Creating a New Form of Reinforced Concrete Construction — Ryukoku University Jojukan —

鉄筋コンクリート造の新たな形態の創出 — 龍谷大学成就館 —

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Synopsis
Ryukoku University Jojukan is a university facility with large and medium-sized halls. The hall building is made of fair-faced concrete with an irregular 26-sided façade, giving it the appearance of a massive sculpture. The aim of this project was to create a new form of reinforced concrete (RC) construction by integrating the open architecture with glass curtain walls and without expansion joints to achieve both aesthetics and structural safety. This paper reports on the structural planning of the complex form and the construction devices used to realize it.

Structural Data
Structure: Reinforced concrete construction, 1 basement floor, 5 above-ground floors
Height: 18.25 m
Building Area: 1,841 m^2
Extended Bed Area: 5,607 m^2
Use: School
Location: Fushimi-ku, Kyoto, Japan
Completion of Construction: Jan. 2020
Designer: Iida Archiship Studio
Structural Designer (*Basic and Execution Design*): Kanabako Structural Engineers
Structural Designer (*implementation design*): Takenaka Corporation
Equipment Designers (*Basic and Execution Design*): Chiku Engineering Consultants
Equipment Designer (*Implementation Design*): Takenaka Corporation
Construction Company: Takenaka Corporation

Photo 1 Front view of building

1. Introduction
Ryukoku University Jojukan is a facility that includes a 350-seat main hall, a 150-seat middle hall, a place to support club activities, and a cafeteria open to local residents. The L-shaped building with glass curtain walls and the massive sculptural hall building are integrated without expansion joints (**Photo 1**). The hall building is an irregular 26-sided structure with a maximum slope of 30° and a 5.5-m-long cantilever. It is an unprecedented form of RC construction, and this paper describes the structural plan of the complex form and the construction devices used to realize it.

2. Outline of Building Plan
Figure 1 shows the axonometric drawings, and **Fig. 2**

shows the third-floor plan. The overall building is a university facility with a cafeteria on the first floor, a hall building consisting of a medium-sized hall and a large hall on the second floor, and a four-story L-shaped building where club activities are mainly held, all of which are integrated through a corridor. The exterior walls of the L-shaped building are glass curtain walls on the north and west sides and strips of fair-faced concrete on the east and south sides.

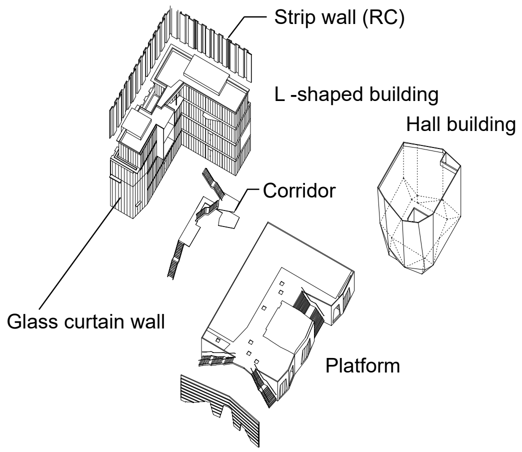

Fig. 1 Axonometric drawings

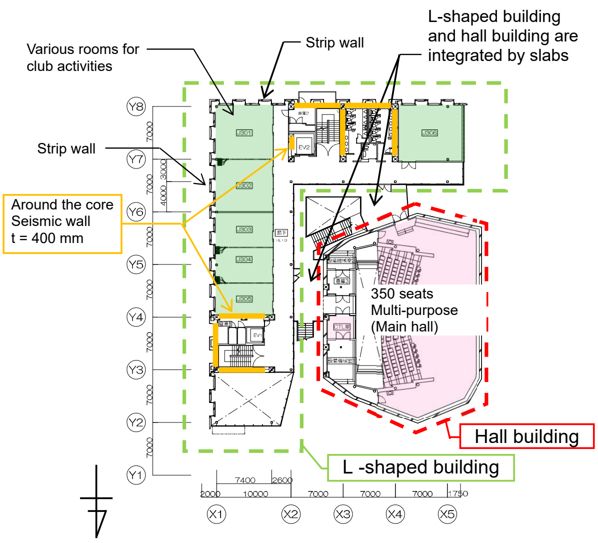

Fig. 2 Third-floor plan

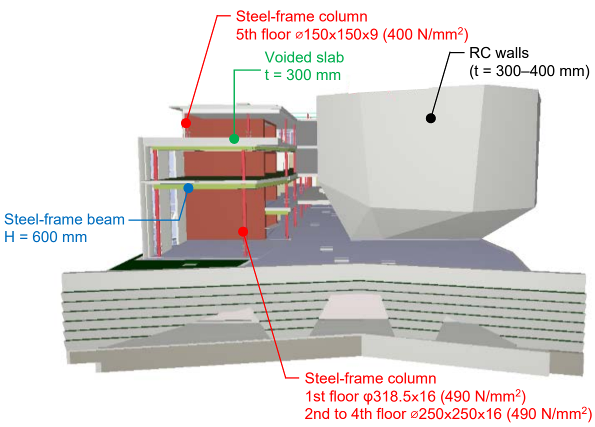

Fig. 3 Outline of structural plan

3. Structural Planning

(1) Overall Structural Plan

Figure 3 shows the outline of the structural plan, in which the open interior space of the L-shaped building, the large spaces inside the hall building, and the massive exterior are realized by using a mixed structure of RC, steel reinforced concrete (SRC), and steel (S).

