APPROPRIATENESS OF THE RIGID FLOOR ASSUMPTION FOR BUILDINGS WITH IRREGULAR FEATURES

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SUMMARY

This paper presents a brief examination of the appropriateness of a simplifying assumption frequently made in the design of multi-level buildings; specifically, the assumption that floor diaphragms are perfectly rigid in-plane when calculating the distribution of lateral forces to walls and frames. To test this assumption, two shear wall buildings with irregular features are studied. For each building, calculated lateral force distribution to walls obtained with a rigid diaphragm assumption are compared to those obtained using the actual in-plane diaphragm stiffnesses. General conclusions regarding the validity of a rigid diaphragm assumption in buildings with irregular features are given.

INTRODUCTION

Designers of buildings in seismic zones must determine analytically the strengths and ductilities required of the components of their structure. In buildings with regular features, these determinations are reasonably made with code requirements and common design procedures. However, in buildings with irregular or unusual features, common design procedures may not be appropriate and more detailed analytical models may be needed to realistically predict the seismic response and associated forces and deformations. A completely general three-dimensional analysis is always possible, but certain simplifying assumptions will greatly reduce the complexity of the analytical model, often with negligible effect on the accuracy of the results.

One such simplfying assumption often made in the design of multi-level buildings is that floor systems act as rigid diaphragms. This paper presents two case studies of concrete shear wall buildings with irregular features and compares the calculated wall shears obtained with a rigid diaphragm assumption to those obtained using the actual in-plane diaphragm stiffness. Also, a range of diaphragm stiffnesses is studied for each example to determine the sensitivity of wall shears to diaphragm stiffness. General conclusions concerning the validity of a rigid diaphragm assumption in multi-level buildings with irregular features are given.

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CASE STUDY I

The first case study presents a building with an unusual floor plan geometry. A rigid diaphragm assumption is found to give reasonable results despite the fact that initially it would not seem that this building is well suited for such an assumption.

A typical floor plan of the building is shown in Figure 1. The structure is fifteen (15) stories tall (height of 142.5 feet) with hardrock concrete shear walls and lightweight concrete, post-tensioned flat plate slabs. The slab thickness is 7½ inches. Lateral resistance in the north/south direction is provided by the four shear walls shown in Figure 1 which have the following gross dimensions constant over the height of the building.

Wall 1:	length = 70 feet,	thickness = 14 inches
Wall 2:	length = 35 feet,	thickness = 10 inches
Wall 3:	length = 35 feet,	thickness = 10 inches
Wall 4:	length = 70 feet,	thickness = 14 inches

The structure is symmetrical about the north/south centerline and code-required minimum torsional shears are not included in this example.

When the typical floor plan in Figure 1 is examined, it becomes apparent that there are several features of the building geometry which suggest that a rigid diaphragm assumption for distribution of north/south lateral forces may be questionable. Exterior Walls 1 and 4 are significantly stiffer than Interior Walls 2 and 3, and, therefore, would take a large percentage of the lateral force in a rigid diaphragm model. However, in the actual structure, the stiff exterior walls are connected to the center area only by the relativly slender "wings" or "arms" of the lightweight concrete slabs and a majority of the building mass (floor area) is concentrated near the interior walls.

The lateral analysis of the structure was carried out using the Computer Program SAP IV (Ref. 1). Shear walls between floors and diaphragm segments between interior and exterior walls were modeled as beam elements with flexural and shear stiffness. A static lateral load was applied with a triangular distribution over the height of the building and distributed in each horizontal plane on the basis of tributary mass. The following floor diaphragm stiffnesses were considered:

a. flexible floor diaphragm

b. 1/4 x actual floor stiffness

c. actual floor stiffness

d. 4 x actual floor stiffness

e. rigid floor diaphragm

The resulting distributions of shears to walls are given in Figure 2. In spite of a floor plan configuration which seems to suggest the inapplicability of a rigid diaphragm assumption, the shear distribution based on actual diaphragm stiffnesses is, overall, very similar to that based on rigid diaphragms. In addition, a rigid diaphragm assumption is reasonable for this building for a wide range of diaphragm stiffnesses ranging from 25% of the actual floor stiffness to 400% of the actual floor stiffness.

