KAWASAKI STEEL TECHNICAL REPORT

No.36 (July 1987)

Overseas Engineering Operations

Engineering and Erection Using Sliding Method for Large Span Roof in the U.S.A.

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The body can be viewed from the next page.

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1 Introduction

As the world wide trend toward large space has been increasing, Kawasaki Steel has developed a large-span structural system using pre-stressed steel truss called "Super Wing"[1]. This system has been adopted in 18 projects that require large spans in industrial facilities, such as plants, goods-distribution bases and air craft hangars, and such sports facilities as gymnasiums and arenas. The structural roofing work for DELTA CENTER constructed in Salt Lake City, Utah in the United States is one of the first embodiments of this system. The novelty of this system and the adoption of the sliding method using hydraulic jacks were highly evaluated in the United States, resulting in the awarding of the contract to Kawasaki Steel.

With respect to the construction of DELTA CENTER (**Photo 1**) this report describes in detail the design of large-span roof trusses by the Super Wing system and the methods for erecting large-span structures including the sliding method.

2 Outline of Work

In Salt Lake City, Utah in the United States the planning of DELTA CENTER was started in 1988 and its consruction was started in June 1990 and completed in October 1991. DELTA CENTER is a multipurpose arena used for basketball and ice hockey games, concerts, etc., and is also used as the home of the UTAH JAZZ of the U.S. National Basketball Association (NBA). This facility has a seating capacity of 22 000 persons and a total floor area of about 51 000 m^2. The structure of this facility is reinforced concrete and the arena portion is composed of 4 stories above ground and 2 stories below. The Super Wing system was adopted in the roof trusses of 105 m span erected in the upper part of the structure. That section of the arena is shown in **Fig. 1**.

An outline of the roof trusses adopted in the Super Wing system is shown in **Table 1**.

In the Super Wing system, economical large spans are obtained by reducing the amount of truss steel, which is achieved by pre-stressing the bottom chords of steel trusses. The advantages of this system are much greater compared with ordinary trusses, especially in districts of heavy snowfall, such as Salt Lake City.

The sliding method in the erection of roof trusses involves assembling, lifting and horizontally sliding trusses at one end of the arena and erecting all the roof trusses by repeating this process: lifting, connection and horizontal sliding of the succeeding trusses. The advan-

* Originally published in *Kawasaki Steel Giho*, **28**(1996)3, 181–186

Photo 1 Interior view of DELTA CENTER

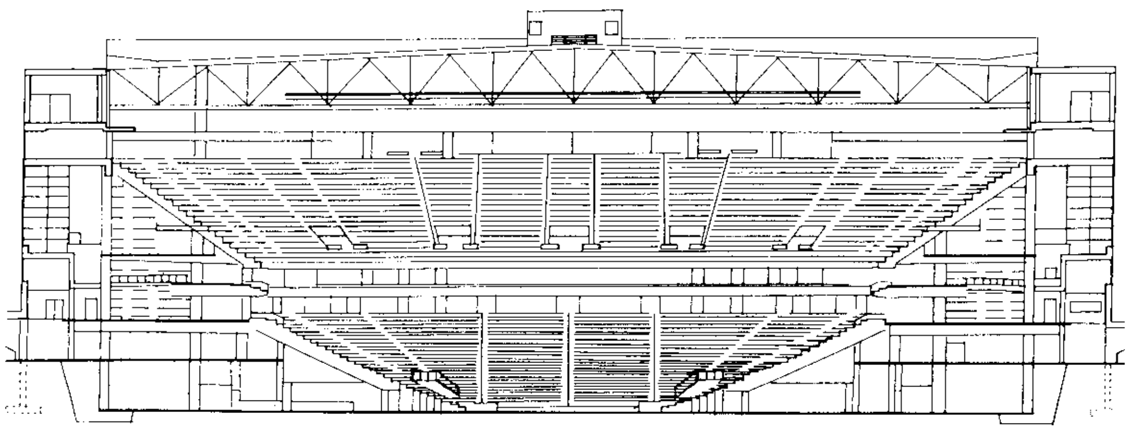

Fig. 1 Section of arena

tage of this method lies in the use of a minimum number of supporting frames for erection and overhead-work stages and resultant substantial improvement in work efficiency and safety. The higher roof trusses are above the ground, the greater becomes this effect.

