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Structural Design of the Osaka Dome

Projet du Dôme d'Osaka

Entwurf des Osaka-Doms

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SUMMARY

The Osaka Dome, to be completed in 1997, is a large domed stadium intended for sports events such as baseball and football games and also for concerts and large assemblies. The Dome is composed of a doughnut-shaped stadium with an outside diameter of 200 m and a roof 166 m in diameter. This paper describes the structural features of the stadium, the basic concept for the dome frame, seismic design, wind-resistant design, and the construction process for the stadium.

RÉSUMÉ

Le dôme d'Osaka, qui doit être achevé en 1997, est un stade couvert immense prévu pour les manifestations sportives, musicales et autres grands rassemblements. Le dôme est de forme torique avec un diamètre à la base de 220 m et un diamètre au sommet de 160 m. La communication présente les caractéristiques essentielles des structures porteuses du stade, le principe du cadre du dôme, le dimensionnement contre les effets des séismes et du vent, ainsi que la méthode de construction.

ZUSAMMENFASSUNG

Der Osaka-Dom, der 1997 fertiggestellt sein soll, ist ein grosses überdachtes Stadium für Sportveranstaltungen, Konzerte und andere Grossanlässe. In Gestalt eines Torus hat der Dom einen Aussendurchmesser von 220 m und einen Dachdurchmesser von 160 m. Der Beitrag beschreibt die Hauptmerkmale des Stadiumtragwerks, das Grundkonzept des Dom-Rahmens, die Bemessung gegen Erdbeben und Wind, sowie das Bauverfahren.

1. OUTLINE OF OSAKA DOME

The Osaka Dome is planned as a multi-purpose dome with a seating capacity of 44,000 persons for sports events and a maximum seating capacity of 55,000 persons for other events. Visually, the dome's exterior features "Fiesta Mall", which creates an image of a floating skyline suggestive of waves and clouds that surround the dome. This "Fiesta Mall" is in a class by itself as it can serve as a place for various events separate from the dome.

The dome is provided with a mechanized system that can change the arena/seating space configurations to those most suitable for the event taking place in the dome.

The ceiling shape is also variable, being composed of layers of ring-shaped elements (called "Super-rings") that can be raised and lowered as necessary to create the internal space configuration desired.

