Stadium Utilizing Characteristic Form as Structural Member — Tochigi Stadium —

特徴的な形態を構造部材として活用したスタジアム — 栃木県総合運動公園陸上競技場 —



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Synopsis

The building shape of the Tochigi Stadium has a characteristic three-dimensional form derived from various computer simulations. The roof structure is designed to take advantage of this form structurally, with the roof structure made of steel and the stand structures made of reinforced concrete. The majority of the stand girders are made of precast concrete members, which show the structural members as the exterior of the building. This paper presents the design of the building.

Structural Data

Owner: Tochigi Prefecture
Name: Tochigi Stadium
Location: Utsunomiya City, Tochigi Prefecture, Japan
Main use: Stadium
Building area: 20,041.77 m^2
Total floor area: 42,168.47 m^2
Number of floors: 4
Highest point: 33.73 m
Foundations: Direct foundation, some pile foundations
Structure: Reinforced concrete, steel frame, steel-reinforced concrete

1. Introduction

This building is an all-roofed athletic field (Class 1 certification) and a natural grass football field (J-League facility standards) to be constructed as the central facility for the development of a comprehensive sports zone in Tochigi Prefecture (**Fig. 1**).
After conducting various simulations (**Fig. 2**) of solar

Fig. 1 Overall view

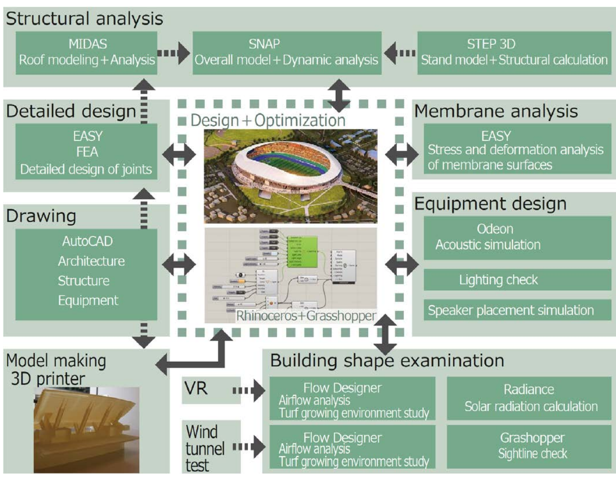


Fig. 2 Analysis tools used in design

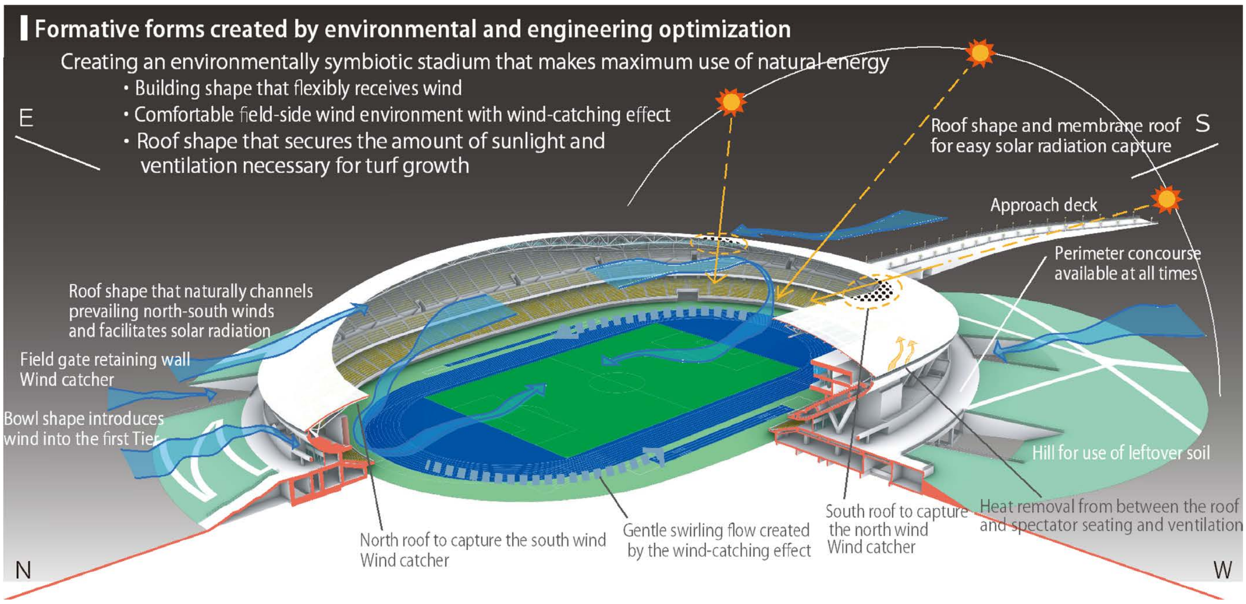


Fig. 3 Conceptual environment

radiation to and ventilation of the field, visibility from spectator seats, structural safety, rationality of formwork for precast concrete (PCa) members, etc., computer parametric design was conducted to realize a three-dimensional shape consisting of various curves, and the optimal shape integrating architecture, structure, and facilities was derived (**Fig. 3**).

