Council on Tall Buildings and Urban Habitat
CTBUH Research Paper
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Title: **Toranomon-Roppongi Area Project**

Authors: Shuichi Otaka, Architect, Obayashi Corporation
Masayuki Yamanaka, Architect, Obayashi Corporation
Shokichi Gokan, Architect, Obayashi Corporation
Toru Tsuchihashi, Architect, Mori Building

Subjects: Construction
Structural Engineering
Urban Design

Keywords: Concrete
Construction
Damping
Structure

Publication Date: 2012

Original Publication: CTBUH 2012 9th World Congress, Shanghai

Paper Type:
1. Book chapter/Part chapter
2. Journal paper
3. **Conference proceeding**
4. Unpublished conference paper
5. Magazine article
6. Unpublished

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Toranomon-Roppongi Area Project

Toranomon-Roppongi地区项目

Shuichi Otaka

Masayuki Yamanaka

Shokichi Gokan

Toru Tsuchihashi

Shuichi Otaka, Masayuki Yamanaka & Shokichi Gokan

Obayashi Corporation
Shinagawa Intercity Tower B, 2-15-2, Konan
Minato-ku, Tokyo, 108-8502, Japan

tel (电话): +81-3-5769-2418, +81-3-5769-1572, +81-3-5769-1587
fax (传真): +81-3-5769-1740
email (电子邮箱): otaka.shuichi@obayashi.co.jp; yamanka.masayuki@obayashi.co.jp; gokan.shokichi@obayashi.co.jp
http://www.obayashi.co.jp/english/index.html

Shuichi Otaka is a First-class architect, Structural design first-class architect and the Member of Architectural Institute of Japan. He work for building structure design department of Obayashi Corporation.

Shuichi是一级建筑师，一级结构设计建筑师，日本建筑学会会员。目前是大林组建筑结构设计部门的一员。

Masayuki Yamanaka is a First-class architect, Structural design first-class architect, APEC Engineer, Member of Architectural Institute of Japan. He joined Obayashi Corporation at1981. His focus is structural design.

Masayuki是一级建筑师，一级结构设计建筑师，亚太工程师和日本建筑学会会员并于1981年加入大林组。他的主要工作内容是建筑结构设计。

Shokichi Gokan is a First-class architect, Structural design first-class architect, APEC Engineer, Professional Engineer in the discipline of Civil Engineering. He is part of the building structural design department of Obayashi Corporation.

Shokichi是一级建筑师，一级结构设计师，亚太工程师，土木工程专业工程师。他是大林组结构设计部门的一员。

Toru Tsuchihashi

Mori Building Co., Ltd.
Roppongi Hills Mori Tower P.O. BOX 1 10-1 Roppongi 6-Chome
Minato-ku, Tokyo, 106-6155, Japan

tel (电话): +81-3-6406-6343
fax (传真): +81-3-6406-9340
email (电子邮箱): tutihasi@mori.co.jp
http://www.mori.co.jp/en/

Toru Tsuchihashi is a First-class architect, Structural design first-class architect, Member of Architectural Institute of Japan. He joined the Structural Engineering Department of Mori Building Co., Ltd. after graduated.

Tsuchihashi是一级建筑师，一级结构设计建筑师，日本建筑学会会员。毕业之后加入森大厦株式会社的结构工程部。

Abstract

This paper provides the overview of structural design, adopted devices and construction methods in the Toranomon-Rappongi Area Project. When this project started, construction costs of high-rise buildings using steel framework had become a problem because of the high price of steel. Therefore, considering the adoption of reinforced concrete structures had emerged. Using high-strength concrete and rebar, the cross-sectional size of frame structures was streamlined. Moreover, in order to realize large spaces of an office floor, the girders were made of steel. Because of this, the usage of reinforced concrete delayed the construction time as opposed to steel. In order to solve this, the precast construction method (LRV/LRV-H method) was adopted to resolve these issues and so the speed of steel construction could be achieved with reinforced concrete.

Keywords: Hybrid, Precast Construction, Reinforced Concrete, Damping Structure

摘要

本论文论述了虎之门——六本木区域项目的整体结构设计、采用的设备以及施工方法。工程开始时，由于钢材价格上涨，所用的钢结构建造费用成为重要问题。因此项目便考虑了使用钢筋混凝土结构。这可以保证钢结构横断面尺寸的流线型。而且为了确保办公楼层有大的空间，主梁均由钢制成。由于混凝土同钢结构相比施工时间较常，所以为了解决这一问题，项目采用了预制施工方法（LRV/LRV-H法），确保了钢筋混凝土结构的施工速度和钢结构施工速度一致。