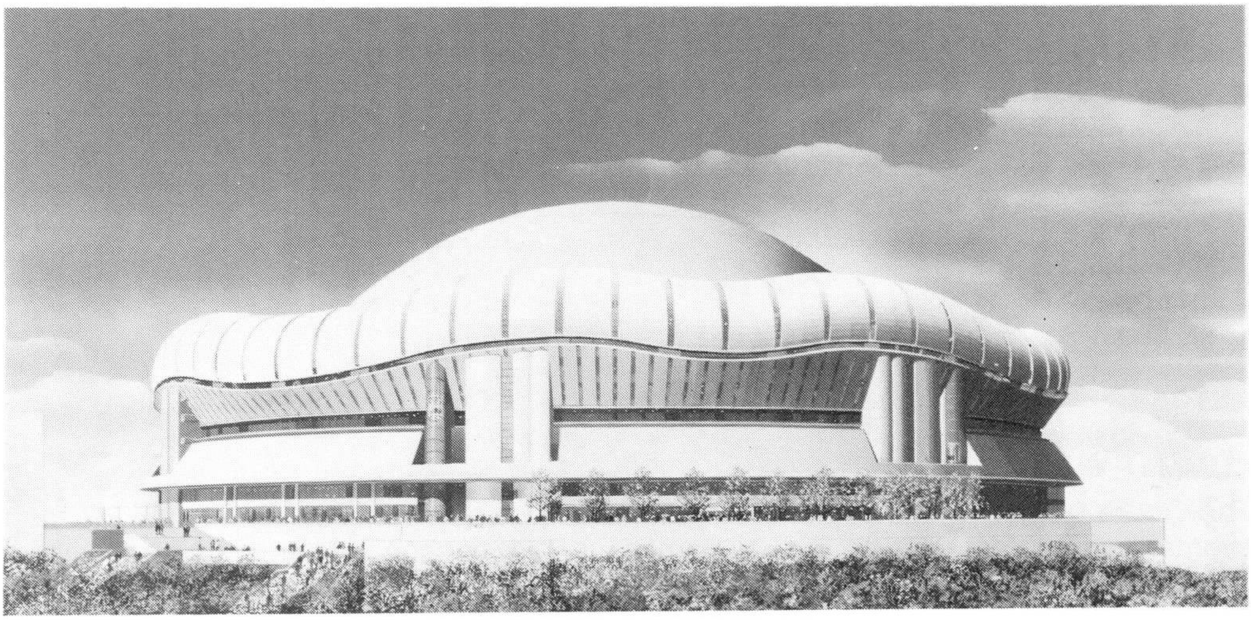


Fig. 1 Exterior Appearance of Osaka Dome

2. OUTLINE OF STRUCTURAL DESIGN

The Dome's roof consists of a 134m diameter center dome portion and a 16m wide perimeter portion which resembles a brim of a hat in shape. This perimeter portion is more gently sloped than the central dome.

Structurally, the roof framing consists of the central dome which is designed to form a uniform geometry of steel lamella and a perimeter portion composed of uniformly laid out 36 pairs of Y-shaped steel girders. The bases of these girders are located on the top of the stands.

As for the stresses developed by the dead loads, compressive stresses are caused in both the radial and the perimeter directions of the center dome portion while compressive and bending stresses are developed in the perimeter portion.

Intensive stresses developed at the borderline area between the center and the perimeter are taken care of by the compression ring beam.

The dome's deadweight which is about 7,000 tons is carried to the substructure by way of the hinged dome bases. Since these hinged bases are interconnected by the tension ring beam and great lateral force is carried by tension hoops, almost no lateral force is transferred to the stand structure below.

The stand structure under the domed roof is of steel framed reinforce concrete construction. From the viewpoint of architectural planning as well as exterior and interior design effects the structure in the radial direction consists of Y-shaped frames which have comparatively low rigidly. On the other hand, the frame in the circumferential direction is provided with shear walls to have high rigidity and strength. The frame in the radial direction and that in the circumferential direction are integrated into one by the floor slab that extends in the circumferential direction to form a rigid and strong structure which looks like a big doughnut.

