Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 71 (1994)

Artikel: Application of Pantadome system to long-span roof structures

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DOI: https://doi.org/10.5169/seals-54125

Application of Pantadome System to Long-Span Roof Structures

Application du système Pantadome aux structures spatiales

Anwendung des Pantadome-Systems für Raumtragwerke

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SUMMARY

Spatial long-span structures are very efficient to cover wide areas without columns after their completion, but are never efficient from constructional standpoints. The principle of Pantadome System which the author developed to solve the problems of spatial structures is explained. Examples of the system to various long-span structures are described.

RÉSUMÉ

Les structures tridimensionnelles à grande portée sont très efficaces quand il s'agit de couvrir des grandes surfaces sans piliers intérieurs, mais ne sont jamais faciles à construire. Le principe du système Pantadome, développé par l'auteur afin de résoudre les problèmes des structures spatiales est décrit. Des exemples sont présentés pour l'application de ce système pour des structures tridimensionnelles à grande portée.

ZUSAMMENFASSUNG

Weitgespannte Raumtragwerke haben eine erprobte Einsatzfähigkeit beim Ueberdachen grosser Flächen ohne Innenstützen, aber auch Schwächen im Hinblick auf die Herstellung. Das vom Autor zur Lösung derartiger Konstruktionsprobleme bei Raumtragwerken entwickelte Prinzip des Pantadome-Systems wird vorgestellt. Beispiele werden beschrieben, wo dieses System für die Abdachung weitgespannter Tragwerke angewandt wurde.

1. PROBLEMS IN CONSTRUCTION OF DOMICAL LONG-SPAN ROOFS

A domical space frame, once completed, is one of the most efficient spatial roof structures capable of covering a very wide area. It is not always efficient, however, from the viewpoint of construction, because it requires big amount of scaffoldings, labor and time and often encounters difficulties in terms of accuracy, reliability and safety of work during its erection. Modern erecting methods such as lifting systems which are very often adopted in erection of double-layer grids of plate type can not equally be applied to a domical space frame.

Buckminster Fuller tried to solve this kind of problems in a few ways when he encountered them in building some of his geodesic domes. For construction of one of his domes in Honolulu in 1957 he adopted a system in which a temporary tower was erected at the center of the dome from top of which concentrically assembled part of the dome was hung by means of wire ropes. As assembly of the dome proceeded the dome was gradually lifted, enabling the assembling work to be done along the periphery of the dome always on the ground. He also adopted another method when he built a huge dome of 117m in diameter at Wood River, U.S.A., in 1959, where the assembled part of the dome was raised on a balloon-like enclosure. Some other cases have also been reported where different lifting methods have been applied to different domes. However, none of the above methods for lifting domes have become popular unlike many lifting methods which became widely used to raise plate-type space frames.

2. PANTADOME SYSTEM AS ONE OF THE SOLUTIONS

A patented structural system called 'Pantadome System' which had been developed by the author for a more rational construction of domical space frames was successfully applied to the structure of a sports hall completed in Kobe 1984. Pantadome System was then applied to the Sant Jordi Sports Palace in Barcelona and the National Indoor Stadium of Singapore and are now being applied to a few other long-span structures.

The principle of Pantadome System is to make a dome or a domical space frame geometrically unstable for a period in construction so that it is 'foldable' during its erection. This can be done by temporarily taking out the members which lie on a hoop circle(Fig. 1). Then the dome is given a 'mechanism', that is, a controlled movement, like a 3-D version of a parallel crank or a 'pantagraph' which is generally applied to a drawing instrument or a power collector of an electric car (hence the name, 'Pantadome').

Since the movement of a Pantadome during erection is 'controlled one' with only one freedom of movement (vertical), no means of preventing lateral movement of the dome such as staying cables or bracing members are necessary during its erection. The movement and deformation of the whole shape of the Pantadome during erection are three dimensional and may look spectacular and rather complicated, but they are all geometrically determinate and easily controlled. Three kinds of hinges are incorporated in a Pantadome system which rotate during the erection. Their rotations are all uni-axial ones, and of the most simple kind. Therefore, all these hinges are fabricated in the same way as normal hinges in usual steel frames.

In Pantadome system a dome is assembled in a folded shape near the ground level. As the entire height of the dome during assembling work is very low compared with that after completion, the assembly work can be done safely and economically, and the quality of work can be assured more easily than in conventional erection systems. Not only the structural frame but also the exterior and interior finishings, electricity and mechanical facilities are fixed and installed at this stage. The dome is then lifted up. Lifting can be achieved either by blowing air inside the dome to raise the internal air pressure, or by pushing up the periphery of the upper dome by means of hydraulic jacks. When the dome has taken the final shape, the hoop members which have been temporarily taken away during the erection are fixed to their proper positions to complete the dome structure. The lifting means such as air pressure or hydraulic jacks can be then removed, and the dome is completed.

