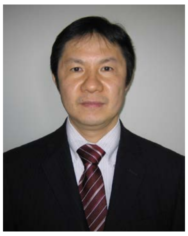
Structural Design of the High-Rise Building with Precast Prestressed Concrete (PCaPC) Beam — Minato Mirai Center Building —

プレキャストプレストレストコンクリート (PCaPC) 梁を有する超高層ビルの設計
— みなとみらいセンタービル —

 *
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Synopsis
The Minato Mirai Center Building is designed and constructed with a new approach to reinforced concrete high-rise office building. It is a 21-story office building in which a central longitudinal core structure is bounded on each side by wide-span office spaces measuring 22.8 m across. A major feature of the building is its column-free spaces offering a high degree of freedom in use; these are made possible by integrating the building's structural columns into the exterior walls. Good earthquake resistance and a sense of ease during earthquakes are secured by implementing a seismic response control system in which the boundary beams linking the wall columns act together with the seismic isolation system.

Structural Data
Number of stories: 21 stories above ground and two basement floors
Height: 98.20 m
Total floor area: 95,150 m^2
Use: Offices, Retail premises
Structure: RC wall column, steel beam and prestressed concrete beam
Designer: TAISEI Corporation
Contractor: TAISEI Corporation
Construction Period: Sep. 2007 – May. 2010
Location: Yokohama City, Japan

Fig.1 Minato Mirai Center Building

1. Building Outline
The building is located in Yokohama City, Japan. It houses retail premises on the 1st to 3rd floors and offices on the 4th to 21st floors. The standard floor plan is a regular rectangle measuring 80.4 m by 54.8 m, while the floor spaces on the two sides of the central longitudinal core have a wide span of 22.8 m. These large column-free spaces offering a high degree of freedom in use are a major feature of the design and are achieved by integrating the building's structural columns into the exterior walls. Good earthquake resistance is achieved using a seismic response control system in which special boundary beams linking these wall columns act together with the seismic isolation system.