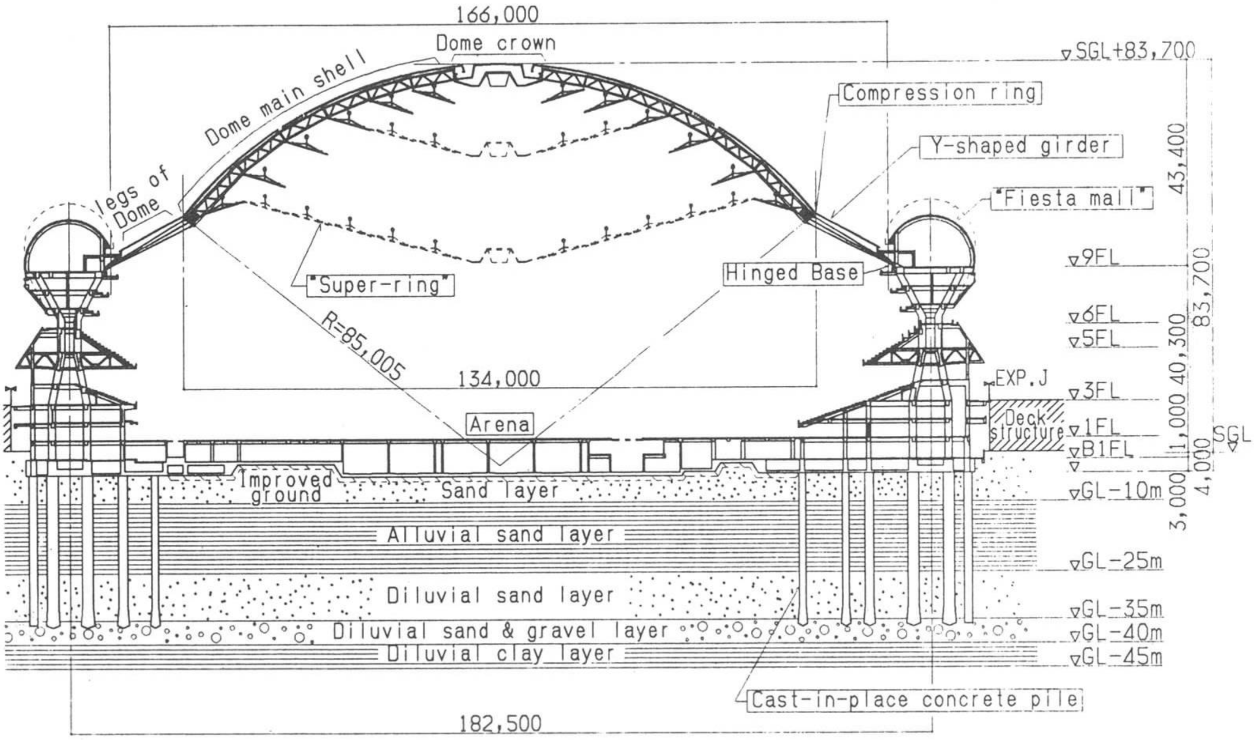


Fig. 2 Outline of Structural System

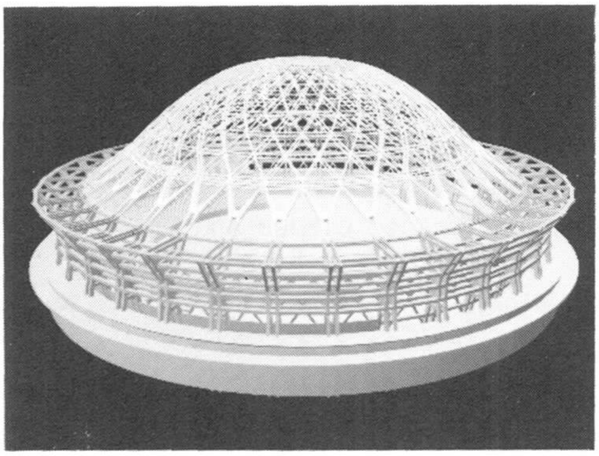


Fig. 3 Structure in perspective

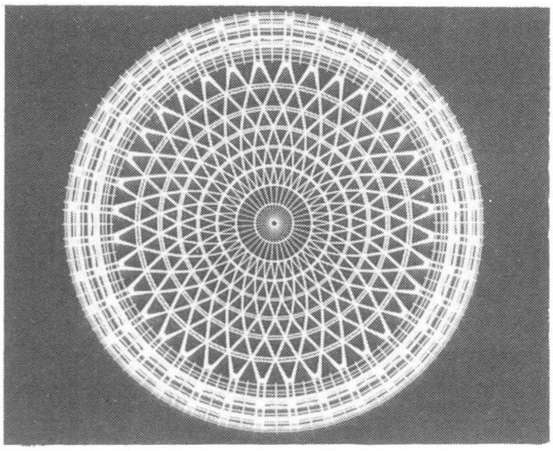


Fig. 4 Structural steel members arrangement

3. DESIGN OF THE DOME

3.1 Design based on dead load

The load per unit surface area of the dome is 250kg/m^2 of which 150kg/m^2 is the weight of the steel frames. Stresses and deflection induced in the dome by this load is as shown in Fig.5