2. Outline of Architectural Plan

The stadium is surrounded by a green hill made of excavated soil, which covers the first floor to make the stadium less oppressive visually and more landscape-friendly. The stadium is designed to have approximately 25,000 spectator seats, all of which are roofed, and the slope of the seating decks is set at a maximum of 35° to create a sense of unity by bringing the spectator seats closer to the field, thereby enhancing the sense of dynamism and presence of the stadium.

The stadium plan is an elliptical shape measuring approximately 210 m by 260 m (**Fig. 4**). The roof is designed to rise almost directly above the plane of the stands and is covered with a Class A membrane. The PCa beams of the stand and the PCa floor slabs are exposed to the public, and the entire building has a bowl shape (**Figs. 5** and **6**).

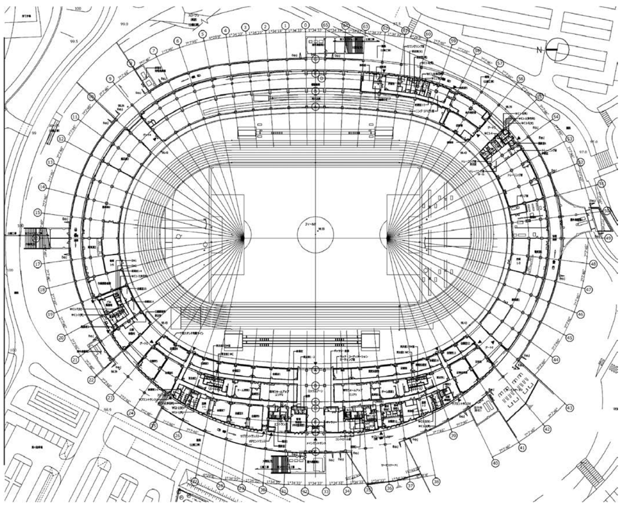


Fig. 4 First floor plan

The first floor consists of administrative offices and rooms for players, while the second floor and the stands are for spectators. Spectators approach the inner concourse from the outer concourse on the second floor through the gates.

On the main stand side, VIP seats, lounges, and broadcast seats (hereinafter referred to as the VIP structure) are located on the third and fourth floors above the stands. Both sides of the structure are designed to overhang by approximately 20 m to provide spectator seating directly under the structure for maximum effective use.

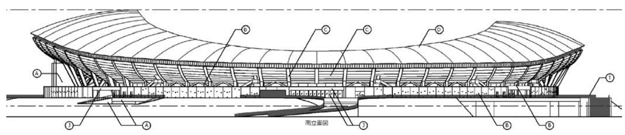


Fig. 5 West elevation

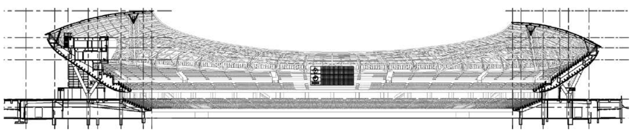


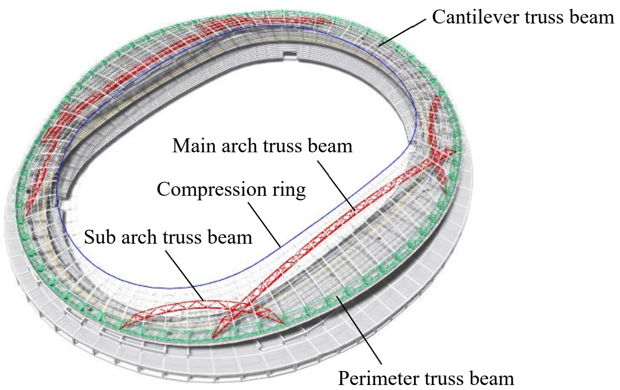
Fig. 6 Cross section in east–west direction

3. Outline of Structural Plan

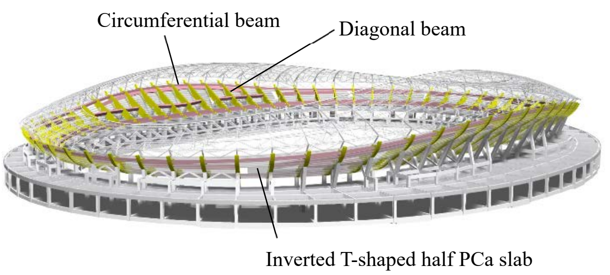
(1) Overall Plan

The structural frame of the stadium is designed so that the roof frame and the stand frame work together to form a stable structure.

