Conical Shells of Precast Prestressed Concrete — Tenri Station Plaza CoFuFun —

プレキャスト・プレストレストコンクリートによる円錐シェル — 天理駅前広場　コフフン —

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Keywords: town planning project, precast prestressed concrete, conical shell structure
DOI: 10.11474/JPCI.NR.2022.69

Synopsis
Tenri Station, a union station shared by West Japan Railway and Kintetsu Railway, is a gateway to Tenri City in Nara Prefecture, Japan. The station plaza is undergoing redevelopment in a town planning project, with a complex of new facilities named CoFuFun being built for residents and tourists. The buildings are constructed with post-tensioned prestressed concrete (PC) using precast (PCa) members. This structure makes it possible to create a large-span, column-free space with a 26-m-diameter conical shell roof. This report describes the design and construction of precast prestressed concrete (PCaPC) conical shells of two buildings: an open-air structure roofed with a large trampoline-like membrane (Cofun A) and a tourist lounge and service center building (Cofun C).

Structural Data
Structure: PCaPC structures with a conical shell form
Location: 816 Kawaharajocho, Tenri City, Nara Prefecture, Japan
Owner: Ken Namikawa, Mayor of Tenri
Designer: O ki Sato from design studio “nendo”
Design Supervisors: Seed Consultant, Inc., Yasui Architects & Engineers, Inc., and Hojo Structure Research Institute
Contractor: Project-specific joint venture of Daiwa House Industry Co., Ltd. and Okatoku Construction
Construction Period: Mar. 2016 to Mar. 2017

1. Architectural Data
Fig. 1 shows a general view of Cofun A and Cofun C.

(1) Cofun A
Use: Open-air stage (open-air viewing platform)
Scale: One floor above ground, 26.0 m in diameter
Building Height: Max. 6.80 m, eave height 5.60 m
Total Floor Area: 188.88 m^2
Foundation: Raft foundation

(2) Cofun C
Use: Lounge (café), tourist service center
Scale: One floor above ground, 26.0 m in diameter
Building Height: max. 7.60 m, eave height 7.60 m
Total Floor Area: 497.47 m^2
Foundation: Isolated footings

Fig. 1 General view

2. Structural Plan

(1) Cofun A

Fig. 2 shows a structural overview of Cofun A.

1) The PCaPC floor slab is an inverted conical shell structure with a diameter of 26.0 m, a rise of 3.60 m, and a thickness of 240–540 mm. An opening of about 1700 mm × 3000 mm is made for the entrance.

2) The shell consists of 36 radially divided PCa segments.

3) The slab has a terraced shape on both front and back sides with paint finishing. The top of the shell is raised by 2.0 m with lightweight banking material, and an air membrane is stretched over it for recreational use.

4) The slab is supported by a cylindrical foundation beam with a diameter of 7.95 m at the bottom center. Concrete is cast in place to connect the slab and foundation beam.

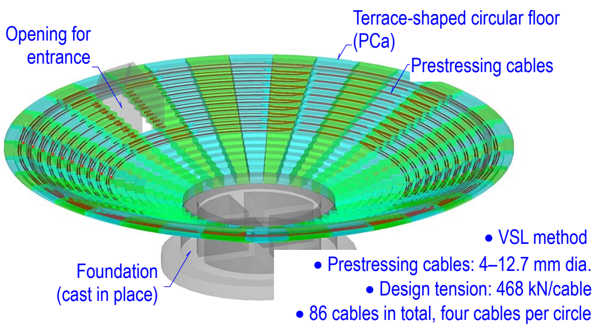


Fig. 2 Structural overview of Cofun A

(2) Cofun C

Fig. 3 shows a structural overview of Cofun C.

1) The roof slab is supported by 12 PC columns spaced evenly along the peripheral edge. The columns have a cross section of 350 mm × 1960 mm curved along the circumference.

2) The vertical prestressing steel bars (6–∅26-mm diameter) installed between the foundation beam and the PC beam built in the roof slab connecting the PC columns to the foundation and the slab.

3) The PCaPC columns, the foundation beam, and the PC beam in the slab together form a circular rigid frame on the outer circumference.

4) The PCaPC roof slab is a conical shell structure with a diameter of 26.0 m, a rise of 4.35 m, and a thickness of 340 mm.

5) The shell consists of 36 radially divided PCa segments.

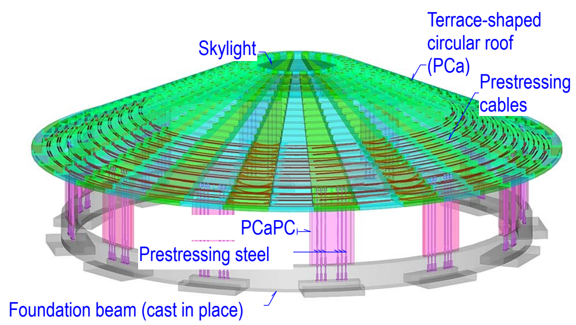


Fig. 3 Structural overview of Cofun C

3. Structural Design Strategy

The prestressing cables was tensioned to 468 kN per cable such that the tensile force would keep the entire shell in compression from the half height of the slab toward the peripheral edge during long-term loading, without acting in the circumferential direction.

