STRUCTURAL DESIGN AND ANALYSIS OF GALLERIA PALACE

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Abstract

This paper presents the structural design and analysis of the Galleria Palace. As a residential development, this building is located at Jamsil district, Seoul, Korea. It is comprised of 3 towers with 46 stories (149.5m-high). The towers are currently under construction. The structural system is a dual system and composed of main core wall, outrigger girder, fin wall, and perimeter frame. The perimeter wall was designed for seismic resistance however for resisting lateral loads. The paper described case study on various combined structural elements in deciding the most effective design for increasing the stiffness of the structures. A detailed analysis of outrigger is also presented.

Keywords: Tall buildings, Structural System, Outrigger Girder

1. Introduction

The increase of the high-rise building gains is in proportion to the development of the structural analysis tools, materials, and construction technologies. The existence of high strength concrete makes it possible of designing the Reinforced Concrete high-rise buildings, hence the increase in R.C. high-rise buildings currently being constructed in Korea. The Galleria Palace was designed as a Reinforced. Concrete building with 46 stories above ground and 5 stories underground. This project focuses on the optimum structural design system as well as, one which satisfies the architectural requirements. The structural system was analyzed by considering a combination of systems and their stiffness being examined.

![The Galleria Palace](image)

2. Layout of Galleria Palace

The Galleria Palace is a reinforced concrete building for residential purposes at Jamsil, Seoul. It comprised 3 towers with 46 stories above ground and 5 stories at underground level. The footing system rest upon a layer of bedrock. The de-watering system was designed at the basement as the ground water level is located at 6m from ground level. The building is 148m x 133m in area. The underground parking was designed as a PC structural system and the diaphragm wall as the outer wall. The underground is 5m in height with 2.95m for typical floors, thus giving an overall height of 150m. The mechanical floor is located on the 15th floor with the outrigger designed at 16th floor.
2.1 Structural Sections and Materials

The concrete strength of the vertical members from the 5th underground floor to 9th floor above ground is 500kgf/cm², whilst 400kgf/cm² for 10th to 19th floor and 350kgf/cm² for those above 20th floor. The horizontal members were made of concrete strength 350kgf/cm². By using high strength concrete, the size of column of the 1st floor can be designed to a dimension of 800x1500mm. By using a slab of 200mm thickness together with a 350mm perimeter girder depth, the story height can be minimized. Additionally, girders of over 1500mm width were designed to play the role of wide beams. The core wall is 800mm thick at underground level and 450mm and 600mm thick above ground level. The analyses for this project were conducted using MIDAS-GEN program. The rigid model is analysed by 3-dimensional modeling whilst the outrigger being modeled partially using solid elements.

Fig 2. Elevation of Building

Fig 3 Typical Floor Plan

Fig 4 16th Floor Plan(Outrigger Girder)

3. Structural System Analysis

3.1 Structural System

As an initial step, the most important for any high-rise building design is the lateral load resisting system. Normally, the shear wall system is used for resisting lateral loads in buildings lower than 40 stories, however this system is uneconomical for the high-rise buildings because its flexibility to resist lateral loads. Therefore, some other various lateral load resisting systems are being applied as alternatives. The outrigger girder improves the stiffness of a structure. The Galleria Palace used a core wall, outrigger girder, frame, and fin wall. Some case studies are carried out to study the stiffness of the system. The case studies are as follows:
Case 1: Core Wall Only
Case 2: Core Wall + Lower Outrigger
Case 3: Core Wall + Perimeter Outrigger
Case 4: Core Wall + Lower & Upper Outrigger
Case 5: Core Wall + Lower Outrigger + Perimeter Frame
Case 6: Core Wall + Lower & Upper Outrigger + Fin Wall
Case 7: Core Wall + Lower Outrigger + Perimeter Frame + Fin Wall

The lower outrigger (1500x1600mm) was set up at the 16th floor and the upper outrigger (1500x1500mm) at the 43rd floor. The perimeter girder is 1500x350mm and is connected to the outer columns. As the outriggers lean relatively towards the lower side against the building height, the fin wall (Thk. 300mm) was then set up between the 15th and 43rd floor in order to satisfy the limit of story drift due to the seismic load. The core wall thickness is 800mm at underground, 600mm from 1st to 16th floor, and 450mm above 16th floor.

3.2 Stiffness Analysis of Systems

The displacement and stiffness in each case will be compared to the results of a structure containing the core wall only (case 1).

The case studies show that an outrigger is effective in increasing the stiffness of structure and limiting the displacement. Of course, the effectiveness of the outrigger system is variable in accordance with its location. In this project, the lower outrigger has a higher stiffness than the upper one. The stiffness of the upper outrigger and frames are increased by 10% as compared with the case 1. For the upper outrigger, a considerable amount of stress is generated due to the deflection difference between the core wall and column. For convenience, the perimeter frame has been adopted as a lateral load resisting system and the upper outrigger removed. However, the perimeter frame is difficult to construct because of seismic detailed requirements and where thinner beam is required. The fin wall has been adopted to increase the stiffness about X-direction. The wall stiffness in X-direction is relatively lower than that of Y-direction due to the shape of the core wall.

