STUDY OF VOLUME LOCATION IN STEEL FRAME BUILDINGS WITH MASONRY INFILL WALLS

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SUMMARY

A pilot study is presented to evaluate location efficiency of larger volumes in steel frame buildings. A typical ten storey frame building with masonry brick single-wythe infill walls is selected as the case study. Variations in volume were limited to ten different sizes and shapes. Volumes were formed by omitting a number of columns, beams and walls from the grid. Linear elastic computer analyses were used to generate building response under typical gravity and lateral loading. The response is monitored by measuring the required weight of the frame. The studies are designed to help conceptual architectural considerations where the matter of location of a larger volume is posed.

INTRODUCTION

Architectural designers are frequently confronted with program requirements for positioning a larger volume in a building. Designers have to deal with complex issues such as program, communication, organization of spaces, connectivity, environmental issues, mechanical system and structural issues. The location of larger volumes typically results from negotiating these and other considerations. The structural aspect of placement of larger volumes is rarely addressed on the conceptual level and needs structural expertise that is usually not available at the preliminary stage of architectural design.

This pilot study is to indicate the relationship between the location of a large volume and the structural response of a building with infill masonry walls. Steel frame evaluation without contribution of infill walls is presented in (1). The study is a part of a larger project to address issues in architectural designs in more systematic way and help architects make decisions based on estimated performance of building. The study is not designed to undergo a rigor of detail structural analysis performed by engineers yet is meant to address the issue of volume location embedded in buildings on a conceptual level with the least interference to structural response. The structural response is evaluated at the level of required weight of material.

To demonstrate the concept a regular rectangular grid steel frame structure with masonry infill walls was selected. The volume is created by omitting a number of structural elements. The frame was then analyzed for typical loading conditions.

CASE STUDY

The relationship between volume location and the response of a building is studied on a typical steel frame building with regular rectangular grid both in plan and elevation. In this initial investigation only the 2-D frame in elevation along the width of the building is studied. The elevation grid consists of 9m x 4m bays. The building is ten stories high with typical floor height of 4m. The height of the first floor is 5m.

Grade S355 steel was used for the entire frame. As the starting point for the frame with no larger volumes all beams are of standard section 406x140x46UC. The columns are of different sections. Columns for floors 1 and 2 had sections 305x305x198UC. Columns for floors 3 and 4 had sections 305x305x137UC and columns for floors 5-9 had 305x305x97UC. These members were later optimized to obtain the benchmark weight. The infill walls were single-wythe brick walls.

The frame was analyzed with readily available liner elastic structural analyses software. The frame was loaded with gravity and lateral loads. The gravity loads consist of 22.8KN/m linear load applied at each floor. The roof load was 16.3KN/m. The lateral load was applied as point load of 18KN at each floor and 9KN at the roof.

Volumes were created by removing a number of beams, columns and walls within the grid of the regular frame. Efficient locations were studied for ten volumes different in size and shape as shown in Figure 1. The volumes were compromised of combinations of two, three and four bays and/or two, three and four stories.