Two different analysis models were used for the design. One was a vertical load model to which vertical dead and live loads were applied (pin support at the bottom end of the foundation beam). The other was a prestressed model in which tension in the prestressing cables was considered (roller support at the slab base). The stress or deformation values of the two models were superimposed to obtain the stress or deformation in the slab during long-term loading. For seismic loading, the allowable short-term stress level was determined using the same vertical load model, with the maximum value of 0.55 of the structural characteristic coefficient (the coefficient used in wall structures with low ductility) taken as the lateral seismic factor.

4. Structural Analysis of the Shells

(1) Cofun A

The edge compressive stress of the inverted conical shell in the circumferential direction (**Fig. 4**) was up to 2.5 N/mm^2 at the center in the vertical load model or up to 7.1 N/mm^2 near the edge of the opening in the prestressed model. Superimposed, the maximum value for long-term loading was about 4.7 N/mm^2, which was sufficiently small for compressive stress. The long-term out-of-plane bending stress in the normal (radial) direction was 280 kNm/m at maximum at the center, which was carried by the main reinforcing bars (16-mm diameter, at 100-mm spacing) which were placed in the normal direction of the slab.

The vertical displacement (**Fig. 5**) at the peripheral edge was 2.4 mm downward in the vertical load model and 4.8 mm upward in the prestressed model, resulting in a superimposed value of 2.4 mm upward for the vertical displacement under long-term loading.

(2) Cofun C

The superimposed edge compressive stress induced by vertical load and prestressing force of the conical shell in the circumferential direction (**Fig. 6**) was about 3.9 N/mm^2 at maximum under long-term loading, which was sufficiently small for compressive stress.

The vertical displacement (**Fig. 7**) was the largest at the half height of the slab in both models: 1.0 mm downward in the vertical load model, and 1.0 mm upward in the prestressed model. The superimposed value for long-term loading was therefore ±0.

The seismic maximum bending stress in the columns was 1135 kNm (**Fig. 8**), which was carried by the prestressing steel bars (6-∅26-mm diameter) in each column. The main seismic elements of the structure are the six columns that form an angle of 0°–30° to the direction of the applied force.

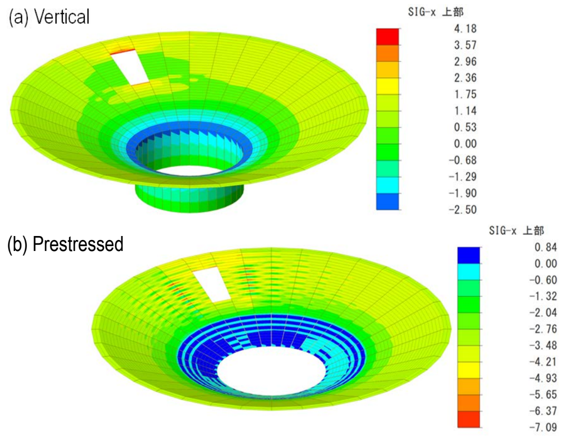


Fig. 4 Cofun A: edge compressive stress (N/mm^2)

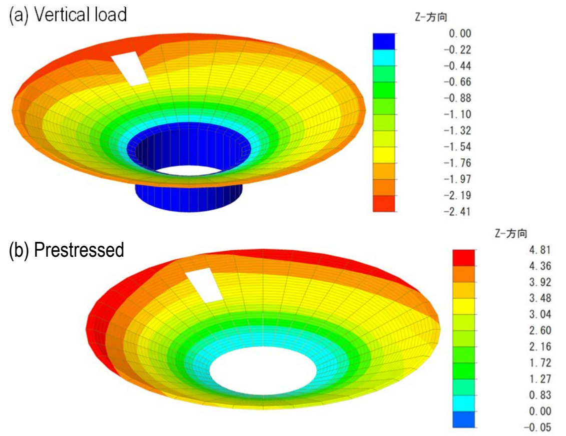


Fig. 5 Cofun A: vertical displacement (mm)

5. Construction

(1) Cofun A

Fig. 9 shows the construction procedure for Cofun A. The slab was divided into 36 segments for transportation reasons. After the assembly of falsework, the slab members (about 15 tons each) were lifted by crane one by one and erected in a circular shape.

The prestressing cables were arranged in a concentric manner, using four cables each to form a circle. To prevent the shell from being subjected to nonuniform in-plane stress by tensioning, each of the four cables on the same circle were tensioned simultaneously at both ends by using eight jacks. After jacking all the cables, mortar was placed in the joints near the center of the slab where tensioning was not performed.

(2) Cofun C

Construction of the roof slab required similar considerations to those given for Cofun A. The prestressing force could flow into the PCaPC columns on the circumference during tensioning of the prestressing cables in the roof slab. In consideration of that, tensioning of the prestressing steel bars in the PCaPC columns for connection between the columns and the roof slab was performed after jacking all the prestressing cables in the slab.

Fig. 10 shows photographs from the PCaPC work phase.

