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Structural Design of the Osaka Dome

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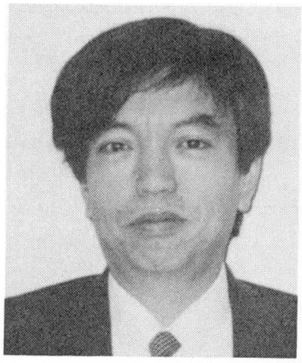


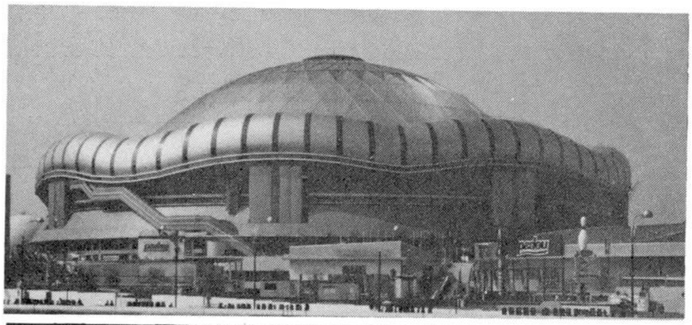
Katsumi Hara, born in 1948, obtained his master's degree at the Univ. of Waseda, Tokyo, Japan in 1974. For nineteen years he was involved in structural design of buildings. Katsumi Hara is now Senior Structural Eng. of Nikken Sekkei in Japan.

SUMMARY

The Osaka Dome, completed in 1997, is a large scale domed stadium intended for sports events such as baseball and football games and also for music concerts and big assemblies.
The Dome is composed of a doughnut-shaped stadium having an outside diameter of 200 m by a dome roof which measures 166 m in diameter.
This paper is intended to describe the design concepts and the structural features of the domed stadium and the dome construction procedure.

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 created an image of a floating skyline suggestive of waves and clouds that surround the dome.



The Osaka Dome has two design concepts. One is to attract regularly many visitors so as to vitalize the entire local area. For this purpose, the dome has to have commercial and amusement facilities to attract many visitors even if there is no events held in the arena. To satisfy this requirement, the dome is designed to have two facilities, one is "Fiesta Mall" which is put round all the circumference of the dome of 600 at the 9th floor level, housing amusement facilities, and the other is commercial mall at the 2nd floor level.
The other design concept is that the arena should have volume-variable indoor space to create most suitable space for each of various events to be held in the arena.
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.

2. Outline of Structural Design

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

Construction Details

Owner:	*Osaka City Dome Co., Ltd.*
Design	*Nikken Sekkei Ltd*
constructionsupervision:	*Nikken Sekkei Ltd*
Cooperation in Design:	*(Takenaka Corporation, Obayashi Corporation, Dentsu Inc.)*
Construction:	*Osaka Dome Construction JV*
	(Obayahsi Corporation, Takenaka Corporation and others)
Design period:	*March 1993 to June 1994*
Construction period:	*July 1994 to February 1997*
Site area:	*34,617m²*
Building area:	*33,765m²*
Total floor area:	*156,408m²*

Roof:	
Top portion:	*Polycarbonate panel*
Other major portion:	*Stainless steel sheet (welding),dull finish*
Festa Mall:	*Stainless steel panel,dull finish*

Structurally, the roof framing of the central dome forms a uniform geometry of a steel lamella and perimeter is composed of uniform laid out 36 pairs of Y-shaped steel girders. The bases of these girders are located on the top of the grandstand.

