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Structural Analysis and Design of Transferred Shear Wall Type Structure

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Abstract

The PARKVIEW is a grand scale residential complex in the suburbs of Seoul. That is comprised of 13 buildings with 30–35 stories above ground and 1 basement floor. The 428m × 276m basement floor is planned to be a parking area, and the deck floor is artificial landscape. The structural system of the apartment buildings is shear wall system. Shear walls support the whole gravity loads and lateral loads. Offset Outrigger walls are placed in the pit space under the top floor to supplement the lack of lateral stiffness. For all buildings, more than half of units are transferred from the shear wall structure to the moment frame. To analyze the dynamic characteristic and estimate the diaphragm effect of the transferred structure, the accurate F.E.M analysis was performed. Besides, for the optimal design of joints, the temperature analysis of basement floor was performed using the F.E.M model that is able to consider the stiffness and deformation of apartment buildings, retaining walls, columns, and slab. In this paper, various cases studies and accurate analysis results applied to the structure design of PARKVIEW are introduced.

Keywords: outrigger wall; transferred structure, shear wall structure

1. Introduction

The growth of the high-rise buildings makes high-storied shear wall type structures possible. These shear wall type structures represent residential buildings. Therefore, the upper part of the building is a shear wall system for a residence, but the lower part of it is a moment frame system with girders and columns for an architectural request. After all, it needs the transferred system.

The PARKVIEW is a RC shear wall type structure for a residence at Bundang, Kyunggi Province. It is comprised of 13 towers with 30–35 stories above and 1 underground. 7 towers are rectangular-shaped buildings and 6 towers are L-shaped buildings. The upper stories (5–35 stories) of buildings are shear wall types for a residence and these walls are transferred to a moment frame system by transfer system at the forth floor. The first story is parking area, and the second story and third story make the deck floor with a park for landscape and road for a fire load. RC beam and girder system resists gravity load at the 1–3rd floor.

The key concern in designing was that the thickness of shear wall was minimized for efficiency of architectural space and maximization of sale in lots. Therefore, structural request is that buildings have thin shear walls for large rooms and joints for a wide parking area.

Fig. 1. This is the View of PARKVIEW.

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2. Structural System

2.1 Building Introduction

PARKVIEW is comprised of 13 towers with 30–35 stories above and 1-story underground (Fig.1.). The Basement and 1st floor are large parking lots with 428mX276m space. And the 2nd floor (deck floor) is the area for an architectural landscape.

In the low storied area except towers the concrete strength, from the foundation to the 2nd floor, is 27Mpa. In towers the concrete strength of the vertical members from 1st basement to 9th above ground is 35Mpa, 30Mpa from 10th to 19th, 27Mpa from 20th to 26th and 24Mpa from 27th to the last floor. But there is one exception to this case. The concrete of strength of the offset Outrigger walls, in the pit space under the top floor, is 35Mpa. The slab of towers has the same strength as shear wall for convenience of the construction.

2.2 Foundation System

The foundation of towers has the pile foundation by the condition of soil. The site can have soil bearing capacity of 650kN/m² or more partially, therefore the shallow foundation can used partially. But pile foundation is applicable as a result of the conference because soil layer ranges somewhat irregularly.

In analysis both the lateral and gravity load (dead load, live load) of shear walls (in towers) are considered. But seismic load only is applied to the design because seismic load is relatively larger than wind load.

The concrete strength of all foundation is 27Mpa for shear of the foundation. The mat under towers is 1800mm thickness, which considers the safety for the embedment of pile and the space for rebar arrangement to shear, moment. The rebar for gravity load and lateral load is added to minimal reinforcement ratio.

In the low storied area except towers, the bearing capacity of soil is considered as 150kN/m² and soil improving reinforces the area below 150kN/m². Mat foundation is used because of low capacity of soil. In the schematic design, the mat with 1000mm thickness was assumed, but the reduction of mat thickness could decrease the construction cost fairly. Therefore, in the stage of design development mat with 900mm thickness is used and shear rebar reinforce the zone around partial columns to punching shear.

2.3 Gravity System

Slab system of deck floor and parking area is RC beam and girder system with slab of 200mm thickness, which is selected for construction and saving of construction cost after comparing the alternative. In towers slab and shear wall resist the gravity load. The thickness of Slab is 150 or 180mm by span of slab. The thickness of shear wall is 200mm for considering the minimal eccentricity.

2.4 Lateral System

Shear walls are used for lateral system in addition to gravity system. Fig.2 shows the typical floor plan with rectangular-shaped plan. As shown in this plan, the stiffness of the long direction (x-direction) is less sufficient than it of the short direction (y-direction). If the link beam of the interior is used as the element for lateral loads, the stiffness of x-direction is enough to resist lateral loads. This method is good to control the displacement by lateral loads, but the link beam in most stories is damaged by shear failure. Therefore, this idea is impossible unless the device for reinforcement (the reinforced plate needs the minimal width of 400mm) is applied.

Fig.3 presents the percentage of the stiffness contribution in each component for lateral loads. If the stiffness of the core is increased (core behaves as a box), insufficient stiffness capacity for x-direction can be improved against removing interior link beams. But the core has the coupled beam (link beam) because of the behavior of the core. Finally the thickness of core walls is 400mm, and 300mm for walls dividing units, 200mm for interior walls. This selection for efficiency makes possible optimal design for lateral system.