(2) Structural Plan for L-shaped Building

The L-shaped building was designed to be as rigid as the hall building, yet open and flexible, by using a hybrid structure of steel frame and voided slabs (**Photo 2**) and a concentrated arrangement of RC shear walls around the cores that the wall thickness of 400 mm (**Fig. 2**). With a 10 m × 7 m standard grid in the plan, the steel beams are 150-mm steel–concrete composite (SC) beams embedded in the void slab with a thickness of 300 mm (**Fig. 4**), eliminating minor beams and allowing the structure to be exposed. This eliminates the need for ceiling finishes and enhances the sense of openness, while keeping the standard floor height low. The strip walls on the south and east façades, shown in **Fig. 2**, are made of cast-in-place concrete to use them effectively as earthquake-resistant walls, contributing to the improvement of the seismic performance, while the staggered layout allows adequate light to enter the building while blocking the line of sight to neighboring properties.

Photo 2 Voided slab construction status

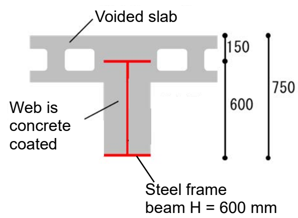

Fig. 4 Composition of SC beam

(3) Structural Plan for Hall Building

The hall building has an RC outer shell and a steel-framed interior, resulting in a column-free interior space and the thinnest outer shell (wall thickness 300–400 mm). **Table 1** gives the seismic design criteria. The hall building, which has many ridges and an acrobatic form with a maximum slope of 30° and a maximum cantilever length of 5.5 m (**Photo 3, Fig. 5**), was designed with structural safety in mind such that the short-term allowable stress is larger than 1G for horizontal seismic intensity and 1G for vertical movement, aiming for no damage even in the event of a major earthquake. The halls were modeled with plate elements (**Fig. 6**) and were designed considering out-of-plane shear and out-of-plane bending in addition to axial forces and in-plane shear.

Table-1 Seismic design criteria

	Long-term	Short-term (in case of a mid-strength earthquake)	Ultimate (at the time of the Great Earthquake)	Margin (horizontal 1G)
Axial force	Long-term allowable compressive stress or less	Long-term allowable compressive stress or less	Long-term allowable compressive stress or less	Short-term allowable compressive stress or less
Bending	Long-term allowable bending stress or less	Short-term allowable bending stress or less	Short-term allowable bending stress or less	Ultimate bending strength or less
Shear	Long-term allowable shear stress or less	Short-term allowable shear stress of concrete or less	0.1 Fc Below material strength of concrete	Short-term allowable shear stress of rebar or less

Photo 3 Hall building jump-out

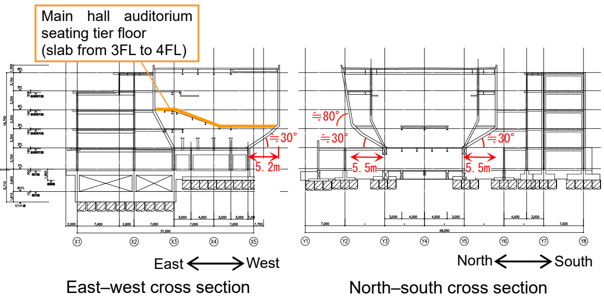

Fig. 5 Cross-sectional views

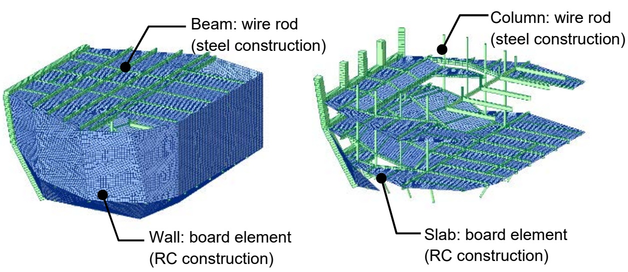

Fig. 6 Analytical model of a hall

4. Realization of New Form of Hall Building

For the hall building, which was extremely difficult to construct, a feasible and rational method was devised through collaboration among workshops, design and construction support departments, and the rebar installation company.

(1) Rebar Arrangement Method

Figure 7 and **Table 2** present the north elevation and the type of wall reinforcement in the hall building. The horizontal ridge line of the hall building slopes from 3FL + 500 to 3FL + 2500 (ridge line ①) on the east side to match the stepped floor of the main-hall seating area. The wall thickness is 400 mm from 2FL to ridge line ①, 300 mm from ridge line ① to RFL, and 200 mm at the parapet section from RFL. For the wall reinforcement, three types of reinforcement are used according to the stress state. The 400-mm wall at the leg with the highest stress has three rows of reinforcement.