关键词：混合结构，预制施工方法，钢筋混凝土，阻尼结构

Introduction

This redevelopment area is approximately 2.0ha, which is across the district of Roppongi-Toranomon, Minato-ku, Tokyo. In the surrounding area, there are many Embassies and hotels, as it is an international and cultural place positioned in a pivotal area of Tokyo. At Sightly Hills, there is the tall building of 47 floors above ground. The lower part (1-24 floors) consists of a commercial facility and urban housing and the upper part (24-47 floors) is planned to be office space. On the south side of the site, the six-story residential building (a seismically isolated structure) exists. The exterior plan is conscious for project measures to restore biodiversity. Vegetation was based on seeds and flora native to the area and the multi-dimensional development of a green area development as an attractive habitat for wildlife. It provides a rich urban space and functions as a shelter according to the earthquake resistance structure plan (see Figure 1).

Building Information

The uses of this tall building are as follows: parking lot (floors B1 to B3), collective housing

简介

这一重建区位于东京港区虎之门——六本木的交叉地带，面积约2公顷。周围有许多大使馆与酒店，是东京核心区域的国际与文化地带。Sightly Hills有一座47层高的建筑，其下半部分（1-24层）是商业与住宅，上半部分（24-47层）拟定为办公楼。该建筑南侧有一6层居民楼（隔震结构）。外部计划是采取工程措施修复生物多样性。 这里的植被均是本地植物，对该绿化区的多维开发可增强对野生动植物的吸引力。根据抗震结构计划，这里可提供广阔的城市空间，并且可作为避难场所(见图1）。

建筑信息

对该高层建筑的使用分配如下：停车场（地下B1层至B3层）、集体住宅（3层至24层）、办公室（25层至46层）。 表1是该建筑的摘要。

结构设计概述

该建筑采用刚性框架结构，标准层形状为边长约50m的正方形（跨度7.2m）。2号3号钢梁之间跨度（见图2与图3）确保了办公楼层的无柱结构。在该建筑核心区域装有粘滞阻尼墙与滞回阻尼器，也称为“制

Use 用途	Office,Residence,Retail,Parking 办公，住宅，零售，停车场
Site Area 占地面积	15,367.75M²
Total Floor Area 房屋面积	143,550.04M²
Floors 楼层	47 Above Ground, 4 Under Ground 地上47层，地下4层
Maximum Height 最大高度	+206.69M
Structure 结构	Reinforced Concrete (Partly: Steel) 钢筋混凝土结构（部分为钢结构）
	Seismic Control Structure 隔震结构

Table 1. Outline
表1. 概要

(floors 3 to 24), and offices (floors 25 to 46).The building summary is shown in Table 1.

Structual Design Overview

The format of this frame structure is a rigid frame structure. The shape of the standard floor is square, about 50m ×50m (7.2m span). The office floors are column-free, which has been achieved by steel girders 2 and 3 span (see Figures 2 and 3). At the central core portion of the building, there are viscous damping walls and hysteretic dampers that are called “Brake Dampers”. A “Brake Damper” is a similar system similar to an automotive brake mechanism and use the frictional energy of brake pads to control vibration energy (see Figure 4).

This structure uses high-strength concrete (maximum Fc120 N/ mm²- and high-strength rebar (σy685,785 N/mm²) along with a mat foundation. The load bearing layer consists of a sandy soil layer which has an allowable bearing pressure of 1000 kN/m². (The second layer Tokyo : standard penetration test value over 50) This building is relatively heavy in weight, because it has 47-stories of reinforced concrete. The external force acting on the tall building mostly has to do with the seismic loads being greater than wind load, which is verified for the structural safety during an earthquake.

Figure 1. Panoramic Photo 2012.3 (Source : Toranomon-Roppongi Work Office)
图1. 2012年3月全景照片（出自：虎之门——六本木办公室）

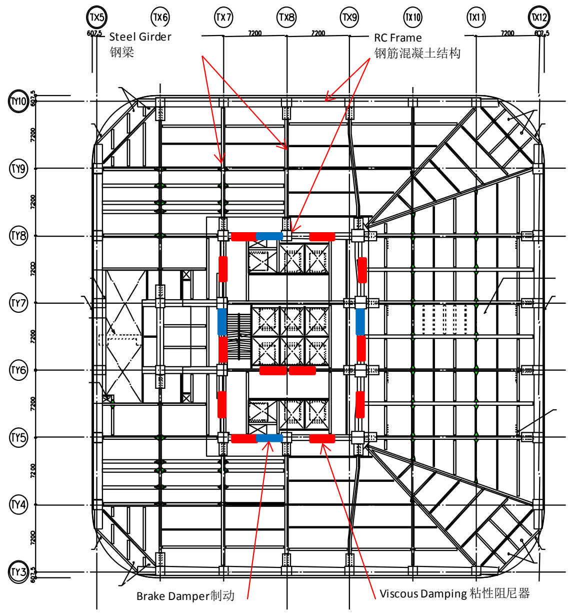

Figure 2. Office Standard Floor Framing Plan (Source : Obayashi Corporation)
图2. 办公室标准层框架平面布置图（出自：大林组）