Fig. 3. Stiffness contribution rate of each component for lateral loads

[x-direction] [y-direction]
3. Special Topics

3.1 Offset Outrigger Wall

13 towers in the site are divided into three types, rectangle-shaped, L-shaped and V-shaped type (Fig.4). Rectangle-shaped type of them needs some addable stiffness components in addition to the system given in the chapter 2.4 because 13 towers have the different capacity to lateral system. Besides, the towers need it when the coupled beam of the core acting as the box is failed in shear.

The outrigger in the Fig.5 is established in the suitable place (x-direction) and it fills the role of controlling the displacement as the stiffness component against the lateral loads. The fit sized-outrigger is designed to satisfy the flexural and shear stress. Addition of the outrigger reduces the excessive stress of core and interior wall (x-direction). Besides it makes to design all elements safely. The supplement of the outrigger has an effect on controlling the deformation as shown in Fig.7.

For reinforcement of insufficient stiffness the offset outrigger walls (let’s call outrigger from now) are added to rectangle-shaped plan by these causes. There is the pit space (H=2.1m) under the large unit (pent houses) and the outrigger is established in this floor for stiffness reinforcement. The plan of pit floor with outrigger is shown Fig.5 and the section of pit with outrigger is shown Fig.6.

The behavior of the system is explained with reference to Fig.8. Actually the extent of efficiency of the outrigger, against lateral loads, is analyzed as shown Fig.8. The figure (a), (b) represent the reduction of displacement by the wind load and drift ratio by the seismic load respectively.

In the rectangle-shaped plan, the outrigger increases the insufficient stiffness of the long direction without the coupled-composite beam. So the outrigger on pit is an efficient system in the maintenance and safety of the structure.

3.2 Transfer System

In 13 towers shear walls are transferred to the moment frame by transfer plate at 4th floor. Transfer plate system is used.

Generally the key in designing the transfer system is as follows.
1) Make the space under the transfer floor to satisfy architectural requests
2) Consider the stiffness irregularity by soft story and discontinuity in capacity by weak story
3) Consider the stress concentration of shear wall above the transfer floor

(1) Application of architectural request
Columns are arranged in three lines to consider the module of columns. This makes the facade with a same line. The thickness of the transfer plate is decided on 1500mm or 1800mm by the module of columns.

(2) Consider soft story and weak story
There are transferred units and non-transferred units in one tower. In transferred units, the thickness of walls connected to the transfer plate is increased from 400mm to 600mm. This also helps the stiffness below transfer floor.

At first, it is checked that the exterior walls in the transferred units can transform into columns. The soft story and weak story are considered in the story below the transfer floor, but the volume of walls under transfer floor is insufficient. Finally the exterior wall is used as it is.

As a result of checking, 13 towers are not applicable to the soft story and weak story. But in discontinued floor, the stirrups are arranged by proposed standards to get sufficient ductility and resist an accidental torsion safely.

To analyze a transfer plate, the modeling using fine plate element is applied (3.2(3)). U-bar, same diameter and space with main rebar, is used to secure the anchorage length and consider the edge effect by an accidental torsion.

(3) Stress concentration of shear wall above transfer floor
In designing shear walls above transfer floor, stress concentration (by gravity loads) and added stress (by differential shortening of shear walls) must be considered.

Shear wall has an adequate strength of concrete to resist the lateral and gravity loads. The differential shortening adds the stress to shear wall. These secondary stresses are produced by lateral and gravity loads (Fig.10). Therefore, it needs a detailed analysis for 5~6th floor in addition to transfer floor (4th floor).

Accurate modeling values the behavior of shear wall above transfer floor accurately as shown Fig.11. Shear wall is modeled with a fine element plate and typical slab is considered as a semi-rigid diaphragm. The difference of stress is estimated by comparing the general analysis and an accurate analysis.
3.3 Plan for Joint

The slab with a large area is affected with a temperature, a drying shrinkage of concrete. The kind and position of joints is key point to decide an architectural plan, a performance for construction work and safety.

Delay joints are installed around towers. They reduce stress of shear wall by drying shrinkage of concrete at deck and 1st slab. And they help to reduce the differential settlement of towers and the rest of towers.

At first, it is designed to reduce stress of slab by movement joint (M.J.) if there is a problem of stress in a slab without M.J. Installed delay joint minimizes the stress of slab by shrinkage of concrete. Last of all M.J. isn’t necessary.

Fig.12 shows a slab analysis model considering an effect of a temperature in planning joints at deck floor. It knows that stress concentration is represented around towers. Fig.13 shows a model for 1st for a parking space. For analysis stiffness of basement wall, shear wall at towers, and columns are considered.

Fig.12. Slab analysis model considering an effect of a temperature in planning joints at deck floor

Fig.13. Slab analysis model considering an effect of a temperature at 1st floor (428mX276m)

4. Conclusion

(1) The strength of concrete is 35, 30, 27, 24Mpa by considering safety, practical part and a performance for construction work. The strength of slab concrete is same as shear wall for workability.

(2) 13 towers are divided into three types, rectangle-shaped, L-shaped and V-shaped type. Because the lateral stiffness of a long direction (x-direction) is insufficient in the rectangle-shaped plan, the key point is obtaining the stiffness of x-direction for lateral loads.

(3) The most efficient core for lateral loads resist lateral loads by box behavior. In the insufficient towers for lateral loads, offset outrigger wall is used as a stiffness component. It contributes to the lateral stiffness by establishing in pit space.

(4) The transfer columns of tower are designed to the system without the soft and weak story. Shear walls above the transfer floor are designed to value the stress by accurate analysis.

(5) In the large area for parking, delay joints are installed around towers to reduce stress of shear wall by drying shrinkage of concrete at deck and 1st slab. Also, the help of delay joint doesn’t establish movement joint.

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