Stadium Utilizing Precast Technology for Various Structural Elements — The National Stadium —

プレキャスト化技術を用いたスタジアム — 国立競技場 —

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Synopsis

The National Stadium (formerly, the New National Stadium) was the main venue for the 2022 Tokyo Summer Olympic and Paralympic Games held in 2021 (**Fig. 1**). This stadium is hoped to become a place where all athletes can perform at their best and loved and used frequently by future generations. Based on the concept of a "stadium in a forest," the new stadium is open to everyone. As part of the forest of the Meiji Jingu Shrine, it forms a green network spreading from the Inner Garden of the Meiji Jingu Shrine to the Imperial Palace. At the same time, it is the new center of a sports cluster where everyone can enjoy walking and participating in various sports.

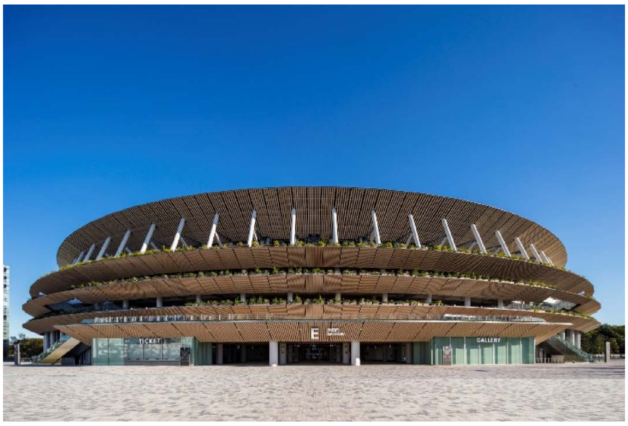

Fig. 1 National stadium

Structural Data

Structure: Steel construction, partially encased steel-concrete
Width: 325 m × 250 m
Height: 47 m
Cantilever Roof Length: 60 m
Owner: Japan Sport Council
Designer: Taisei Corporation, Azusa Sekkei Co., Ltd., and Kengo Kuma and Associates Joint Venture
Contractor: Taisei Corporation
Construction Period: Dec. 2016 – Nov. 2019
Location: Tokyo, Japan

1. Building and Structural Outline[1]

The maximum building height is below 50 m, and the low-sloping roof consists of a cantilever truss structure of about 60 m in length (**Fig. 2**). The sense of oppression to the neighborhood is reduced by large building setback from the street and inclined outer columns. The main structure of the stadium above ground is a steel structure. A steel-reinforced concrete (SRC) (i.e., steel encased in concrete) structure using precast and prefabricated products is adopted for the oblique beams (i.e., raker beams) that support spectator seats and for the outer columns that support the roof trusses. Furthermore, a response-controlled structure by means of a soft-first-story system provides this stadium with high seismic performance. The hybrid structure comprising wood and steel for the lower