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 section are

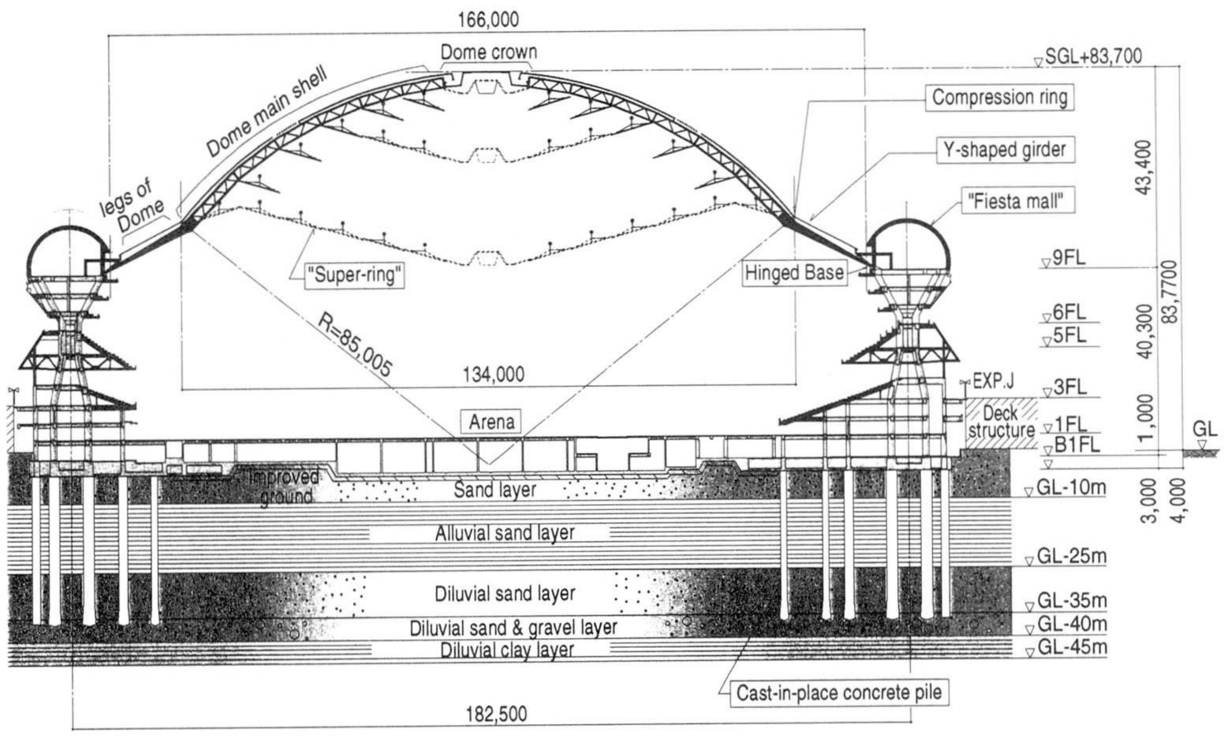


Fig.1 Outline of Structure

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 Grandstand structure below.

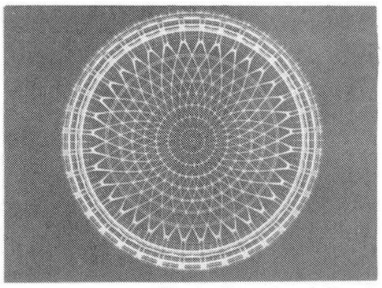


Fig.2 Structural Steel Members Arrangement

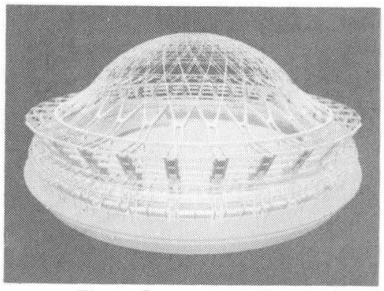


Fig.3 Structure in Perspective

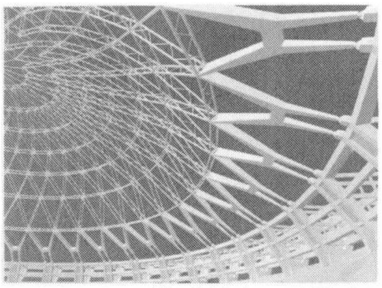


Fig.4 Y-shaped Girder

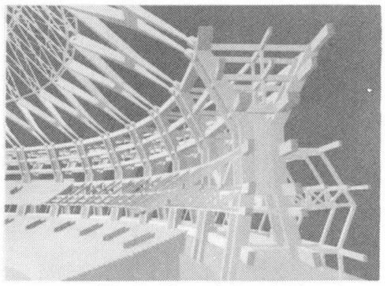


Fig.5 Grandstand Structure Supporting Dome

The grandstand structure under the domed roof is of steel framed reinforce concrete construction. From the view point of architectural planning as well as exterior 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.

2.1 Design of the Dome

Stresses and deflection induced in the dome by the deadweight is as shown in Fig. 6.
The spherical dome portion is subjectzed to compressive force both in the radial and 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. 8). 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. 7).