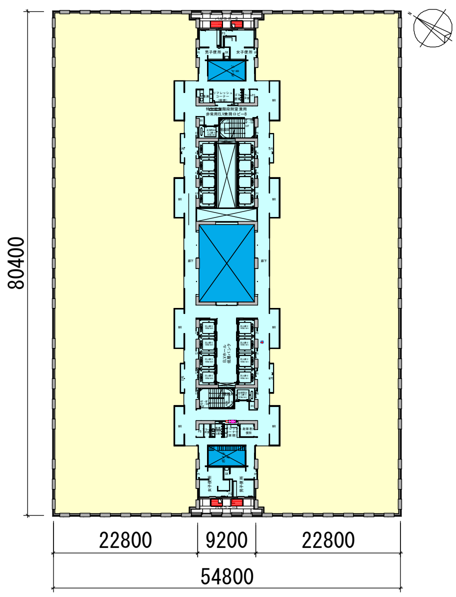


Fig.2 Standard floor plan

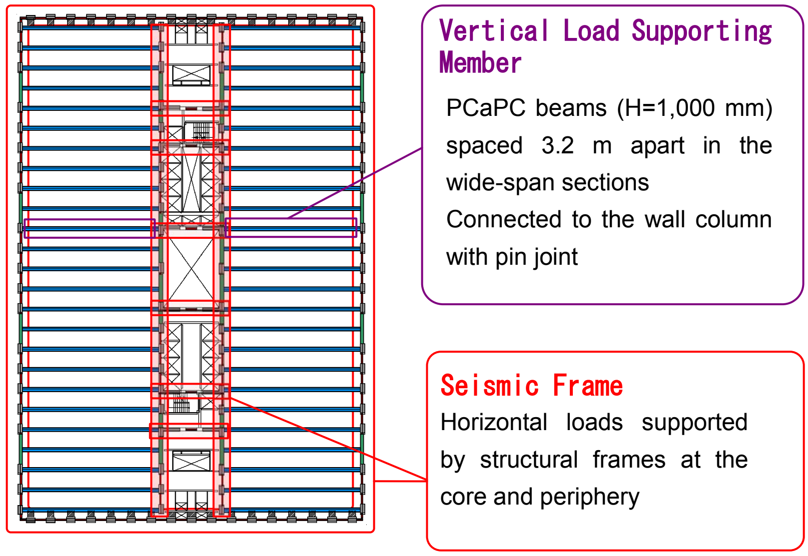


Fig.3 Structural floor plan

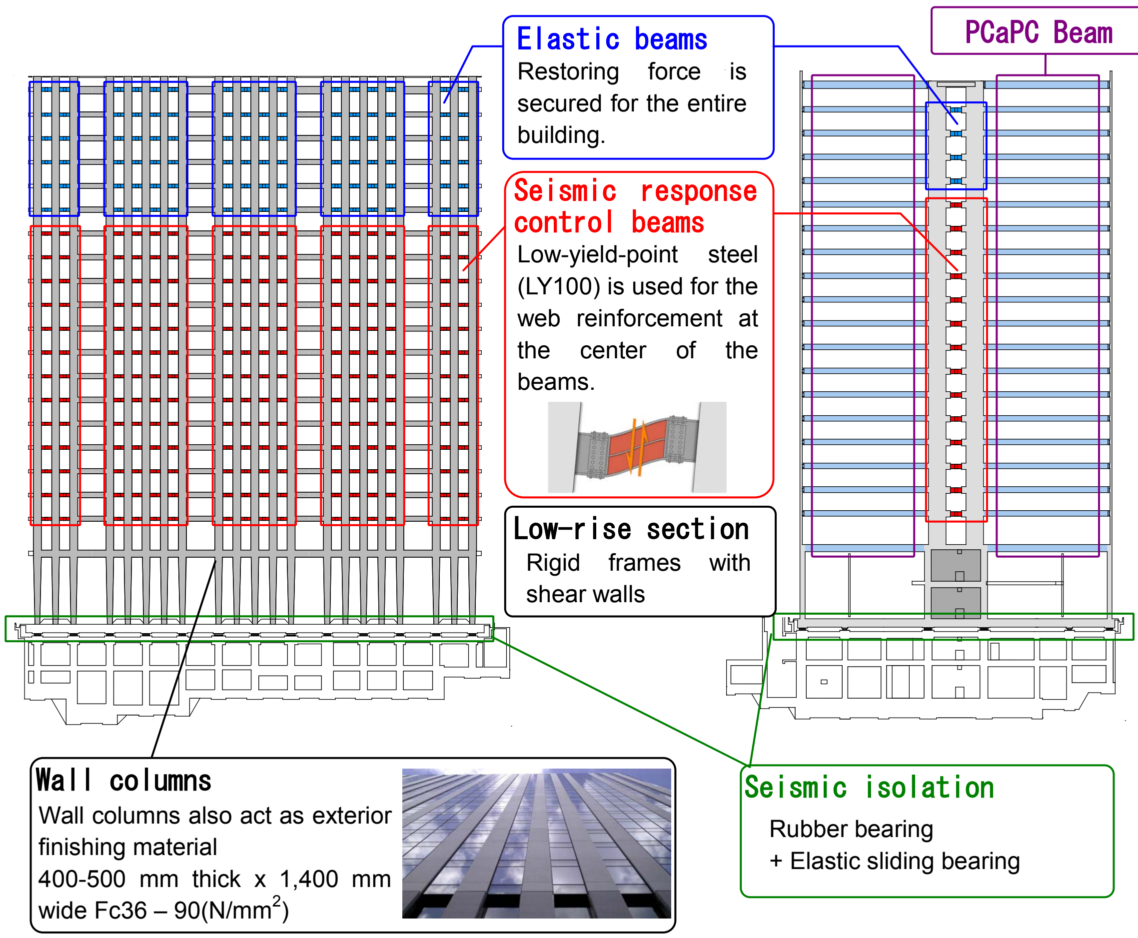


Fig.4 Structural outline

2. Outline of structural system

A seismic isolation system is adopted in order to reduce the seismic response of the superstructure and ensure continuing functionality of the building even after a major earthquake. This isolation system consists of rubber bearings and elastic sliding bearings under the 1st floor.

A reinforced concrete (RC) structure was chosen for the superstructure of the building so as to take advantage of its superior cost performance as compared with a steel(S) structure and ensure a comfortable interior space.

