figure (1-c):**
Middle-core arrangement.

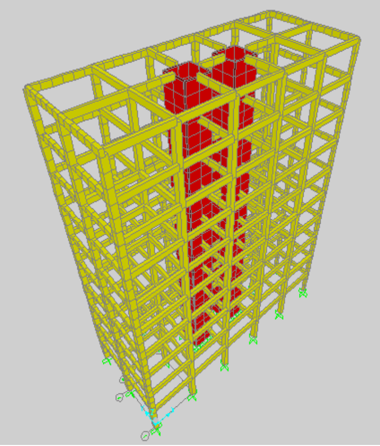


**Figure (1-d):**
Double-core (C3) arrangement.

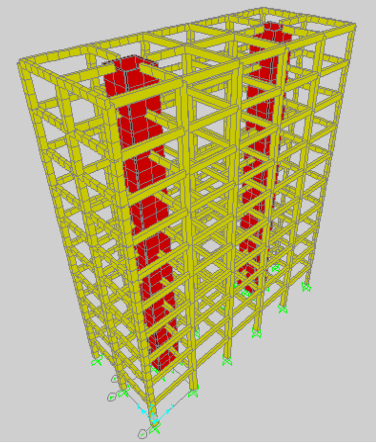


**Figure (1-e):**
Double-core (C2) arrangement.

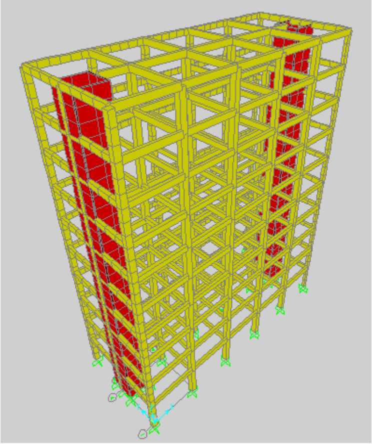


**Figure (1-f):**
Double-core (C1) arrangement.

**Figure 1:** Typical images for shear wall arrangements used in this study.

All buildings are modeled by using the finite element method via computer program SAP2000 V14 [7]. Each building is assumed to be subjected to the seismic loading according to the IBC 2006 [8].

Two nodes beam element has been selected to represent the beams and columns in the buildings. The beam element includes the effects of biaxial bending, biaxial shear deformations, torsion, and axial deformation. The walls in the buildings have been represented by four nodes thick shell element which includes the effect of transverse shear, in addition to the effects of in – plane and out of the plane rotational and translational stiffness components , and combines both the membrane and plate bending behavior.
The information for analysis used in this work is as follows:

- The 0.2 sec. spectral acceleration $S_s = 2.29$
-The 1 sec. spectral acceleration $S_1 = 0.869$
- The long period transition period = 8
- Damping ratio = 0.05
- Site class = B (Rock).
- Site Coefficient $F_a = 1$
- Site Coefficient $F_v = 1$
- Modal combination: CQC (Complete Quadratic Combination).
- Directional combination: SRSS (Square Root of the Sum of Squares).

The Dynamic analysis based on modal analysis in Eigen vectors mode type. Various mode shapes have been investigated for the models to choose the required number of these shapes for the analysis. Due to the symmetry in geometry of the buildings, and also due to the specified approach adopted in this study, two main mode shapes have been selected to represent the behavior of such buildings. Typical mode shapes for a typical building (model 4BDC2) is shown in figure 3.