Originally, a construction period of at least 22 months was considered necessary in this arena project. However, it was necessary to complete the work in 16 months to

Table 1 Principal data of roof truss

Roof dimension	Span	(m)	105
	Bay	(m)	118
	Total area	(m^2)	12 390
Number of trusses			10
Dimension of roof truss	Length	(m)	105
	Depth	(m)	7.5
	Max. unit weight	(t)	83
Total weight of roof structure	Steel structure	(t)	1 313
	PC strand	(t)	27
	Total	(t)	1 340

Table 2 Loading condition for roof truss

Dead load	Truss & roof	(kg/m^2)	164
	Catwalk	(kg/m)	119
	Scoreboard	(kg)	18 143
	Ventilator	(kg)	20 411
	Curtain wall	(kg/m^2)	98
Live load	Concert load	(kg)	45 359
Snow load		(kg/m^2)	168
Seismic load		(factor)	0.1375
Wind load	Windward	(kg/m^2)	105
	Leeward	(kg/m^2)	66
	Upward	(kg/m^2)	92
Temperature fluctuation		(°F)	40

be ready for the beginning of the NBA season. Therefore, the adoption of the sliding method was inevitable because it enables the work on the lower seating area and the arena floor, which is usually carried out after the completion of the roof truss erection, to be executed simultaneously with the erection of roof trusses.

The proposal related to Kawasaki Steel's sliding method using hydraulic jack system of Kawatetsu Kizai Kogyo Co., Ltd. was the main cause of the successful receiving of the order owing to the high evaluation of the record and reliability of the jack system.

3 Project System

In the U. S. general system for the execution of a project, which is very different from that of Japan, actual work including the design, temporary work and heavy-machine work, is carried out by subcontractors while the general contractor mainly acts as coordinator among the subcontractors and between the owner and the authorities with respect to cost, schedule, quality and safety, and is paid accordingly. As a subcontractor, Kawasaki Steel contracts and is responsible for all roof truss work ranging from design to execution.

In the roof truss work for Kawasaki Steel's Utah project, the company conducted design jointly with Kawatetsu Engineering, Ltd. and employed local contractors in fabrication, erection, etc. Extraheavy H shapes, which are the main truss chords, and PC strands for pre-stressing, were of Japanese make, and the jack system made by Kawatetsu Kizai Kogyo Co., Ltd. was used in the sliding work.

4 Outline of Design

The difference in the work system between Japan and the United States was described in the preceding section, but there is also a great difference in design and construction permits between the two countries. Because project expenses including design and work are financed by banks, full-scale work begins as early as possible arter the project start and the earliest possible completion is aimed at in order to minimize interest costs. Therefore, a technique called FAST TRACK was devised, in which detailed design is gradually conducted as the project progresses. In FAST TRACK, there are only basic plans (general drawings, conceptual drawings at completion, etc.) used as the design drawings at the start of construction and there is scarcely any structural or detail drawing. Detailed design and structural design are conducted by each subcontractor in accordance with the requirements of the owner or architect. However, when the lower structure and roof trusses are constructed by different subcontractors as in the present work, it is difficult for logistical reasons to conduct the structural analysis of the whole building, so each subcontractor individually conducts design and obtains construction permits.

In the United States there are three design standards according to a broad classification and each state, county or city adopts one of these. The present work is in accordance with the 1988 edition of the UBC CODE that is used mainly in the West. The loading conditions for roof truss design are shown in **Table 2**.

Steel structure design standards are broadly divided into allowable stress design (ASD) and load and resistance factor design (LRFD) by AISC. Which to select is left to the discretion of designers and this is the great difference in design between the United States and Japan. In this project, the former design method was selected in consideration of the degree of familiarity with the two design methods and our adaptability to the structural characteristics.