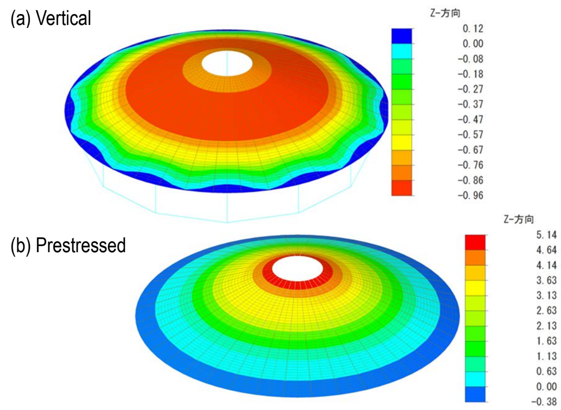


Fig. 6 Cofun C: edge compressive stress (N/mm^2)

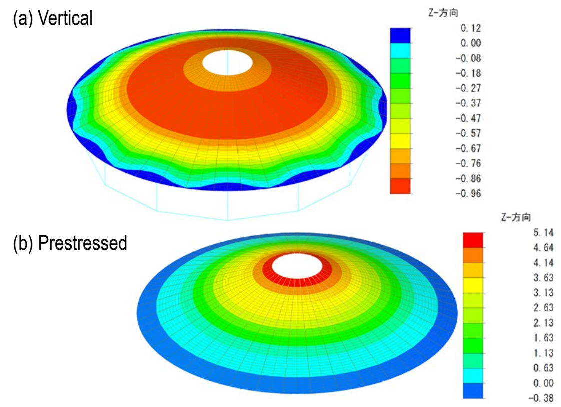


Fig. 7 Cofun C: vertical displacement (mm)

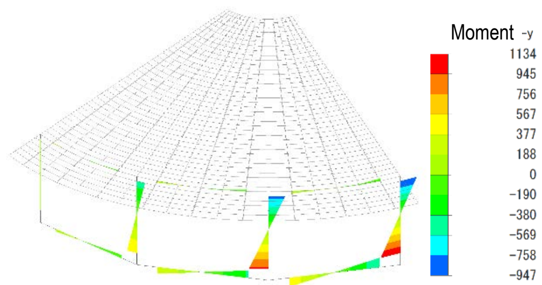


Fig. 8 Cofun C: seismic bending stress (kNm)

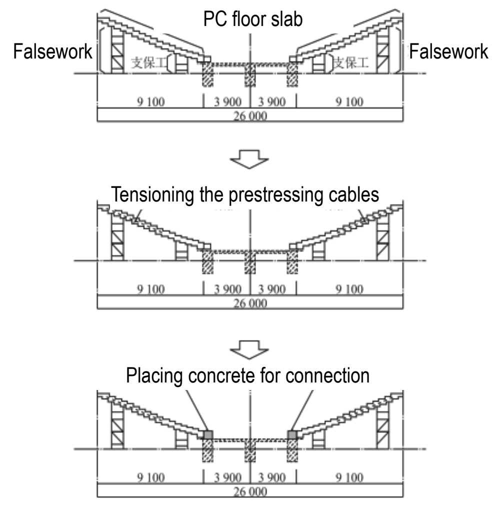
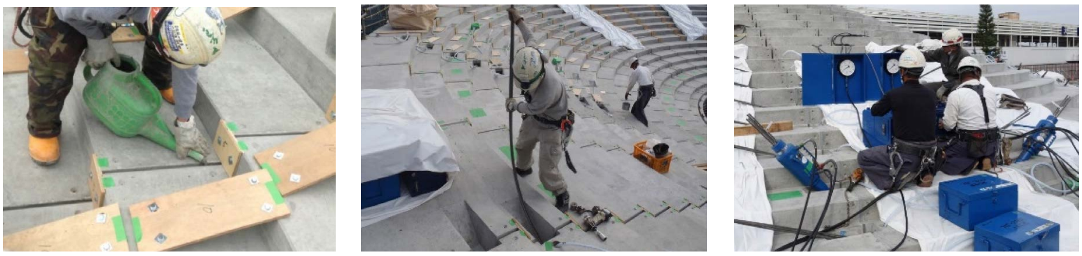


Fig. 9 Construction of Cofun A

6. Conclusion

Fig. 11 shows photographs of the completed structures. This report presented the structural design of PCaPC conical shells. With the use of the PCaPC shell structure, these buildings with impressive designs were created with high precision.

Building the falsework　　Placing the PCa members (left: Cofun A; right: Cofun C)



Filling the joints with mortar　　Installing (left) and tensioning (right) the prestressing cables

Fig. 10 Photographs from the PCaPC work phase

Fig. 11 Photographs of the completed structures
(from the website of Tenri Station Plaza CoFuFun [http://cofufun.com/])

概　要

奈良県天理市の玄関口である JR・近鉄天理駅駅前広場が生まれ変わった。駅周辺地区のにぎわいのある街づくりを目的として，屋外ステージや周遊観光拠点となる複合施設が新設された。構造形式にはプレキャスト部材を用いた現場緊張によるプレストレストコンクリート構造を採用した。本構造により，直径26m の円錐シェル屋根をもつ大スパンの無柱空間を実現した。