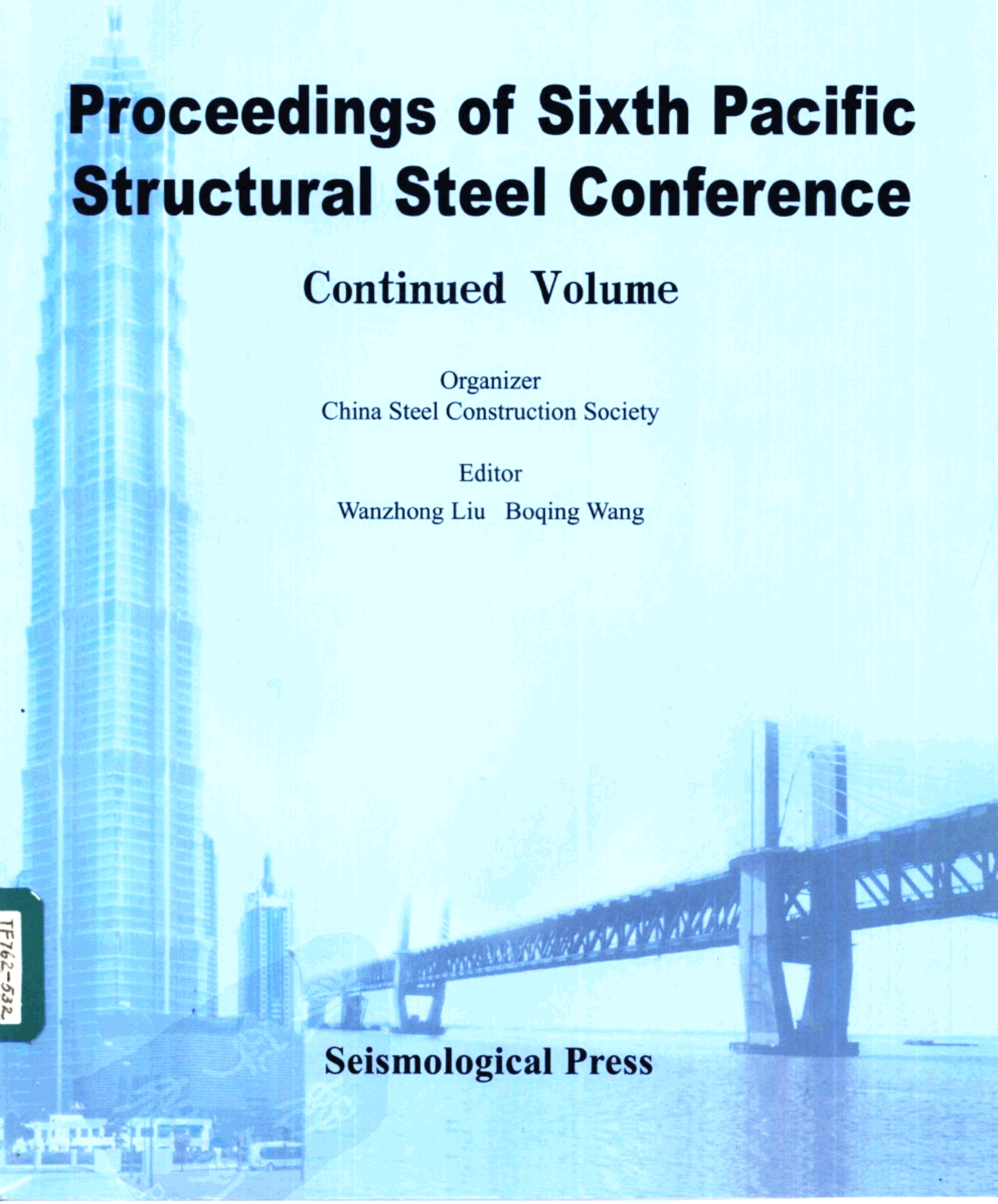

15~17 October 2001, Beijing, China

Proceedings of Sixth Pacific Structural Steel Conference

Continued Volume

Organizer
China Steel Construction Society

Editor
Wanzhong Liu   Boqing Wang

Seismological Press

15~17 October 2001, Beijing, China

第六届 太平洋地区 结构钢会议录

续集

Proceedings of Sixth Pacific Structural Steel Conference

Continued Volume

Organizer

China Steel Construction Society

Editor

Wanzhong Liu　　**Boqing Wang**

Seismological Press

Table of Contents

Continued Volume

Structural Analysis and Design of High-Rise Complex Building in Korea

Sangdae Kim[1)]

Department of Architectural Engineering, Korea University
Seoul, 136-701, South Korea

ABSTRACT

In recent years, the structural system for complex building in Korea is greatly changed. In the early 1960's, the complex building is mainly composed of residential apartment in upper stories and convenience stores (or storage place) in lower stories. The vertical load transfer system connecting the walls of apartments with the long columns of stores, is the key factor on making efficient design. In present days, the RC core with outrigger or moment resisting frame is new structural system.