In Japan, new methods such as Super Wing require individual approval of the Minister of Construction. In the United States, structural calculations themselves are left to the discretion of designers, although construction permits must be obtained. The Super Wing system passed the Salt Lake City municipal inspection without a problem because the safety of Super Wing trusses had already been proven by many experiments and analyses, the approval of the Minister of Construction had already been obtained in Japan and, there was already a successful track record in Japan. The following three points were checked and no problem was found.

(1) Structural stability of trusses when PC strands are broken
(2) Strength and ductility of PC strands at very low temperatures (–20°)
(3) Danger of emission of toxic gases from the polyethylene coating of PC strands during a fire

5 Working Design

When the working design of the roof trusses was started, the design of the substructure had been finished and the work had been started after the construction permit was obtained. Therefore, the design requirement of roof trusses was to prevent the generation of excessive thrust from the bearing parts of trusses that affect the substructure. In order to prevent thrust from occurring, the design provided simple support for the trusses, that is, a truss would be supported with a pin at one end and with a roller at the other end, and the horizontal restraint of the whole roof surface would be provided by horizontal braces arranged in the structural planes of top and bottom chords, while the horizontal force from the roof surface was to be transmitted through these horizontal braces to the shear walls installed in eight places in the substructure.

Bearing shoes for a bridge capable of permitting rotations up to 1° were used in the bearing portions at the two ends of a truss in order to accomplish pin condition while also ensuring that the bearing portions would be stable not only during sliding, but also during the final erection. Teflon is buried at the bottom of the bearing shoe and the generation of thrust by frictional force is prevented due to the low coefficient of friction between the stainless sheet installed on the substructure side and the Teflon. This bearing shoe is also used for the smooth sliding during the erection of roof trusses.

The stability of the bearing plate in the fixing part of a PC strand was ascertained by stress analysis using the finite element method. For the longitudinal structural planes, the calculation of the section of members and the design of connections were carried out so that the tractive force during sliding could be positively transmitted.

6 Fabrication of Roof Trusses

The fabrication of the roof structural steel including trusses was conducted at a steel fabrication shop in Salt Lake City. Given the favorable road access to the site in addition to assembly and ease of execution at the site, it was decided to transport the trusses 105 m in total length to the site in three transportable portions each 35 m in length. The method of transport is shown in **Photo 2**.

Photo 2 Transportation of truss

7 Construction of Arena Roof

7.1 Procedure for Construction

The steel trusses themselves, which are 105 m in total length, have little out-of-plane stiffness and are incapable of self-standing. Furthermore, because the bottom chords are pre-stressed in the Super Wing system, it is important to ensure truss stability during erection.

The procedure for erecting the Super Wing roof trusses using the sliding method is described below:

(1) The first two trusses are assembled in a box shape to ensure out-of-plane stiffness.
(2) These two trusses are pre-stressed.
(3) They are then slid over a distance of one span.
(4) The next truss is two-dimensionally assembled and erected, the box-shaped trusses, beams and braces are more structurally integrated to ensure out-of-plane stiffness, and are pre-stressed after that.
(5) The trusses are slid by one span.
(6) Steps (4) and (5) are repeated.

7.2 Erection of Structural Steel

Because the trusses were transported to the site in three portions, they were first assembled into box-shaped or two-dimensional trusses on the ground. In consideration of the capacity of the erection crane, the box-shaped trusses were erected in three portions and the two-dimensional-trusses were erected in a single piece. For this purpose, supporting frames were necessary in the truss joining places. These supporting frames were installed in the stand within the arena and hydraulic-jacks were installed to control internal stress and deformation of the trusses by deadweight and prestress during erection. They were also used during the erection of the two-dimensional trusses. A work platform was installed on one span at the end of arena where

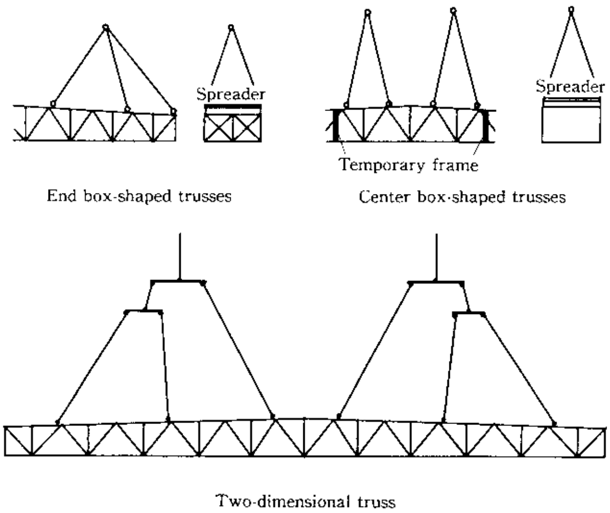

Fig. 2 Hoisting method

the trusses were erected to ensure work safety and improve efficiency.

