

**Dynamic Behavior of Reinforced Concrete Structures with
Masonry Walls**

السلوك الديناميكي للمباني الخرسانية المسلحة المحتوية على جدران

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Abstract

The inclusion of a soft storey in multistory concrete buildings is a feature gaining popularity in urban areas where the cost of land is exorbitant. In earthquake prone zones, this feature has been observed in post earthquake investigations. Although engineers are prepared to accept the notion that a soft storey poses a weak link in Seismic Design, yet the idea demands better understanding. The following study illustrates the importance of the judicious distribution of shear walls. The selected building is analyzed through nine numerical models which address the behavior of framed structures. The parameters discussed include, inter alias, the fundamental period of vibration, lateral displacements and bending moment. It is noticed that an abrupt change in stiffness between the soft storey and the level above is responsible for increasing the strength demand on first storey columns. Extending the elevator shafts throughout the soft storey is strongly recommended.

Keywords: Multistory Building, Seismic Analysis, Mode Shapes, Shear Walls, Soft Storey

ملخص

شاع استخدام الطابق الرخو في المباني الخرسانية المسلحة متعددة الطوابق في المدن بسبب غلاء الأراضي وندرة المساحات الأفقية. وقد تم دراسة سلوك هذا النوع من المباني بعد تعرضها للزلازل. وبالرغم من وجود حكم هندسي يشير إلى ضعف الرابطة في الطابق الرخو إلا أن هذا النوع من المباني بحاجة إلى دراسة أعمق. تهدف هذه الورقة إلى توضيح الضعف في الطابق الرخو وطرح أهمية حكمة توزيع جدران القص على واجهات المبنى. تم تحليل البناء المختار من خلال تسعة نماذج مختلفة تمثل سلوك المباني الخرسانية الإطارية المسلحة. العوامل المدروسة تمثل زمن التردد، الإنحناء الجانبي بالإضافة إلى العزوم والقوى القصية والمحورية. لوحظ أن التغير المفاجئ في قيمة الصلادة بين الطابق الرخو والطابق الذي يعلوه هو السبب في زيادة قيمة القوة المطلوبة للأعمدة في الطابق الأول مما يؤكد ضرورة اجتناب الطابق الرخو في الأماكن الزلزالية. كما تبين أن امتداد جدران المصعد خلال الطابق الرخو من النصائح الهامة التي تستحق المراقبة.

Introduction

In metropolitan areas Architects and Planners have a tendency to allocate the first level or first levels of high rise buildings for functional or vernacular requirements such as parking facilities or public service areas. This feature is particularly true and is gaining popularity in urban areas in many geographical locations worldwide especially in locations where land cost is exorbitant or where land is a scarce commodity. Such a task is normally accomplished by removing the walls that surround the building, thus reducing the stiffness of that particular floor and producing a soft storey. It is also possible that a soft storey may also be included in intermediate floor levels. However, since Palestine lies in a seismically active zone, it becomes an indispensable task to thoroughly evaluate the behavior of such structures. Furthermore, since it is customary for facades of buildings to be covered either by infill masonry walls with no reinforcement or by reinforced concrete shear walls with natural stone cladding; the seismic evaluation task becomes even more pressing. According to the IBC 2003 (International Building Code, table 1616.5.1.2, p. 328) a soft storey is defined as the storey in which the lateral stiffness is less than 70 percent of the value of the story above it or less than 80 percent of the average stiffness of the above three storey levels.

Building codes and engineering practice place little or no restrictions on structural modeling. Three dimensional models with comprehensive seismic analysis is, to date, not an obligatory practice. This is so, in spite of the fact that 1D and 2D models are approximate at best. This is obviously due to the omission of real and accidental torsion effects. The IBC allows the use of an equivalent static load analysis under certain conditions but also allows, but without demanding, a thorough dynamic analysis procedure. It has been shown that the columns in a soft storey are prone to failure; this is because the upper structure would behave as one stiff and rigid beam attracting the major portion of the induced lateral forces. This happens as a result of the energy absorption that happens in the lower flexible portion of the building with little absorption in the rigid part above. The concentration of forces and energy absorption requirements render the design of such structural elements quite critical in nature. In many geographical locations the choice of the analysis methods is customarily left to the discretion of the designer.