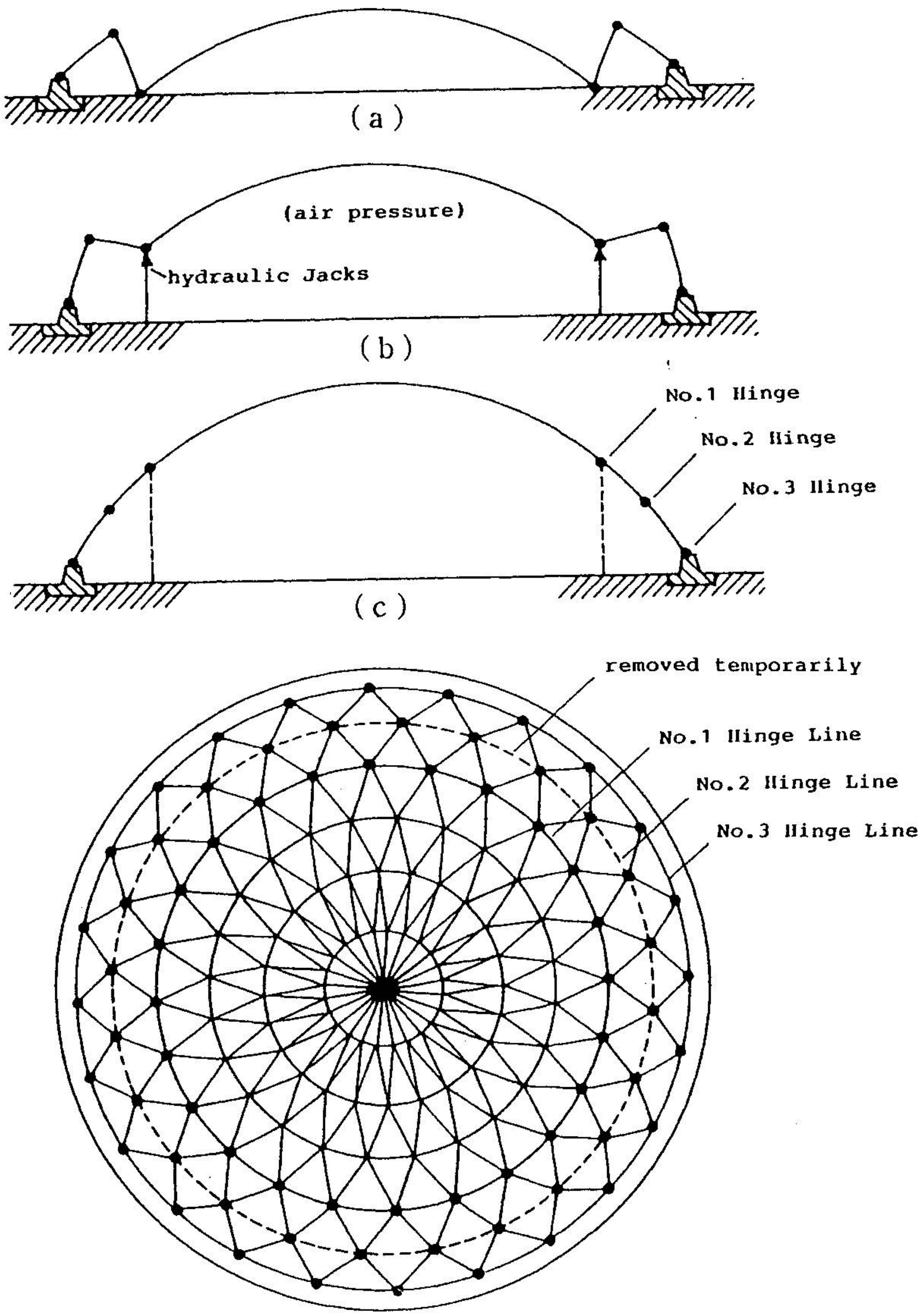

Fig. 1 Principle of Pantadome System

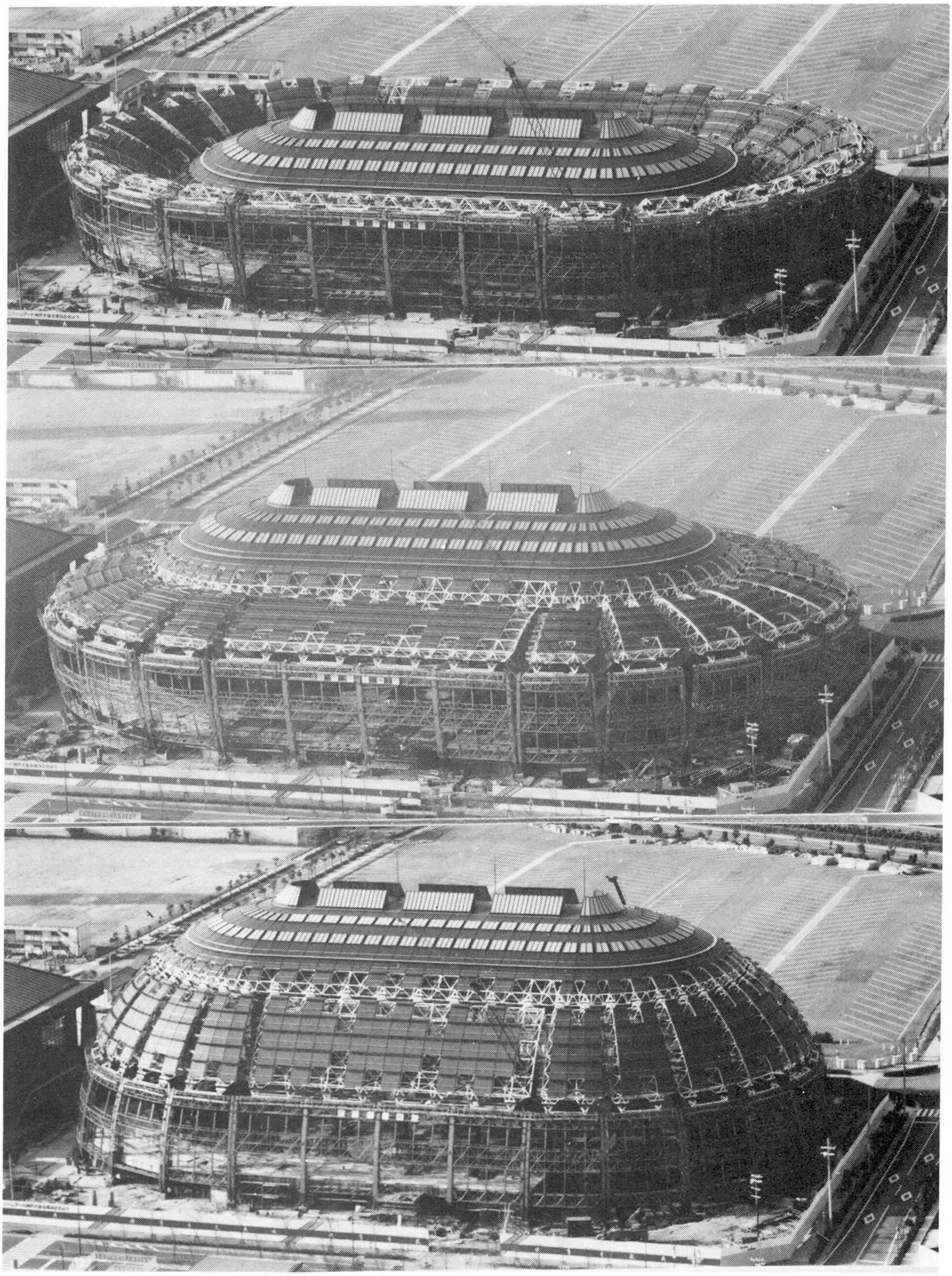

Fig. 2 Lifting sequence of World Memorial Hall

3. APPLICATION OF PANTADOME SYSTEM

Pantadome system can be successfully applied to domical frames of various configurations. World Memorial Hall in Kobe in which the Universiad '85 was celebrated has an oval plan of 70m x 110m. It was designed by the author in cooperation with Architect Mitsumune, and it was constructed by means of Pantadome System as shown in Figure 2. It was the first dome to which Pantadome System was applied.

The second example of Pantadome application is the Singapore National Indoor Stadium having a rhombic plan of 200m x 120m in the diagonal directions, the structure of which was designed by the author in cooperation with Architect Kenzo Tange(Fig. 3). The National Indoor Stadium has an arena of 3000 m^2 and grandstands for 12000 seats. The geometry of the roof is constituted by four cylindrical surfaces, each convex inward, having the axes of the cylinders parallel