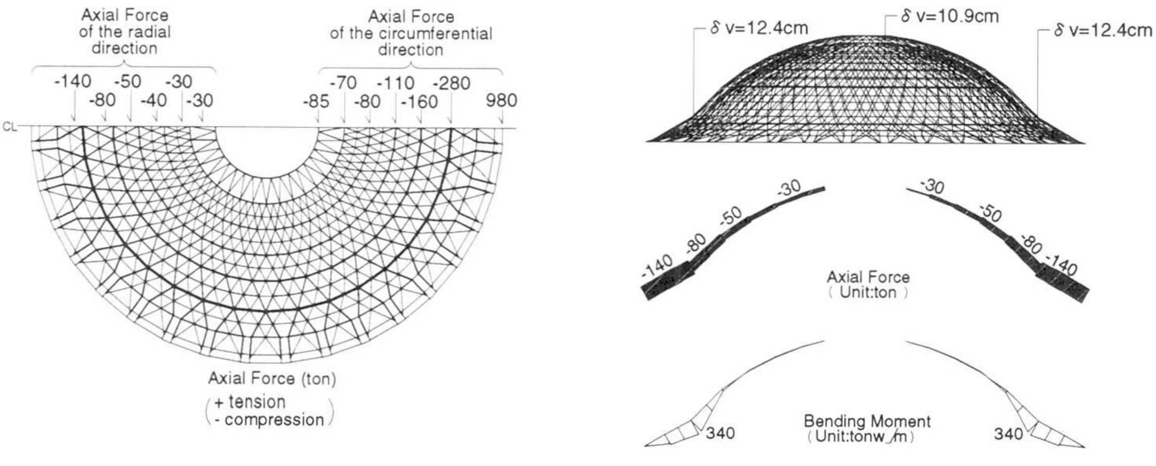


Fig.6 Stress and Deflection Induced by Dead Weight

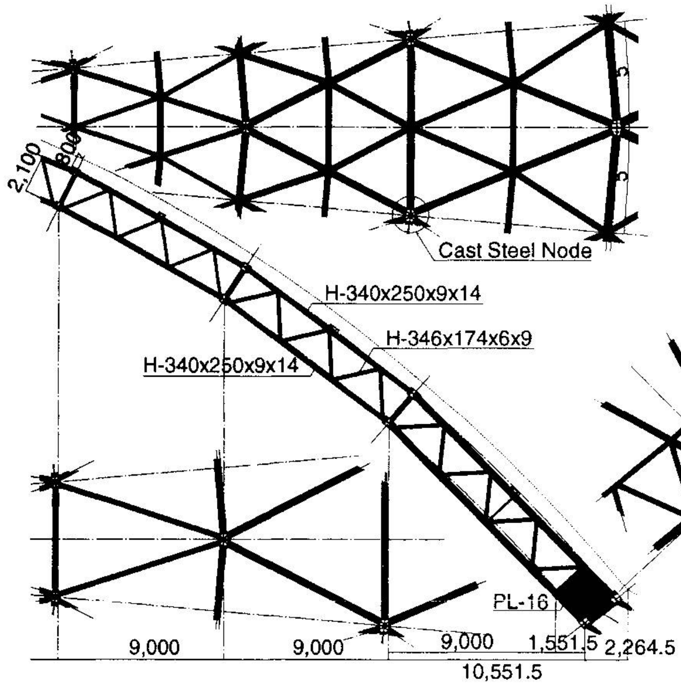


Fig.7 Lamella Dome

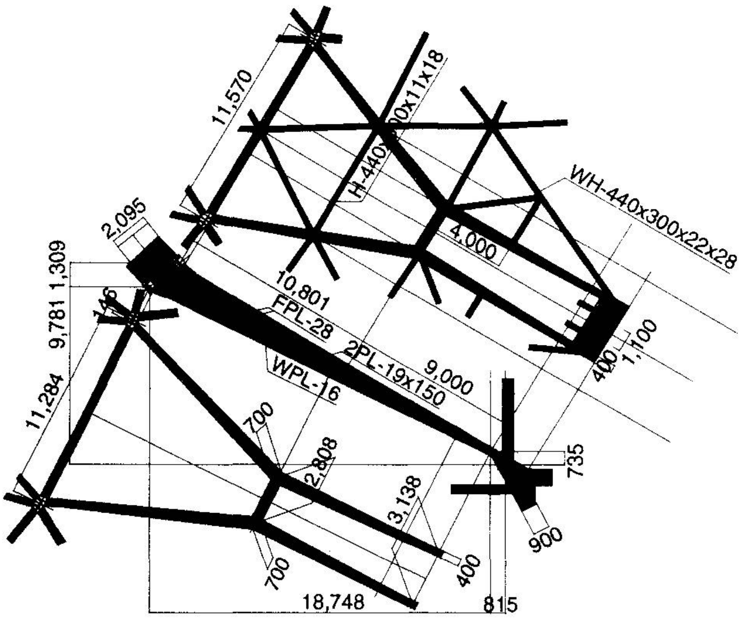


Fig.8 Y-shaped Girder

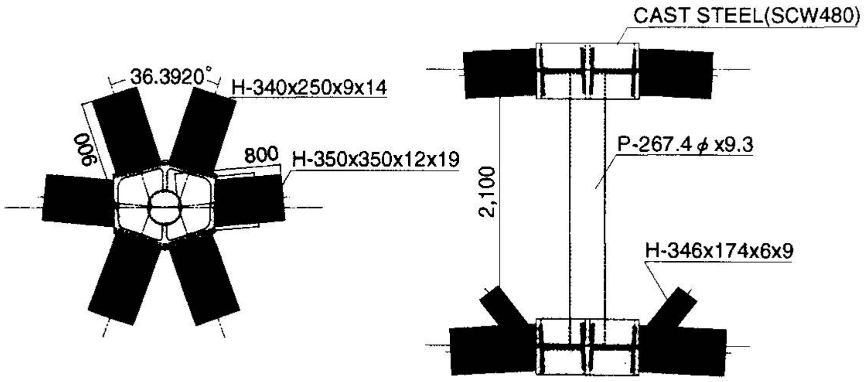


Fig.9 Cast Steel Node

3. Outline of Construction Work

3.1 Severe Conditions for Construction Work

There were very severe conditions for implementation of the construction work. Namely, the building structure occupies almost all the site area, which meant that the 16-m wide road surrounding the site was the only and sole circulation line and loading/unloading area for the work. Infrastructure including sewage lines runs under the road and aerial decks had to be constructed above the road. How to use this road was the key for smooth implementation of the construction work all the time from the very beginning of the work to the completion of the work. Therefore, the plan of using the road was carefully worked out but it should be reviewed with great effort on the day-by-day basis.

Another severe condition was the short construction term of two and a half years.

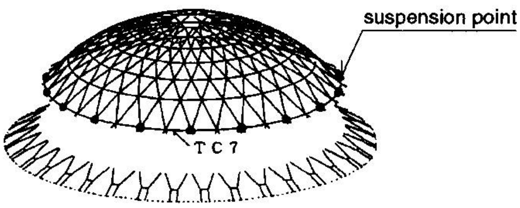


Fig.10 Lift-up Method Construction

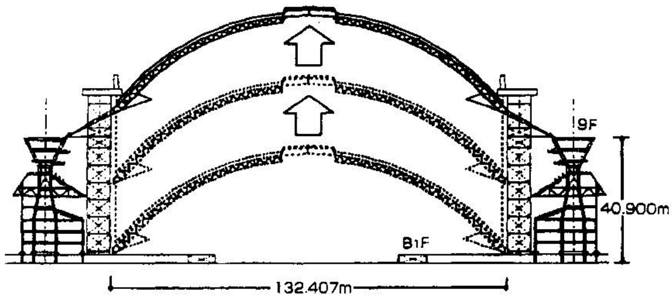