For the complex buildings, the development of vertical load and lateral load system is briefly discussed and a sample project is also presented.

1. INTRODUCTION

The commercial buildings with residential facilities are new trends in the housing market of Korea. A complex building is defined as the multi-use building which consists of residential, commercial, cultural and recreational functions. The Sewoon commercial complex is the first multi-use building in Korea. The building consists of commercial facilities in lower stories and apartment in upper complex stories. In early 1980's, renovated apartments were constructed at Doreum and Mapo district as part of the Seoul city planning. The complex structure was planned and constructed by the government.

Since 1990, the complex buildings are constructed by several private companies. The Daelim Acroville, Daewoo Trump world, Samsung Tower palace, Hyundai Hyperion are some of such constructions (Figs. 1 through 3). It differs from the complex prior to 1990 in that the height of the building is higher, and interior is more expansive.

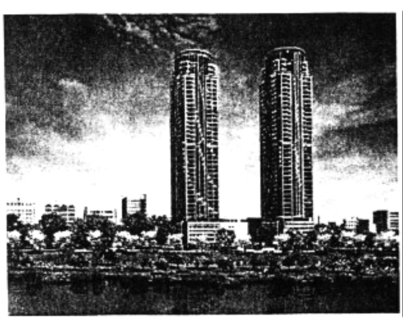

Figure 1. Daewoo Trump World (41 Story)

1) Professor

Figure 2. Samsung Tower Palace (69 story)

Figure 3. Hyundai Hyperion (69 story)

In view of the complex structure system, a proper force transfer mechanism must be provided between the upper apartment and the lower commercial parts. It maybe noted that the structural system of apartment complex is a bearing wall type in which there are no beams and columns. The walls of upper stories do not continue in lower stories. Therefore, the loads in wall must be transferred to the lower column by transfer girder or the corresponding structural system. That is the reason why the large girder in depth is used and it is the key component in designing such complex. However, as the lifestyle is nowadays changing from oriental to western style, the structural system is changed. Recently, the lateral load resisting system is changed to RC core with outrigger or exterior moment frame in column.
In this paper, the development of vertical load transfer system and lateral load resisting system in complex building is summarized, and the Hyperion complex building is presented as a case study.

2. VERTICAL LOAD TRANSFER SYSESMS

In design of complex buildings described above, the most important factor is the force transfer system which transfers the load in walls of upper stories to the lower stories columns. In addition, it must be kept in view that the span of the apartment complex in upper part is less than that of store in lower part. The transfer systems can be categorized as follows:

1) Transfer Plate Type (P)
2) Transfer Grid Strip Type (GS)
3) Transfer Steel Truss Type (ST)
4) Transfer Girder Type (G)
5) Transfer Beam Type (B)
6) Transfer Plate with Post Tension Type (PP)

The general comparison of transfer systems is shown in Table 1. The upper part is a wall type apartment or column type apartment. The lower part is 8.0m or 9.0m span moment frame. The cost is based on the structural quantity alone. The more the stars, the cheaper is the cost.

Table 1. Transfer systems

Transfer Systems	Upper Structures	Depth or Thickness (m)	Cost	Characteristics
Plate Type (P)	Wall Type Apartment	3.0	**	Use Thick Plate
Grid Strip Type (GS)	Wall Type Apartment	3.0	**	Use Grid type Beam
Steel Truss Type (ST)	Wall Type or Column Type Apartment	5.0	**	Use Large Steel Truss
Girder Type (G)	Wall Type Apartment	2.0	*	Use Large Transfer Girder
Beam Type (B)	Wall Type Apartment	2.0	***	No Transfer Girder
Plate with Post Tension Type(PP)	Wall Type Apartment	2.0	*	Use Thick Plate and Post Tension

The concept of each transfer system is presented in the following section.

2.1 Transfer Plate Type

For the building with irregular wall type apartment in upper stories, the thick plate is used as the force transfer system. By using this type, the stiffness of the transfer story transforcing the force becomes uniform. The elevation and plan of the corresponding building, Hill Top Tower, are shown in Figure 4 and Figure 5. The building is 33 stories in height located in Pusan and the depth of the plate is 3.0m. As letters A, B, C and D in Figure 4 represent the upper apartment, transfer system, lower stores, and underground stories, respectively. The dimension of a typical plate bay is 8.4m in width and 10.2m in length. From a next page the square in Figure 5 represents the column in lower stories. The double line indicates the walls in upper apartment. Since the wall line is different from the column line, a vertical force transfer mechanism is needed.