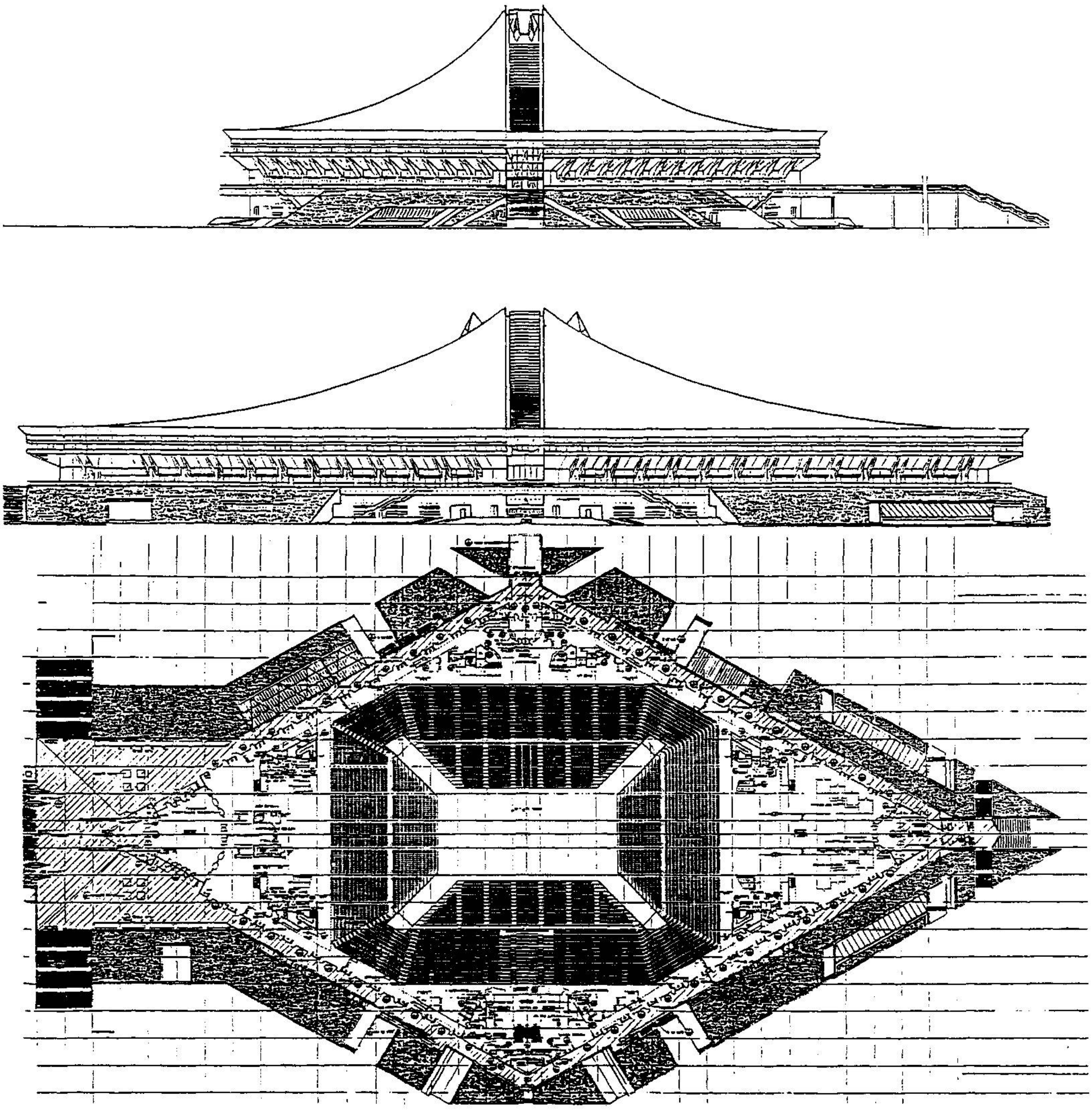

Fig. 3 Singapore Indoor Stadium

to the four sides of the rhombic plan. Although the roof surface which is convex inward gives the visual impression of a hanging roof, actually it has a sufficient dome effect. The hinge lines for Pantadome mechanism were set along the straight lines parallel to the boundaries of the roof plan.