CASE STUDY II

The second case study examines a structure in which the relative stiffnesses of shear walls change abruptly at the lowest level. The building studied, shown in isometric view in Figure 3, is similar to the type of structure studied in a previous paper by Lerner and Stafford-Smith (Ref. 2). It is found that, for this case, diaphragm stiffness does have a significant influence on the distribution of lateral force to walls.

The building is eleven (11) stories tall, composed of hardrock concrete shear walls and slabs, and symmetrical about the centerline in the transverse direction. The slab thickness is 7½ inches. The structure has two exterior and two interior shear walls which are each 10 inches thick. All walls are 40 feet wide except at the first level of the interior walls where the width is set back to 15 feet for functional reasons.

The lateral load distribution in the transverse direction was analyzed with a planar computer model. Shear walls were modeled as beam elements with flexural and shear stiffness between each floor level. The floor diaphragms were modeled as one-dimensional truss elements capable of transmitting only axial forces in the two-dimensional model. To correctly model the effect of diaphragm stiffness on shear distribution, the axial stiffness of the truss elements was set equal to the actual in-plane diaphragm stiffness desired. For this building, diaphragm deformations were considered to be primarily due to shear deformations; therefore, the truss element stiffness was set equal to the in-plane shear stiffness of the diaphragm. As in Case Study I, the static lateral load was applied with a triangular distribution over height and distributed in the horizontal plane on the basis of tributary mass.

The resulting distributions of wall shears for the various diaphragm stiffness cases are given in Figure 4. The distribution for the true diaphragm stiffness case is significantly different than that for the rigid diaphragm case, especially in the lower levels. For the interior walls, the wall shear at the second level obtained with a rigid diaphragm assumption is about 300% greater than that obtained with the actual diaphragm stiffness. Also, the range bounded by 1/4 x actual stiffness and 4 x actual stiffness is much wider at the lower levels than for Case Study I.

The sensitivity of wall shears to diaphragm stiffness in the lower levels of this building can be attributed to the sudden change in relative stiffness of the exterior and interior walls between the first and second levels. The abrupt change in the width of the interior wall at the first level necessitates a large shear redistribution in the lower level slabs. Because relatively large shears are being redistributed through the diaphragms, the resulting force distribution to walls is sensitive to diaphragm stiffness.