To obtain wide-span floors, prestressed concrete beams built by precast method (PCaPC beams) are adopted to support vertical loads only. These beams, spanning the distance between the peripheral and core wall columns, are pin-jointed so as to avoid exerting out-of-plane bending moment on the wall columns. Lateral loading during earthquakes acts on the structural frame, consisting of peripheral and core wall columns with steel beam linkages. Low-yield-point steel (yield strength = 100 N/mm^2) is for the web of the steel beam linkages so as to ensure shear yielding and absorb seismic energy in earthquakes. The wall columns with 400-500 mm in thickness are achieved by controlling the loads that act on them; they are precasted and form the exterior finish of the building. Good earthquake resistance and a sense of ease during earthquakes are secured by reducing the response shear force and response acceleration at every floor by implementing a seismic response control system in combination with the seismic isolation system. Elastic steel beams are installed on the 17th and higher floors to secure sufficient restoring force for the entire building and to reduce residual deformation after an earthquake.

3. Seismic Design

The target performance levels for earthquake resistance are defined as listed in **Table-1** under the design earthquake motions for small/moderate and major seismic events.

To gain a full understanding of the earthquake-resistant performance of the building, a nonlinear dynamic response analysis was carried out using the design earthquake motions.

4. Adoption of PCaPC Beams

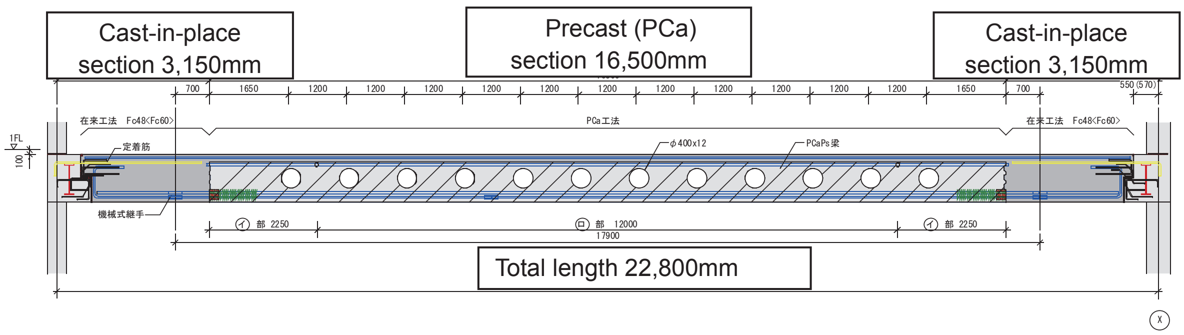
(1) Design of PCaPC Beams

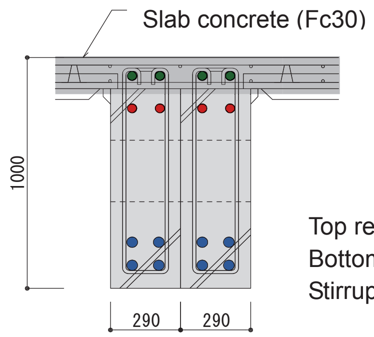
The PCaPC beams are adopted for this building so as to make possible large column-free office spaces. The PCaPC beams are arranged as simply supported beams in the transverse direction (with a span of 22.8 m) between the peripheral and core wall columns. **Fig.5** outlines the PCaPC beam design. The beams are spaced 3.2 m apart. From the viewpoint of transportation and lifting of precast members, the central 16.5 m long section of the 22.8 m span consists of two PCaPC beams placed in parallel, while the end sections are of cast-in-place concrete. The beams are 1,000 mm depth. In the central precast section of the PCaPC beams, there are through holes of diameter 400 mm spaced 1,200 mm apart.

As a structural solution to minimize the cross-sectional dimensions of the PCaPC beam, a study was made into the use of high-strength materials and the application of high levels of prestressing force. As a result, a cross section measuring 580 mm width (290 mm width x 2 beams in parallel) by 1,000 mm depth is realized, using concrete with a specified design strength of 80 N/mm^2 and high-strength reinforcement (USD685A, yield strength = 685 N/mm^2) as prestressing tendons. In conventional prestressed concrete beams using prestressing steel as tendons, there is a limit to how much the cross-sectional dimensions of the beams can be reduced due to the existence of the longitudinal reinforcement apart from tendons and the need to secure adequate spacing between tendons. In contrast, a feature of this method is that extra tendons in the axial direction are eliminated by the use of high-strength reinforcement in the axial direction that act as main