As mentioned above, the trusses themselves were unstable due to the absence of restraint out of the truss plane. Under some hoisting methods during erection, compressive forces act on the truss members, causing out-of-plane buckling to occur. The hoisting method adopted during erection is shown in **Fig. 2**. In erecting the boxed trusses, a spreader was used to prevent the buckling of the tie beams. For the two-dimensional trusses, there was a difference between the wire length required for causing the assembled trusses to stand upright and that required for erection. Levers were used as hoisting jigs to adapt to this change in the required wire length. Although the hoisting positions were set so that the large-span trusses that were as long as 105 m in total length did not buckle out of plane during erection, it is likely that the use of the levers resulted in the equalization of lifting load and was effective in preventing buckling. The erection condition of box-shaped trusses and the work stages are shown in **Photo 3** and the erection condition of two-dimensional trusses is shown in **Photo 4**.

7.3 Pre-stressing

The work for tightening PC strands is carried out after the erection of secondary members such as the tie beams between the erected trusses and braces.

Two PC strands are arranged for one truss along the bottom chord of truss. Two levels of pres-stress of 320 t (160 t/strand) and 237 t (118.5 t/strand) were used appropriately according to the difference in the loading requirements. Two hydraulic jacks of 200 t capacity were used and two PC strands were pre-stressed at the same time.

The control of pre-stressing was conducted by measuring the hydraulic pressure of jacks and the apparent