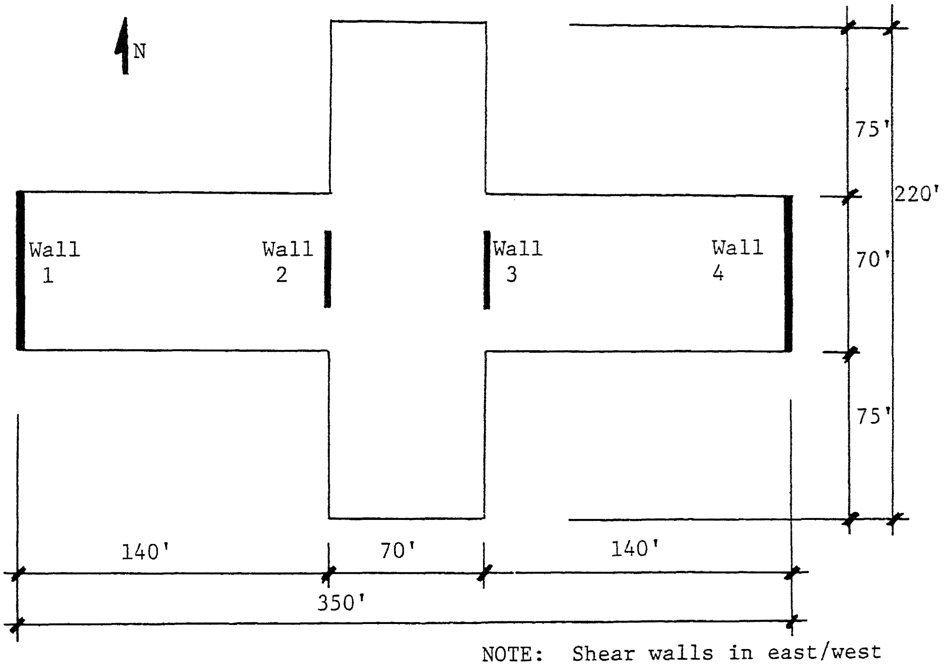
CONCLUSIONS

Use of the rigid diaphragm assumption as a basis for calculating lateral force distribution in multi-level buildings of the type studied in this paper will usually give reasonable results, especially for buildings with regular features. Also, as shown in Case Study I, even buildings with unusual floor plan geometry often behave in such a way that the floor diaphragms may be considered rigid for purposes of analysis. However, in situations where large shear redistibutions are required through the slabs, as in Case Study II, the resulting distribution of force to walls may be sensitive to in-plane diaphragm stiffness and significant differences may exist between forces obtained using the actual diaphragm stiffness and forces obtained using the rigid diaphragm assumption. Large shear redistributions may occur at floor levels where there are sudden changes in the relative stiffnesses of walls above and below the diaphragm such as at shear walls with large openings or set-backs and at discontinuous shear walls. Although the forces in individual structural elements may be strongly influenced by diaphragm stiffness in regions where wall stiffnesses abruptly change, the effect on overall building response (such as period or top-story drift) tends to be much less important.

REFERENCES

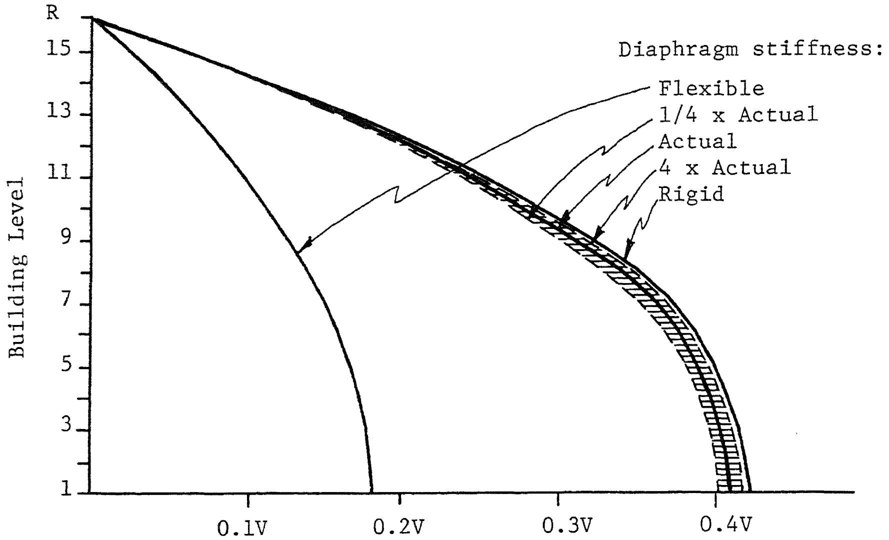
1. Bathe, K. J., Wilson, E. L., and Peterson, F. E., "SAP IV--A Structural Analysis Program for Static and Dynamic Analysis of Linear Structural Systems", EERC Report No. 73-11, College of Engineering, University of California, Berkeley, June 1973.

2. Lerner, E., Stafford-Smith, B., "Severe Interaction Effects Between Plain and Irregular Shear Walls", Proceedings of the 4th Canadian Conference on Earthquake Engineering, Vancouver, Canada, June 1983.