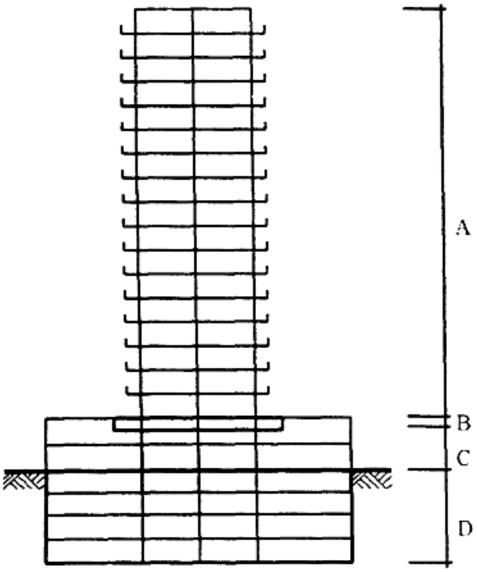

Figure 4. Elevation of Transfer Plate Type Building

In this type of transfer system, the addition of a pit story must be made for the vertical duct system in upper floors. For the considered case study, the reinforcement of the plate is HD32 at 20cm or 30cm spacing.

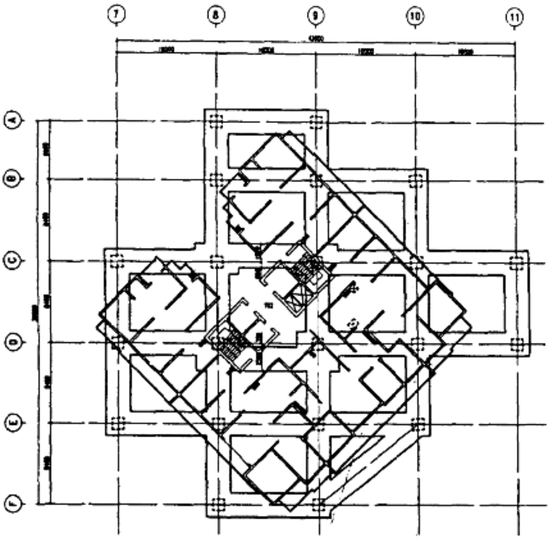

Figure 5. Plan of Transfer Plate Type Building

2.2 Transfer Grid Strip Type of Transfer System

It is also used for the building with irregular wall type apartment in upper stories. Instead of thick plate, grid type beam is used as the vertical load transfer system. By using this type of system, the stiffness of the transfer story becomes uniform. The plan of such system is shown in Figure 6. The shape of the grid strip beam is similar to a waffle slab. The depth of the grid beam is 3.0m which is same as that of plate type. However, contrast with the plate type, the pit story is not needed. The opening between the grid beams can be directly used to supply the vertical duct system in upper floors.

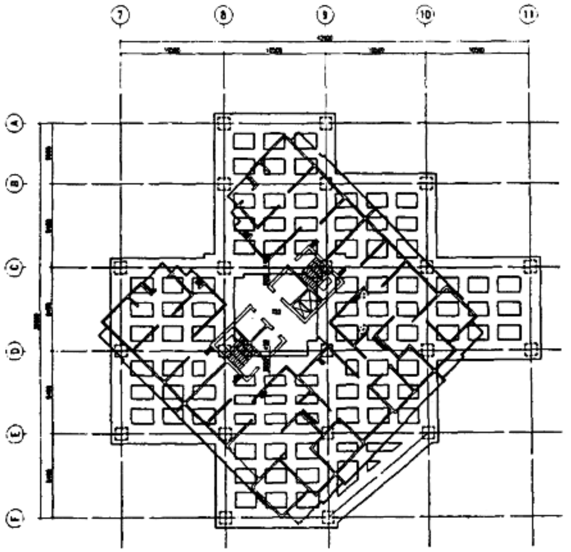

Figure 6. Plan of Transfer Grid Strip Type Building

2.3 Transfer Steel Truss Type

For the building with irregular wall or column type apartment in upper stories, the steel truss can also be used as the vertical load transfer system. Instead of a beam or a plate, the large steel truss is used. The detail of such system is shown in Figure 7. This type is adopted in the Kunyong Complex Building in Seoul. The depth of the plate is 5.0m which is deeper than other systems. The span of the upper apartment wall is 3.1m and that of lower column is 9.6m. The upper wall line does not coincide with the lower column line. The upper chord of truss is H-900×900 and the bottom chord is H-600×600 steel. By using a considerable amount of steel, the construction cost is higher than other systems. Since there are large space available between steel trusses, the additional pit area is not required. The space can be used to supply the vertical duct system in upper floors.