The response of any structure including its base shear is a function of its seismic properties, namely its mass and stiffness. The basic indicator in this case is the array of modal frequencies and mode shapes which, in association with the nature of the ground excitation, predetermine the emerging structural response. Structures may vary in form, in shape and in mass distribution in both the lateral and vertical directions. Some buildings, due to local government regulations are also required to have abrupt vertical setbacks. As a direct result of all this, forces get unevenly distributed and the induced stresses and deflections are never uniform but may substantially vary in magnitude. This underlines the need for thorough and careful investigative study. An elementary two dimensional frame analysis or even incomplete three dimensional frame analysis may lead to erroneous results.

The present paper is intended to present, in a concise manner, a conceptual methodology for tackling design problems of structures with a soft storey present at their first level. It also attempts to point out a scheme that introduces a balanced distribution of panel walls between the first floor and the underneath soft storey in order to avoid abrupt changes

lateral displacements and the torsion rotations associated with the lower frequencies of the system. The numerical models are built using SAP 2000 version 10. The live load contribution to the seismic mass is estimated at 30% in addition to the contribution of the full dead load of the structure.

In the following study nine different models are numerically investigated; they vary in infill walls distribution and in the wall material properties. Both the long and the short directions are as such included. The models are described as follows:

1. Model 1: Bare frame for all levels, (Figure 1):
2. Model 2: 15 cm infill un-reinforced walls at all levels but at the soft storey level no walls are included. Window openings are assumed small thus they are totally neglected, (Figure 2).
3. Model 3: 15 cm infill un-reinforced walls in all floors. In the first storey few side infill walls are included, (Figure 3).
4. Model 4: Same as in 2 but reinforced walls are included to act as shear walls, (Figure 2).
5. Model 5: Same as in 2 but the columns of the first storey are made substantially stiffer (60 cm x 60 cm), (Figure 2).
6. Model 6: Same as in 2 but the short direction has one shear wall in the soft storey, two shear walls in the above story and three shear walls in the third storey while in the long direction the soft storey has one shear wall, the second story has three shear walls and the third has 5 shear walls. Thus presenting a gradual increase in stiffness, (Figure 4).
7. Model 7: Same as in 2 but a shear wall corresponding to core in four directions is introduced at the soft storey level, (Figure 3).
8. Model 8: Same as in 1 but introducing an elevator shaft of 20 cm reinforced concrete wall in four directions in the center core of the building, (Figure 5).
9. Model 9: Same as 4 but the added walls are reinforced walls but with stone cladding. The stones add mass without considerable increase in stiffness, (Figure 2).

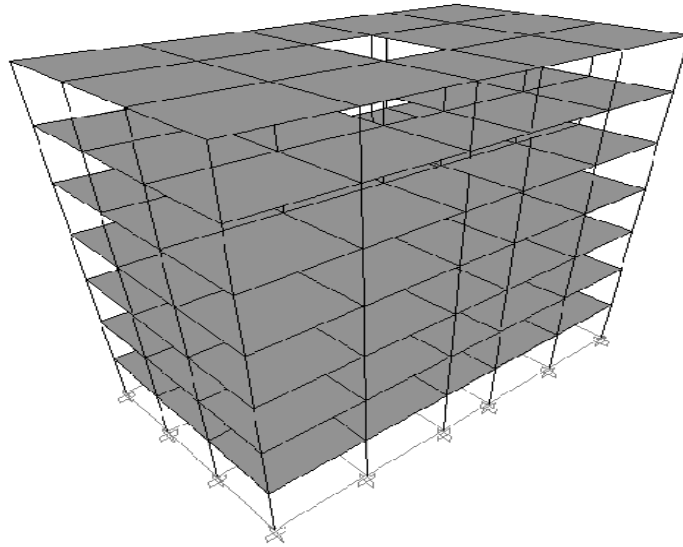


Figure (1): Schematic diagram for model 1.