动片阻尼器”。制动片阻尼器类似于汽车制动器系统，使用刹车片的摩擦能控制振动能量（见图4）。

该建筑采用了高强度混凝土（最大抗压强度120 N/mm²）、高强度钢筋（σy 685，屈服强度785 N/ mm²）以及筏式基础。承载层包括可承载1000N/ m²的砂质土层。（第二东京土层：标准贯入试验N值超过50）该建筑为47层的钢筋混凝土结构，因而相对较重。该建筑所受的外部作用力主要是地震荷载，其影响远大于风荷载，该结论已在一次地震中得到证实。

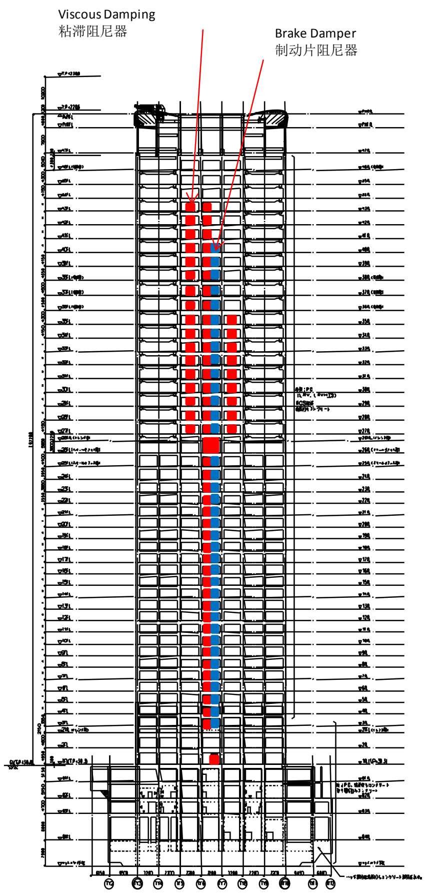

Figure 3. Figure Axis Set (Source : Obayashi Corporation)
图3. 轴设置（出自：大林组）

Figure 4. A Viscous Damper and a Brake Damper (Source : Toranomon-Roppongi Work Office)
图4. 粘性阻尼器与制动片阻尼器（出自：虎之门——六本木办公室）

Table 2 shows the structure performance targets as well as the results of this building.

Seismic response analysis was done for level 1 and 2 earthquake motion at study levels. At each level of earthquake motion, the members were designed by the state of stress and deformation obtained from incremental static three-dimensional analysis. Policy design is shown below for both design levels of earthquake motion.

Level 1 Earthquake Motion
(The ground motion that may be encountered more than once, during the useful life of the building with a 100-year return period.)

The design shear force is static shear, which is stipulated to include the maximum response shear force when level 1 earthquake acted. The magnitude and distribution are determined based on the response analysis; however minimum value of shear force coefficient for the design (Ci) is 0.05. A stress test for each member was confirmed to be within short-term allowable stress and the maximum drift angle is 1/349 at the 28th floor.

Level 2 Earthquake Motion
(On the site of the building, the ground motion that is considered the strongest in the past and the future with a 500-year return period.)

The design shear force is static shear, which is stipulated to include the maximum response shear force when level 2 earthquake acted. The magnitude and distribution are determined based on the response analysis. A stress test for each member was confirmed to be within the ultimate strength and the maximum drift angle is 1/147 at the 28th floor.

Damping Device

Brake Damper

The Brake Dampers are vibration control devices, within an earthquake resistant element like post and brace, or in the junction of the main structure frame and seismic resistant element. This is configured by the combination of a stainless steel plate and brake materials, sandwiched by disk spring. It applies the structure of the disc brake of a car. By sliding under a constant load, it converts vibrational energy of the building to heat friction, which reduces the response and the damage of the building (see Figure 5). The Brake Damper has the stability of an axial force and friction coefficient with excellent abrasion resistance, so system maintenance is unnecessary. The cost per unit performance of a commonly used Hysteretic damper is pretty much the same with Brake Damper's. However, the former absorbs seismic