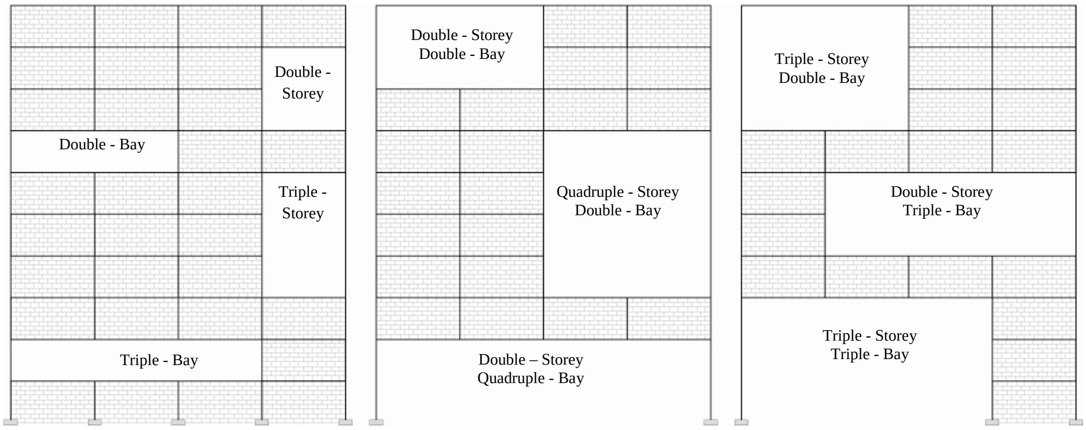


Figure 1. Ten Volumes Different in Size and Shape

Each particular size and shape of the volume was systematically repositioned within the frame in vertical and horizontal directions. Structural analyses were performed for each particular position of the volume. For the given location of the volume the members of the frame are automatically sized and optimized to best meet the British code (BS5950-1) with the least amount of the material. Total take-off of the material was recorded for each frame.

Structural analyses were performed for 2-D frame. Volume is represented by the clear surface in the plane of the frame with no walls, columns and beams. The response of the building was quantified by monitoring weight ratio. The weight ratio is defined as:

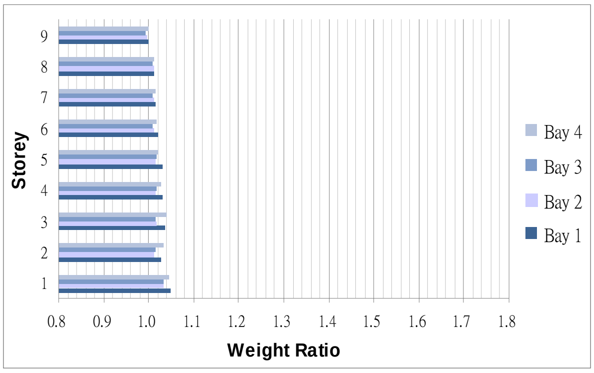
$$(\text{Weight Ratio})_i = W_i/W_0$$

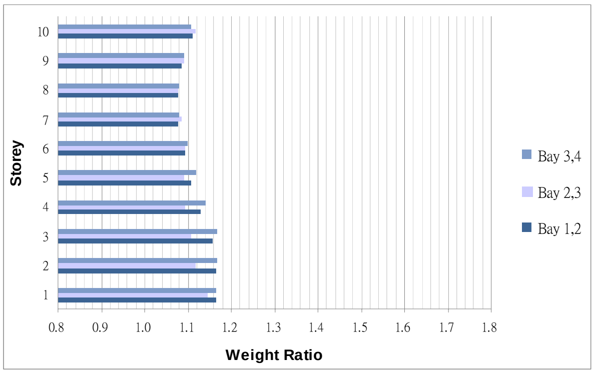
where, *Wi*, is the total weight of the frame members for the embedded volume, W_0, is the total weight of the frame members without any large embedded volume, and ,*i*, indicates the location of the considered volume. The size of the steel frame members was modified to optimize the total weight of the frame members for the given loading condition.

RESULTS OF THE ANALYSES

Number of analyses were performed to generate results presented in the graphs. All graphs are organized in the similar fashion with weight ratio being plot along the horizontal axis and the sets of volume location along the vertical axes. The sets for each storey summarizes data for volume occupying one, two, three or for bays as described by the key in the graphs. For example, bay 1,2 index for double-bay volume in Figure 3 indicate volume double-bay volume or volume occupying bay one and two only .

Figures 2 and 3 show the results for double-bay and double-storey volume being placed at different stories and along various bays. Double-bay volume is less favorable than double-story volume. Placement of the double-story is more efficient at the upper storey and inner bays such as bay 2 and 3. On the other hand, placement of double-bay volume is more efficient at approximately 2/3 of the height regardless of the bay selection. At the lower storey the inner bay location is still more efficient.