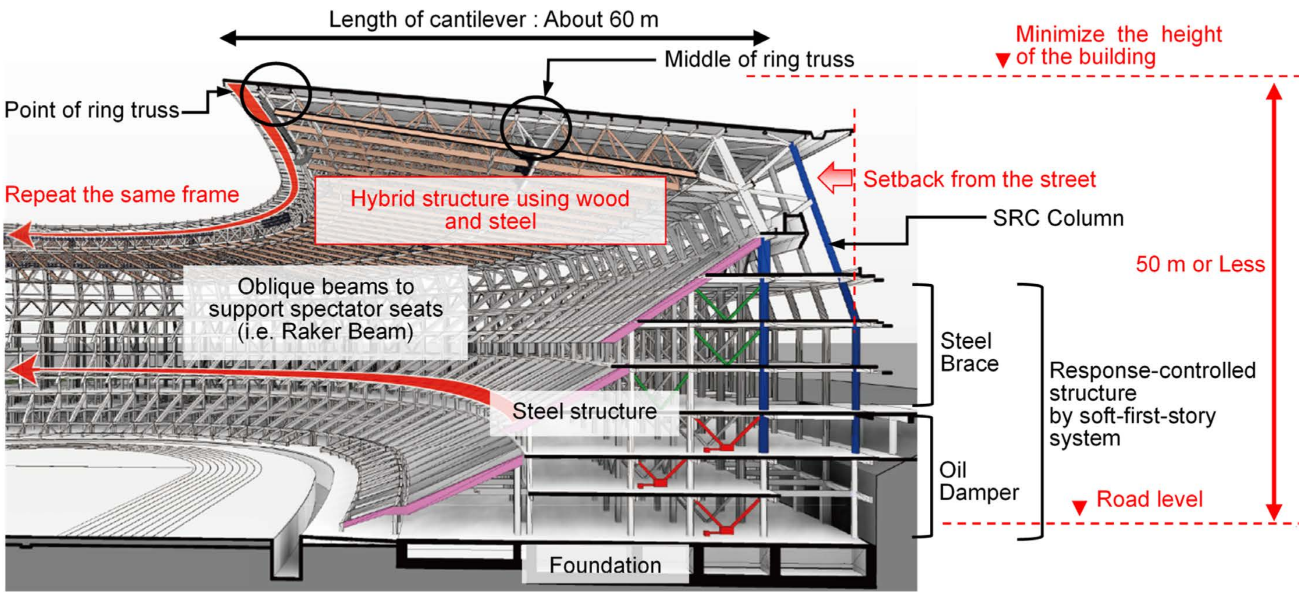

Fig. 2 Outline of cross section

chords (Japanese larch) and the lattice members (Japanese cedar) arranged in the three-dimensional roof trusses create a space that feels sufficiently Japanese. The wood is used for the members that control truss deflection due to earthquakes or strong winds.

2. Simple Stand Structure Considering High Constructability

Using the same frame composition repeatedly in the circumferential direction for both the roof and stand frame systems improved productivity, transportability, drawing efficiency, and constructability. Furthermore, this resulted in a substantial reduction in the construction period and cost (**Fig. 3**). Also, unitization and use of factory prefabricated elements were promoted, given labor shortages at the construction sites and the need for higher efficiency of construction site work. In particular, unitization was used for the roof trusses, the precasted foundations, and the outer SRC columns.

3. Efficient Construction of the Cantilever Roof Frame

The roof trusses were unitized to achieve efficient construction and to reduce the construction period. By creating a one-frame free-standing structure of a cantilevering truss, simultaneous construction of the stand, the field, and the roof portion was achieved

