# Design of “Rikkyo University LLOYD HALL” — Planning of Precast Prestressed Concrete Slabs Considering Architectural Design and Mechanical Engineering —

# 「立教大学ロイドホール」の設計 — 意匠性・設備機能性を兼ねた PCaPC 床版の計画 —


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**Keywords:** PCaPC slabs with curved surfaces, architectural design and mechanical engineering
**DOI:** 10.11474/JPCI.NR.2014.21

## Synopsis
In order to provide an affluent atmosphere within the limited floor height, precast prestressed concrete (PCaPC) slabs with curved surfaces were applied diligently for a university building consisting of a main library and research facilities. The slab was designed not only considering structural rationality and construction workability but also design characteristics and functionalities of the building facilities. As a consequence an attractive design method employing PCaPC slab was accomplished.

## Structural Data
*Structure*: steel encased reinforced concrete, Precast prestressed concrete (floor slab, beam, post)
*Number of stories*: B2, 7F, P1
*Maximum height, eaves height*: 32.1 m, 26.6 m
*Construction period*: August 2010 - July 2012
*Constructors:* Shimizu Corp. and Kenken Co. Ltd
*Location*: Toshima-Ku, Tokyo

## 1. Introduction
The building was designed to be the largest building in the university campus with 7 stories above ground and 2 below. Net floor area is more than 20,000 $m^2$. The building hosts an integrated large scale library with a capacity of two million books and a seating capacity of 1520 seats. The faculty libraries were originally scattered around the campus. The second basement floor is dedicated for automated storage. The first basement floor up to the third floor is for the library functions. Research laboratories with small rooms are located from the fourth floor and above. The long span PCaPC slab was designed to be exposed on the ceiling without finishing in order to provide an affluent space within the limited floor heights. It was planned as a skeleton considering structural rationality, construction workability, cost performances, design, and building facility functionalities.


**Fig. 1 Over view**


**Fig. 2 Night view**

## 2. Structural Planning

### (1) Outline of structural planning

Steel encased reinforced concrete (SRC) construction was adopted considering its capacity in strength, stiffness and ductility against input forces. As for the framing system, rigid frame structure with shear walls was adopted. The low-rise section of the building (from the second basement floor to the third floor) hosting library functions has shear wall type reinforced concrete cores concentrated in the four corners, which contributes not only to having an efficient resistance against earthquake but also creates a clear zoning which matches the architectural planning. This design allows one large open space (ca. 48m x 40m) without walls obstructing views. The high-rise section of the building (from the fourth floor above) hosts small rooms such as research laboratories. Reinforced concrete cores resist against seismic forces which are located in the spaces designated to elevators, staircases, or machine rooms located in the east and west sides of the building for concrete walls. PCaPC slabs which show superior characteristics in strength and stiffness have been applied to the library floors requiring heavy duty floors with the maximum span of 14.6 meters, realizing the large space with much flexibility. Most of the precast slabs has no ceiling finish and is exposed to the interior space to realize an affluent atmosphere within the limited floor heights.

### (2) Structural member design

Columns of main structural frames are designed with SRC sections measuring 900mm by 900mm and 800mm by 1000mm. SRC girders in the low-rise section of the building in the X direction - which support PCaPC slabs with spans of 14.6m and 12.1m - have a standard section of 600mm x 950mm and span 6.6m. In the Y direction the girders have the same standard section of 600mm x 950mm by considering the details with the PCaPC slabs (adjusted at bottom side). In the high-rise section of the buildings, the girders have the standard section measuring 500mm by 750mm, and cast-in-place concrete slab of the thicknesses of 150mm - 180mm was adopted. Reinforced concrete shear walls have the maximum thickness of 650mm to maintain the sufficient stiffness and strength against seismic forces.

## 3. PCaPC member designs

### (1) Curved surface PCaPC slab designs in the low-rise section of the building

The slabs in the low-rise section of the building were designed with curved surface PCaPC slabs of the bilge shape, and planned as one large space by eliminating girders as much as possible by considering the expanse of the space. The curved surface PCaPC slabs have the maximum span of 14.6m, affording ample flexibility. PCaPC slabs are exposed by eliminating ceiling finish as much as possible, and were designed considering the structural rationality, construction workability, cost performance, or the design characteristics. The shape of the PCaPC slabs was determined by following the stress lines of the simple beam. At the slab centers the bending moment is maximum and no shear forces arise, while the opposite is the case at the both ends. Structural forces can be directly represented by the downward-convex shape, however in the practice, the upward-convex shape were applied for the PCaPC slabs and reserving space at the upper side of the both ends, thus the space were utilized efficiently for the ducting route under the flooring. Curved surface steel