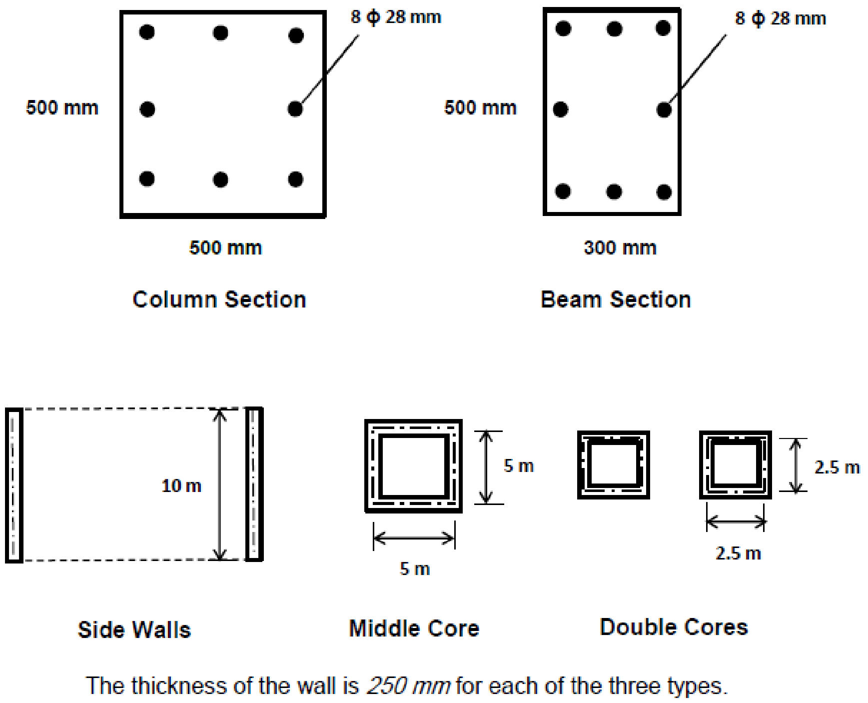



**Figure 2:** Details of sections of the members and dimensions of the shear walls.

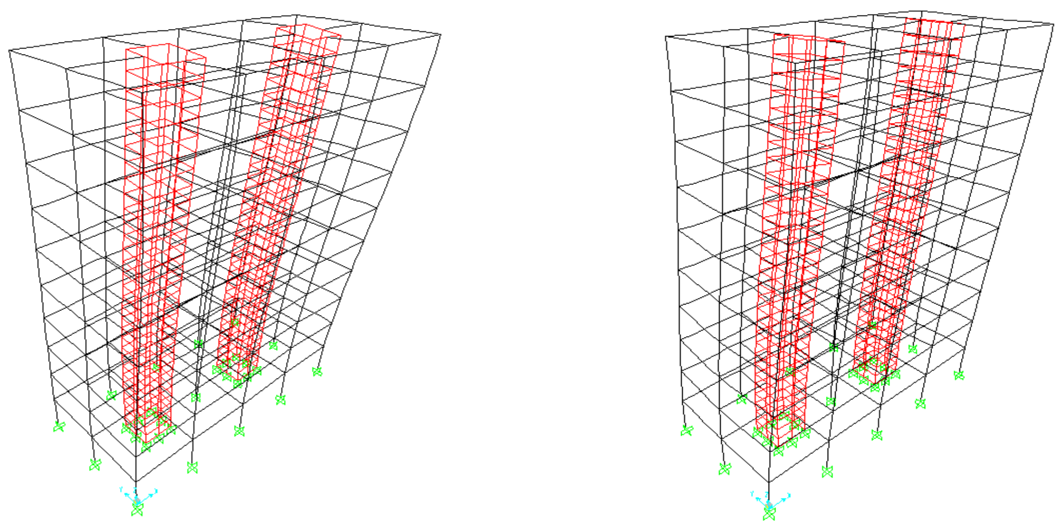


**Figure 3:** Mode shapes for a typical building (model 4BDC2).

## 3. Results and Discussion

After carrying out the analysis, three different variables where examined to draw a conclusive result. These variables are: the drift of the 10 story, the resultant shear base along the edge and center line of the building, and the resultant bending moment in columns of the ground story along the edge and center line of each building.

### 3.1 Story Drift

Values of the story drift for all buildings are plotted and shown in figure 4. The models have been designated based on the number of bays in x – direction, and the type of shear wall, e.g. 2BSW means the model has two bays in x – direction with side walls type.

It can be noticed that sidewall arrangement shows the maximum reduction for story drift of the two-bay and three- bay buildings, while the double-core arrangement produces the maximum reduction for the other building types.

