Report on Spatial Structures Damaged by the 1995 Great Hanshin Earthquake

by

K. Kawaguchi [1] and Y.Hangai [2]

ABSTRACT

In general, spatial structures for large span enclosures are thought to be more aseismatic than other structures, such as tall office buildings or multi-story reinforced concrete buildings. However, a few spatial structures were heavily damaged by the Great Hanshin earthquake. In this article the damage to shell and spatial structures are briefly reported and remarks on the damage to suspended facilities are given.

1. INTRODUCTION

In the emergency of the Great Hanshin Earthquake many public spaces covered by large roofs, such as public halls or school gymnasiums, were converted to refuges for numerous refugees. For such large roof buildings the light weight structural systems, e.g. space frames, large steel truss beams, or shells, which are generically called spatial structures, are usually employed. Because of their light weight spatial structures are usually thought to be much safer than ordinary buildings under seismic loading. As was reported in many articles, the heavy damage to various kinds of structures was brought about by the Great Hanshin Earthquake. The damage to spatial structures were comparatively minor. On the other hand, however, a few cases in which spatial structures were heavily damaged were reported. This is the summary of the preliminary report of the damage to spatial structures brought about by the earthquake.

2. STRUCTURAL DAMAGE TO SPATIAL STRUCTURES

2.1 An Elementary School Gymnasium

The building had two stories and the gymnasium was at the 1st floor while the ground floor was used for class rooms (Photos 1-4). The dimension of the floor was 18m x 40.5m. Pre-cast cylindrical shell beams, having slight anticlastic curvature along their axial directions, had been used to span the gymnasium. A single span of the pre-cast beam had covered minor direction of the floor. Total number of the pre-cast beams was sixteen and ten of them slid off from the eastern supports. The beams had been anchored at the top of short walls in a simple manner, so that the anchors broke through the walls and the beams slid horizontally by several decimeters.

1 Ken' ichi Kawaguchi, Associate Professor, IIS University of Tokyo, Tokyo, Japan
2 Yasuhiko Hangai, Professor, IIS University of Tokyo, Tokyo, Japan

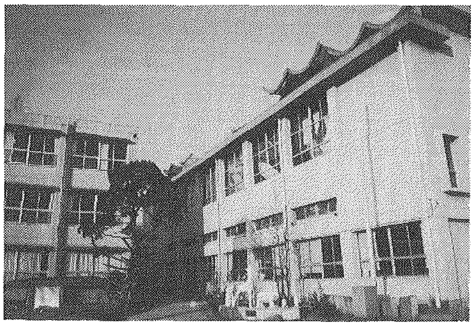
Photo 1: The elementary school gym.


Photo 2: Interior view of the school gym.

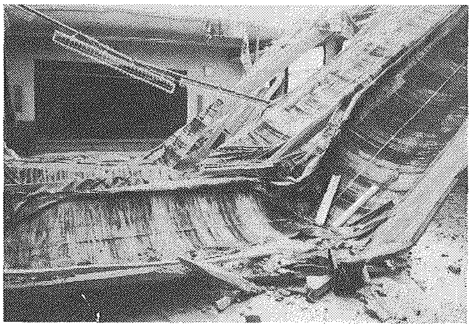
Photo 3: Collapsed beams of the school gym.

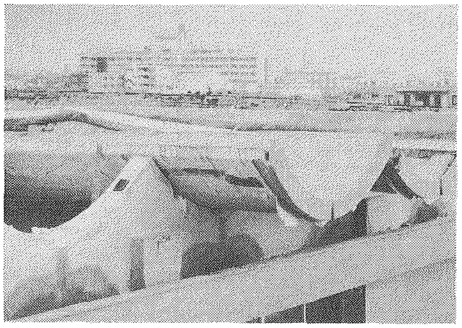
Photo 4: Slid pre-cast beam

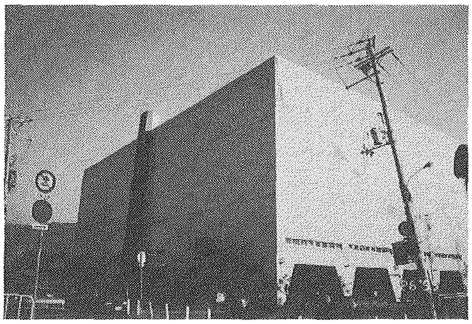
Photo 5: The public gym.