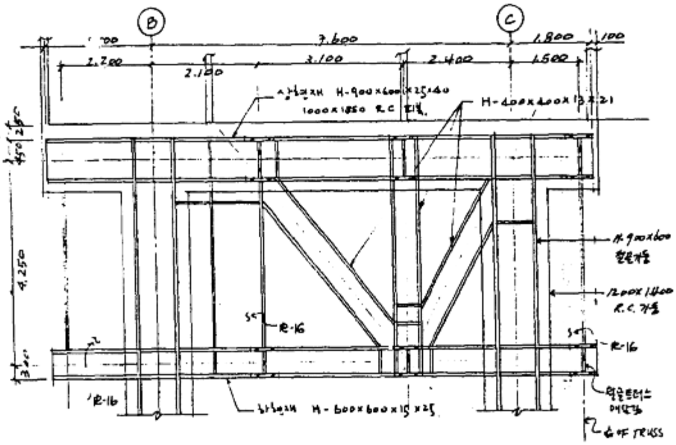

Figure 7. Details of Transfer Steel Truss Type

2.4 Transfer Girder Types

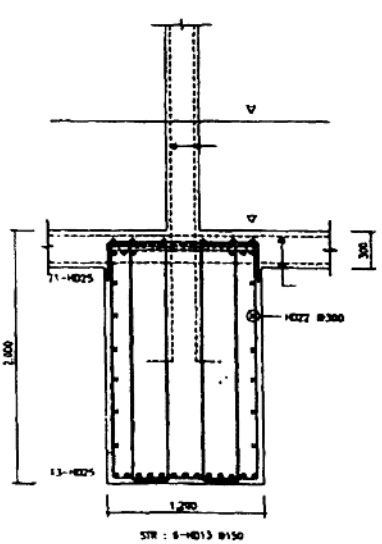

Figure 8. Details of Transfer Girder Type

For the building with irregular wall type apartment in upper stories, the deep girder can be used. This type of system is commonly used in Korea and is adopted at Nasan Complex Building in Inchon, and Panteon Complex

Building in Bundang. The depth of the girder ranges from H/13 to H/10 in which H is the story height. The details of the corresponding system are shown in Figure 8. The dimension of the transfer girder is 2.0m high and 1.2m wide. The depth of the transfer floor is 30cm which is deeper than that of typical floor. Since the space between transfer girders can be directly used for pit space, no additional pit story is needed.

2.5 Transfer Beam Type

For the building with regular wall type apartment in upper stories, a beam is used as the transfer system. Since the upper wall line coincides with that of lower column, a small beam is sufficient for the load transfer. The depth of the beam is significantly less than that of other systems. The purposes of the rooms in both parts are different. Therefore, the spans of the column or the wall are generally different. A great amount of work in design is required to make the vertical members in sequence. For the pit space, additional pit story is required in this system.

2.6 Transfer Plate with Post Tension Type

To save the story height of the transfer plate type, an additional post tension can be used. By using the post tension, the depth of the transfer plate is reduced to 2.0m that is 1.0m less than that of plate type. The Keumho Complex Building in Seoul is constructed by this type of transfer system. The plan of that building is shown in Figure 9.