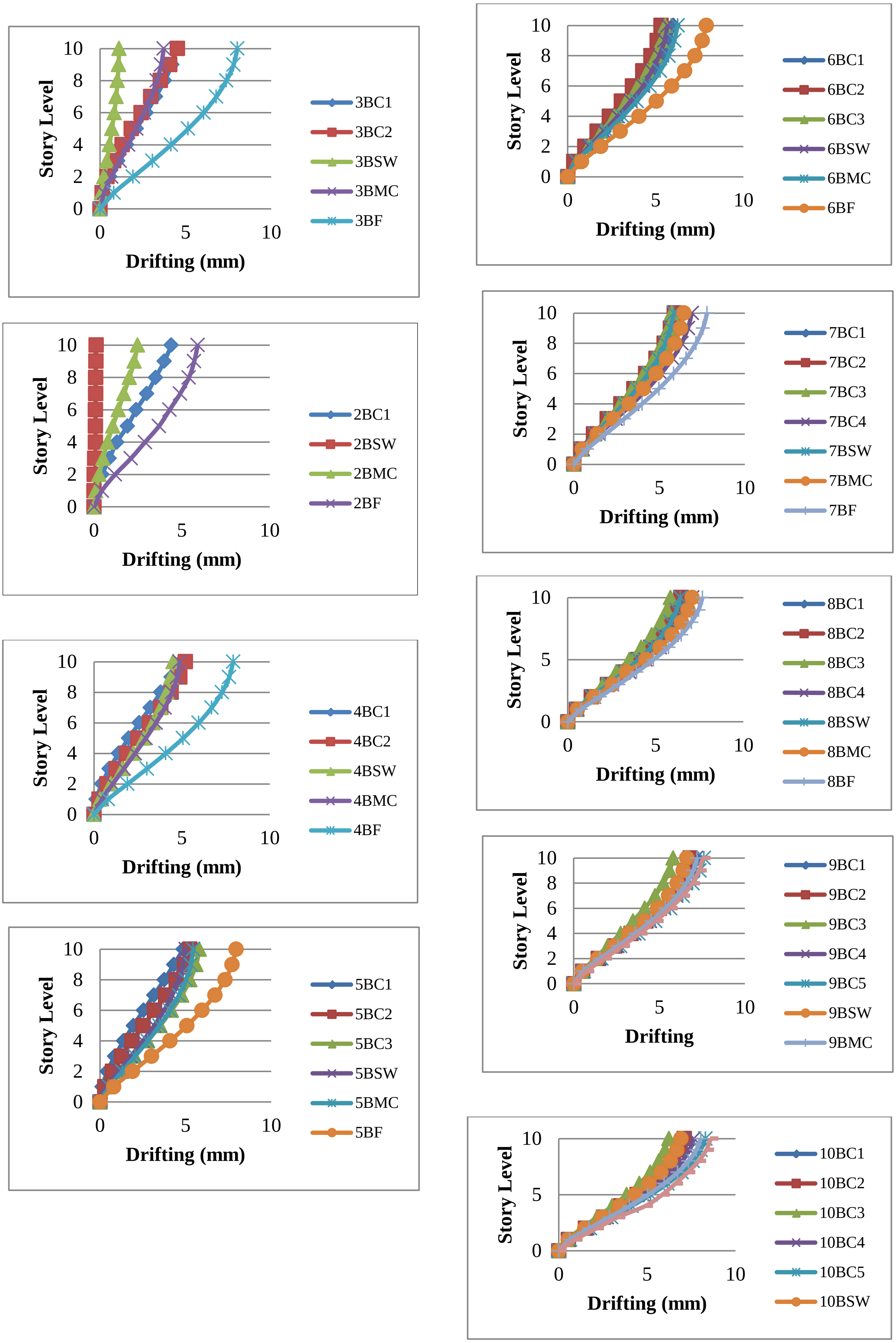



**Figure 4:** Story vise drift for the models.

## 3.2 Base Shear

The resultant shear force at the edge and center line (middle) of the ground story is presented in figures (5 to 13). The maximum shear forces are generated for the free-wall (F) system, while the minimum forces occurred in the sidewall (SW) system of the two-bay and three-bay buildings. The double-core system recorded the minimum shear force as compared with the other building types.

## 3.3 Bending Moment

The resultant bending moment at the edge and center line (middle) of the ground story is presented in figures (14 to 22). The maximum value of the resultant bending moment is seen in the free-wall (F) system and the minimum resultant bending moment occurred in the sidewall (SW) system of the two-bay and three-bay buildings, while the double-core arrangement recorded the minimum bending moment as compared with the other building types.