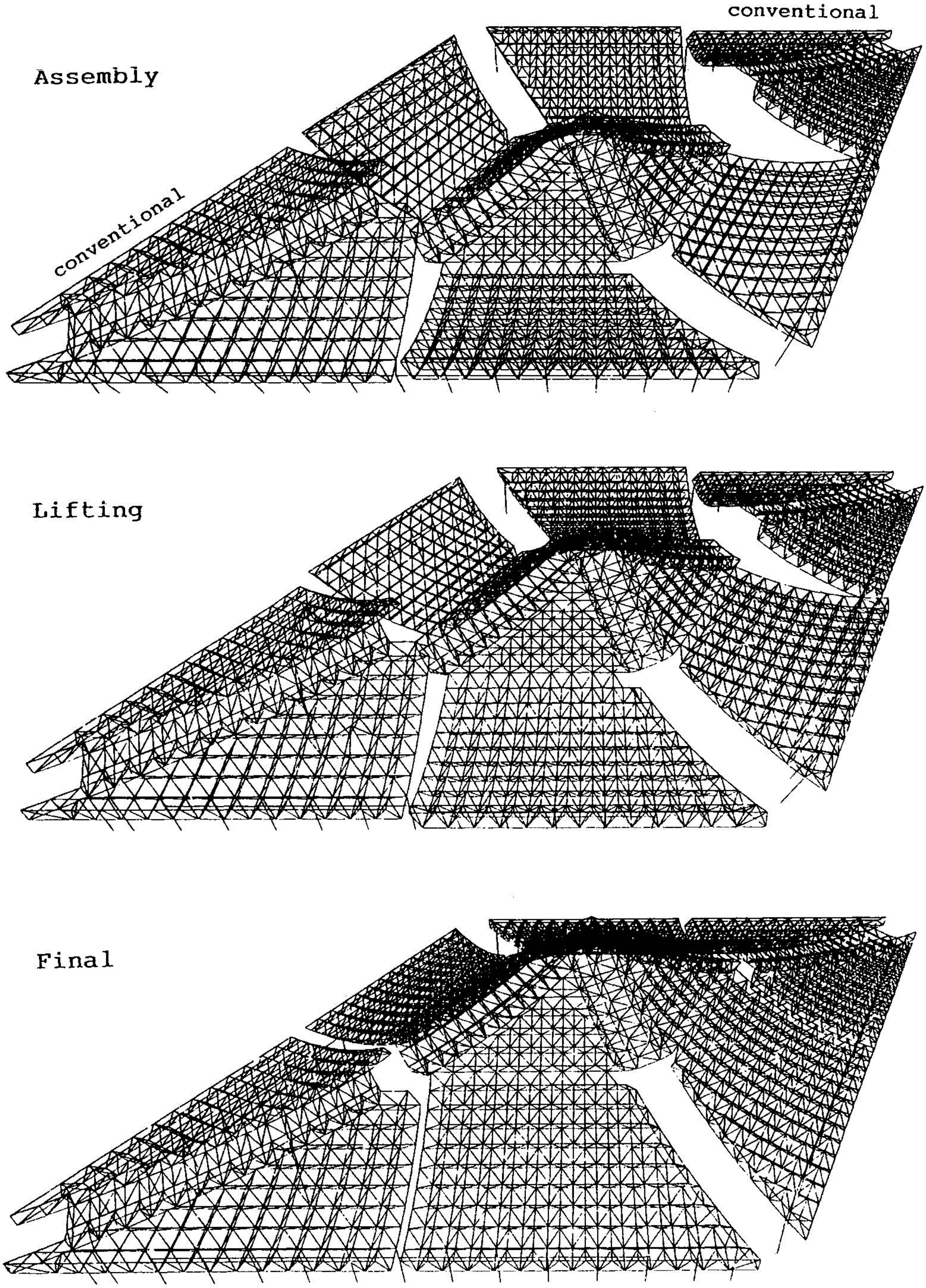

Fig. 4 Lifting sequence of Singapore Indoor Stadium

The processes of erection of the roof of Singapore National Indoor Stadium is shown in Figure 4. Around the two opposite corners of the rhombic plan the floor levels are elevated, and the height of the roof is lower. So it was considered that the erection of the roof could be easily carried out by means of conventional methods around these areas. This is why the Pantadome System was applied only to the central part of the roof.

4. SANT JORDI SPORTS PALACE IN BARCELONA

Sant Jordi Sports Palace in Barcelona was one of the venues for the Olympic Games '92. As a result of an international design competition the author had the opportunity of designing the structure of this important building (Fig. 5).

The roof structure which covers an area of 128mx106m for the arena and the grandstands seating 15,000 is constructed by a steel space frame consisting of 9,190 tubes connected by 2,403 joints. The shape of the roof structure is constituted by the central domical part and the four toroidal parts surrounding it. The area of the whole roof surface is 13,460 m^2. The type of the space frame is what is called a double layer grids structure having a depth of 2.5m. The diameter of the steel tubes of the space frame ranges from 76mm to 267mm with exceptions of bigger tubes for valley and ridge members(406mm) and for the peripheral members(508mm).
The roof has a rise of 21m as a dome. The weight of the whole roof including finishing is about 3,000 tons, of which 1,000 tons are the weight of the steel space frame. the roof structure is supported by 60 columns which stand on the reinforced concrete substructure along the periphery of the grandstand. The height of the roof is 31m above the base of the columns. Since the floor on which the columns stand is 14m high from the arena level, the maximum height of the roof from the arena floor is about 45m.