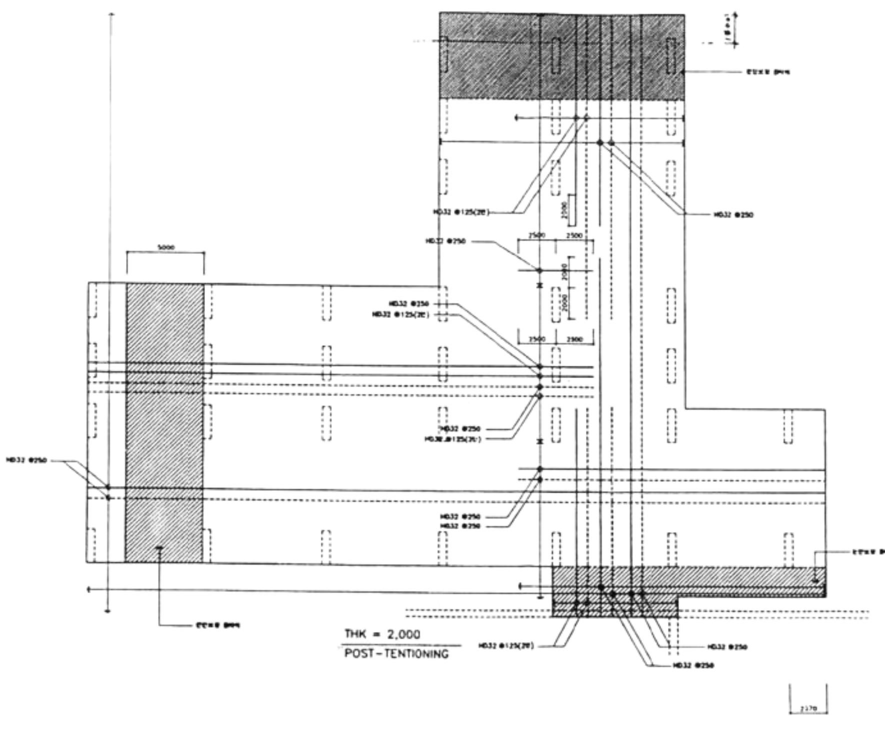

Figure 9. Plan of Transfer Plate with Post Tension Type Building

The load path within the plate with post tension is shown in Figure 10. Since the upper wall line differs from that of lower column, the compressive force is generated (Symbol C in Fig. 10). Such compression is resisted by concrete plate. If the depth of the transfer plate is enough, the tension can be resisted by the reinforcement alone.

However to make the plate more slender, tension must be shared and resisted by the post tension. The symbol T in Figure 10 stands for tension.

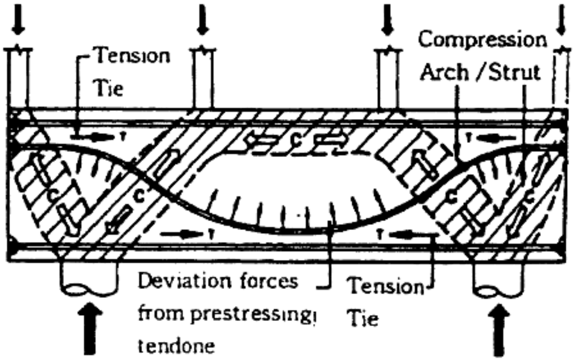

Figure 10. Detail of Transfer Plate with Post Tension Type

3. LATERAL LOAD RESISTING SYSTESMS

Recently, to make the design of transfer system simple, a RC core with outrigger of moment resisting frame is adopted for the complex building. For the complex building in Korea, the lateral load resisting systems are categorized as follows:

1) RC Core System (RC)
2) RC Core with Outrigger System (O)
3) RC Core with Column Type Moment Frame System (C)

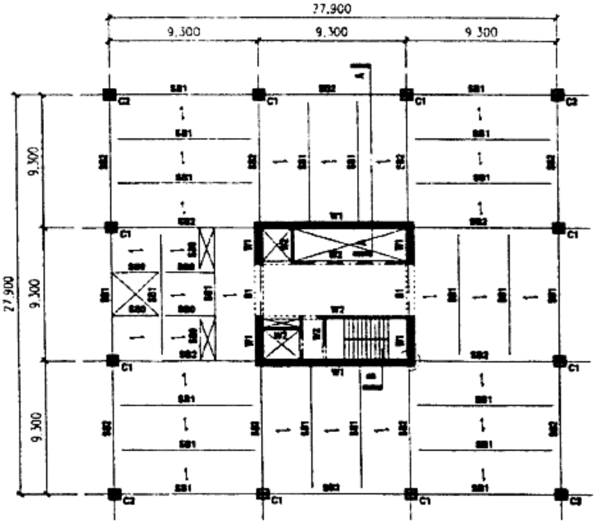

Figure 11. Plan of Sample Building

For the 36-story complex building, the general comparison of lateral load resisting systems is listed in Table 2.

The plan of a sample building is shown in Figure 11. The building is 27.9m wide and 27.9m long. The plan is divided by 9 sectors. Each sector is 9.3m wide and 9.3m long. Each building satisfies the allowable displacement criteria of code. The thickness of the core and cost are also compared in Table 2. The RC core with outrigger need less thickness and was lower cost. The cost is based on the structural quantity alone. The more the stars, the cheaper is the cost.