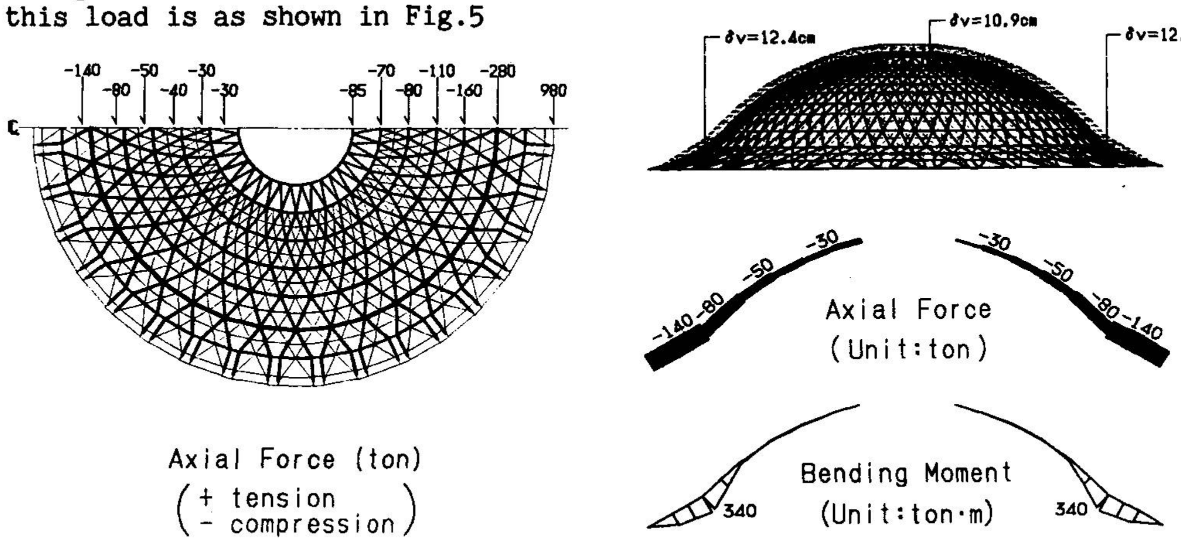


Fig. 5 Stress and Deflection Induced by Dead Weight

The spherical dome portion is subjected to compressive force both in the radial direction and in the circumferential direction. Since Y-shaped girders are subjected to bending moments in addition to compressive forces, these girders are designed to have an H-shaped cross section which has high rigidity against bending (see Fig. 6). As the circumferential direction of the boundary portion formed by the Y-shaped girders and the spherical dome must carry large compressive force, a compression ring made up of highly rigid trusses are located at this portion (see Fig. 6).