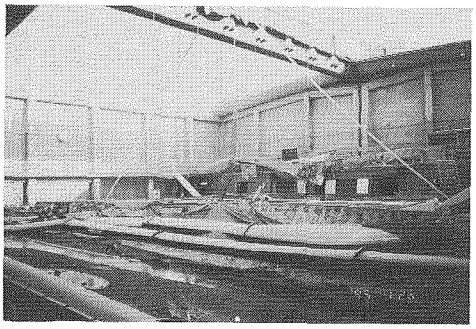
Photo 6: Interior view of the public gym.

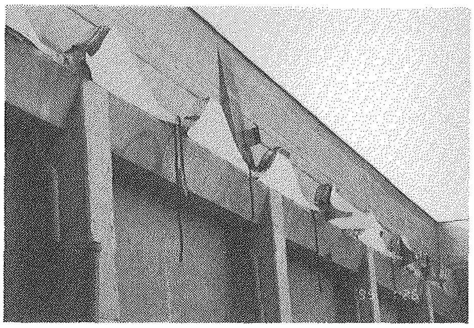
Photo 7: Supports and anchor for the tie

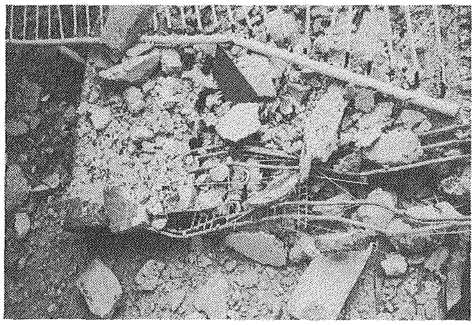
Photo 8: Collapsed beam of the public gym.

2.2 A Public Gymnasium

Pairs of the pre-cast shell beams, which are the same type used in the gymnasium in the previous subsection, were leaned on a steel girder spanning the center of the gymnasium floor (Photo 5-8). The dimension of the floor was 29.5m x 38.5m. The girder had a pair of steel pipe ties, anchored at the tops of columns, preventing the girder from horizontal movement. During the earthquake most of the shell beams have fallen on the floor. Only four beams which were attached on the walls on their longitudinal edges remained at the position. All of the anchor bolts of the ties were broken off and ties had become ineffective. Cracks which seemed to had been caused by out of plain bending deformation were observed on the wall.

2.3 A High School Gymnasium

Photo 9 through 12 shows damage to a high school gymnasium. Most of school gymnasiums in this area are extensively built on the roof floor of class room buildings. School buildings are mainly constructed as reinforced concrete structures while the roofs of the gymnasiums are built as steel structures. Structural damage to such buildings is mainly found at the reinforced concrete parts. Damage to steel roof structures is comparatively minor. Some removals of concrete at the supporting parts or break off of braces are often found.

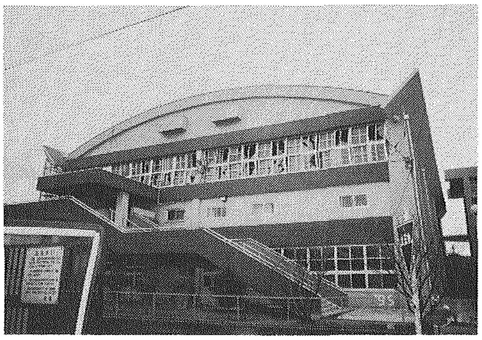

Photo 9: The high school gym.

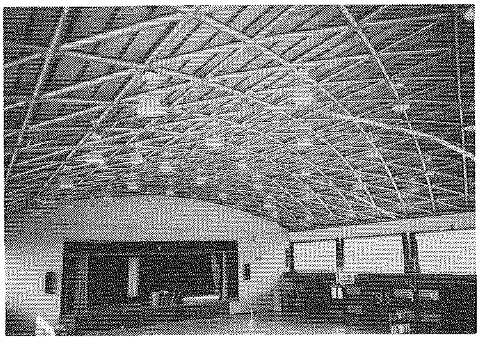

Photo 10: Interior view of the high school gym.