Fig. 5-1 Story Drift of Rx
Fig. 5-2 Story Drift of Ry
Table 1. Comparison of Stiffness of Each System (System 1 is 100% versus others)

<table>
<thead>
<tr>
<th>Contents</th>
<th>System 1</th>
<th>System 2</th>
<th>System 3</th>
<th>System 4</th>
<th>System 5</th>
<th>System 6</th>
<th>System 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness</td>
<td>Tran x</td>
<td>100%</td>
<td>133%</td>
<td>109%</td>
<td>110%</td>
<td>143%</td>
<td>140%</td>
</tr>
<tr>
<td></td>
<td>Tran y</td>
<td>100%</td>
<td>119%</td>
<td>111%</td>
<td>108%</td>
<td>129%</td>
<td>124%</td>
</tr>
<tr>
<td>Rot z</td>
<td>100%</td>
<td>124%</td>
<td>97%</td>
<td>96%</td>
<td>120%</td>
<td>116%</td>
<td>134%</td>
</tr>
<tr>
<td>Wind Disp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-axis</td>
<td>Disp.(M)</td>
<td>0.5846</td>
<td>0.4484</td>
<td>0.4917</td>
<td>0.4632</td>
<td>0.3822</td>
<td>0.3712</td>
</tr>
<tr>
<td></td>
<td>K(%)</td>
<td>100%</td>
<td>130%</td>
<td>119%</td>
<td>126%</td>
<td>153%</td>
<td>157%</td>
</tr>
<tr>
<td>y-axis</td>
<td>Disp.(M)</td>
<td>0.3051</td>
<td>0.2591</td>
<td>0.2550</td>
<td>0.2533</td>
<td>0.2206</td>
<td>0.2221</td>
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<tr>
<td></td>
<td>K(%)</td>
<td>100%</td>
<td>118%</td>
<td>120%</td>
<td>120%</td>
<td>138%</td>
<td>137%</td>
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</table>

4. Analysis of Outriggers

4.1 Outline

The stiffness of outrigger is 20~30% of the overall stiffness of building. In general an outrigger is effective in controlling displacement and story drift and reducing the moment generated in the core wall. While the study focuses on the effectiveness of the locations and numbers of outrigger, in this project the outrigger connections have been studied through some detailed analysis. Due to the width of outrigger being larger than that of core wall, an eccentric moment at the connection is generated and the stiffness reduced. Therefore, a detailed design and the stiffness reduction have been considered to the lateral stiffness of this building. Total of 7 outriggers and Perimeter Frame (1500x1600m) along the boundary have been set up. Despite that 8 outriggers are more effective, only 7 outriggers have been established because at one of the outrigger the distance between the core wall and column is so close that majority of the stress is generated by lateral loads and column shortening.

4.2 Analysis of Outrigger

Regarding the stiffness evaluation, 4 of the models have been evaluated by the stiffness change in accordance with the location of core wall and outrigger. To examine the local torsional moment in outrigger and out of plane moment in the retaining wall, the 16th floor has been modeled by solid elements. The span between the core wall and columns is about 9m; outrigger size is 1500x1600mm, and core wall thickness is 600mm. Accordingly, the eccentric distance between the core wall and outrigger girder is 450mm. The vertical loads are applied randomly to evaluate moment and shear force generated from the entire model. The following cases are considered in the analyses.

Case 1: set up the outrigger inside of the core wall
Case 2: set up the outrigger at the center of the core wall
Case 3: set up the outrigger outside of the core wall
Case 4: One Span Model By Solid Element

![Fig 6-1. Case 1](image1)
![Fig 6-2. Case 2](image2)
![Fig 6-2. Case 3](image3)

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Table 2. The stiffness evaluation according to the outrigger location

<table>
<thead>
<tr>
<th>Case</th>
<th>Displacement (cm)</th>
<th>Rate according to Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>14.54 cm</td>
<td>72.08 %</td>
</tr>
<tr>
<td>Case 2</td>
<td>14.12 cm</td>
<td>74.22 %</td>
</tr>
<tr>
<td>Case 3</td>
<td>14.28 cm</td>
<td>73.39 %</td>
</tr>
<tr>
<td>Case 4</td>
<td>10.48 cm</td>
<td>100 %</td>
</tr>
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</table>

4. Results and Rebar Arrangement

The displacements for the various outriggers locations are shown in Table 2. It is evident that the system of case 3 i.e. when the outrigger is set outside the core wall, will cause a reduction in displacement by 27% in comparison with case 4. Hence considering the cracked section, 50% of the stiffness reduction is then applied in the 3-Dimensional modeling. Fig.7 shows the moment generated due to the eccentricity of outrigger girder and core wall. The tension and compression forces are generated in the slab, the torsional force in beams, and the out of plane moment and shear stress in upper and lower part of the core wall. Thus, additional stirrups were introduced to act against torsion in the outrigger. Additional bars have also been used vertically in the core wall and horizontally to overcome tension.

Fig 7-1. Section Shape  
Fig 7-2. Gravity + Lateral Load(↓)  
Fig 7-3. Gravity - Lateral Load(↑)  
Fig 7-4. Reinforced Design concept  
Fig 7-5. Outrigger Girder Elevation  
Fig 7-6. Section of Outrigger

Top Bar : 22-SHD32
Bottom Bar : 22-SHD32
Stirrup : Outer 2-leg-HD22@100
Inner 4-leg-HD13@100
Conclusions

(i) The design of lateral load resisting system is considerably important. When the building system in the design of high-rise buildings has been decided, it is important to consider the effect of each system upon the stiffness of the overall structure.

(ii) When the upper outrigger is designed, it is required to consider the effect of elastic or inelastic deflection on the building.

(iii) When the outrigger stiffness is evaluated, it is required to reflect the stiffness reduction about entire model with considering every condition. The location of outriggers influenced the stiffness of the overall structure, hence it is important to analyse every possible location of outriggers before concluding on the final location(s).

(iv) It is required as the inelastic behaviour depends on the outrigger girder establishment.

(v) When the core wall is designed, the reinforcement about the local stresses due to the eccentric load is required at the same time.

Reference

5. Korea Concrete Institute. (1999), Ultimate Strength Design Method for Reinforced Concrete Building Structures