Level 级别		Target Value 目标值	Results结果			
			Direction 方向	Calculated Value 计算值	Generating Floor 楼层	Seismic Wave 地震波
Level 1 1级	Drift Angle 位移角	R<1/200	0°	1/349	28F	Taft-EW
			90°	1/413	26F	Taft-EW
	Ductility Ratio 延性比	μ<1	Yielding does not occur未出现弯曲			
Level 2 2级	Drift Angle 位移角	R<1/100	0°	1/147	28F	KOKUJI-HT
			90°	1/155	14F	KOKUJI-KB
	Ductility Ratio 延性比	μ<2	0°	0.73	9F	KOKUJI-HT
			90°	0.76	1F	EL Centro-NS

Design seismic wave
设计地震波

Level1;25kine, Level2;50kine modified the configuration of maximum ground motion speed
11级；速度25，12级；速度50 经修正的地面运动速度

KOKUJI- :Simulated ground motion waveform is created based on the spectrum was defined in the Building Standards Law
压力-：基于建筑标准法设定模拟地面波形

Table 2. Criteria And Review The Results
表2 标准与结果审核

表2显示的是该建筑结构特性指标与结果

研究还进行了1级与2级地震运动的地震反应分析。在这两种地震运动下，根据三维静力分析不断获得的应力状态与形变设计了构件。下面是针对两种地震运动等级设计的策略。

1级地震运动
（该建筑在使用期内可能碰到的在100年重现期内一次以上的地面运动）

设计剪力为静态剪切，应包括当发生1级地震时的最大反应剪力。根据反应分析决定震级和分布。然而，设计中采用的剪力系数(Ci)最小值为0.05。所有构件的应力测试结果均在短期容许应力范围内。28层位置的最大位移角为1/349。

2级地震运动
（地面运动为过去与将来500年重现期内的最大值）

设计剪力为静态剪切，应包括当发生2级地震时的最大反应剪力。根据反应分析决定震级和分布。所有构件的应力测试结果均在短期容许应力范围内。28层位置的最大位移角为1/147。

阻尼装置

制动片阻尼器

制动片阻尼器是一种消振器，位于柱子或支撑等抗震元件或者主结构与抗震元件的连接处。它是由盘簧夹住不锈钢板与制动材料构成。它采用汽车使用的盘式制动器结构，通过在恒定载荷下滑动，将建筑的振动能量转换为摩擦热能，从而减少建筑的反应以及对建筑的损害（见图5）。该制动片阻尼器具有稳定的轴向力和摩擦系数以及优异的抗磨性，因而不必要对其进行维护。制动片阻尼器的单位成本性能与普遍使用的软钢阻尼器基本相同。但是滞回阻尼器是通过使钢屈服从而吸收地震能量，所以一旦发生大地震，就要对其进行检查工作并恢复其状态。制动片阻尼器不存在这些问题。综合考虑，制动片阻尼器具有极高的性价比。

粘滞阻尼墙

粘滞阻尼墙是一种利用高粘度物质的粘性剪力阻力的消振器。建筑物内有一内置钢板与一独立外置钢板。将外置钢板插入装满粘性体的外置钢制容器中（见图6）。当地震或者刮大风时，固定于上梁的内部钢板与固定于下梁装满粘性体的铁箱之间会发生相对运动，由于这一粘滞阻尼系统的形变而产生的阻力可以吸收振动能量，减少建筑位移。

每一阻尼器都由受拉的PC钢棒固定于横梁处。这些阻尼装置性质

energy by yielding the steel, so once it receives a major earthquake, the inspection work and the need to take recombination occurs; a Brake Damper does not incur any cost for that. Considering the overall, a Brake Damper has excellent cost performance.

Viscous Damping wall

A viscous damping wall is the vibration control device using viscous shear resistance by viscous material with high viscosity. The structure has an internal steel plate, an independent outside plate, which is inserted into an external steel plate container, filled with a viscous body (see Figure 6). A viscous damping system absorbs the vibration energy and reduces the drift due to the shaking of the building when an earthquake or strong winds occur by resistance due to deformation between layers caused by relative motion, between the inner plate fixed to the upper beam and the container of viscous body fixed to lower beam.

Each damper is fixed to a beam by PC steel rods under tension. Using these damping devices with different properties, viscous damping is effective for small and significant swaying within the tall building and a Brake damper is effective for significant swaying of the tall building during an earthquake. So it is possible to reduce the building's structural damage and to improve its environmental vibration by using viscous and brake damping.

Precast Construction Method

This building has applied using the LRV method (Left Right Vertical Installation Precast Method) and the LRV-H method (Left Right Vertical Horizontal Installation Precast Method) that is integrated over beam-column joints (see figure 7).The LRV method has been applied to the outer part of the frame structures and the LRV-H method has been applied from the beam cross part to the internal. The sleeve joint and grouting are used for the combining of LR beams, V columns, H beams, and H columns. For the residential floors, half-precast void slabs were implemented.