Table 2. Lateral Load Resisting systems

Lateral Load Resisting Systems	Displacement(cm)	Wall Thickness(cm)	Cost	Characteristics
RC Core (RC)	23.3(X-direction) 29.0(Y-direction)	90	*	Good Workability
RC Core + Outrigger (O)	25.6(X-direction) 31.7(Y-direction)	50	***	Good Structural Performance Large Lease Space
RC Core + Column MRF (C)	22.8(X-direction) 28.0(Y-direction)	80	**	Moment Connection

The concept of each lateral load resisting system is presented in the following section.

3.1 RC Core System

As shown in Figure 12, the lateral load is resisted by the core alone. The girder connects the core with exterior column by pin connections. Therefore, the thickness of wall is larger. For the sample building, the thickness of core is 90cm. The thickness of the slab is 13.5cm. The exterior column is SRC of 75cm wide and 75cm long. This type of system is useful for the mid- and low-rise buildings.

Figure 12. Detail of RC Core System

3.2 RC Core with Outrigger System

To make the structural system more effective, an outrigger is added. The RC core with outrigger system is generally used in western countries. Recently, the use of this system was increased in Korea. The outrigger is made by steel truss. For several complex projects such as Trump World, Acrovista, Richensia, the outrigger is made by a deep girder or wall.

For the sample building, the RC core with outrigger is shown in Figure 13. The section of outrigger is H-$356\times352\times14\times22$. The height of the outrigger is 5.0m. The story height of the typical floor is 3.2m. The outrigger story height is 1.8m higher. However, the mechanical floor should be placed at the middle story for the high-rise building. The outrigger story can be directly used for mechanical floor.

In addition, the thickness of core wall is reduced to 50cm. Since the wall is not thick, the effective lease area is larger. It is very attractive lateral load resisting system for the building developer.

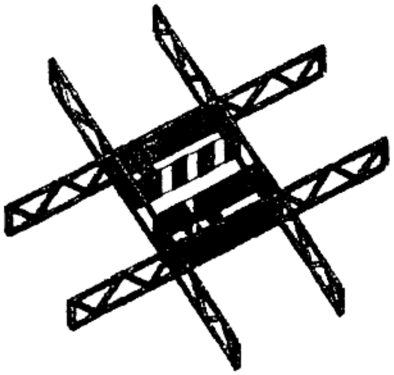

Figure 13. Detail of RC Core with Outrigger System

3.3 RC Core with Column MRF System

The tube in the tube system is an efficient lateral load resisting system for high-rise buildings. The inner tube is a core wall and outer tube is a moment resisting frame. To make the outer moment resisting system, the connection between exterior column and girder is made rigid. General view of this system is shown in Figure 14. For the sample building, the thickness of the core wall is reduced to 80cm. The girder between core wall and exterior is pin connected. To make the rigid connection in the outer tube, additional work and material is needed. It is also widely used for the complex buildings in Korea.

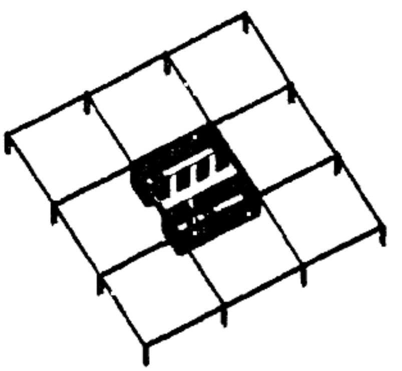

Figure 14. Detail of RC Core with Column MRF System

4. SAMPLE PROJECT – HYUNDAI HYPERION

In this chapter, Hyundai Hyperion Project is introduced for the description of a typical complex building system in Korea. The vertical and lateral load resisting system as well as the key points in the structural design process and engineering characteristics have been presented.

4.1 Project Synopsis

Hyundai-Hyperion Project is a residential and commercial development located at Mok-dong, Seoul, Korea. The development comprises of 3 proposed residential towers ranging in height from 200 m (53 stories) to 254 m (69 stories) above the ground, nine levels of podium and six levels of basement for parking, retail area and club house and nine stories for development store (Figure 15).

The total floor areas of the different parts of the development are 225,600m^2 for Towers, 41,000m^2 for Podium, and 138,000m^2 for Basement. The towers typically comprise of a central concrete core with perimeter composite columns and floors. Two or three outrigger levels are located at approximately quarter height of the towers to provide lateral stiffness.

The architect of this project is Yeh Art Group Inc., in Korea, and structural engineering services has been provided by Ove Arup & Partners International Limited and Dong Yang Structural Engineers Company. Hyundai Construction & Engineering Company has started the construction work in November 1999, and finished about 27% of work as of June 2001.