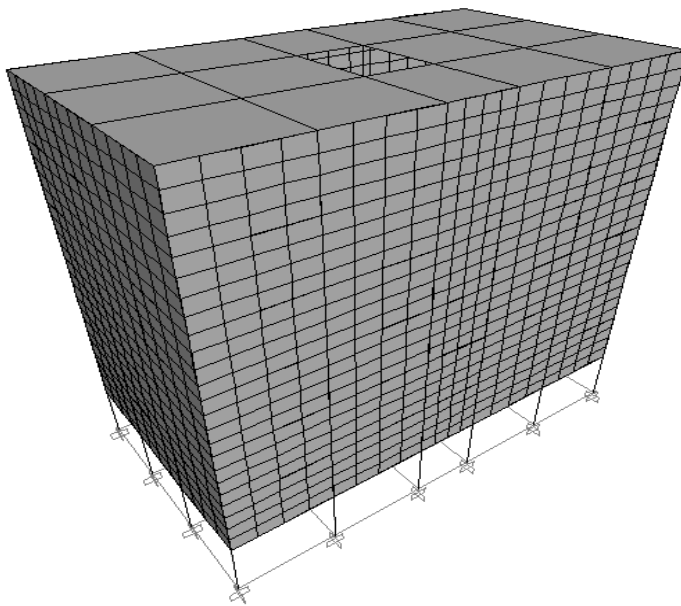


Figure (2): Schematic diagram for models 2, 4, 5 and 9.

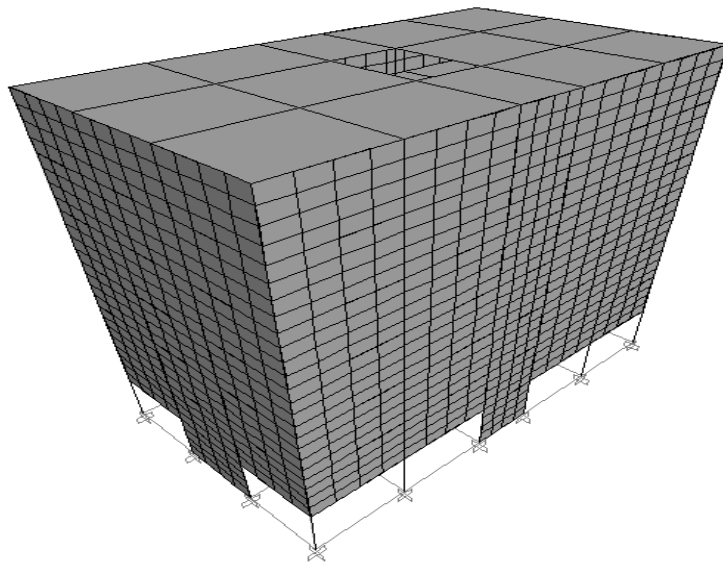


Figure (3): Schematic diagram for models 3 and 7.