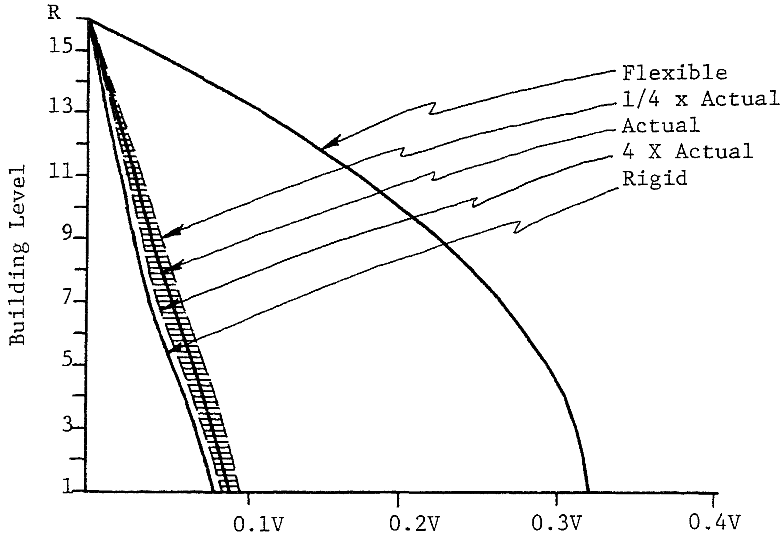


NOTE: Shear walls in east/west direction and interior columns not shown for clarity.

FIGURE 1 - TYPICAL FLOOR PLAN, CASE STUDY I



Shear - Walls 1, 4 (V = Total Base Shear)