Fig. 7 shows an overview of the structural frame. The roof is a steel truss structure that utilizes a gently curved surface for an arch effect and is designed to resemble an overlapping image of a horse chestnut leaf, which is the prefectural tree of Tochigi Prefecture (**Fig. 8**). The structure below the stands is made of reinforced concrete (RC), and only the four frames supporting the two main arch trusses—which carry a particularly large load—are made of steel-reinforced concrete (SRC).



(1) Roof structure



(2) Stand structure

Fig. 7 Structural frame outline drawing

(2) Stand Structural Plan

The second-floor stand frame consists of diagonal beams of factory-made PCa. The members in the radial direction and the circumferential beams are on-site-made PCa units post-tensioned in the circumferential direction with steel wires, similar to the configuration of the side plates and hoops of a Japanese bucket (**Fig. 9**). The diagonal beams are deep beams with a 2.5-m-high section. The PCa members in the radial direction were divided into transportable blocks of 25 tons or less, brought to the on-site yard, and erected using a super-large 750-ton crawler crane (**Figs. 10** and **11**). The diagonal beams are members that bear large loads, but because of their inclined arrangement along the shape of the stands, long-term and seismic stresses tend to concentrate on the short columns on the field side. However, the stress concentration on the short columns is reduced by structurally utilizing the under-structure of the concourse stores and restrooms (**Fig. 12**). The inverted T-shaped half PCa floor slabs (**Fig. 13**) were placed on the undersides of the diagonal beams and integrated with them by casting the top concrete on-site, and this floor rigidity is used to disperse the stress of frames with low bearing capacity or those where stress is easily concentrated (**Figs. 14** and **15**). Many of the first-floor walls are RC shear walls, which bear between 60% and 70% of the seismic load.