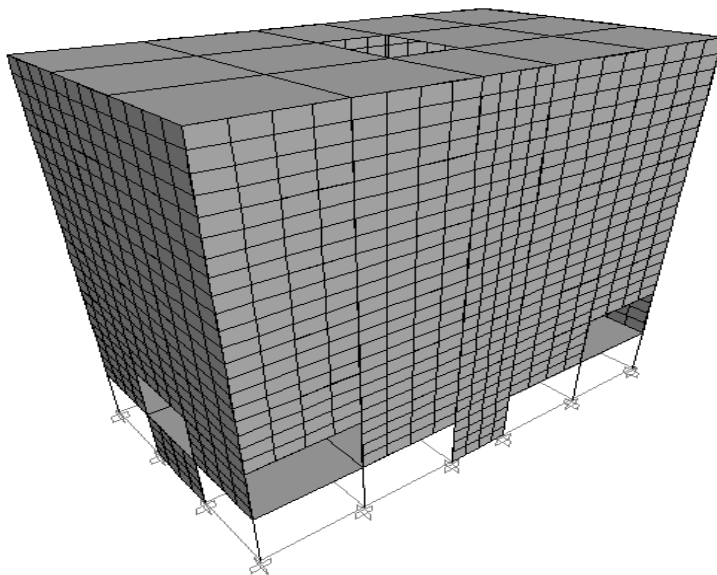


Figure (4): Schematic diagram for model 6.

a rotational stiffness component in the direction normal to the plane of the element. The plate bending behavior includes two-way, out-of-plane, plate rotational stiffness components as well as a translational stiffness component in the direction normal to the plane of the element (a thin plate Kirchhoff formulation that neglects transverse shearing deformation is used). The stairs are modeled as part of the building roof or floor system. This is in order to eliminate any induced torsion and to keep the structure as symmetrical as possible. Furthermore, only elements of prime significance to structural behavior are modeled. Window openings are assumed tiny relative to the overall wall area thus not included as they have no appreciable bearing on the general behavior of the structure (Jain, et al., 1997, p.1). Supports at the base are assigned a total fixation. Since the design is not the objective of the present discussion, uncracked sections are specified. The construction material is assumed isotropic and linear. Figure 6 shows the general layout plan of the building used in the study. The height of the structure is randomly selected at seven floors. A higher elevation does not provide added illustration to the targeted concept. A set of 12 eigenvectors are requested. Masonry walls with no reinforcement bars are modeled as contributing to the mass of the structure and providing no ductility provision. Appropriate meshing of all shell elements was generated to assure solution convergence.

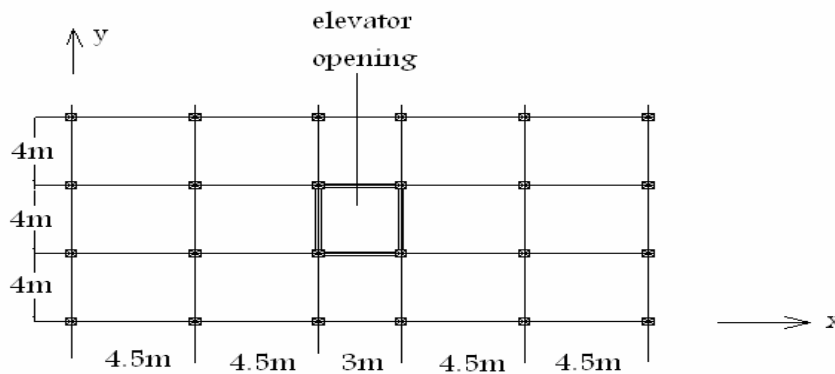


Figure (6): Floor plan of all structural models.

Model 1, as unrealistic as it is, but most widely adopted by designers has the largest mass to stiffness ratio hence the largest period. It provides almost equal periods in both directions with a mass participation factor of 0.83 for the first three modes. This makes it imperative that additional modes be included in the analysis in order to reach a code desired 90% mass participation ratio. While reinforced shear walls add substantial stiffness to the structure, pure infill walls add little stiffness. It is shown that reinforced infill walls in upper floors combined with some side reinforced walls at the first storey provide the best alternative from a strict vibration vantage point.