Table-1 Target earthquake-resistant performance

Level of earthquake motion		Level 1 earthquake motion Small or moderate seismic event	Level 2 earthquake motions Major seismic event
Superstructure		Stress induced in structural member: not higher than the allowable stress Story deformation angle: not more than 1/200	Stress induced in structural member: within elastic limit Story deformation angle: not more than 1/100 Accumulated damage of seismic response control member: not more than 0.2
Seismic isolation system		Rubber bearing: • Pull-out force should not be induced in the bearing.	Rubber bearing: • Compression stress: within compression limit stress • Tension stress: within tension limit stress of 1.0 N/mm^2
		Sliding bearing: • Sliding deformation: not more than 500 mm • Bearing should not lift.	Sliding bearing: • Sliding deformation: not more than 500 mm • Bearing should not lift.
Substructure		Stress induced in structural member: not exceeds the allowable stress	Stress induced in structural member: not exceeds the allowable stress
Footing beams and mat slab Piles		Stress induced in structural member: not exceeds the allowable stress	Stress induced in structural member: not exceed the design strength





1．Concrete

Specified design strength: Fc = 80 N/mm^2

Strength when prestressing force is introduced: Fc = 60 N/mm^2

2．Tendon

Steel bar: USD685A, prestressing force: 2,620 kN (σs = 575 N/mm^2)

Top reinforcement : 4-D32 (1st) SD390 + 4-D38 (2nd) SD390

Bottom reinforcement : 4-D38 (1st) USD685A + 4-D38 (2nd) USD685A

Stirrup: 2xD13-□-@200

Fig.5 Outline of PCaPC beam

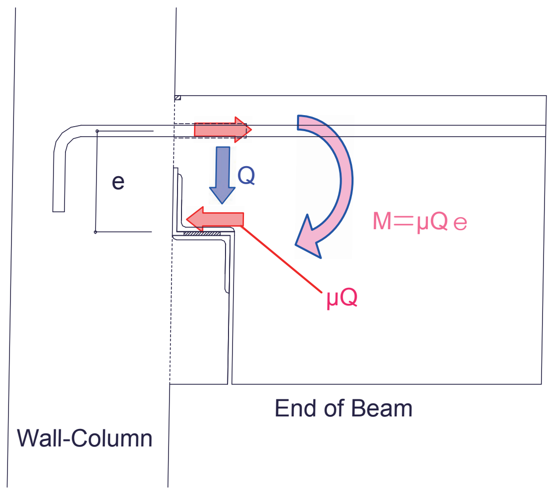


Fig.6 Pin joint of PCaPC beam

reinforcement and tendons, so tensioning force can be introduced in the lowermost area of the beams.

(2) Pin Joint of PCaPC Beams

To prevent excessive out-of-plane bending moment acting on the thin wall columns that support the PCaPC beams, structural details were developed with the aim of realizing a pin joint for the ends of the beam. A full-scale test of the pin joint (**Fig. 6**) was conducted to confirm its shear strength and rotational performance. The test results confirmed that the degree of fixation of the pin joint at the end of the beam was decreased very much compared with that of a rigid joint. Further, the shear strength of the bracket at the end was shown to have a margin of safety three times greater than the design vertical load due to gravity.

5. Conclusion

The Minato Mirai Center Building incorporates a new type of seismic response control system in which the structural members that absorb seismic energy are completely separated from the structural members bearing the permanent vertical load. This seismic response control system operates in combination with a seismic isolation system, making it possible to secure good earthquake-resistant performance and, at the same time, achieve an open architectural design. Further, the building makes use of a prefabrication method using PCaPC beams with high strength material. The result is an office building of superior quality, constructed with good cost-performance in a reasonable construction time.

概　要

本建物は地上21階建の超高層オフィスビルであり，センターコアの両側に22.8mのロングスパンの執務空間を有している。本建物の特徴は，外壁を構造体の壁柱として利用し，柱型のない自由度の高い空間を確保していることである。ロングスパン部に採用したPCaPC梁には高強度コンクリートと高強度鉄筋を使用し，断面を最小化するとともに，優れた経済性も確保している。また壁柱同士をつなぐ境界梁を利用した制振構造と，免震構造を組み合わせることにより，高い耐震性能と地震時の居住性・安心感を確保しており，RC造による超高層オフィスの新しい試みを示す建物である。