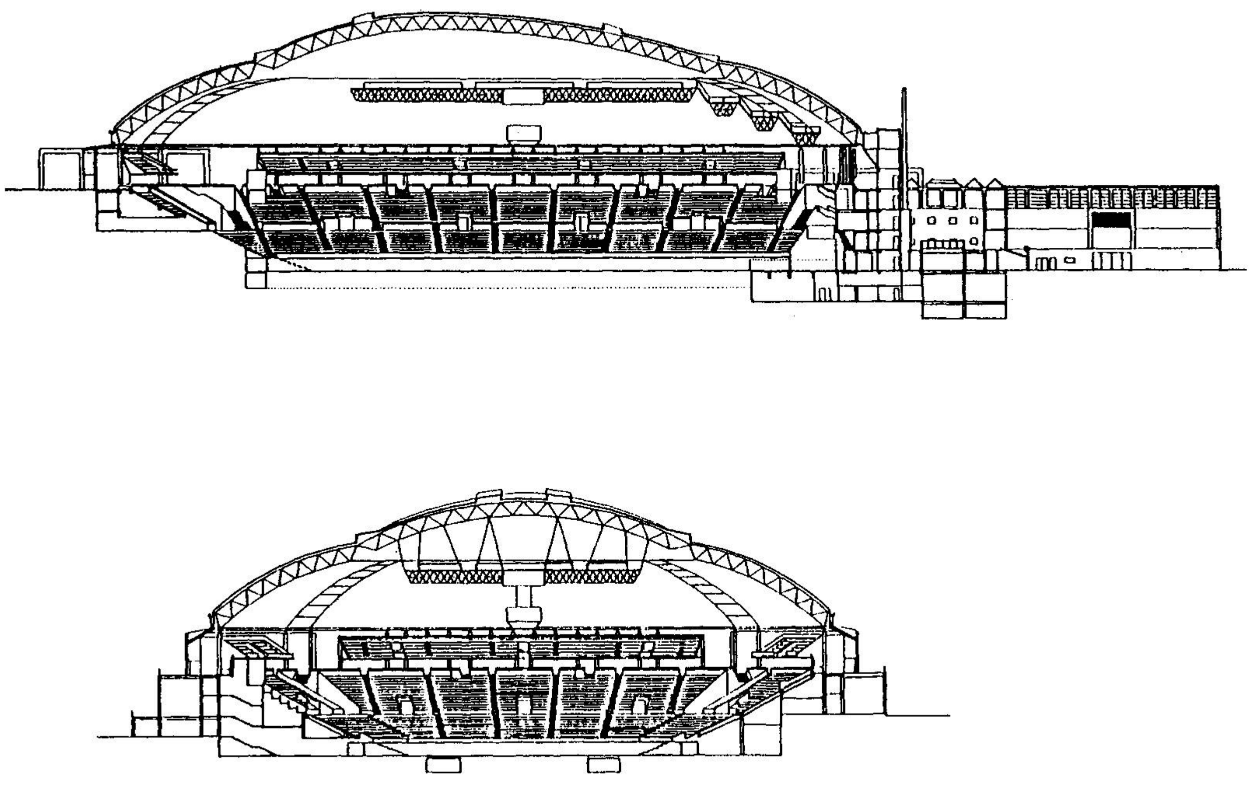

Fig. 5 Sant Jordi Olympic Sports Palace

Each adjacent pair of the 44 columns is rigidly connected to each other at their tops by means of a lattice girder to form a portal frame in the peripheral direction. Since all the columns are kept hinge-connected at their tops and bottoms even after completion so that the roof is free to expand and shrink without producing thermal stresses in the structure when temperature changes, the lateral resistance of the roof structure is exclusively given by those 22 portal frames (14 in the longitudinal and 8 in the transverse directions, respectively) along the periphery of the roof.

Assembly of the roof structure was effected in the site by means of hoisting systems. It consisted of the following two different stages(Fig. 6):

a) Assembly of the central dome on the arena, supported by provisional light steel columns.
b) Assembly of the 16 peripheral segments of approximately 400m^2 weighing up to 40tons.

The equipment for pushing up the roof was composed of 12 lifting towers.

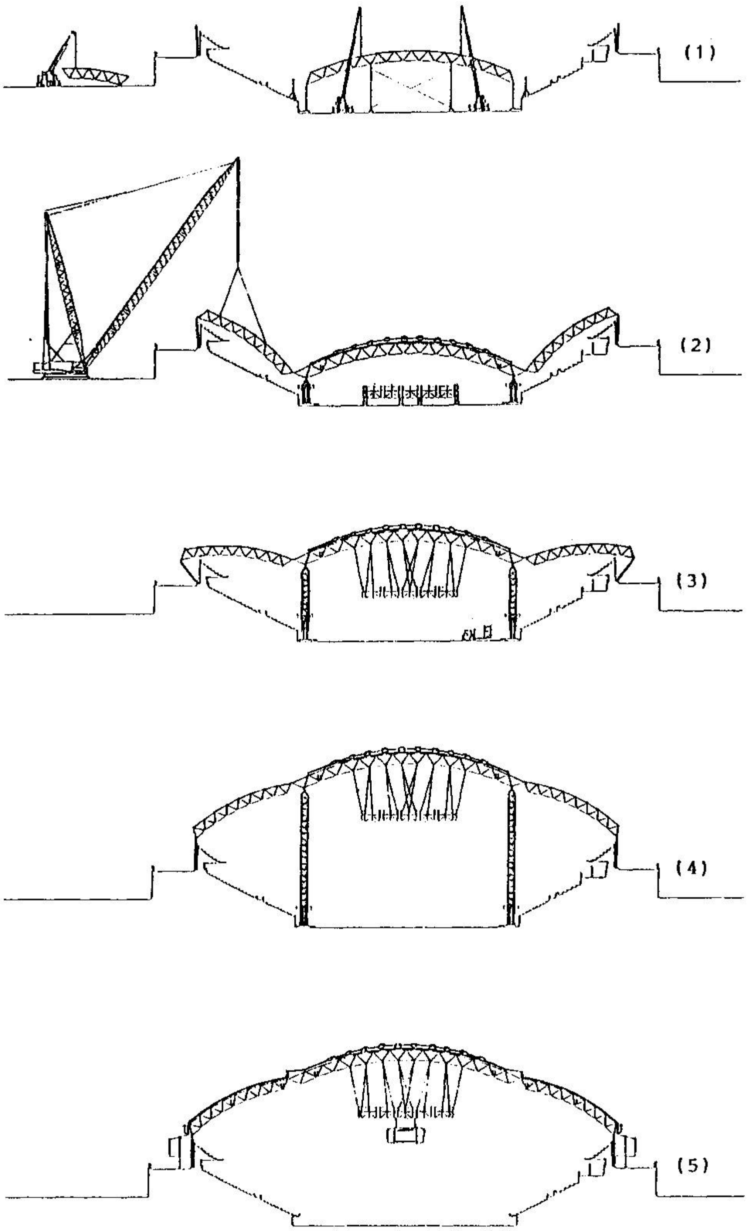

Fig. 6 Erection of Sports Palace

When all the specified roof members had been assembled, and necessary lifting equipments had been installed, the lifting operation began. The lifting operation was carried out in stages of 3.04m, which corresponds to the height of one full tower element.