Comparison of the Lateral Displacements

For easy comparison of the lateral deformation of the selected systems, plots of the storey level displacement in the short and in the long directions versus height are made for the first eight models, all imposed on the same graph. These are presented in Figure 7 and Figure 8. It is clear that model 1 has the largest displacements; hence it has the smallest stiffness. The first storey displacement that is most sudden in slope appears to be in models 2, 3 and 4 then it is followed by a smooth displacement distribution. These are the models with a soft storey and irregular stiffness distribution. Gentler displacement profiles for all stories are noticed in models with uniform stiffness distribution such as models 5, 6 and 7. Model 8 resembles model 1 but with smaller amount of displacements. Models 1 and 8 have an almost linear displacement variation, unlike the other models, implying that the assumption of linear displacement variation is only acceptable if uniform stiffness distribution over the height of building prevails. Model 6 has a small first storey displacement of about 15 % of that of model 3. This implies that the crucial displacement may be effectively reduced if the stiffness of the first storey is made within order of magnitude equal to the stiffness of the story above. A similar conclusion is manifested from the displacement profiles in the long direction of the building.

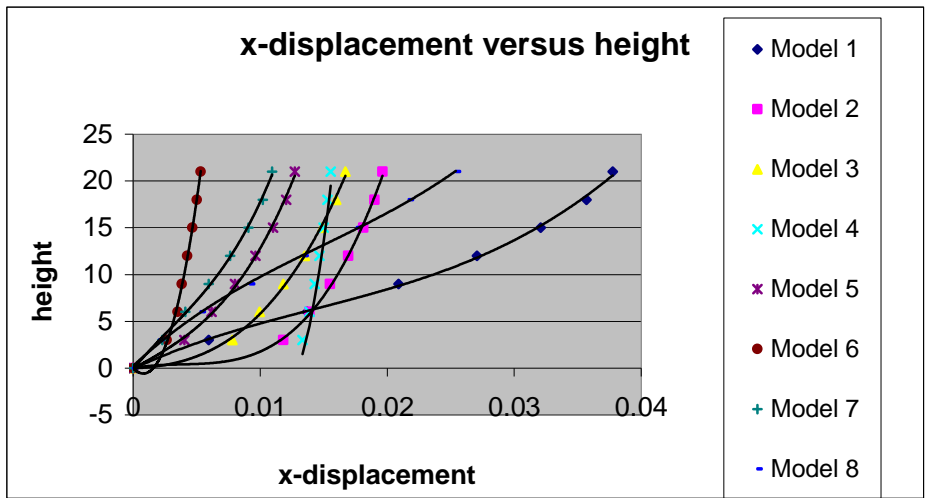


Figure (7): Displacement in the short direction versus height (units in meters).

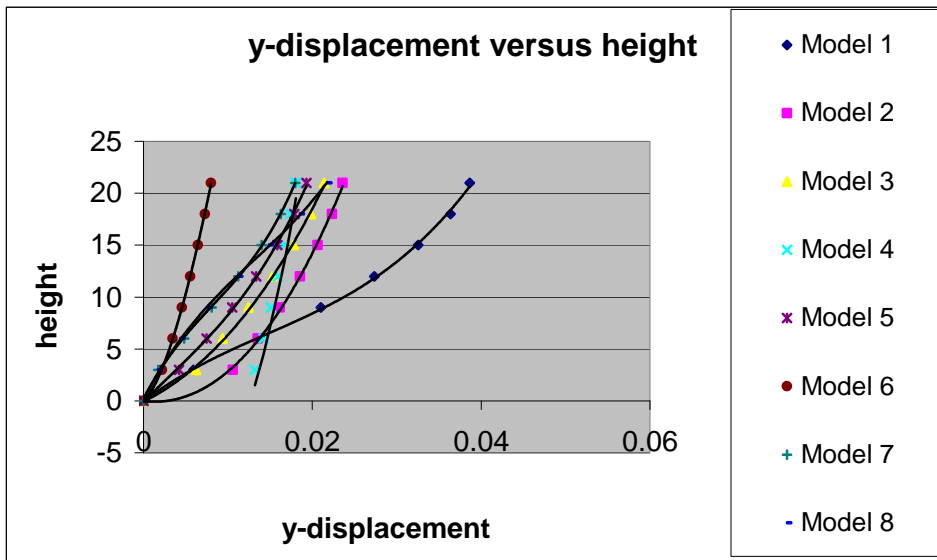


Figure (8): Displacement in the long direction versus height (units in meters).