Fig.11 Lift-up Method Construction

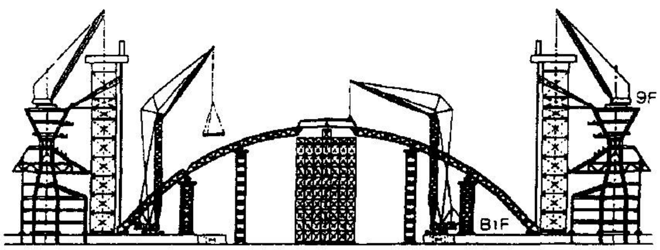


Fig.12 Steel Members Erection of the Dome

3.2 Erection of roof truss on the ground level

As a result of various study on construction sequence of the doom roof, lifting-up method was selected, in which the roof doom truss is erected on the ground and then lifted up to the required position. In the actual construction, the erection was done at the 1st basement level, and also finishing of ceiling and roofing and relevant building services work were conducted as much as possible to reduce such works after lifting up the doom truss structure. At the perimeter, construction of the stand structure were carried out simultaneously with construction of bent bases for the lifting-up operation and Y-shaped girders. Ninth floor-level structure should be a tension ring to receive deadweight of the dome roof structure at the time of jack-down operation when the lifted up dome roof structure was lowered to the final position and connected with Y-shaped girders, shifting supporting structure form the jack mechanism to the stand structure. Therefore, the construction of the stand structure had to be completed before the lifting-up operation.