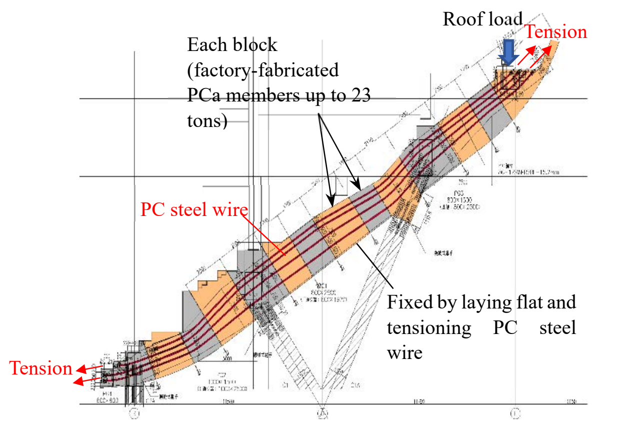


Fig. 10 Diagonal beam

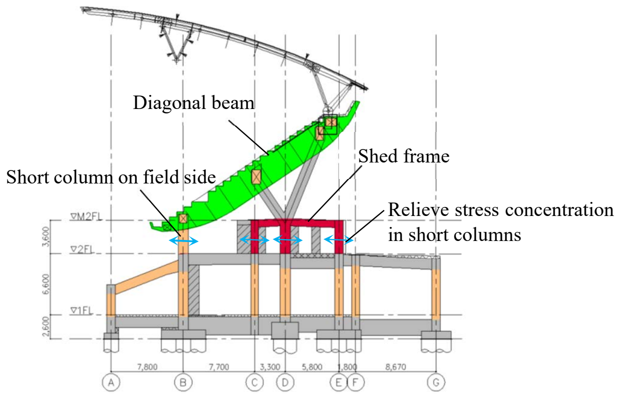


Fig. 12 Structural use of shed frame

Fig. 8 Image of horse chestnut leaf

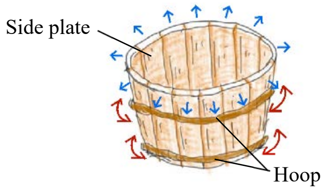


Fig. 9 Image of Japanese bucket

Fig. 11 On-site installation of diagonal beams

Fig. 13 Inverted T-shaped half PCa slab

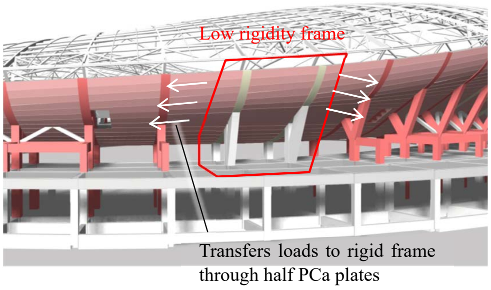


Fig. 14 Effect of half PCa plate

Fig. 15 Exterior view of stand structure

(3) Structural Plan Under Roof Truss Beams

The roof structure supports about half of the roof weight with six arch trusses, of which the main arch trusses on the main stand side and the back stand side each support about one-fourth of the total roof weight. In addition to the vertical load, the main arch truss is subjected to a horizontal load (thrust force) that causes the truss to open outward, and because it bears a large amount of stress, cast steel is used for the joints to ensure that the load is transmitted to the stand structure. For vertical loads, the stand frame is constructed of SRC, which allows the stress to be transmitted directly from the roof steel frame to the internal steel frame of the stand frame. Horizontal loads are balanced mechanically by the prestressing introduced into the circumferential beams at the tops of the diagonal beams of the stands (**Fig. 16**).

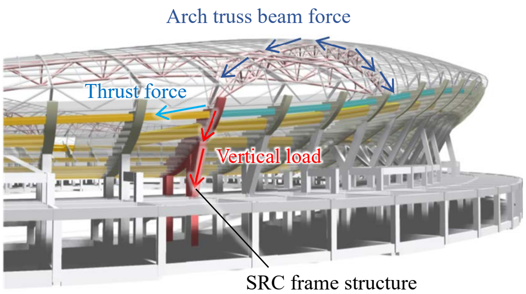


Fig. 16 Force flow of frames supporting arch truss

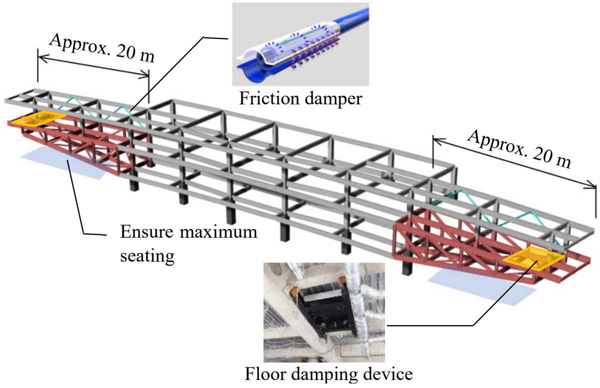


Fig. 17 VIP structure

Fig. 18 Exterior view of VIP structure

(4) VIP Structure Plan

The VIP structure is on diagonal beams and is a two-story steel frame structure (**Figs. 17** and **18**). Because the VIP structure is approximately 100 m wide, it is cantilevered for approximately 20 m at both ends, with no columns on the stands. These cantilever frames are supported by a one-layer truss frame. Because of the large cantilever arm length, consideration had to be given to the vertical swaying during daily walking and in the event of an earthquake. To reduce the sway by walking, floor damping devices were installed at the cantilevered ends, and actual measurements have confirmed that these reduce sway by approximately 50%. To reduce seismic sway, braced friction dampers were installed, which have been confirmed analytically to reduce sway by between 40% and 50%.

4. Conclusion

This building has a unique shape, and there are many parts where the structural frame is exposed without being concealed, which caused a series of hardships. Finally, the authors would like to express their sincere thanks to the owner of the building and all the people involved who worked so diligently on this project.

概　要

栃木県総合運動公園陸上競技場は，陸上競技場（第 1 種公認）兼天然芝サッカー場（J リーグ施設基準）で，全席屋根付きのスタジアムである。フィールドへの日射・通風のほか，観客席からの視認性，構造安全性など様々なシミュレーションを行った上で，多様な曲線で構成された特徴的な 3 次元形態を導いた。

観客席は約25000席で，客席勾配を最大35度に設定し，観客席とフィールドとの距離を近付け，競技場の躍動感や臨場感を高める計画とした。

構造架構は，スタンド架構と屋根架構が相互に作用する安定した構造を目指した。屋根は鉄骨造のトラス架構とし，スタンド架構は RC 造を主体とし，荷重負担の大きい箇所を部分的に SRC 造としている。構造的な課題に対し，応力状態に適した材料を用い，特徴的な形態を利用することにより解決し，設計時に意図した通りの形態を実現することができた。