The lifting operation began on November 21st, 1988. The load on the 24 lifting units were initially 760 tons. After 2.74m of lifting, a platform measuring 60x20m and weighing 80tons which carries electrical and ventilation equipment was hung from the central part of the roof by tensioning the suspension cables. In 10 days the roof was pushed up the height of 9 full and one half tower elements, which corresponds to 28.83m. Once the final height had been reached, the towers were set down onto steel plate packers of 16cm height. Thereafter, lifting units, pumps and controls were dismantled and removed.

The members which had been kept away from their positions during the lift were then fitted in and welded to complete the roof structure. At the same time the installation works of insulation, roofing and interior finishing continued. After completion of the structural system the loads on the temporary towers were relieved successively in small steps by jacking up one tower at a time and by removing gradually the packer plates. The vertical displacements of the center of the roof due to removal of the lifting towers was 140mm, showing a close agreement with the result of analysis.

5. EXAMPLES UNDER CONSTRUCTION

Out of three other buildings which are now under construction on the Pantadome System, two major buildings are described here.

5.1 Sun-dome Fukui

One of them is Sun-dome Fukui being built in fukui Prefecture, Japan.
This building is a multipurpose hall to be used for the World Championship Games of Athletics in 1995. It has a circular plan of 116m in diameter, and the maximum height of 40m. The building is located in a heavily snowed region with a snow load of $6kN/m^2$. For functional reason the roof of the building was so designed that it keeps snow which has fallen on it. Consequently the structure itself is also rather heavy, the weight of the steel frame being $2.5kN/m^2$, and the total roof including finishing $4kN/m^2$. The lifting process of the roof is as shown in Fig.8 in section and Fig.9 for a model study. The lifting of the roof is scheduled for August 1994.

5.2 Osaka Sports Center

Another application of Pantadome System is being tried for a Osaka prefectural sports hall to be built in Osaka. It has an oval plan of 110mx125m and the maximum height of 42.65m. The main structural feature of the building is that the roof is slightly(5 degrees) tilted, and so the lifting direction is not vertical. This roof is to be lifted in November 1994.

