Precast prestressed concrete truss railway bridge using extremely high strength concrete

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Precast Prestressed Concrete Truss Railway Bridge using Extremely High Strength Concrete

Pont ferroviaire en treillis en béton préfabriqué et précontraint utilisant du béton de très grande résistance

Eine Eisenbahn-Fachwerkbrücke aus vorfabrizierten vorgespannten Bauteilen aus höchstfestem Beton

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1. Introduction

The Akkagawa railway bridge, completed in 1975 by the Japan Railway Construction Public Corporation, is the first precast, prestressed, concrete truss bridge to be erected in Japan and is also the first structure in which autoclave cured, extremely high strength concrete has been used.

2. Planning of the Truss Bridge

The Akkagawa bridge was planned as part of the construction of a new railway line. An Akkagawa Bridge Committe was set up and the planning and design of the bridge discussed thoroughly by experts from each field.

In selecting the type of structure for the bridge, main consideration was given to the following three points:

(1) The structure should incorporate aspects of the most recent technical developments in bridge design.

(2) In view of its proximity to the sea coast, the bridge should be a concrete structure because of its advantage of requiring almost no maintenance.

(3) Since the bridge was to be located in a scenic, steep-sided valley, the structure should reflect aesthetic considerations.

With these considerations in mind, various structures were proposed and after detailed examination by the Bridge Committee, the PC truss structure was selected. It was also decided that autoclave cured concrete with a compressive strength of 800 kg/cm^2 should be used in the PC truss structure.

3. Preliminary Testing

Prior to the construction of the truss bridge, a series of preliminary tests were conducted to determine and iron out any problems in the materials, autoclave curing, design, erection, etc. The following were the main tests carried out.

3-1 Compressive Fatigue Test on Extremely High Strength Concrete

Because truss members are subject to repeated axial stress, the behaviour of compressive fatigue was investigated using autoclave cured concrete with a compressive strength of more than 800 kg/cm^2.

The tests showed that the behaviour of compressive fatigue in members made of extremely high strength concrete differed little from that in members made of ordinary strength concrete and it was found that the compressive fatigue strength after one million repeated loads was 55-60% of the static compressive strength.

3-2 Autoclave Curing of Large Section Members

The representative section of the truss members was 55 x 55 cm and to determine a suitable cycle for the curing of such massive concrete members, a thermocouple was used to investigate the internal temperature distribution. Through these tests, the optimum temperatures and time for the curing cycle were determined.

3-3 Photoelasticity Test and Finite Element Method Stress Analysis

Photoelasticity tests were carried out to examine the degree and flow of secondary stress which occurs in a truss structure as a whole through differences in panel point dimensions and joining methods and the results were incorporated in the design data.

A stress analysis using the finite element method was made on the panel points and the results used in determiming the measurements and form of the panel points.

3-4 Model Test

Using a four span, 1:5 scale model , as shown in Fig. 1, static tests were conducted to investigate the flexural rigidity, stress, crack development and type of fracture which occur in the truss structure. Dynamic tests were also carried out to study fatigue behaviour.

The test results agreed very closely with the calculated values and confirmed the suitability of the PC truss structure.

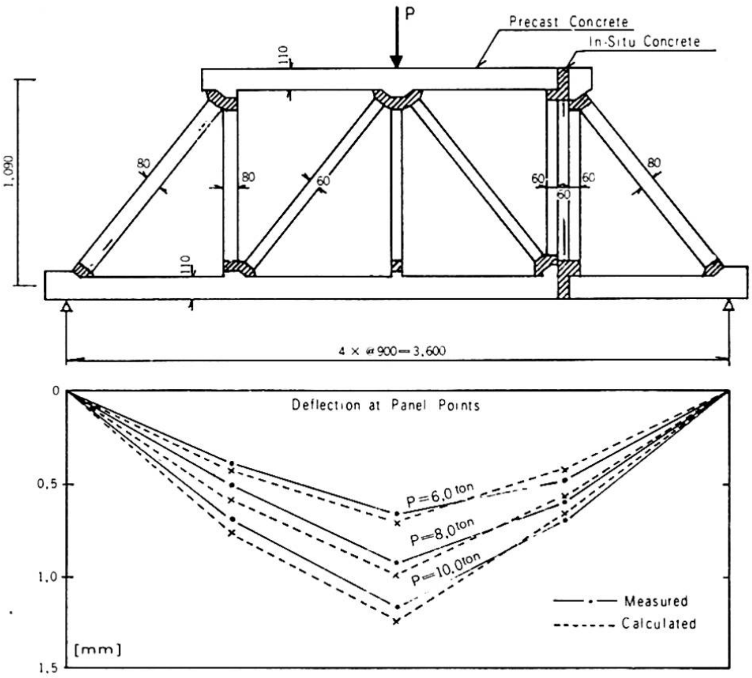

Fig. 1 Deflection Determined From Load Tests on 1:5 Model.

3-5 Load and Vibration Tests on a 24 Meter Span Bridge

Before construction of the Akkagawa bridge, a bridge of identical design, but with a single span of 24 meters, corresponding to a scale of 1:2, was erected at Otanabe and as well as studying problems arising from the design and erection of the bridge, manufacture of the members, etc., load and vibration tests were carried out and the safety of the bridge confirmed.

The ratio of measured stress to calculated stress when a 72 ton load was applied was between 0.80 and 0.96 and the relatively close agreement of these values was confirmed.