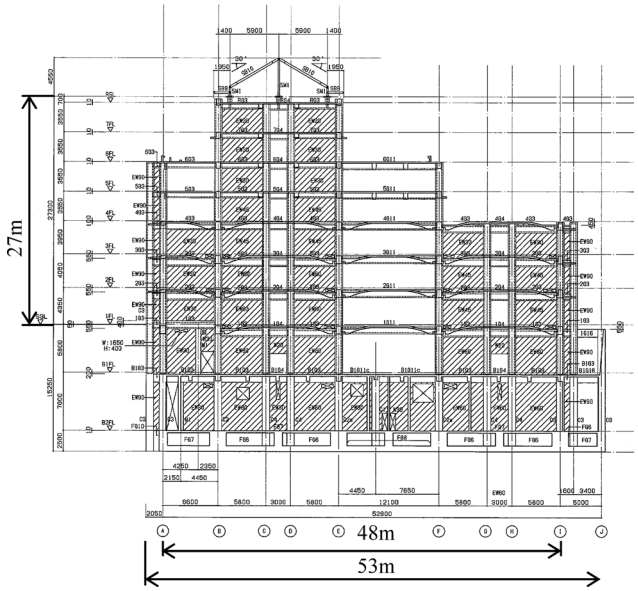


Fig. 3 Framing elevation

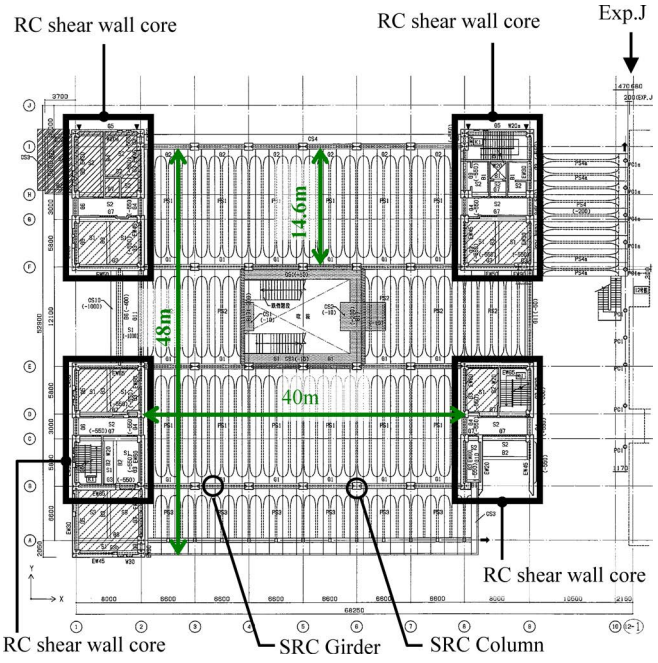


Fig. 4 Floor plan

moldings were used for the production of the PCaPC slabs, and the appearance of the figurative shapes which are difficult to realize with the cast-in-place concrete were investigated. The distribution pattern (width) of the PCaPC slabs has been determined as 1,650mm by considering the layout of the bookshelves and construction workability (transportability). Thus, architectural design, structural and mechanical engineering have been equally considered.

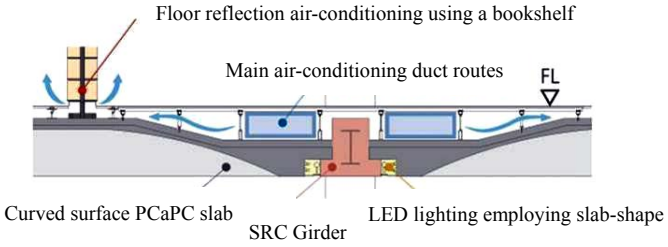


**Fig. 5 System of PCaPC slabs with curved surfaces**

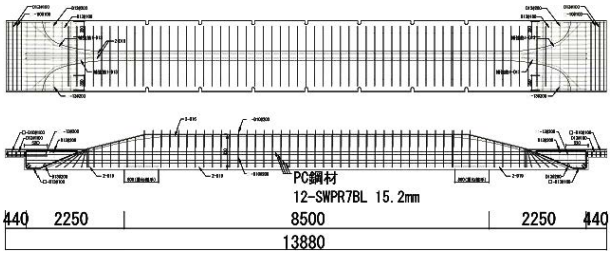


**Fig. 6 Detailed drawings of PCaPC slab with curved surfaces**

### (2) Curved surface PCaPC slab with beam

Curved surface PCaPC slab with canopy-beam was planned for the slab of the south facade. The edge of the slab was tapered toward outside to obtain the open inner space toward the campus in the south direction. The perimeter columns and beams have the flat section shape, which contributes to the openness of the facade. The flat beams of section measuring W:500mm by H:400mm has been formed by having a rectangular section at the edge of each slab and unifying by in-situ tensioning with prestressing cables after the placement of the slabs. Every other PCaPC slab of 1,650mm width is supported at the beam by the precast concrete (PCa) post columns of the section measuring 300mm by 450mm distributed at the distance of 3,300mm, which, by eliminating the number of the posts at the perimeters as much as possible, contributes to the openness of the facade.