Comparison of Design Forces

For completeness, it is prudent to compare moment and shear forces in building columns of the soft storey in all the models. The bar charts in Figure 9 and Figure 10 show the pertinent values. A quick examination of the plots reveals that there is no significant difference in behavior between the short and the long directions in regard to the shear force distribution. Axial forces, however, are consistently larger in the short direction than in the long direction.

Models 2 through 7 are almost similar in increasing force demand as compared to model 1. However, with the inclusion of elevator shaft in the first storey the shearing force demands on columns are significantly reduced.

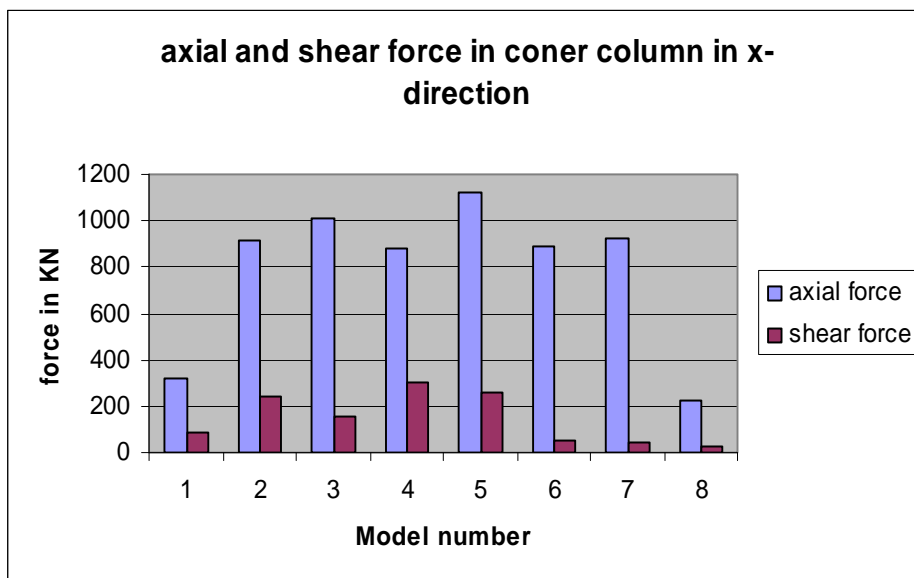


Figure (9): Forces in a typical corner column in the first storey level.