Photo 11: Failure of a column of the gym.

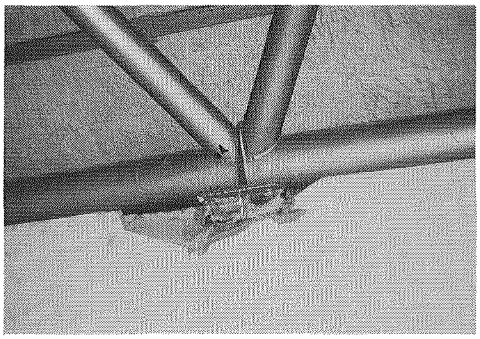

Photo 12: Damage at an anchor to concrete wall

2.4 Space Frames

Photo 13 through 15 show damage to space frame roof structures of a hippodrome stand. Many members were buckled and broken off from joint globes. Some of the anchor bolts of a main arch was pulled off from an anchor block.

Photo 16 shows interior view of a system truss roof used for a theater atrium. A lot of members were bent or broken off in the middle of the length or at the connections.

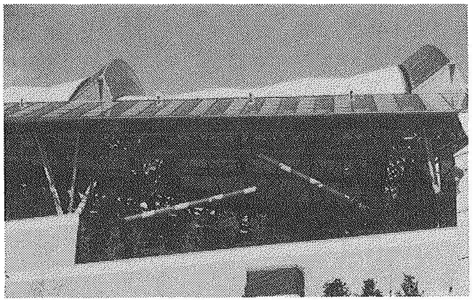

Photo 13: The hippodrome stand roof

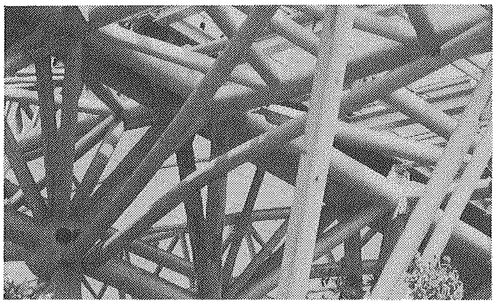

Photo 14: Disconnection at a joint and bent members (photo by prof. T.Saka)

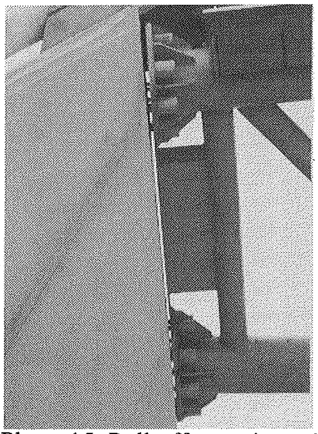

Photo 15: Pull off at main arch anchor of the hippodrome (photo by prof. T.Saka)