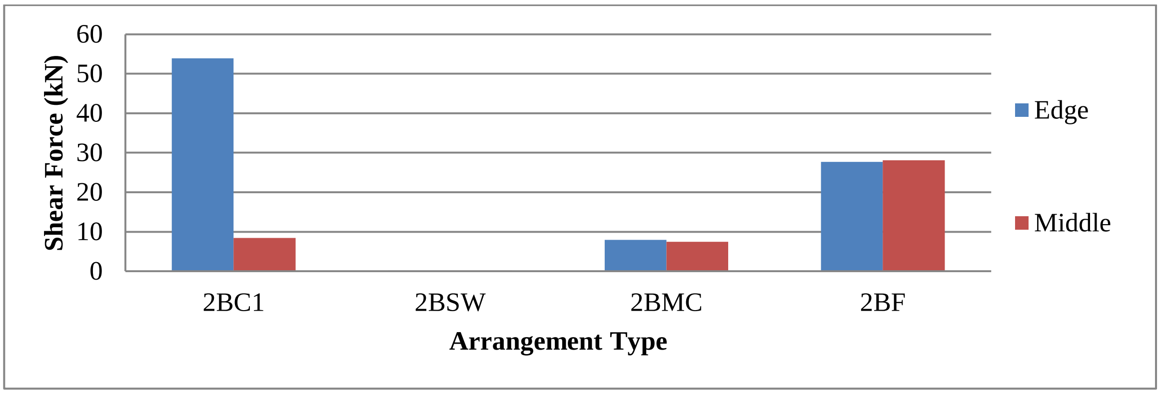



**Figure 5:** Shear force (kN) computed in the ground story for the two-bay building.

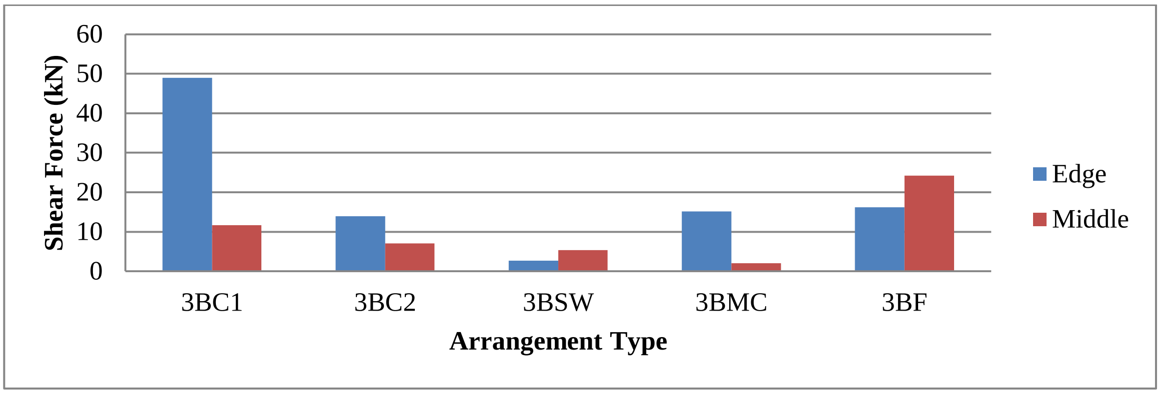



**Figure 6:** Shear force (kN) computed in the ground story for the Three-bay building.

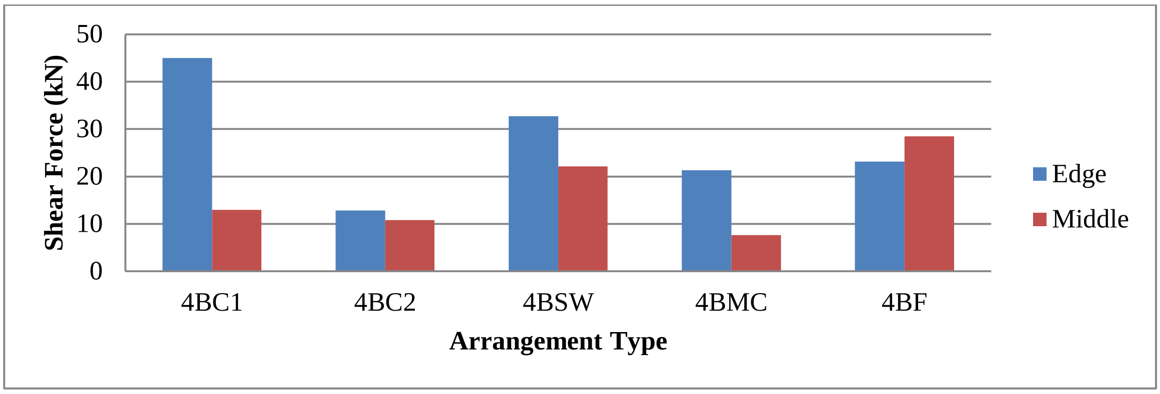



**Figure 7:** Shear force (kN) computed in the ground story for the Four-bay building.

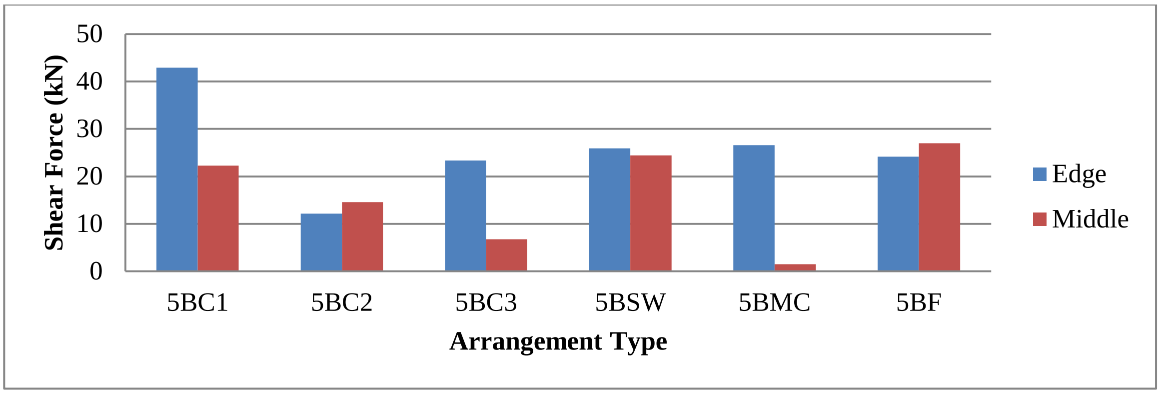



**Figure 8:** Shear force (kN) computed in the ground story for the Five-bay building.

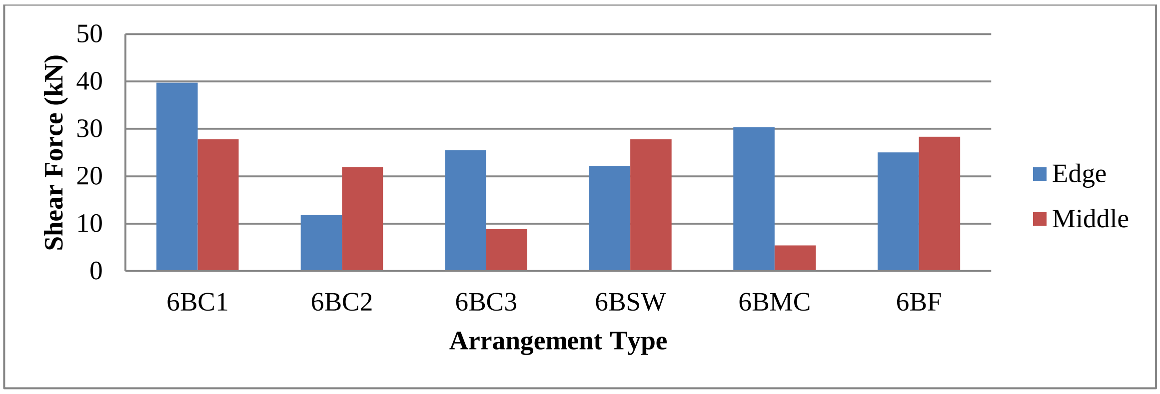



**Figure 9:** Shear force (kN) computed in the ground story for the six-bay building.

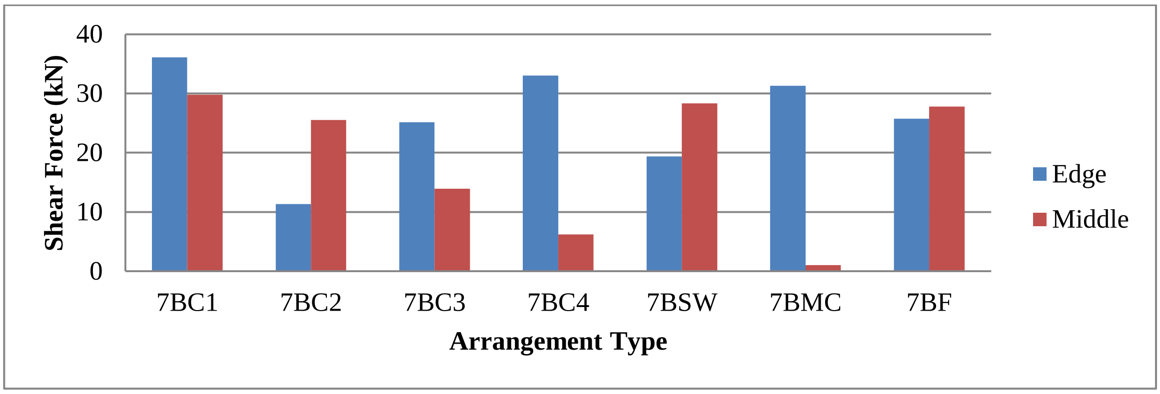



**Figure 10:** Shear force (kN) computed in the ground story for the seven-bay building.

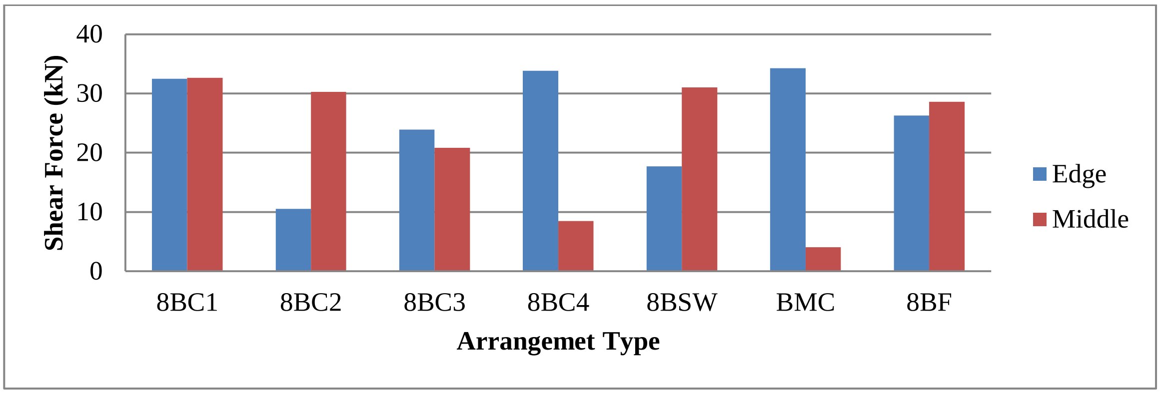



**Figure 11:** Shear force (kN) computed in the ground story for the eight-bay building.

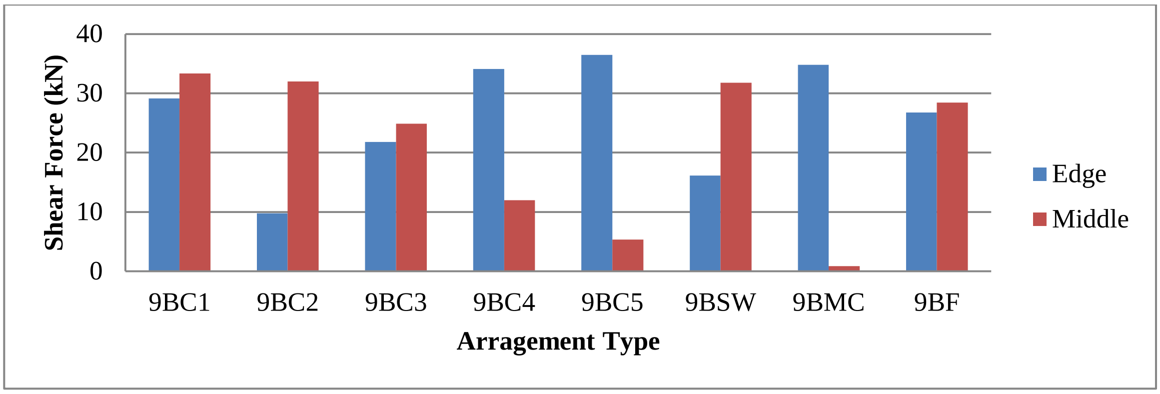