LRV Method

The LRV method is a precast construction method using precast members as part of the junction of the columns and beams. It is composed of a precast beam integral junction (LR beam) and has a through hole by using a sheath tube at the position of the main reinforcements and precast column (V column). It also has the main reinforcements projecting downward and the mechanical mortar-filled joints for main reinforcements in the capital. The frame structures have each member built as the joint part of the mutual precast, main reinforcements in the through hole and the joints are filled with mortar.

LRV-H Method

LRV-H method is a precast construction method using precast column members that are integrated into the column and the panel zone with a length similar to floor height (H column) and a precast beam that is a part of the inside measurement span (H beam). The column members have a horizontally disposed beam hole of the main reinforcement. The sleeve joints have been installed near the end of the beam and the precast beam on the opposite side across the column has main reinforcements of the beam. The beam's main reinforcements pass through the through-hole and are inserted into sleeves at the end of the other side beam. The frame structures are integrated by filling in the mechanical joints with mortar, the through-hole, and the joints of frames.

The Process Planning

For construction of part of the ground, the industrial district was

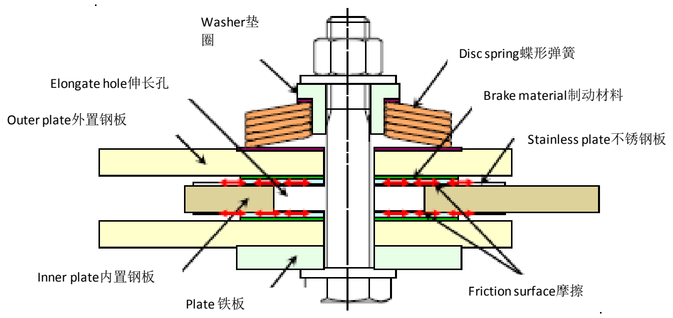

Figure 5. Basic Composition of a Brake Damper (Source : Obayashi Corporation)
图5. 制动片阻尼器基本组成（出自：大林组）

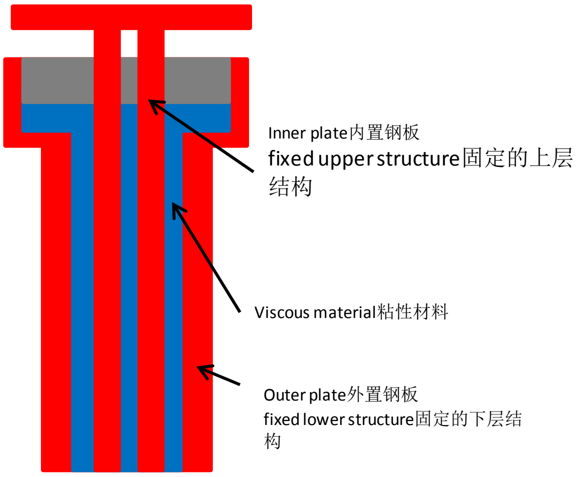

Figure 6. Basic Composition of a Viscous Damper (Source : Obayashi Corporation)
图6. 粘性阻尼器基本组成（出自：大林组）

各不相同，粘滞阻尼对于应对高层建筑内部较小与重大摇摆效果显著，而制动片阻尼器则更善于应对地震中建筑物的摇摆。因而利用粘滞阻尼与制动片阻尼器可以减少对建筑物的结构性破坏，减少环境震动。

预制施工方法

该建筑已申请采用LRV方法（从左向右垂直安装预制法）与LRV-H（从左向右双向安装预制法）与梁柱节点结合（见图7）。现已在部分外框架结构上使用LRV方法，在梁与内部的交叉部分使用了LRV-H方法。使用套管接头与水泥浆连接左右梁、V形柱、工字梁以及工字柱。住宅区地板使用半预制空心板。

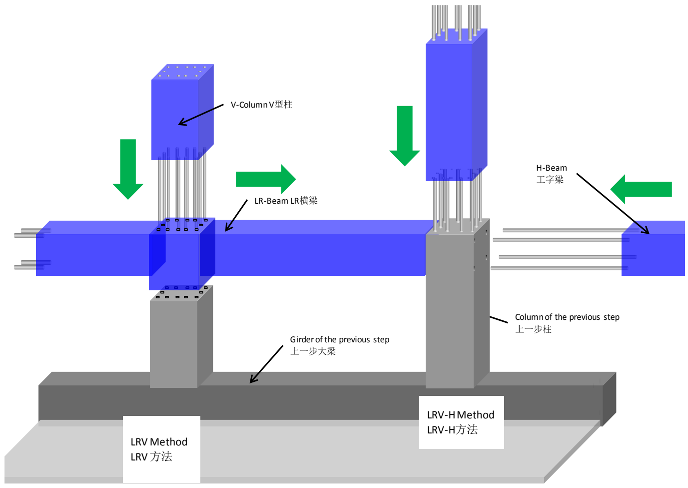

Figure 7. Overview Of LRV Method And LRV-H Method (Source:Obayashi Corporation)
图7. LRV法与LRV-H发概览（出自：Obayashi Corporation）