Shear - Walls 2, 3

FIGURE 2 - SHEAR DISTRIBUTION TO WALLS, CASE STUDY I

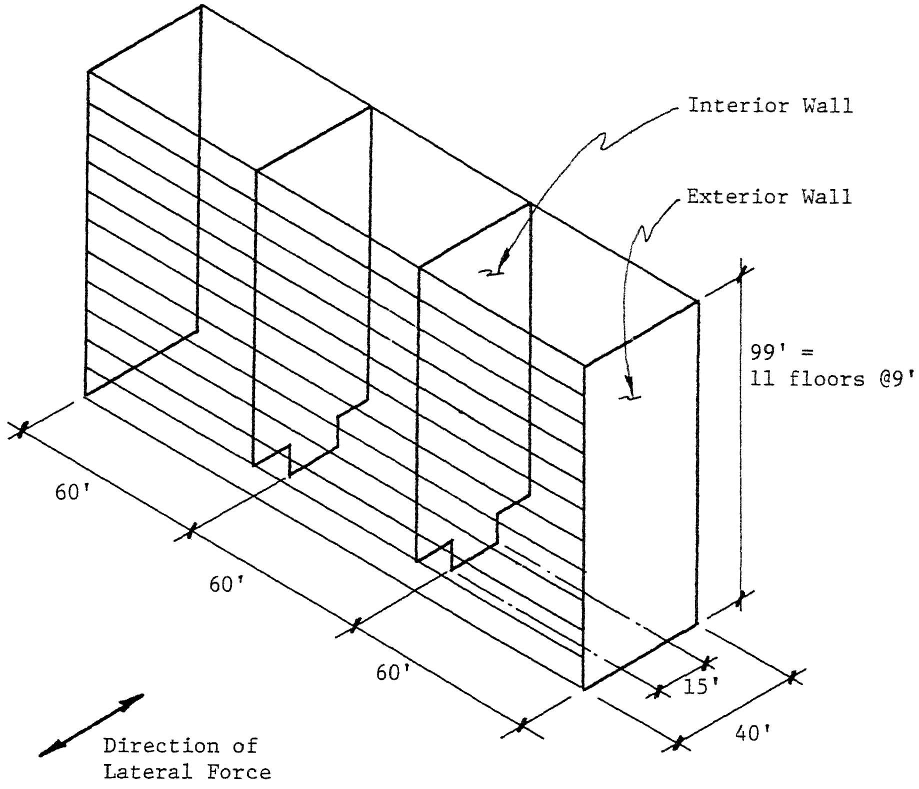


FIGURE 3 - ISOMETRIC VIEW OF BUILDING, CASE STUDY II

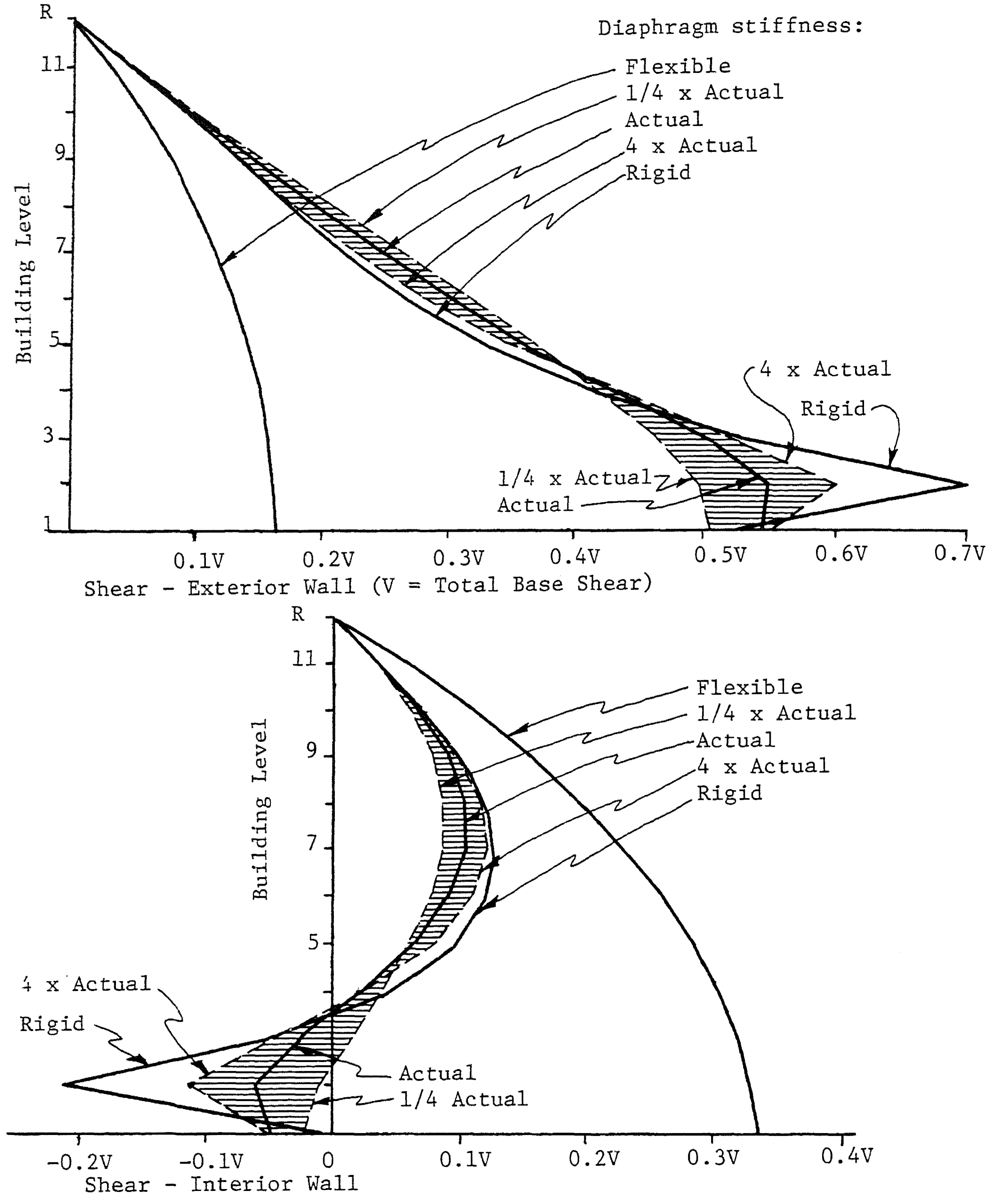


FIGURE 4 - SHEAR DISTRIBUTION TO WALLS, CASE STUDY II