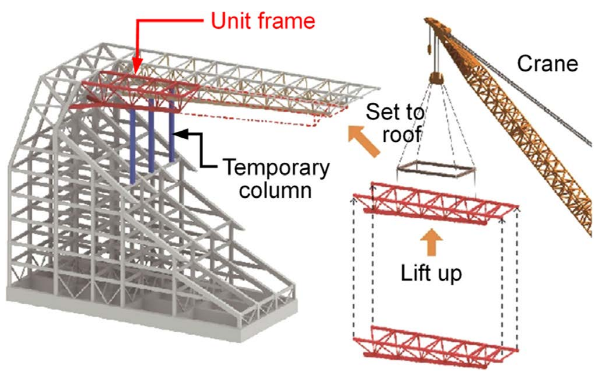

Fig. 4 Image of roof construction

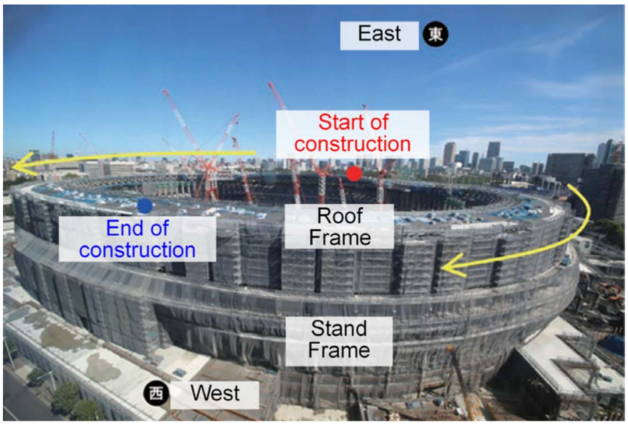

Fig. 3 Simplified structure plan

Fig. 5 Unit of roof truss

(**Fig. 4**). The roof frame adopts a frame system that has cantilever space trusses with triangular cross sections arranged continuously in the circumferential direction. Two upper chords and one lower chord are connected using lattice diagonal members. Lattice members contribute to avoid buckling of the upper chords and the lower chord and behave as horizontal braces in the roof surface. The roof was united by joining the webbing of the upper chords of each unit with high-tension bolts. Channel steel is used for the upper chord (**Fig. 5**).

4. Response-controlled Structure by a Soft-first-story System with High Seismic Performance

Expecting the unspecified number of people using the stadium at any time, it was decided to ensure higher seismic performance than that of general buildings. Ordinary, the raker beams that support spectator seats behave as brace members, providing high seismic resistance, but this leads to a short natural period. Therefore, the response of the stadium from the time history analysis would be fairly large and made it impractical to design the structure that would satisfy the given structural criteria. To deal with this, it was necessary to either install response-control devices that absorb earthquake energy or increase the natural period of the building. However, the installation of additional dampers to absorb earthquake energy was not enough for the stadium to satisfy the criteria. Therefore, the natural period of the lower part of the stadium was intentionally increased by designing it as the base isolation structure (soft story), and by installing a sufficient number of response-control devices (oil dampers) concentrically. This creates a response-controlled structure by means of a soft-first-story system with high seismic performance. Soft-story frames that are less stiff than those of the other stories were designed by using a three-story moment-resisting frame from B2F to 1F. By making these three stories soft, the stadium achieves high redundancy (**Fig. 6**).

5. Technology for Precast Members

Considering the labor shortages at the construction sites, it was decided to unitize the roof trusses and precast the foundations, the SRC columns, and the raker beams (**Fig. 7**).

(1) Precasting of Foundations[2]

The size of a precast foundation element was determined by its weight and the lifting capacity of the crane, with the maximum weight of a precast element being about 280 kN. The size of a precast member was standardized to three different heights and three different widths considering constructability at a precast factory. Cast-in-place concrete was adopted at the ends of the foundation beam. Mechanical joints were used at the rebar joints of the beams (**Fig. 8**). Because the building's plan shape is elliptical, there is an angular difference of about 4° between beams in the circumferential direction. The foundation beams remain in a linear arrangement, and the angular difference is adjusted at the joints. The angles of the reinforcement bars are made by using the space inside the mechanical