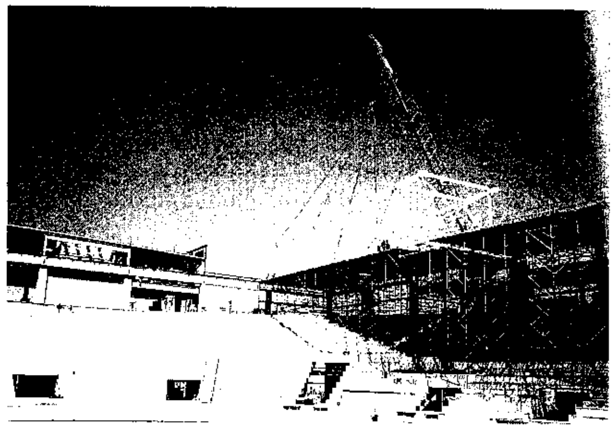

Photo 3 Hoisting boxed truss

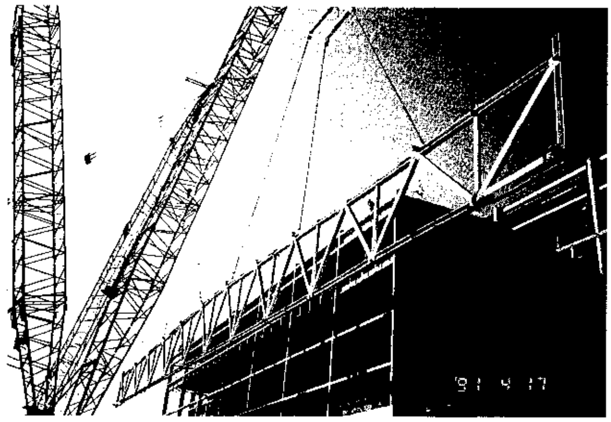

Photo 4 Hoisting assembled truss

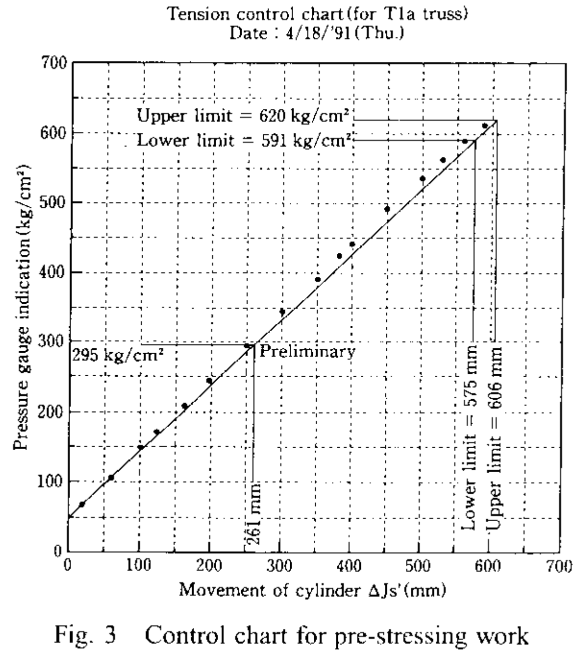

Fig. 3 Control chart for pre-stressing work

elongation of PC strands (elongation + compressed shrinkage of bottom chord). An example of pre-stressing control chart is shown in **Fig. 3**. Tension is controlled so that the hydraulic pressure and elongation corresponding to the design pre-stress are eventually within 0% to +5% while ascertaining that they do not deviate from the relationship between hydraulic pressure and elongation predicted by calculation.

7.4 Sliding Work

An outline of the sliding equipment is shown in **Fig. 4**. The sliding hydraulic jack installed on the side opposite the truss erection side is connected to the steel rod provided with nodes, which is called the step rod. A stainless steel sheet is spread over the sliding surface and the application of liquid detergent enables the load necessary for sliding (the tractive force) to be reduced. This is owing to the low friction coefficient (not more than 0.1) between the stainless steel sheet and the Teflon at the bottom of sliding shoe installed in the above leg portion of truss. The maximum weight to be considered during sliding is about 1 000 t and two hydraulic jacks with a capacity of 150 t each are used in consideration of the friction coefficient and safety factor.

The greatest problem in the sliding method is that when hauling the two ends of truss, a difference occurs in the moving speed and amount of movement, resulting in the walk of the truss even if they are hauled with the same force. This occurs because the two ends of the truss, which are 105 m away from each other, have different actual values of sliding resistance. In other words, it is important to control the moving speed and amount of movement during sliding.

In selecting the sliding equipment, the hydraulic jack system made by Kawatetsu Kizai Kogyo Co., Ltd. was adopted in terms of the reliadility of the control mechanism of the right and left amounts of slide and the operability of the equipment although systems capable of