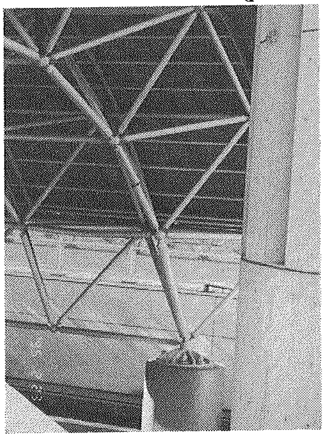

Photo 16: Cut off member of the theater atrium

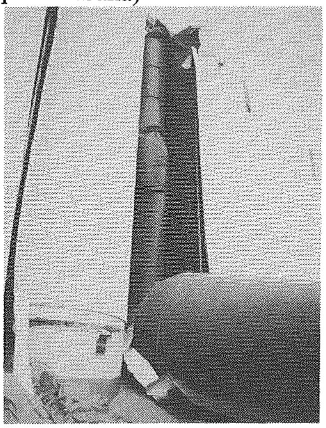

Photo 17: Buckled and collapsed silos

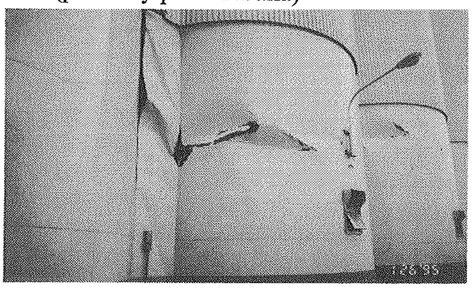

Photo 18: Buckled silos

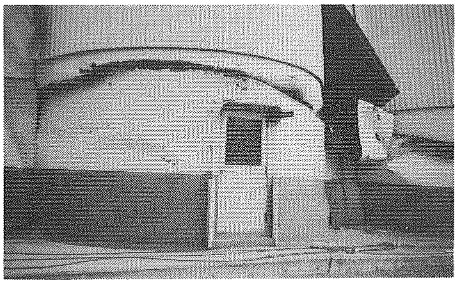

Photo 19: Buckled silos (Compare with Photo 18.)

2.5 Silos

Eighty silos for wheat storage were standing on an artificial island. Sixteen silos of them were made of steel and the others reinforced concrete. Twelve steel silos were heavily damaged by buckling (Photo 17-19). Diameter of each silo was 7.2 m and thickness of steel was 4.5mm at the top and 14mm at the bottom. The silos were filled with wheat by eighty percent of the capacity when the earthquake hit them. The buckling was occurred near the bottom of a silo where wheat inside is gathered to the center by a hopper. No internal pressure of filling restrains the shell from buckling at this part. After the buckling the height of the silos were reduced by about 3m so that hoppers reached the ground. No damage was found to reinforced concrete silos.

2.6 Two Sports Arenas

Photo 20 through 22 show two sports arenas which were built on a major artificial island. The arena at left hand side in Photo 18 is a space frame dome structure having 110m x 70m dimension in plan. The other arena is a large space truss structure of which dimension is 100m x 74m in plan. The maximum horizontal ground acceleration recorded on this island was 340.8 gal at the surface while 678.8 gal at -79m down hole. No major structural damage was found in both arena structures.

On artificial islands, heavy ground sinking was observed. As the ground sank, structures on piles were relatively floated up.

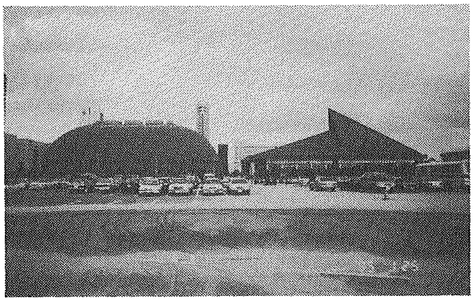

Photo 20: Two arenas on an artificial island

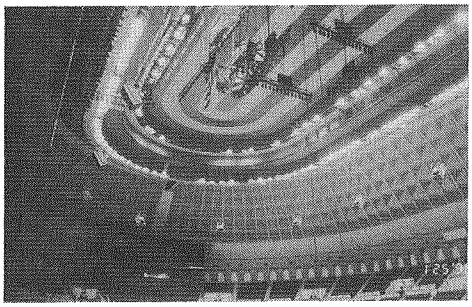

Photo 21: Interior view of the l.h.s. arena

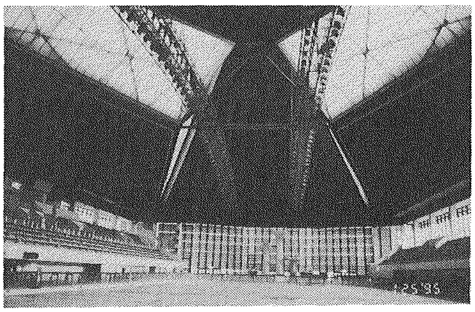

Photo 22: Interior view of the r.h.s. arena

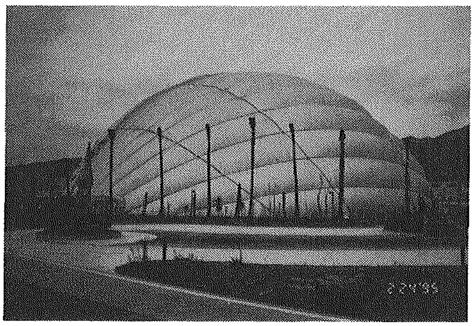

Photo 23: A pneumatic dome

2.7 A Pneumatic Dome

A pneumatic structure on artificial land safely survived (Photo 23). After the earthquake, the public electric power failed and the independent electric generator started to keep the necessary internal air pressure. Since the reserved oil could drive the generator only for five hours a lot of efforts have been paid to maintain the independent electric supply system for a week.