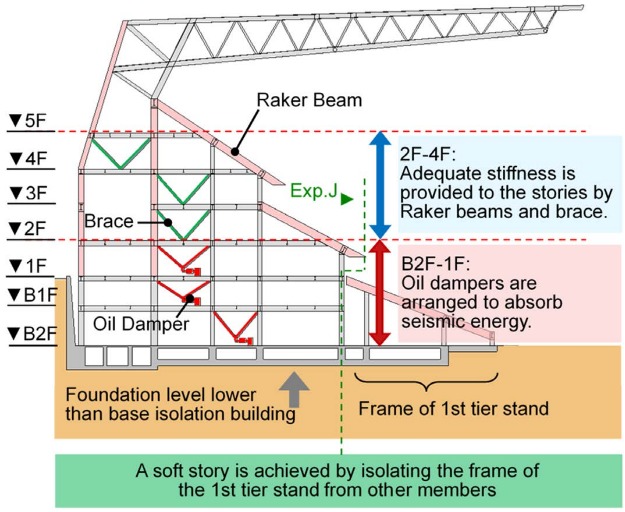

Fig. 6 Response-controlled structure by means of a soft-first-story system

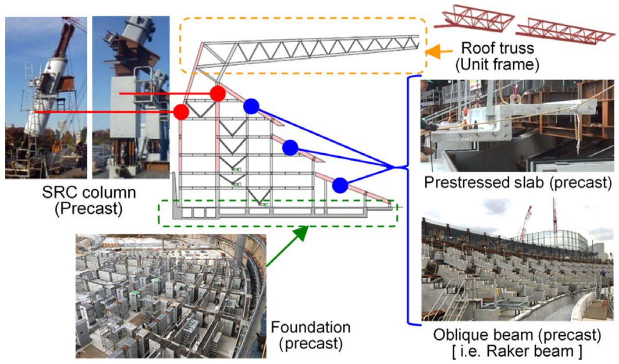

Fig. 7 Unitization and prefabrication of members

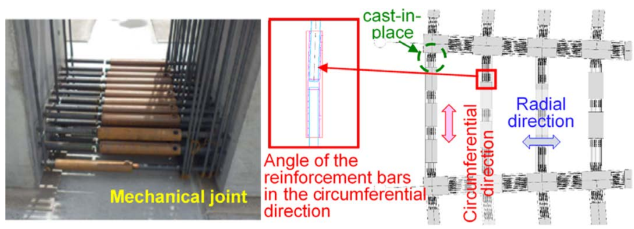

Fig. 8 Details of precast foundations

Fig. 9 Self-leveling material under foundations

Fig. 10 Precast prestressed SRC columns

Fig. 11 SRC column manufactured at the precast factory

joints. Because the spread foundation was adopted, it was necessary to transfer the weight of the building to the ground directly below the foundation. For that reason, by forming a flat surface with self-leveling material on the ground and by placing a foundation beam on top of it, stress is transferred from the foundation beam to the ground (**Fig. 9**).

(2) Precasting of SRC Columns[3]

A precast prestressed SRC structure with sufficient rigidity and bearing capacity was adopted for the outer peripheral roof-supporting columns to bear the tensile force from supporting roof. By using such columns, a slender circular cross section is achieved in consideration of the exterior design (**Fig. 10**). A prestress force of about 3000 kN was introduced at the precast factory, and the axial stress in a column is about 4.8 N/mm^2. Generally, columns with a round cross section are manufactured while standing vertically, but to introduce the prestress force into the present columns at the precast factory, they were manufactured while lying horizontally (**Fig. 11**). After the concrete was placed from the top, its upper surface was covered with arc-shaped formwork.

Conclusion

Various unique structural ideas were used for the National Stadium, such as flat roof frames that are coordinated with the surrounding environment by minimizing the height, a simplified structure to limit the construction period, use of precast and prefabricated products to reduce the construction period and ensure high quality, a cantilever roof structure with hybrid members made of lumber and steel, and a response-controlled structure by means of a soft-first-story system for high seismic performance.

After the Tokyo Olympic Games, it is hoped that this stadium will be a wonderful place where visitors enjoy playing and watching sports in a space that feels Japanese.

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概　要

国立競技場は，日本らしさを世界に誇れるスタジアム，災害に強いスタジアムなどをテーマに設計された。片持ち長さ約60m の屋根トラスに鉄と木材のハイブリッド構造を採用し，スタンドはソフトファーストストーリー制振構造を採用して高い耐震性能を確保した。また，徹底した施工性の追求を行い，スタンドの基礎から屋根を支持する柱まで可能なかぎり PCa 化することで工期の遵守を図った。

基礎梁の PCa 化にあたり，設計初期段階から部材断面の規格化と楊重可能な部材分割の設定を行うとともに，円周方向の角度を有する鉄筋の接続方法や精度良く部材を設置できる方法を考案し，実施した。

屋根を支持する外周の柱は，屋根からの引張力を受けることを考慮し，PCaPC-SRC 造の柱を採用することで，十分な剛性と耐力を確保しつつ，外観デザインに配慮し，スレンダーな円形断面を実現した。