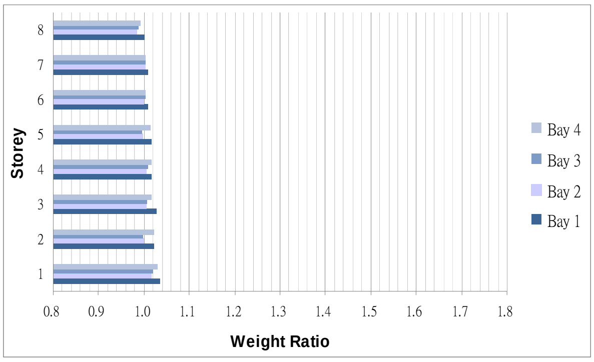


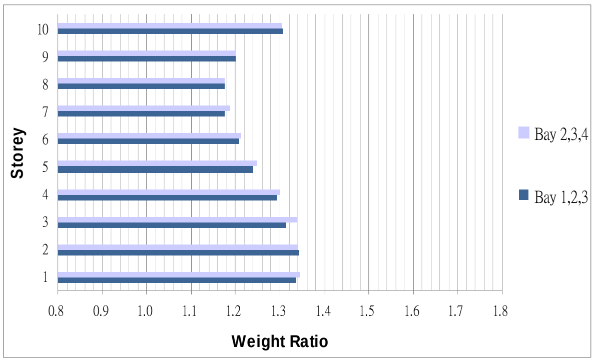


Figures 2. Double-Storey Volume

Figures 3. Double-Bay Volume

Figures 4 and 5 show the results for triple-storey and triple-bay volume. Efficiency of triple-bay volume is about 20% less than triple-story and about 10% less than double-bay volume. An efficient location is again approximately 2/3 of the height of the building.

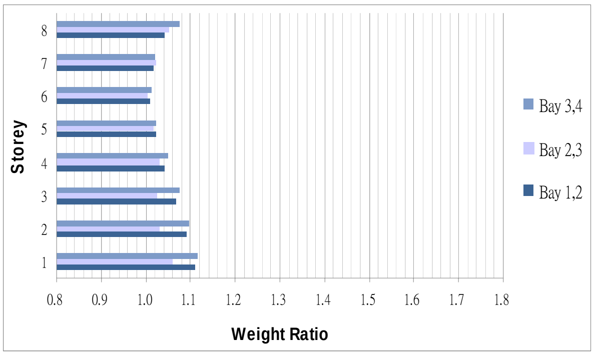


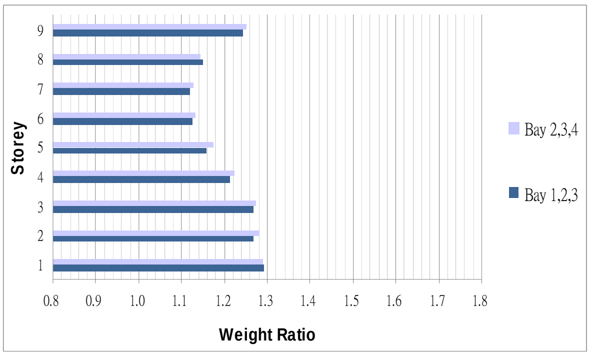


Figures 4. Triple-Storey Volume

Figures 5. Triple-Bay Volume

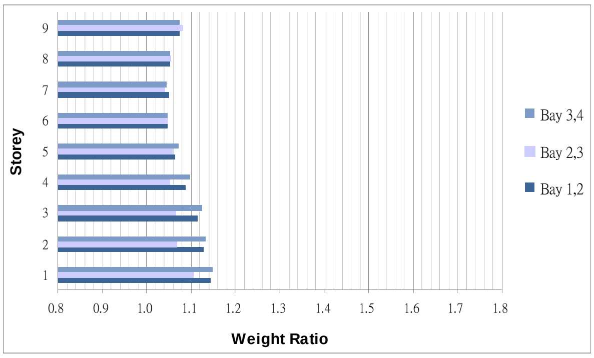
Figures 6-11 show the similar trend. Creating volume by increasing span is less efficient than creating volume by increasing height. Larger spaces occupying more than one bay and storey are efficiently placed if at 2/3 of the height of the building. Location dependency on inner or outer bay is less significant than the clear span of the volume. It is interesting to note that results for triple-storey-triple bay volume presented in figure 9 indicates more efficient volume than smaller double-storey-triple-bay volume presented with results in Figure 7. Volume occupying space from one façade to the opposite façade, quadruple-bay, significantly increases the need for more material as shown in Figure 11.