3. DAMAGE TO SUSPENDED FACILITIES IN SPATIAL STRUCTURES

In many halls suspended ceiling panels or other facilities suspended from the roofs fell off while the roof structures themselves remained undamaged (see Photo 24). In Photo 27, one can see a huge speaker frame fell on the floor of the arena. So far, 117 damaged spatial structures, such as public halls or gymnasiums, were reported to us. From the view point of structural engineering, most of the damage to them were minor. Among the damage to spatial structures, the rate of damage to suspended facilities, especially damage to suspended ceiling systems, is very high. Fig.1 shows items in fall of suspended facilities. Fall of suspended facilities is reported in 38 cases among 117 investigated spatial structures. Above all, the major failure is fall of suspended ceiling systems, which is reported in 31 cases. Fig. 2 and 3 show distribution of damaged spatial structures. Fig. 3 shows JMA intensity 7 area and distribution of damage to spatial structures. Most of the spatial structures damaged to structural elements are around the intensity 7 area while spatial structures damaged to suspended facilities are found in broader area.

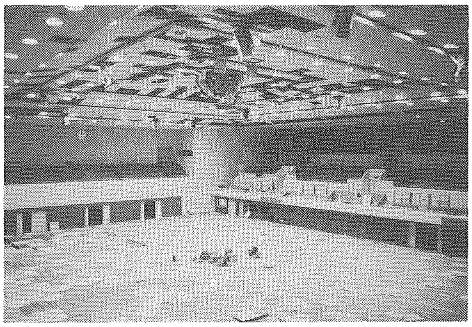

Photo 24: Fall of suspended ceiling panels

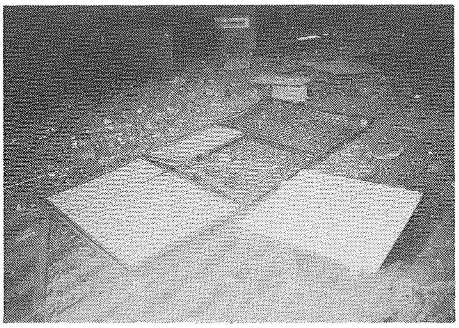

Photo 25: Fall of suspended ceiling systems

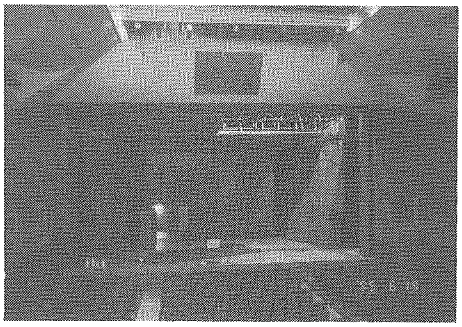

Photo 26: Fall of a mobile acoustic panel

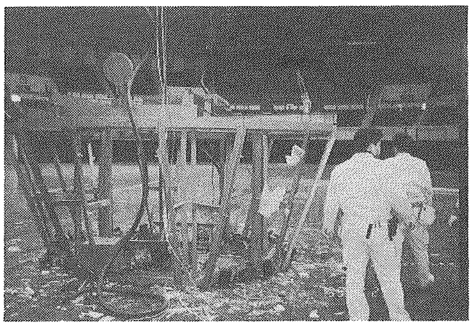

Photo 27: Fall of a huge speaker frame

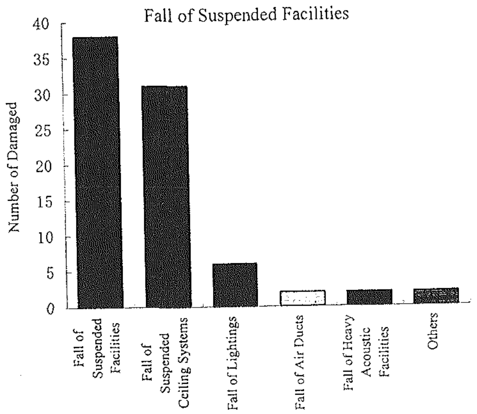

Fig. 1: Fall of suspended facilities
(Total number of investigated = 117)