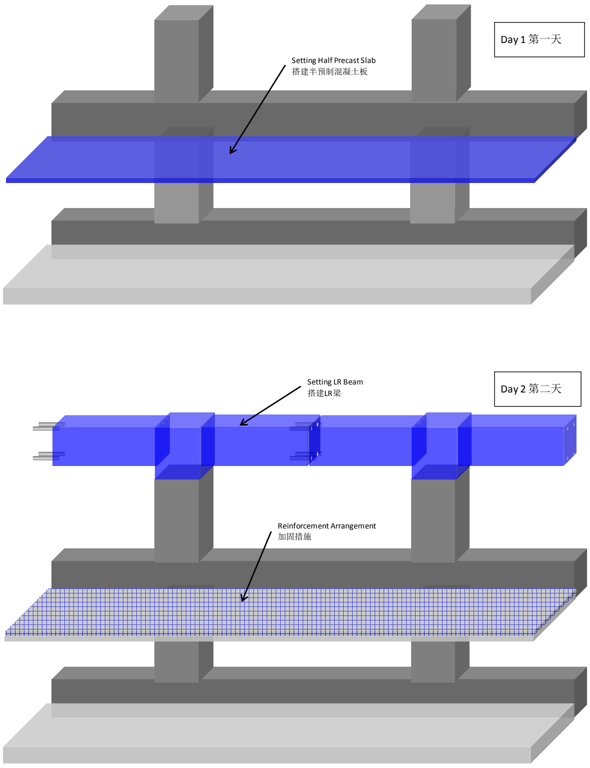

Figure 8. Construction Process (Source:Obayashi Corporation)
图8. 施工过程（出自：大林组）

divided into three portions. Each portion was placed one by one in each industrial district by a 720t tower crane. By using the LRV method, the plan to build a floor in three days was planned. Figure 8 shows the flow of work in 3 days in tact housing floor (assembly condition shown in Figure 9).

- First day
  The preceding Lifting and the half precast floorboards are laid.
- Second day
  The reinforcement of the slabs is arranged to form rising portions of the formwork and to attach the girders (LR Beams) on the top of the columns.
- Third day
  Casting the floor concrete and part of the upper beams in order to attach the columns (V Columns) by joints are filled with mortar.

The LR beam is moved laterally while the main bars are inserted in sleeve joints. The V column is moved vertically As the main bars are inserted in penetrating holes and sleeve joints. The LRV method and LRV-H construction method have many beneficial features. As each member is joined by sleeve joints directly, there is no portion of casting concrete in the field between the members. For the beam-column, joints are made of precast concrete, without waiting for casting concrete of the slab or the other part the beams and columns in the next section to be attached. Without the complication of the fit of the main bars of the girder in beam-column joints, as done in the conventional precast construction method, assembly efficiency of the LRV and LRV-H method is very good, accurate and fast. All complex work of placing bars can be done at fabricating plants, which can significantly reduce the workload and increase the overall quality of structures. LRV precast system has a lot of advantages when compared with the general construction method.

Figure 9. Construction Situation (Source : Obayashi Corporation)
图9. 施工位置(来源:大林组)

LRV方法

LRV方法是一种采用预制构件作为柱子与横梁连接处部分预制的施工方法。它是由预制梁以及通孔组成，在主筋与预制柱（V形柱）的位置设有保护套管。同时它也包括下部向下投影钢筋，以及加固柱头而填充了力学砂浆节点。框架结构的每一构件都是共同预制的一部分。主要加固通孔与接合处都填满了砂浆。

LRV-H方法

LRV-H法是一种预制施工法，它采用的是结合接近层高高度的柱子（工字柱）与支座的预制柱构件，以及一部分在计量宽度内的预制梁（工字梁）。柱子构件有一水平方向与主筋对应的束孔。套筒接头已经安装在梁尾端，柱子对面的预制梁上有梁的主筋。横梁主筋穿过束孔插入横梁尾部的套筒中。该框架结构包括机械砂浆，束孔以及接合框架。