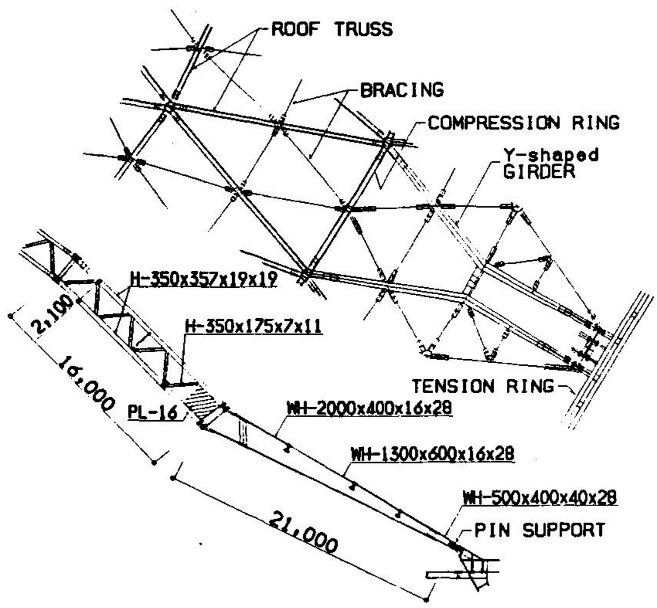


Fig. 6 Y-shaped Girder and Compression Ring

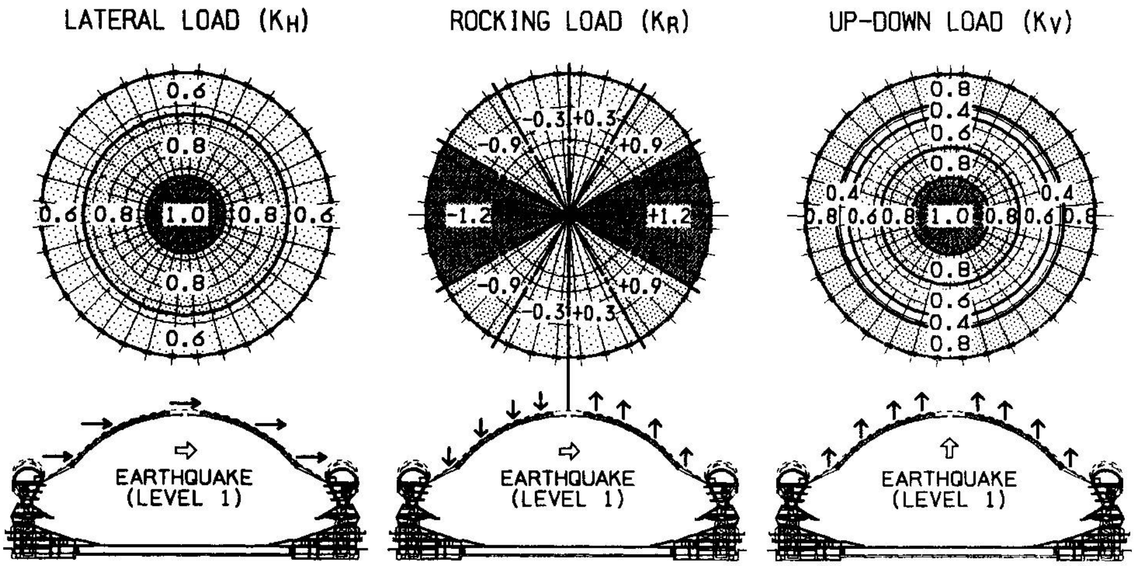
3.2 Seismic design

Earthquake response analyses were conducted to compute the seismic forces acting on the dome during Level 1 and Level 2 earthquakes. The analyses indicated that the dome should be subjected to a lateral force combined simultaneously with rocking motions due to seismic force, and, in addition, up-down motion of the ground should act on the dome. Shown in Fig. 7 is the design seismic loads. Stresses of the dome induced by seismic loads are shown in Figs. 8 and 9.

<u>Notes</u> Level 1 earthquake motions are those which are caused by earthquakes of such magnitude as the structure will encounter a number of times during its life span. (They correspond to Seismic intensity 4 - 5 on Japan's Standard Scale.)

Level 2 earthquake motions are those which will be caused by exceptionally great earthquakes that the structure might encounter during its life span. (They correspond to Seismic intensity 7 on Japan's Standard Scale.) Level 2 load is two times that of Level 1.

As an seismic design principle, the members were required to stay in the elastic region under Level 2 earthquakes and a buckling safety factor of not less than 1.2 was to be secured under Level 2 earthquake.



NOTE: K_H, K_R, K_V are co-efficients of seismic load to be multipled to the weight of roof.

Fig. 7 Design Seismic Loads

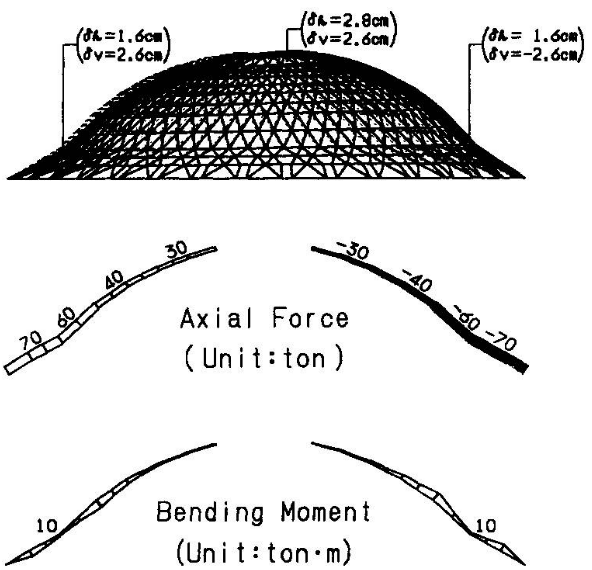


Fig. 8 Stress & Deflection due to Lateral Load

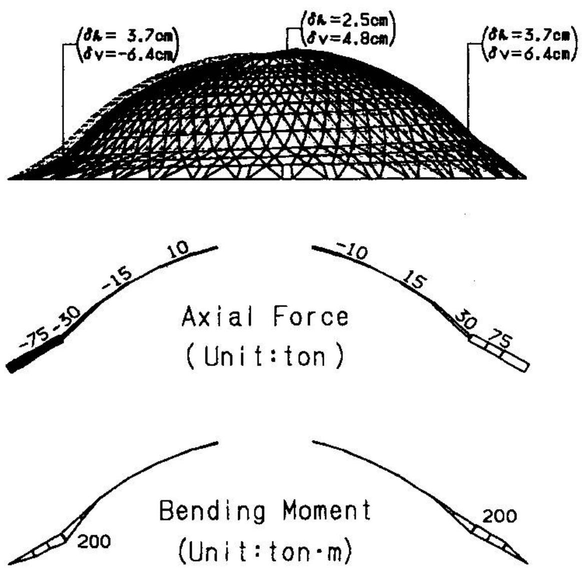


Fig. 9 Stress & Deflection due to Rocking Load

3.3 Wind resistant design

As a design principle, the dome members were required to remain in an elastic region under Level 1 and Level 2 wind forces.

Notes Level 1 wind is such a typhoon that occurs at a 100-year interval and has a wind velocity of 35m/sec at the crown of the dome.