**Figure 12:** Shear force (kN) computed in the ground story for the nine-bay building.

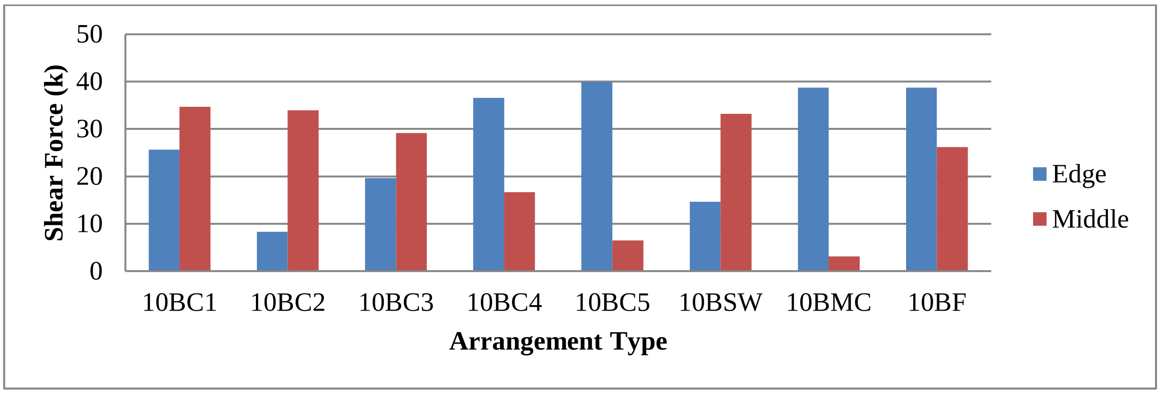



**Figure 13: Shear force (kN) computed in the ground story for the ten-bay building.**

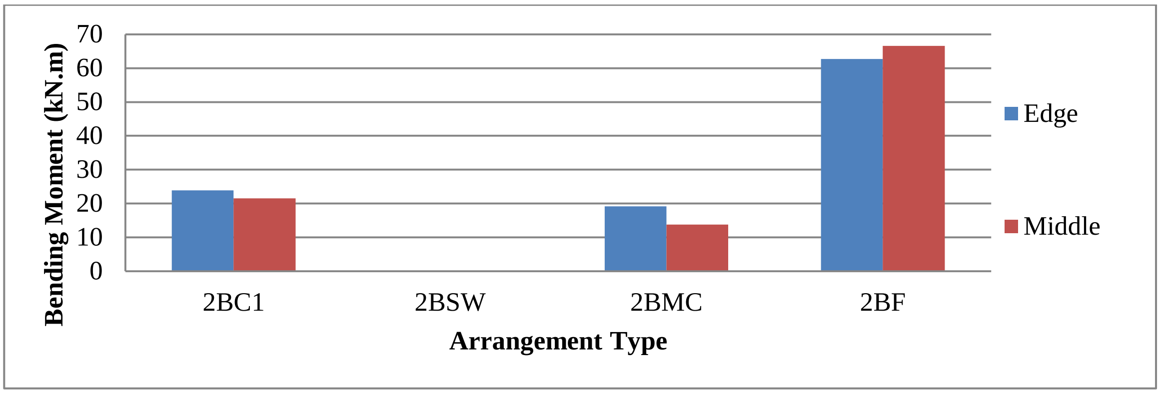



**Figure 14:** Bending moment (kN.m) computed in the ground story for the two-bay building.

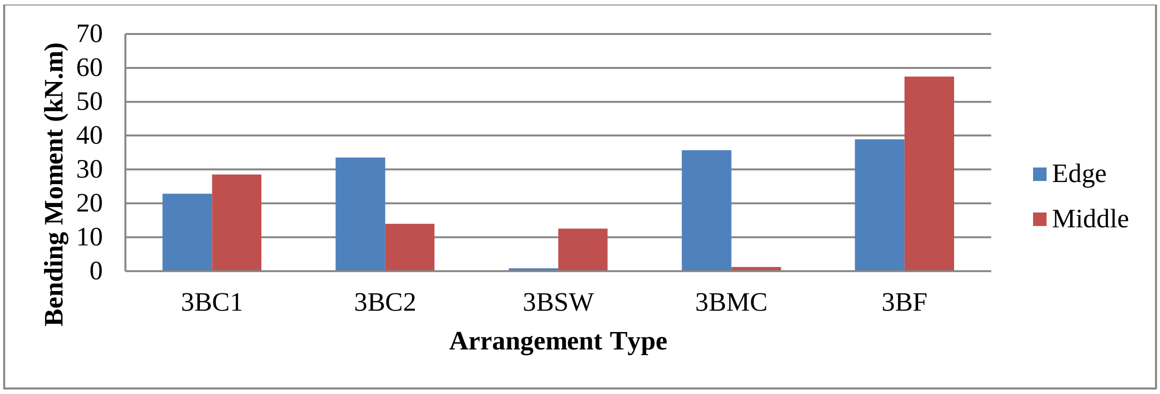



**Figure 15:** Bending moment (kN.m) computed in the ground story for the three-bay building.

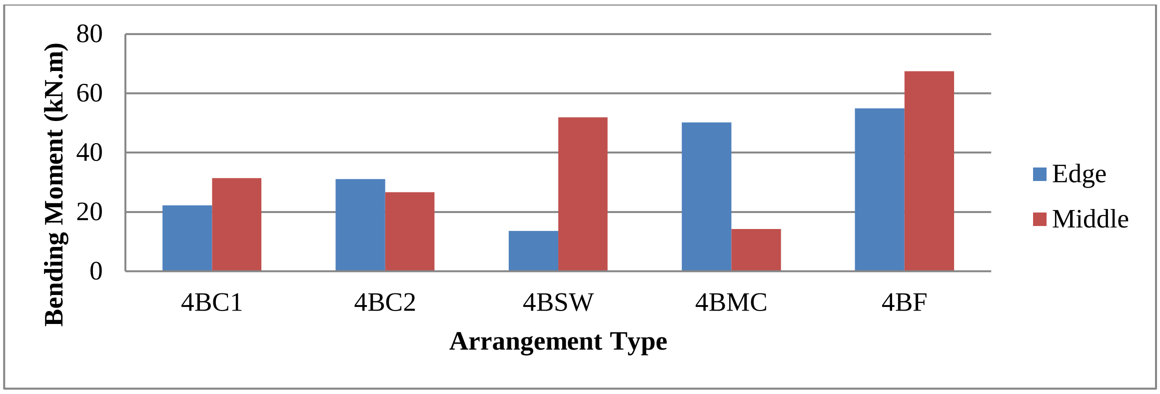



**Figure 16:** Bending moment (kN.m) computed in the ground story for the four-bay building.

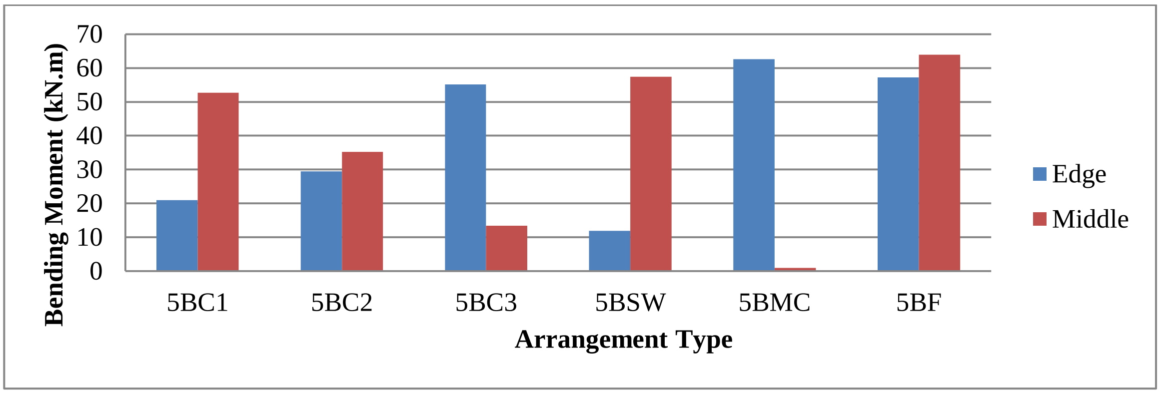



**Figure 17:** Bending moment (kN.m) computed in the ground story for the five-bay building.

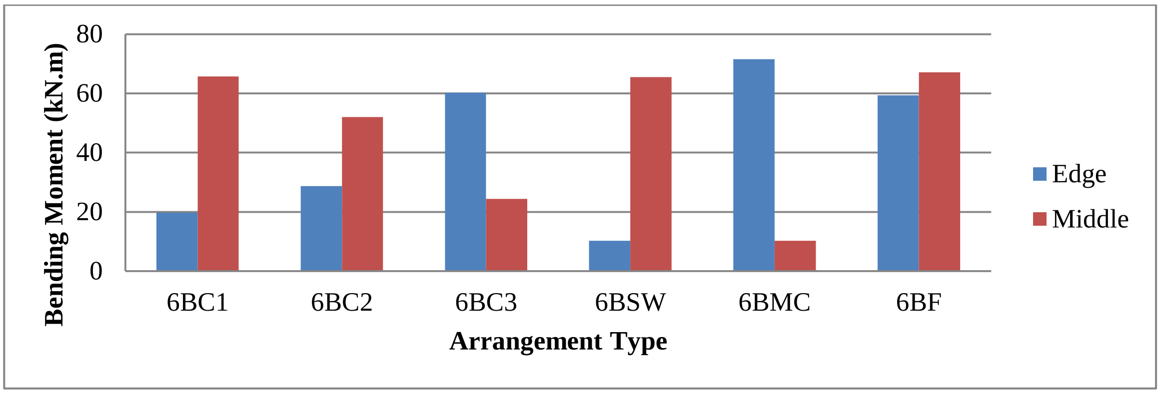



**Figure 18:** Bending moment (kN.m) computed in the ground story for the six-bay building.

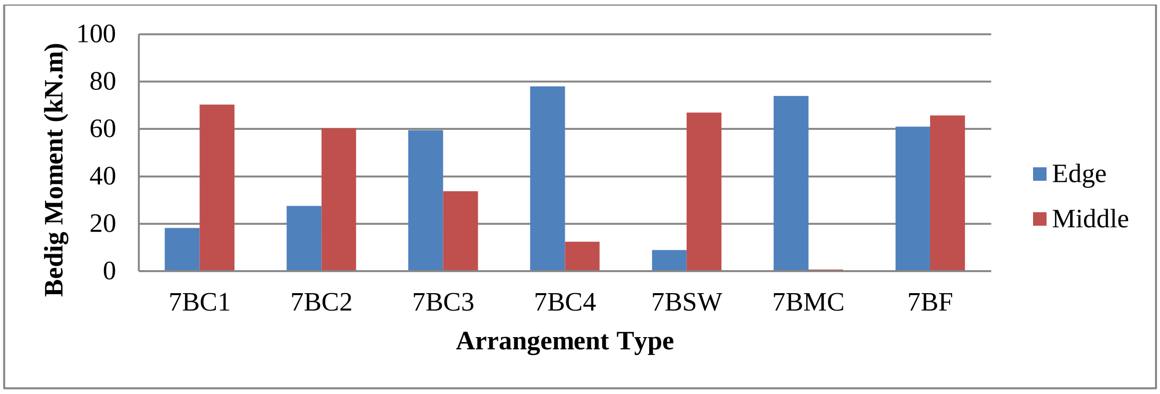