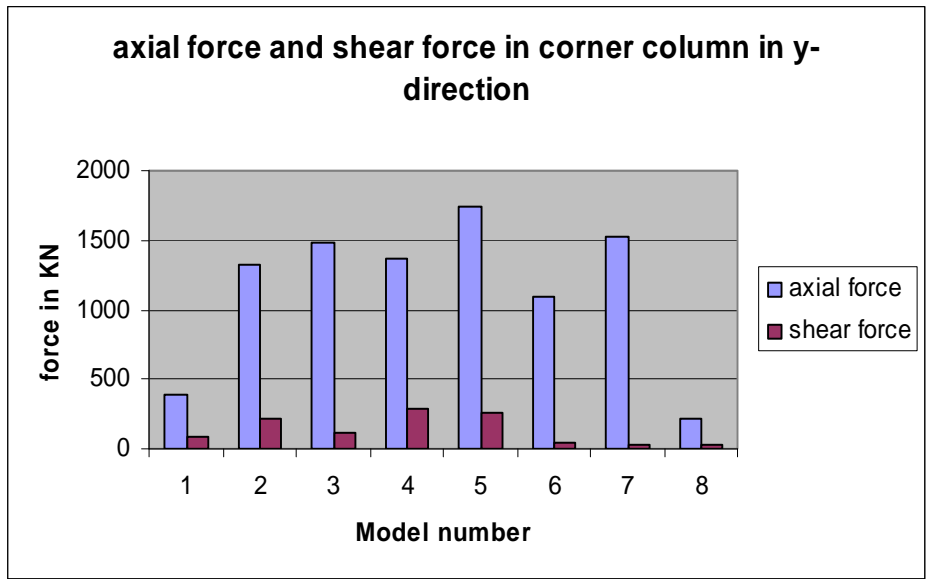


Figure (10): Forces in a typical corner column at the first storey level.

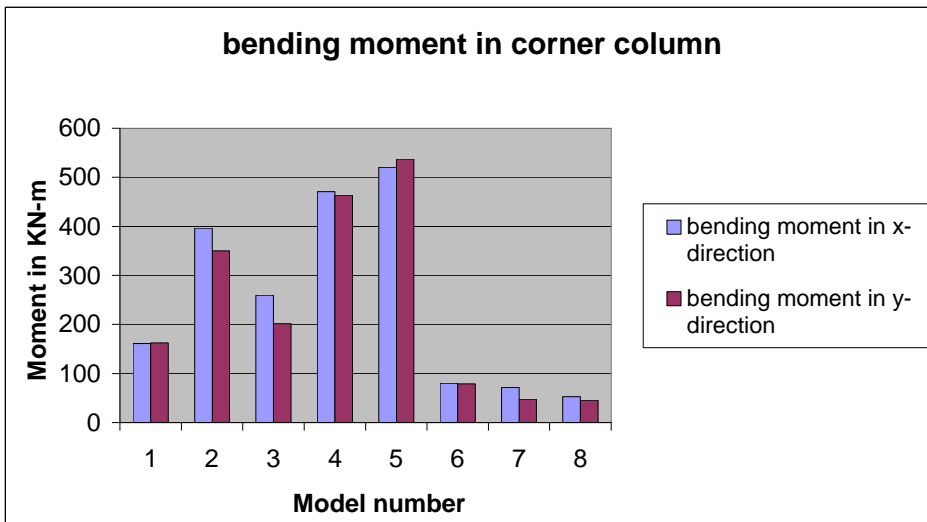


Figure (11): Bending moment in a corner column in the short and in the long directions.

Conclusions

Reinforced concrete multistory buildings with stone facades and a soft storey form an attractive and popular architectural feature in urban areas in Palestine and elsewhere in the Middle East. They will continue to gain popularity and will be adopted for many long years to come. Therefore it is essential for the structural system selected to be thoroughly investigated and well understood from a dynamic behavior vantage point as this geographical area lies within a well known active earthquake prone zone. This is also because it is a standard practice to specify masonry wall facades with no reinforcement on a bare frame structure. This is prescribed while analyzing the building as a bare frame. It is noticed that the addition of unreinforced masonry wall has an adverse affect on the response of the structure due to the resulting appreciable decrease in its fundamental frequency. The practice also calls for leaving the first floor with columns only. The forgoing presentation shows, through a rigorous analysis and examples, that a typical residential building having the said system is a vulnerable one that defies the intended goals of increasing the fundamental frequency and relieving the flexural thrust at the soft storey level columns thus avoiding the abrupt displacement. Furthermore, the results of the analysis indicate that an abrupt change in storey stiffness is responsible for the sudden change in displacement, hence placing a greater strength demand on the first story columns. It should be noticed that failure of such buildings is catastrophic. Therefore, it is suggested that immediate action be taken to avoid leaving walls without reinforcement and to never rely on column action alone to resist the bulk of the seismically induced lateral forces. It is of paramount importance that the change in stiffness between the lower soft storey and the upper floors be gradual and never abrupt. This is to be governed through shear wall placement manipulation. The influence of support conditions i.e. the soil structure interaction forms a substance for future investigative study.