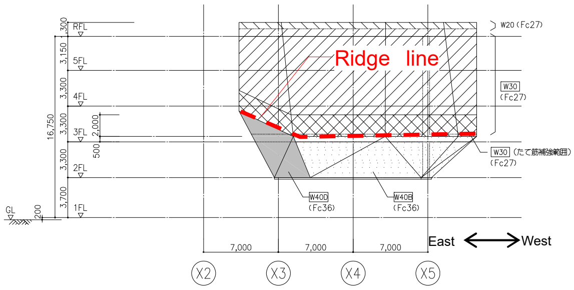

Fig. 7 North elevation

Table-2 Reinforcement list for hall building

Sign	Vertical reinforcement			Horizontal reinforcement		
	Outside	Central	Inside	Outside	Central	Inside
W40B (t = 400 m)	D16@100	D16@100	D19@100	D16@100	D16@100	D16@100
W40D (t = 400 m)	D19@100	D19@100	D19@100	D19@100	D19@100	D19@100
W30 (t = 300 m)	D16@200	-	D16@200	D16@100	-	D16@100

(2) Use of Digital Technology

The shapes of the rebar on the exterior walls of the hall building—both vertical and horizontal—differed from one another; thus, it was necessary to simplify the process as much as possible to make it possible to construct the building. In addition, because the exterior of the hall building is made of RC and its interior is S-framed, it was necessary to check the interference between the rebar and the interior steel frame. The use of digital technology made it possible to realize a complex reinforcement arrangement. For the rebar processing, a 3D model of the rebar was created using Rhinoceros (3D CAD software) and Grasshopper (plug-in algorithm editor), and the rebar angles and lengths were calculated to enable detailed pick-out with different lengths for each rebar. For interference with the steel frame, Solibri (superposition software) was used to check the interference between the rebar and steel frame 3D models of each (**Fig. 8**).

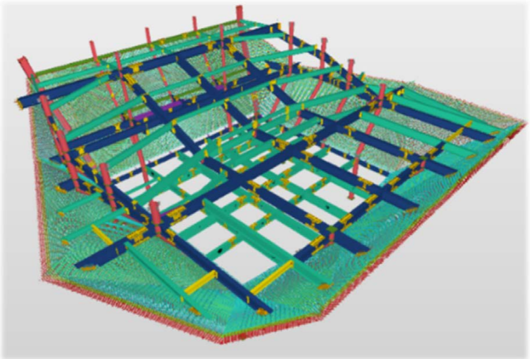

Fig. 8 Confirmation of interference with steel frame by Solibri

(3) Preliminary Confirmation by Mock-up

As shown in **Photo 4**, a mock-up of the most complicated part of the rebar was created to confirm the workability, delivery, and anchorage procedure in advance, and then the rebar was installed (**Photo 5**).

Photo 4 Mock-up

Photo 5 Hall reinforcement

(4) Crack Prevention

The exterior walls of the hall building were designed without joints; thus, cracks were restrained by placing a sufficient amount of reinforcing steel to control the crack width. The walls were made progressively thinner to distribute the shrinkage of the concrete over the entire building. In the concrete mix plan, an expansive material and a shrinkage-reducing high-performance air-entraining water reducer were used as the admixture to reduce drying shrinkage, while mountain gravel—which has low drying shrinkage—was used as the aggregate.

5. Summary

A new form of RC construction was realized through close collaboration among designers, workshops, and subcontractors, as well as the use of digital technology. Photographs of the completion are shown in **Photos 6** and **7**. The authors hope that the technology introduced in this paper will contribute to the further development of RC structures.

Photo 6 Front view (evening)

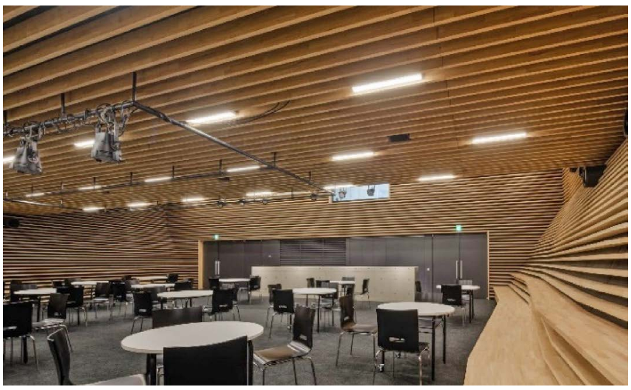

Photo 7 Interior view of middle hall

概　要

龍谷大学成就館は，大・中の音楽ホールを含む大学施設である。ホールは不定26面体の打放しコンクリートで，彫刻のようなマッシブな建築である。これをガラスのカーテンウォールによる開放的な建築とEXP.J無しに一体とし，美観性と構造安全性を両立させることで，RC造の新たな形態の創出を目指した。本稿では，複雑な形態の構造計画を実現するにあたっての工事上の工夫点について報告する。