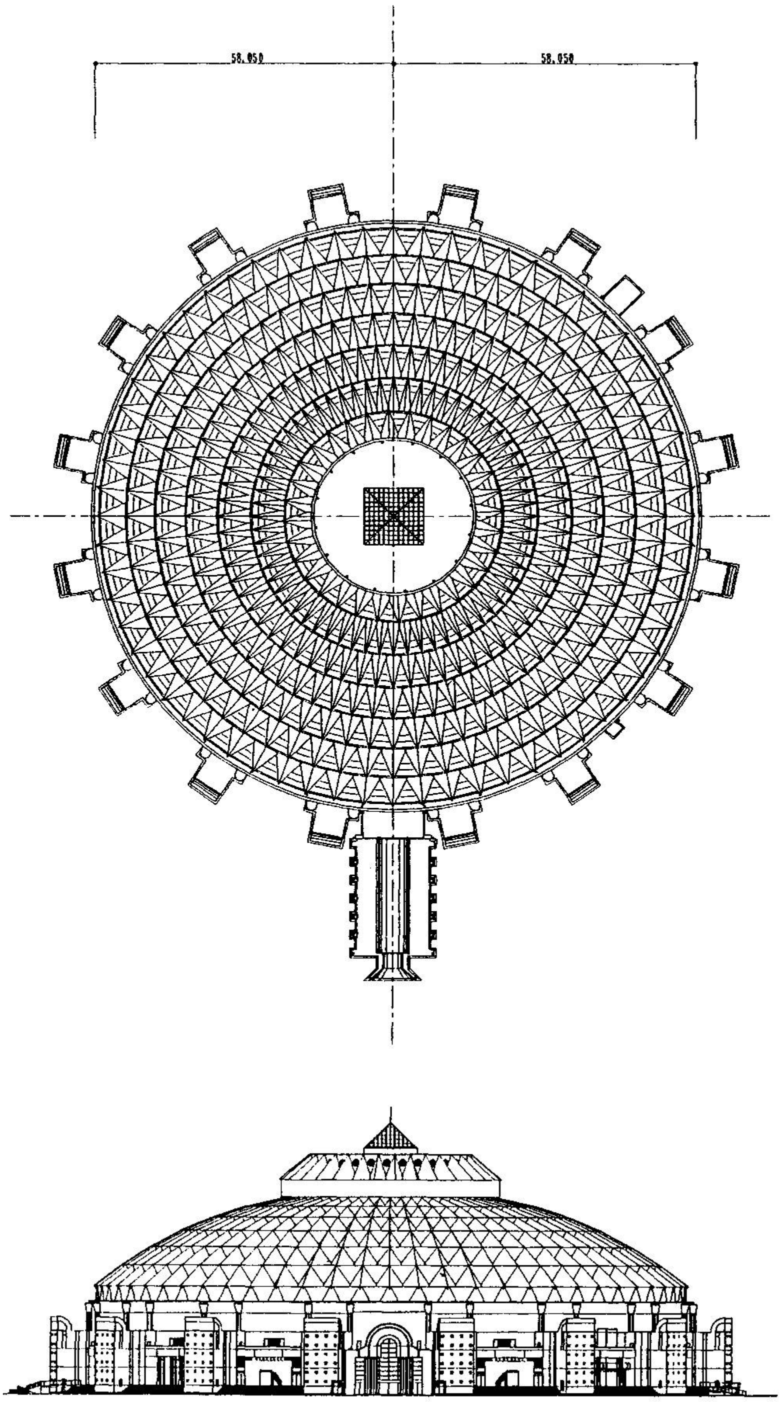

Fig.7 Sun-dome Fukui

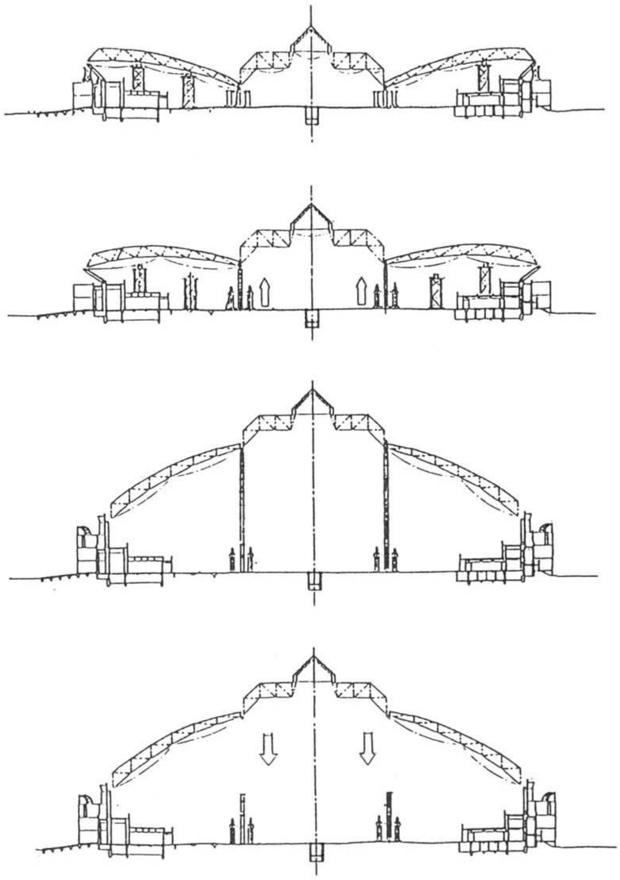

Fig. 8 Erection process

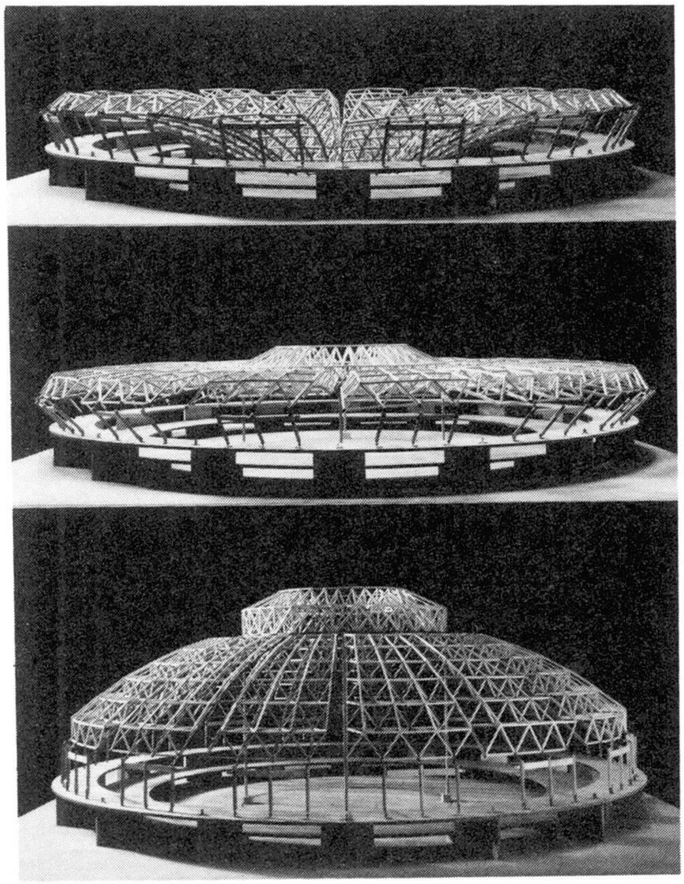

Fig. 9 Model study of lifting

6. CONCLUSIVE REMARKS

As a solution for the construction problems of domical space frames a patented structural system named Pantadome System has been presented. Pantadome System has been applied to large-span domes of a few different geometries. It has so far been successfully applied in a few different countries (Japan, Singapore and Spain) where local building conditions are different from each other. It seems that these examples support rationality of the system in terms of safety, construction speed, quality of built structures and economy of space frames.

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