过程设计

为了在土地上分开施工，施工现场被分成三部分。由一台720吨的塔式起重机依次将每个部分放在不同现场。若使用LRV方法，项目计划用3天时间铺设一层楼。图8为3天的工作流程。（图9所示组装情况）。

- 第一天
  安装前期电梯，铺设半预制地板。
- 第二天
  加固混凝土板，让框架呈上升状态，将主梁（LR横梁）安装在柱子上。
- 第三天
  在地板与部分上梁上浇筑混凝土，用砂浆使其与柱子（V型柱）结合。

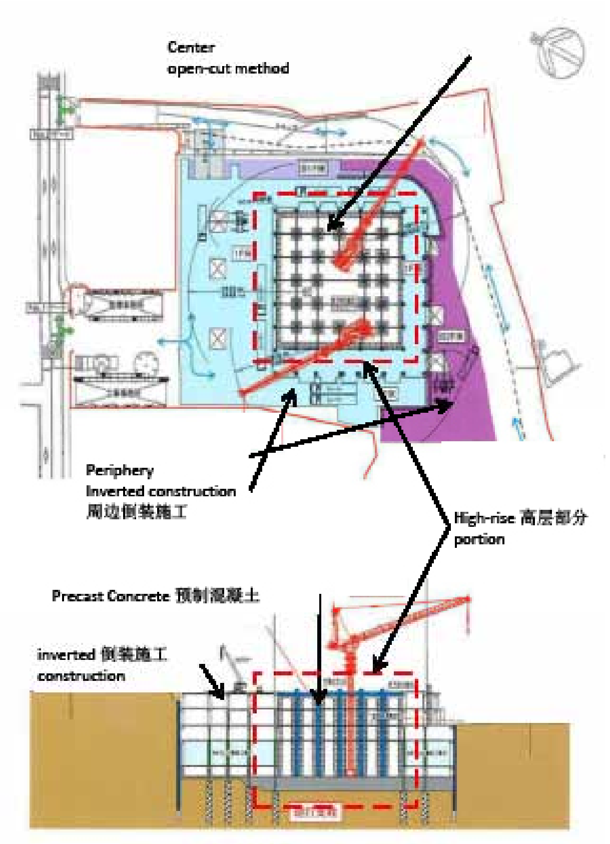

Figure 10. Plan of Temporary Works of Underground Construction (Source : Obayashi Corporation)
图10. 地下建筑临时工程计划（来源：大林组）

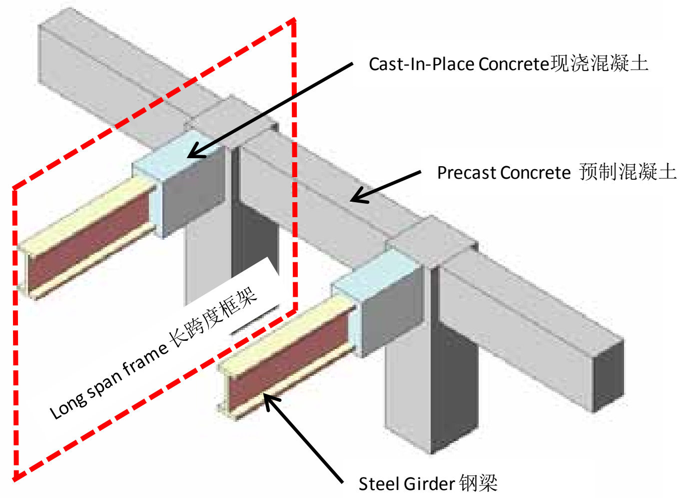

Figure 11. Figure 11: Configuration of a portion scramble steel Girder-Reinforced Concrete (Source:Obayashi Corporation)
图11. 梁-加固混凝土混合结构（来源：大林组）

LR横梁可从外侧移动，而主钢筋则插入套筒接头内。主钢筋插入束孔与套筒接头，因而V型柱可垂直移动。LRV与LRV-H施工方法有许多优点。每一构件都通过套筒接头直接连接起来，构件之间不需要浇筑混凝土。利用预制混凝土将横梁-柱连接起来，不需要用混凝土连接混凝土板或者下一部分的柱或横梁的其他部分。也不需要像传统预制施工法那样要求横梁与柱接合处主钢筋完全吻合，LRV与LRV-H法的装配效率高，精度高，速度快。通过建造厂即可以完成安装钢筋的复杂工作，这可以在很大程度上减少工作量，增加建筑整体质量。相较于一般施工方法，LRV预制系统有许多优点。

Underground Work Summary

There were challenged with the underground construction of this structure. The difference between the ground level was approximately 10 meters and the vehicle motion line was the only road in the northwestern part of the site. The construction period was too short to carry out a large construction volume and the weight of the building was going to be greater because the high-rise structure needed to made of reinforced concrete. To resolve these issues, an Inverted and Open Cut Construction method (the outer periphery of the building is inverted construction, the central part of high-rise directly under is open cut excavation method) was adopted. Thereby, it was able to achieve the rationalization of the work environment. And since the columns located directly under the high-rise are also precast members, a short period of underground construction of the structure was able to be realized (see Figure 10).