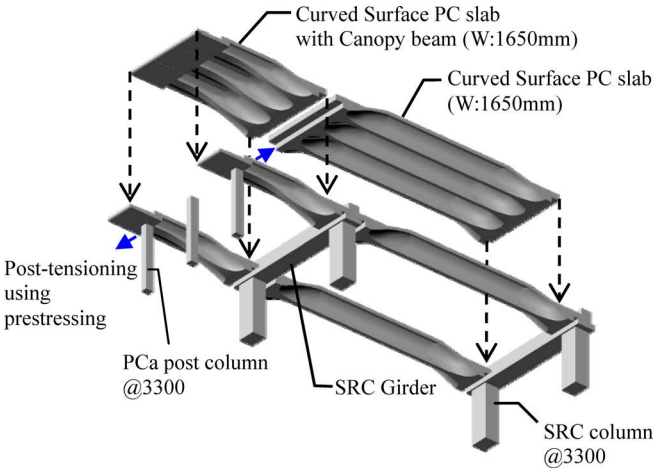


**Fig. 7 Structural system**

**Fig. 8 Interior view (Reading area)**

### (3) Design of the r-shaped curved surface PCaPC slab at the entrance

R-shaped curved surface PCaPC slab in the entrance hall having double height called “Learning Square” was carefully designed whose shape was determined as 11.5m-long and r-shaped by considering lighting and illumination planning and air-conditioning planning. Both side-ends of PCaPC slabs are post-tensioned with prestressing cables to form the beam shapes within the slabs, and intensive distribution of PCa post columns contributes to the flexibility of the entrance hall.

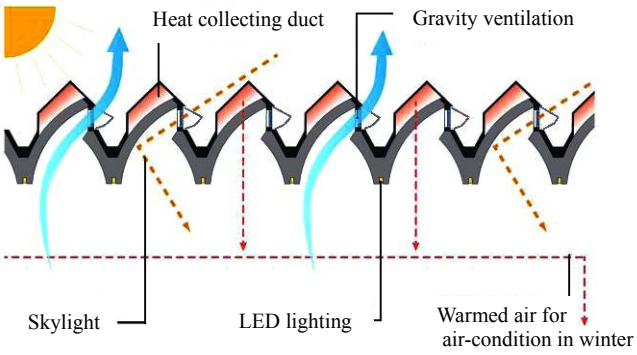


**Fig. 9 System of R-shaped curved surface PCaPC slab**

**Fig. 10 Interior View (Learning Square)**

## 4. Outline of construction

Curved surface slabs, rectangular posts, r-shaped roof slabs and cross-shaped post above the double height area of the Learning Square, and stair slabs are adopted as the PCa components. Amongst the PCaPC slabs, PS1, PS2, PS4, PS5 are the ST slabs with the distinctive forms in the edge curved surfaces. These ST panels were manufactured as pre-tensioned members with prestressing cables in the linear alignments in the ribs. In the PS3 slabs composed of the edge canopy and edge curved surface prestress was introduced along the curve through the unbonded prestressing cables (tensioned in the factory). The PCaPC slabs adopted in this project have three-dimensional curved surfaces, and to realize the edge curved surface, naval engineering was employed in the manufacture of concrete form. Before the manufactures mock-up was made and the shape, colors, shading with illuminations by night were confirmed. Construction areas for the PCa members are divided in a plane and the construction planning employing the crawler crane using the double height area in the central part of the building was made by considering the working radius of the crane. Timbering planning of the exposed PCaPC slabs, systemized timbering (rectangular tower method) was adopted aiming to the shortening of the construction period and maintaining high accuracy, which enabled the consecution with the vertical and horizontal tolerances of +- 3mm.

## 5. Conclusion

PCaPC slabs are employed in this building enabling an affluent atmosphere within the limited floor heights. The slab was designed not only by considering structural rationalities or construction workability but also design characteristics or functionalities of building facilities. As a consequence an attractive design method employing PCa floor slab was carried out.


### Acknowledgements

Acknowledgement is in order for the staffs from Shimizu Corporation and Kenken Co. Ltd. involved in the construction of this building to a high quality and high accuracy and to a very precise construction schedule.


**Fig. 11 Steel form for PCaPC slabs**

**Fig. 12 Placement of PCaPC slabs (PS3)**

**Fig. 13 Tension end of PCaPC slabs (PS3)**


## 概　要

大学の中央図書館と学部研究施設から成る施設として計画された建物において，限られた階高で豊かな空間を実現するために，曲面 PCaPC 床版を積極的に用いた計画を行った。

曲面 PCaPC 床版は，力学合理性や施工性だけでなく，意匠性，設備機能性にも配慮した三位一体の躯体として計画し，PCaPC 床版の魅力ある設計の一手法を実践した。