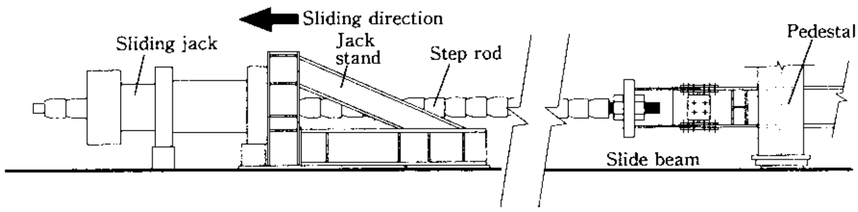

Fig. 4 Sliding equipment

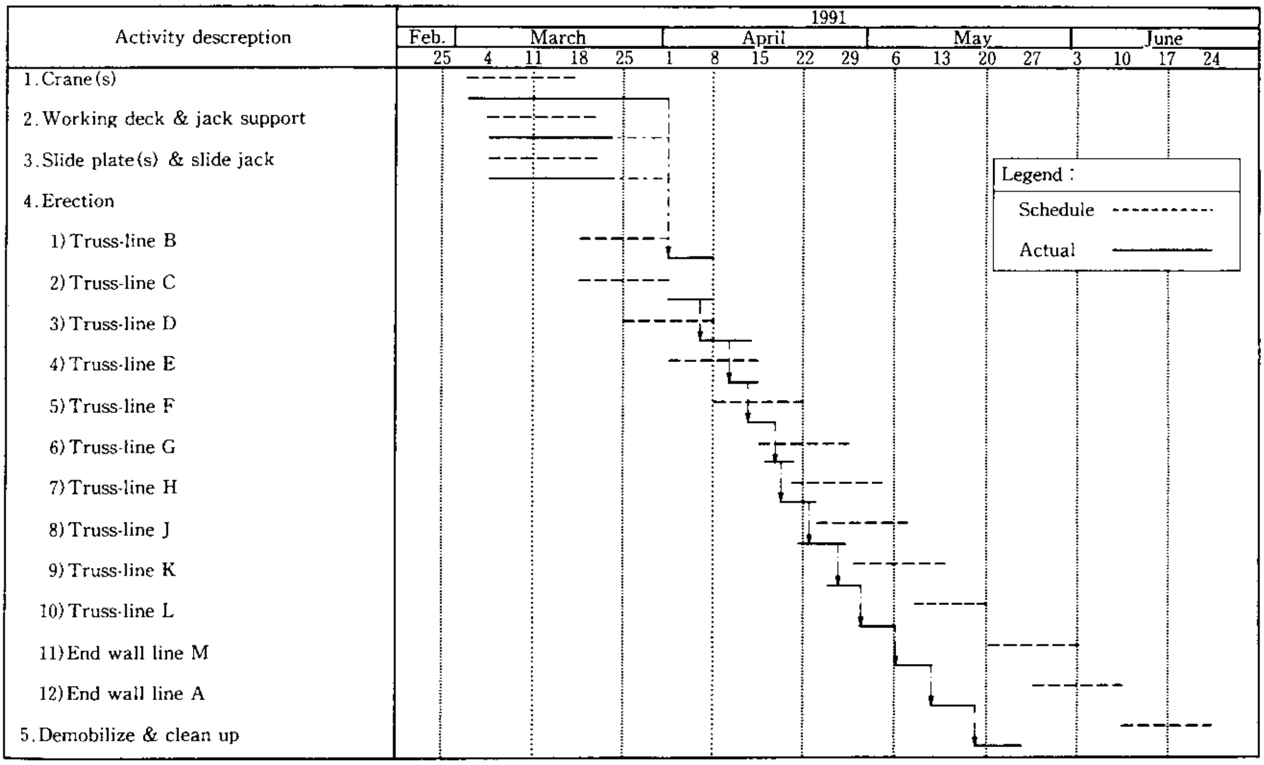

Fig. 5 Construction schedule of super wing truss

being locally procured were also examined. In this jack system, the amount of slide of one stroke is 150 mm and constant due to combined use of the step rod and no difference in the final amount of movement per stroke arises even if a difference in the right and left sliding speed occurs for some reasons. Operation is easy because the control of the two hydraulic jacks after the initial setting of the moving speed can be conducted collectively using a control panel. Each leg portion of truss is provided with guide rollers for preventing the walk of truss.

The amount of slide per operation was 10.7 m and the time required was about 2 hours. As a result of the adoption of the sliding method, in the erection of the roof trusses including the structural framework of the two gable ends, it took 8 weeks to execute only the erection work, but it took only 12 weeks to finish the work including assembly and disassembly. The actual construction schedule is shown in **Fig. 5**.

8 Conclusions

The roof truss work using the Super Wing system which Kawasaki Steel designed and constructed for first time in the United States was reported. This work was carried out mainly by Kawasaki Steel's building and structural engineers by joining the technologies of Kawasaki Steel group, i.e., design of Kawatetsu Engineering, Ltd. and sliding method of Kawatetsu Kizai Kogyo Co., Ltd. Furthermore, the extraheavy H shapes and PC strands made by Kawasaki Steel were adopted as main truss members to ensure the quality of work.

The authors intend to increase technological competitiveness by further improving design and construction methods and, at the same time, to expand business using the Super Wing system in which the company can demonstrate its total engineering abilities.

Reference

1) K. Kosaka, H. Takemoto, J. Hashimoto, H. Koizumi, K. Fujisawa, and N. Yamamoto: *Kawasaki Steel Giho*, **20**(1988)4, 315