Level 2 wind is such a typhoon that occurs at a 500-year interval and has a wind velocity of 41m/sec at the crown of the dome.

In computing the wind loads for this dome, the external pressure coefficients were established by wind tunnel tests (see Figs. 10 and 11 and also for reference Fig. 12).

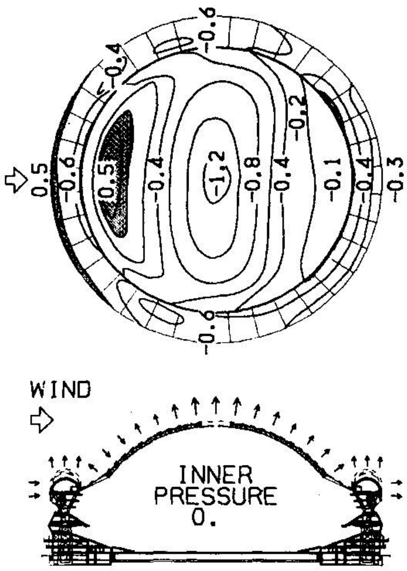


Fig.10 Average External Pressure Coefficients

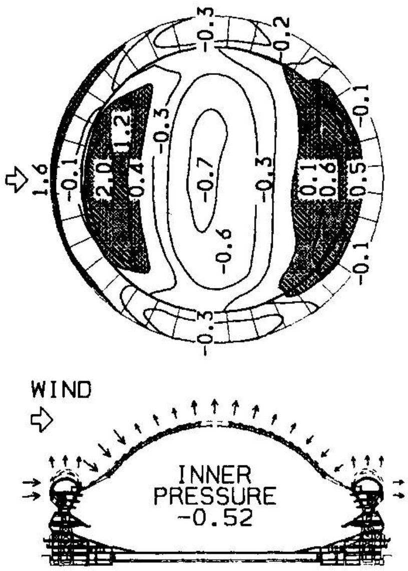


Fig.11 Max. Positive External Pressure Coefficients

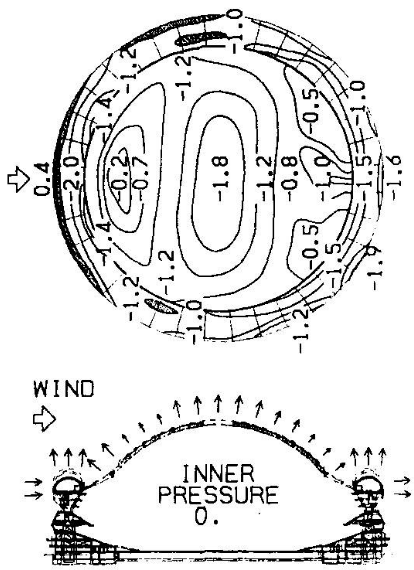


Fig.12 Max. Negative External Pressure Coefficients

It should be noted that the wind loads being smaller than the seismic loads do not constitute a predominant factor for the structural design of this dome.

4. OUTLINE OF CONSTRUCTION

The steel members of the dome will be erected by the lift-up method (see Fig. 13). They will be lifted into place by wires manipulated from 36 erection platforms. Stresses and deformation of the members at principal locations will be measured while these lifting operations are performed.

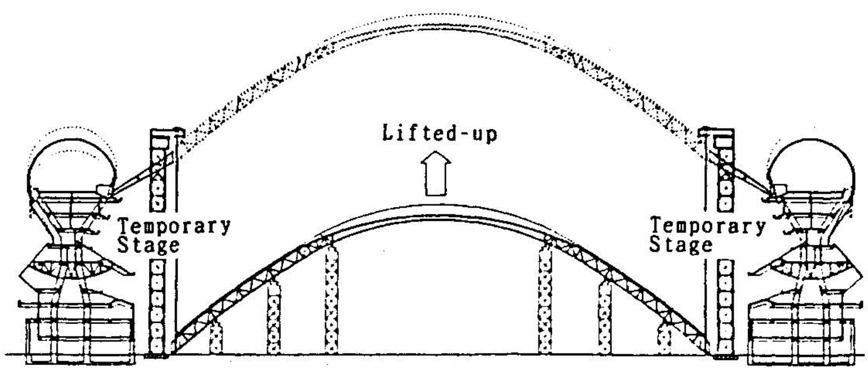


Fig. 13 Construction method