Figure 15. Birds-Eye View of hyundai Hyperion

4.2 Vertical Load Resisting System

Recently, "core wall and moment resisting frame system" has replaced "upper wall, lower column and transfer system", described in the chapter 2 of this paper, for the vertical load resisting system of high-rise complex buildings. This trend has been manifested in this project, and the towers typically comprise of a central concrete core with perimeter composite columns and floors (Figure 16). Two or three outrigger levels are located at approximately quarter height of the towers to provide lateral stiffness.

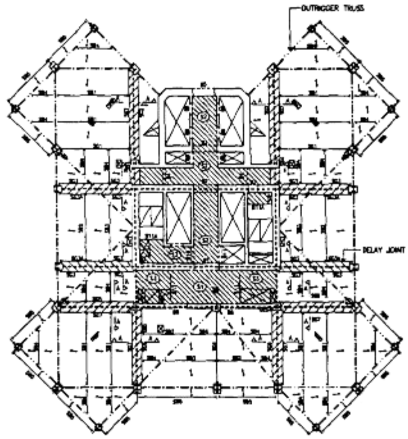

Figure 16. Framing Plan of Tower

4.3 Lateral Stability System of Tower

Scheme 1 – Core with Transfer Fins + Outrigger + Podium Shear Wall with Podium Frame Tube
This scheme comprises of two or three outriggers and a reinforced concrete core with steel moment frame and concrete shear wall at podium/basement level. The fin walls are extended from the core between the top and bottom outrigger to enhance the lateral stiffness of the core.

Scheme 2 – Core with Transfer Fins + Outrigger
In order to reduce the amount of moment connection and construction time, no podium frame tube and shear walls are provided for this scheme. The core wall and columns should be strengthened to compensate for the reduced building stiffness due to removal of the podium restraint.

Scheme 3 – Core with Fins + Outrigger
This scheme is similar to scheme 2 except for the fin walls extending from the core are relocated and extended down to the foundation level from the roof.

Scheme 4 – Core + Outrigger (Adopted Scheme, Figure 17)
The transfer fins in scheme 2 and fins in scheme 3 have been removed finally to avoid the architectural implication.

4.4 Wind and Dynamic Behavior of Tower

Acceleration Prediction According to NBCC
In advance of carrying out the wind tunnel studies, the NBCC (National Building Code of Canada) prediction of the acceleration which are likely at the top of the tallest tower has been undertaken. The NBCC represents one of the most detailed and reliable means of acceleration prediction in the absence of wind tunnel data.

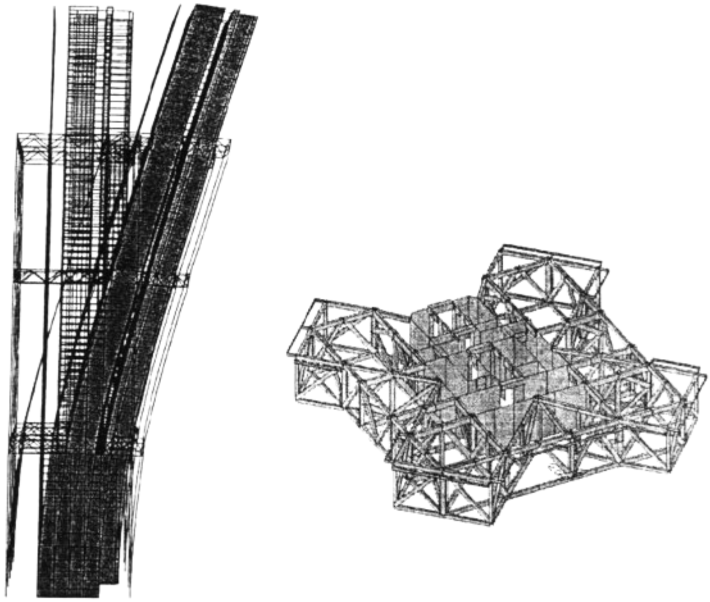

Figure 17. Adopted Scheme

The mass of the building, including 25% live load, is equivalent to approximately 324 kg/m^3. The mass and building stiffness characteristics were used to determine the NBCC predicted acceleration for the wind speed of 10 years return period. The results are shown in Table 3.

Table 3. NBCC Predicted Accelerations for 10 Years Return Period

Period (sec)	X direction Wind		Y direction Wind	
	Along Wind Acceleration (milli-g)	Across Wind Acceleration (milli-g)	Along Wind Acceleration (milli-g)	Across Wind Acceleration (milli-g)
6.8 (X direction) 6.3 (Y direction)	7	14	6	15

Limiting Acceleration Criteria

Figure 18 represents the limiting accelerations which should be adopted. The figure shows the recommended NBCC limits for residential buildings together with the ISO Criteria and the Davenport Criteria for offices. From the structural engineer's international experience, it has been suggested that the following limiting values be adopted for different codified criteria.