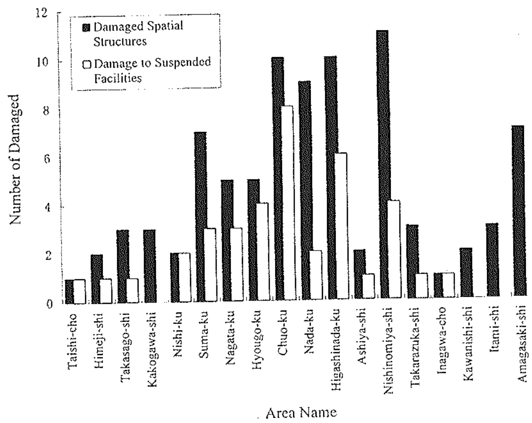

Fig. 2: Distribution of damage to spatial structures in wards

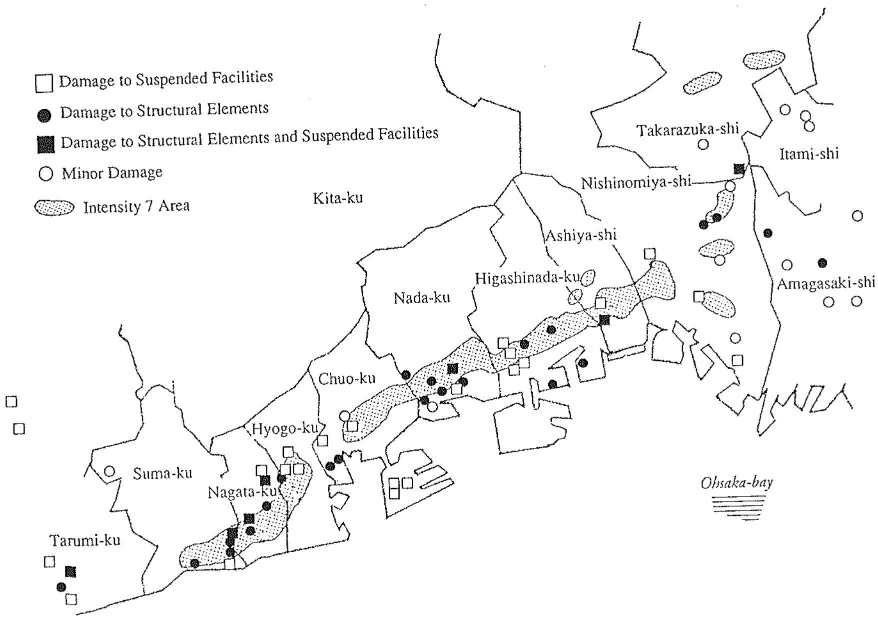

Fig. 3: JMA intensity 7 area and damage to spatial structures

After the earthquake many public halls were converted to refuge place for numerous refugees. However, at the same time, many halls could not be of service to such purpose because of dangerous condition of suspended facilities which could be fallen off by after shocks.

4. CONCLUSIVE REMARKS

Several cases of damage to spatial structures were briefly reported. Most of the structural damage to spatial structures can be related to the supports of structures. Appropriate design and construction of boundary parts of roof structures is essential for the aseismatic performance of spatial structures. However, most of the damage to spatial structures is relatively minor, comparing to damage to other large structures, since spatial structures are usually designed as light weight structures, which is of great advantage to structural performance during earthquakes. On the other hand, it is often said that the structural performance of spatial structures under UD excitation is rather question because they span wide area without any columns. Although strong UD acceleration was recorded during the earthquake, we could not identify the damage which was mainly caused by the UD motion, so far.

In most of public halls and arenas a lot of heavy facilities are suspended from the roof structure at very high place above the audience and spectators. Aseismaticy of suspended ceiling systems or other facilities suspended from the roof structure should be come to attention since their fall off could injure many people inside and mar the function as public shelters or refuges after the disaster, even if the structure itself survived safely.