**Figure 19:** Bending moment (kN.m) computed in the ground story for the seven-bay building.

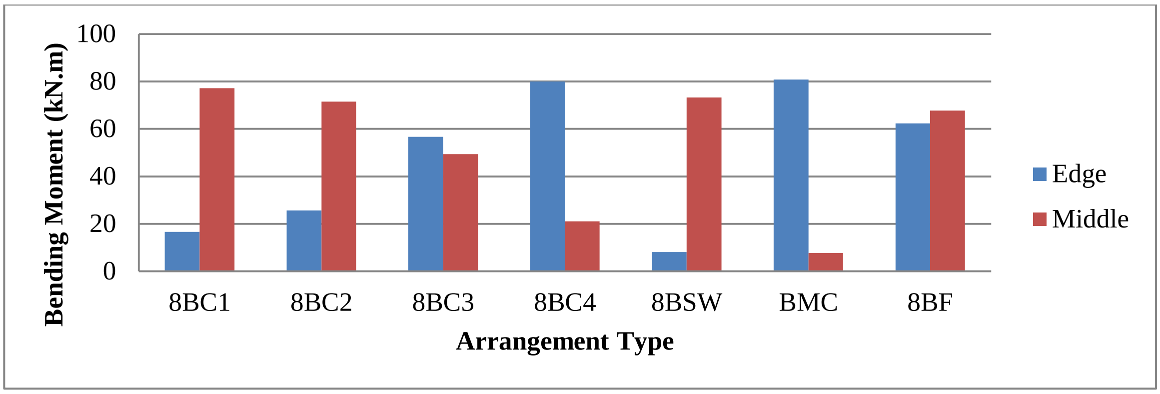



**Figure 20:** Bending moment (kN.m) computed in the ground story for the eight-bay building.

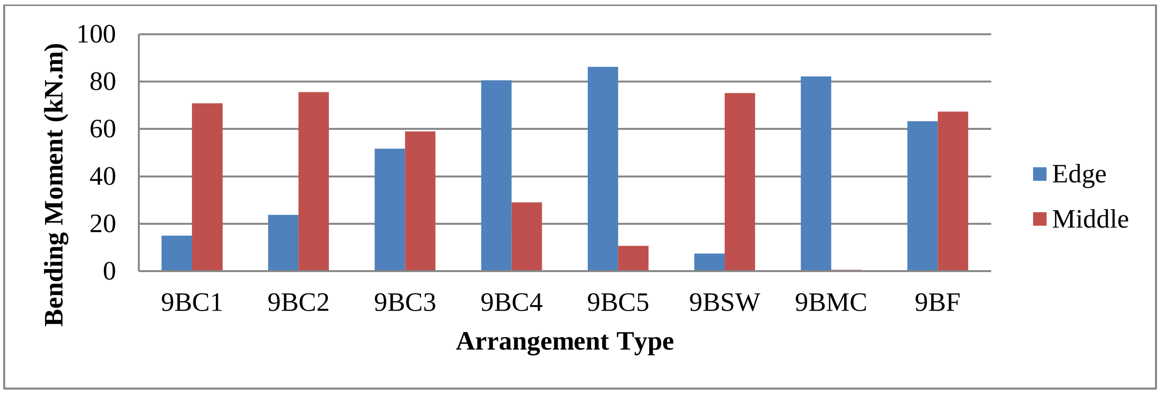



**Figure 21:** Bending moment (kN.m) computed in the ground story for the nine-bay building.

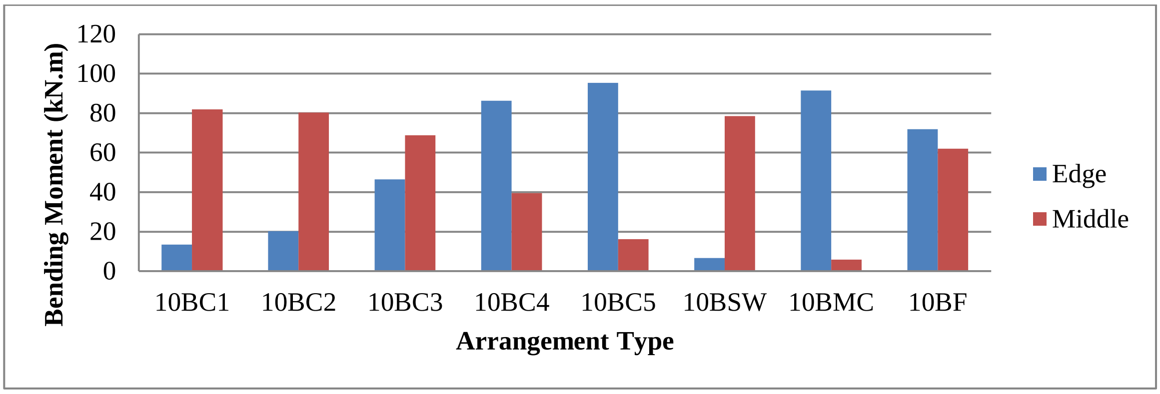



**Figure 22:** Bending moment (kN.m) computed in the ground story for the ten-bay building.

## Conclusions

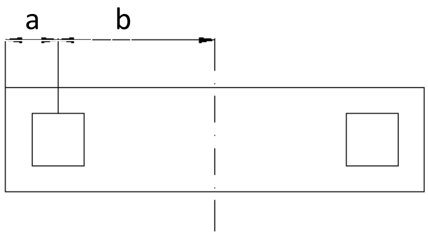
The following conclusions are obtained from this work:

1- Seismic load resisting capacity of the frame building is significantly improved in the presence of shear walls as is clear from the story drift, base shear resultant, and bending moment when comparing the free-wall arrangement with the other arrangements.