1) 80% of the "2% objecting" Davenport limiting criteria for offices should be used for residential developments, and
2) 1.5% g (15 milli-g) should be used as an appropriate limiting criteria for luxury accommodation compliant with the NBCC specified range of 1% ~ 3% for a ten years return period wind event.

It is evident that these predictions are within the 80% of the "2% objecting" Davenport criteria and NBCC criteria of 1.5% g.

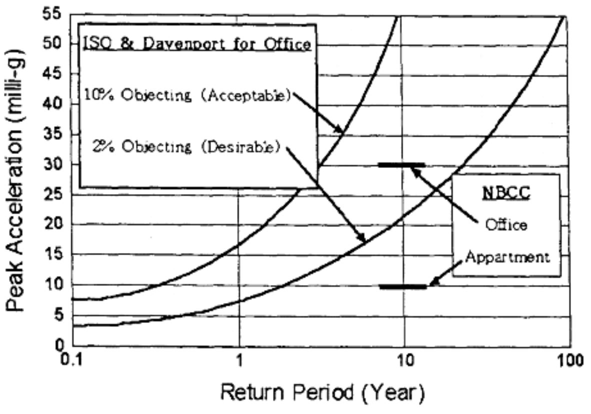

Figure 18. Limiting Acceleration Criteria

Wind Tunnel Test

Wind tunnel studies have been carried out in the Research Institute of Hyundai Construction and Engineering Company. The accelerations are evaluated via force balance test on the basis of 2% damping, and summarized in Table 4.

Wind tunnel test results show comparatively similar values to the NBCC predicted accelerations, and satisfy the above limiting criteria.

Table 4. Evaluated Peak Accelerations via Wind Tunnel Test

Tower	Direction	Peak Acceleration (milli-g)
A	X	11
	Y	10
B	X	14
	Y	7
C	X	11
	Y	10

4.5 Axial Shortening Prediction

The differential shortening of column and core wall is due to different amount of axial shortening of columns with respect to the core wall under various contribution factors. The factors include:

1) Shrinkage effect of concrete
2) Elastic shortening of steel and concrete
3) Long term creep effect of concrete

The axial shortening predictions of the tower were performed initially according to the general material data, properties of axial members, loading schedule and construction sequence. The predicted absolute and differential shortenings are summarized in Table 5.

Table 5. Predicted Axial Shortening at the Top Level (After 10,000 Days)

Tower	Axial Members	Absolute Shortening (Up to and Subsequent to Casting Floor) (mm)	Differential Shortening (Only Subsequent to Casting Floor) (mm)
A	RC Core Walls	116 – 168	-
	Composite Columns	129 – 207	14 - 45
B	RC Core Walls	97 – 119	-
	Composite Columns	130 – 168	12 - 28
C	RC Core Walls	98	-
	Composite Columns	96 – 153	6 - 36

The compensation for axial deformation may be based on the absolute shortening or the differential shortening. The target for compensation process is set to be the absolute shortening, and in this case the compensation values should be applied to the core walls as well as composite columns. The shortenings up to casting floor are compensated for automatically in the leveling process of horizontal floor system; thus, only the post-floor-deformation may need compensation. The proposed compensation values for each core wall and composite column are provided on the basis of predicted absolute values.

The differential axial deformation between the core wall and the perimeter column will induce additional loading onto the outrigger members. The outrigger members may be overstressed and undergo plastic deformation, which ultimately cause instability problem to the overall structure. Therefore, the special considerations for reducing the effect of differential deformation in the outrigger floor are required. The proposed method is described in the next chapter.

4.6 Outrigger Construction

Location of Outrigger Floors

Table 6 shows the location of outrigger floors in each tower.

Table 6. Location of Outrigger and Belt Truss

Tower	Height above Ground (m)	Stories above Ground	Outrigger Floor
A	254	69	50th
			32nd
			9th
B	216	59	32nd
			9th
C	200	54	32nd
			9th

Connection between the Outrigger and the Shear Wall

The most complicated part of the outrigger construction is the connection of outrigger to core wall. Three possible connection methods of outrigger are identified and the merits of each are summarized below:

1) Embedded plate detail (Figure 19(a))

The advantage of this simple detail is its ease of construction. The disadvantage is that in order to deal with the potentially large forces in the outrigger, it is expected that the load transfer into the concrete could become a little problematic.