3.3 Lifting-up Operation

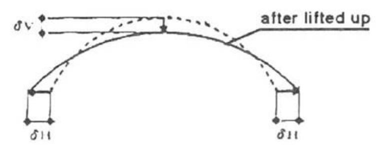
Total deadweight of the dome roof as lifted up was about 5,500 ton. Lifting up was made by using 18 jacks, each with 600-ton capacity. Lifting up system was elaborated to automatically and precisely control the levels of each suspension points, keeping horizontal level difference among those points within 20 mm. The lifting-up volume was taken at 48.97 meters. The lifting up could be successfully done after 8 hours of careful operation. In the operation, real-time measurement of deformations of and stresses in the dome roof was carried out, which could confirm that deformations and stresses of the structure during the operation were within the range estimated by structural analyses conducted in advance. They are shown in Fig.13.

3.4 Jack-down Operation

Jack-down operation is to shift the entire lifting-up load to th e stand structure by connecting the dome roof structure to Y-shaped girders after the lifting-up operation. The total jacking-down weight including those of Y-shaped girders was 6,700 tons. In the construction work, the compression ring (forming perimeter part of the dome structure itself) functioned as a tension ring to receive 610-ton tensile force during the lifting-up operation, and carries 240-ton compressive force after the jack-down operation.

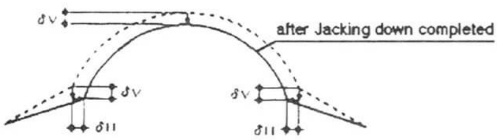
The deformation and stresses during the jacking down work showed about 80% of those estimated by the analysis. (Fig. 14)

This means that the stand structure effectively functioned also in the construction procedures without any special reinforcement to the stand structure itself.



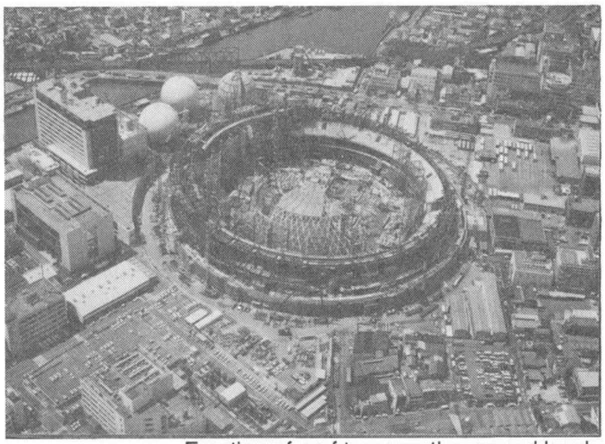
	Suspending point Measured vs Computed	Top of Dome Measured vs Computed
Horizontal disp. δ_H	28 mm vs 39 mm	——
Vertical disp. δ_v		38 mm vs 40 mm
C-Ring's Axial	430 ton vs 610 ton	——

Fig.13 Stresses and Deformations during Lifting-up Operation

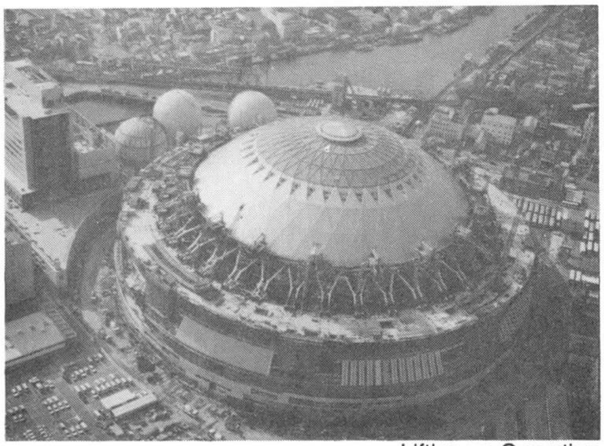


	Suspending point Measured vs Computed	Top of Dome Measured vs Computed
Horizontal disp. δ_H	-32 mm vs - 38 mm	——
Vertical disp. δ_v	65 mm vs 74 mm	29 mm vs 33 mm
C-Ring's Axial	-190 ton vs - 240 ton	——
Y-Girder's Axial	-100 ton vs - 160 ton	——

Fig.14 Stresses and Deformations during Jacking-down Operation



Erection of roof truss on the ground level



Lifting-up Operation

After completion of Dome's construction