Hybrid Construction

Because a reinforced concrete beam does not allow for a column-free workspace for an office, using steel beams were used as a solution. The rationalization of the bonding method between steel and reinforce concrete was required to achieve this solution. In addition, the connection method for rolling steel beams with concrete was adopted. For incorporation into the design, the performance was confirmed by the structural performance of the confirmation experiment (see Figure 11). By setting the steel beam as part of its yielding position, it is possible that the property after yielding has toughness (see Figure 12). A Hybrid structure is a structure utilizing each structural characteristic.

The original design of the building was planned to be in steel. During the design phase, however, there was an increase in steel material

地下作业概述

建筑物的地下施工具有一定的挑战，它位于地平线下10米，供机动车通行的唯一路线就是位于建筑西北方向通道。施工期太短，无法进行大面积施工。由于要采用钢筋混凝土结构，建筑物重量将增加。为了解决这个问题，项目采用了倒装与明挖的施工方法（建筑物外部周边采用倒装施工方法，建筑正中心采用明挖施工方法）。从而达到了工作环境的合理化。由于建筑正下方的柱子也是预制构件，从而可以在短期完成地下建筑的施工工作（见图10）。

混合结构

由于钢筋混凝土梁结构必须在办公空间使用柱子，因而项目换用了钢梁结构。为了达到这一要求，钢筋与混凝土之间需要使用合理的凝结方法。另外，项目采用了轧钢钢梁与混凝土所用的凝结方法。为了采用这一设计，验证实验的结构性能证明了这一设计的性能。（见图11）。将钢梁作为弯曲位置的一部分，钢梁弯曲后的将更有韧性（见图12）。混合结构是一种采用各种结构特性的结构。

该建筑最初设计方案是钢结构。但在设计过程中，钢材料价格上涨。因此，合适的方法便是节约成本效益，改用钢筋混凝土结构，以最大程度减少钢材使用。

即便如此，建筑的施工期与采用钢结构的施工期基本相同，这全都有赖于设计阶段对施工计划的充分研究，以及与设计者和施工人员的充分讨论。这是由于这些，工程才取得了成功。

作者希望可以在将来根据建筑条件与社会环境，提出最佳结构形状与施工方法，以满足不同需要。

prices. Because of this, the cost benefits of changing to a reinforced concrete structure and minimizing the amount of steel used, became a suitable solution.

The construction was able to be completed as an equivalent to the construction of a high-rise building with a steel frame because of the study of sufficient construction plans at the design stage, along with a full discussion with designers and builders. Because of these factors, this project was able to be made into a success.

In the future, according to the building conditions and social situations, the authors would like to propose the optimal structure forms and construction method, as it can satisfy the needs of various orders.

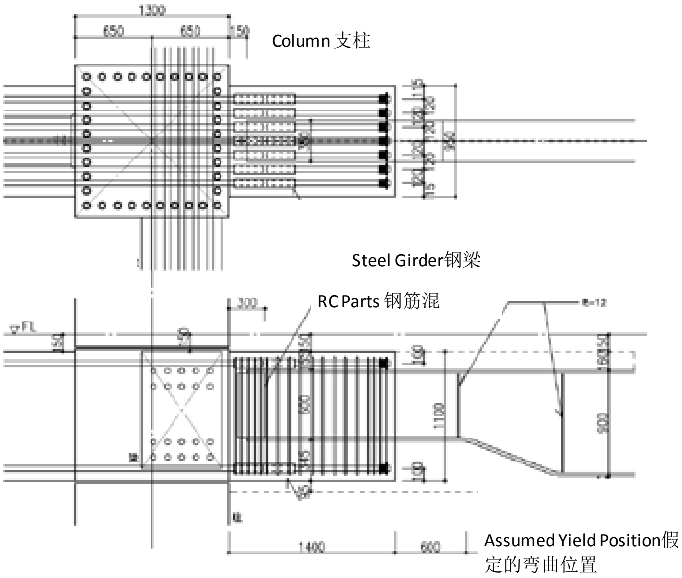

Figure 12. Detailed Drawing RC-S Joint (Source : Obayashi Corporation)
图12. 钢筋混凝土-钢梁接合处详图（来源：大林组）