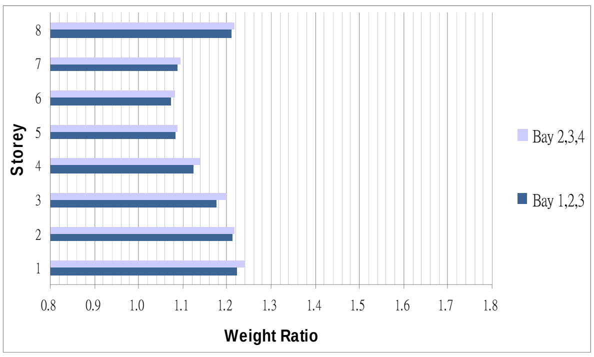




Figures 6. Triple-Storey-Double-Bay Volume

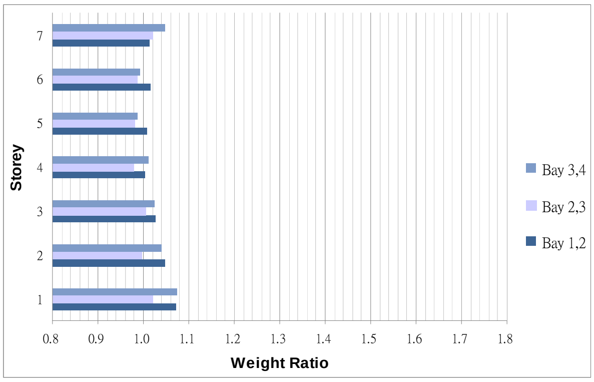
Figures 7. Double-Storey-Triple-Bay Volume



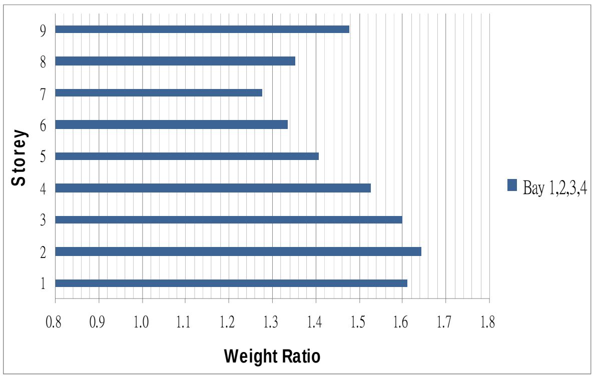


Figures 8. Double-Storey-Double-Bay Volume

Figures 9. Triple-Storey-Triple-Bay Volume



Figures 10. Quadruple-Storey-Double-Bay Volume



Figures 11. Double-Storey-Quadruple-Bay Volume

CONCLUSION

Efficiency in placing larger volumes in a regular steel frame building with brick infill walls was investigated. Computer analyses were performed for typical gravity and lateral loads. Response of the building was measured by monitoring the required weight for the material.

The study reveals that embedment of a larger volume in a regularly grid frame carries the penalties with respect to the weight of the required material. Clear span of the volume is more critical than clear height of the volume which was expected for the particular width to height ratio of the building. It also reveals that efficient location of the larger clear span is about 2/3 of the height of the building. The effect of the volume location in adjacent inner or outer bays is less significant than story location. Full contribution of the masonry infill walls to the efficiency of the volume location would require further studies.

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