2- Sidewalls arrangement is considered to be the best option for buildings with length (in the X-direction) less than or equals to 20 m since it has been recorded that the least values of drifting, base shear, and ground floor bending moment occurred with reduction percent ranging between (80-98)%.

3- Double-core shear wall arrangement is considered the best option for buildings with length (in the X-direction) of greater than 20m.

4- Since the double core arrangement has more than one case, it has been concluded that placing the core at a distance (a), measured from the center of the core to the edge of the building, would give the minimum values for drifting, base shear, and ground floor bending moment when the ratio (a/b) is about 0.75, in which (b) is the distance from the center of the core to the center line of the building, as shown in figure 23.




**1Figure 23:** Optimum location of the double-core shear wall arrangement (a/b is about 0.75).

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# دراسة مقارنة لأنواع مختلفة من جدران القص في البنايات المعرضة الى أحمال الهزات الأرضية

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الخلاصة

تعتبر جدران القص من العناصر الانشائية الفعالة, حيث تستخدم بشكل رئيسي في البنايات المتعددة الطوابق لتوفير مقاومة ضد الأحمال الجانبية مثل أحمال الهزات الارضية وأحمال الرياح. هنالك عدة أنواع وعدة أشكال لجدران القص تعتمد بشكل رئيسي على شكل وارتفاع البناية. إن كلاً من نوع وشكل جدار القص يؤثر في كفاءة مقاومة الأحمال الجانبية. في هذه الدراسة تم تحليل ست وخمسون نموذجاً من الأبنية باستخدام طريقة العناصر المحددة بواسطة برنامج SAP2000 النسخة الرابعة عشر. كل نموذج مؤلف من عشرة طوابق, معرض الى أحمال الهزات الأرضية, وبأعداد مختلفة من المجالات, وبثلاثة انواع من جدران القص هي : جدران قص جانبية, لب قص وسطي , ولبين مزدوجين, وبنفس حجم المادة الانشائية لكل نوع من هذه الأنواع الثلاثة. تمت دراسة نتائج التحليل لاختيار النوع المناسب والموقع المناسب لجدران القص , وتم تقديم استنتاجات محددة للحصول على السلوك الأمثل للأبنية المتعددة الطوابق تحت تأثير أحمال الهزات الأرضية.