The vibration tests were conducted by setting up a 15 ton duplex vibration generator in the middle of the span. The peak of the resonance curve appeared at 7 Hz vertically and at 4-6 Hz horizontally, confirming the safety of the design against earthquakes.

4. Design

The Akkagawa railway bridge is a precast, prestressed concrete truss bridge with an overall length of 305 meters, consisting of six 45 meter spans and one 27 meter span, as shown in Fig. 2

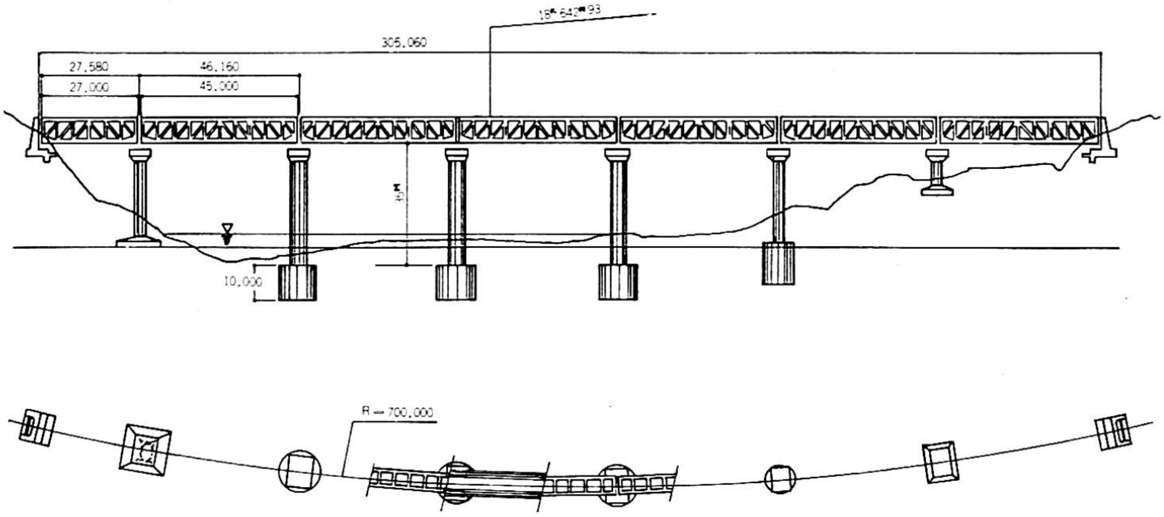

Fig. 2 Side View and Plan of PC Truss Bridge

The Howe truss was chosen because of the simplicity of manufacture of its members, assembly and erection and because of its suitability as a concrete structure. Consideration of the problems associated with the foundations and high piers led to the adoption of the deck bridge structure.

Fig. 3 shows the dimensions of a 45 meter span made up of 10 panels, each 4.5 meters long. The representative section of the upper and lower chord members is 55 x 55 cm and that of the diagonal and verticle members is 30 x 55 and 40 x 55 cm. A tension of 800 tons (280 kg/cm^2 prestress) was introduced in the eight cables in the lower chords, 100 tons in the two cables in the upper chords and a suitable degree of prestress was introduced in the verticals. However, no prestress was introduced in the diagonals, these being compression members.

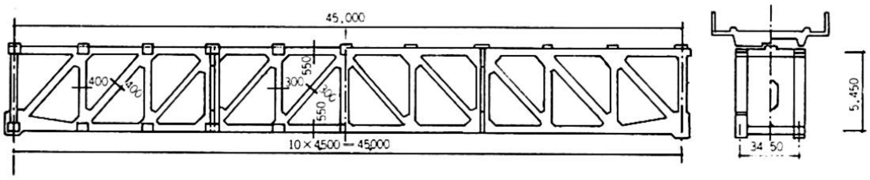

Fig. 3 45 Meter Span Plane Truss

The design compressive strength of the concrete used in the precast members was 800 kg/cm^2 and this was attained through autoclave curing. The design strength of the in-situ concrete for joining members at the panel points was 600 kg/cm^2 and it was possible to obtain this strength by using a high performance water reducing agent and without special curing.

Fig. 4 shows the precast members in a 45 meter span. Each of the plane trusses is made up of 3 upper and 3 lower chord members with the diagonal and

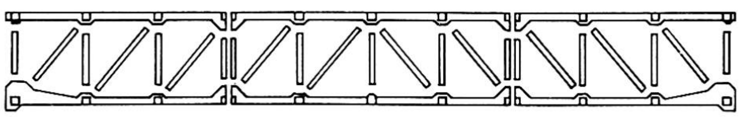

Fig. 4 Precast Truss Members

vertical members all being separate components. With 58 members in each 45 meter span, a total of 384 precast members were manufactured. The largest of these were the upper and lower chord members in the central blocks which were 18 meters long and weighed 15 tons.

5. Manufacture of Precast Members

5-1 Mix Proportions of Concrete

In selection of the aggregates, fine and coarse aggregates with a high silica content were chosen because silica forms high strength crystals during autoclave curing.

The concrete mix used a 0.30 water-cement ratio with a cement content of 530 kg/m^3 and a high performance water reducing agent. While concrete using this water reducing agent has a high viscosity and is difficult to handle, the object was to obtain concrete with a slump of 12 cm $\pm$ 2.5 cm which is relatively workable and stable.

5-2 Manufacture of Precast Members

The precast members were cast in steel molds into which pre-assembled wire reinforcement cages had been arranged, great care being taken that all the splices, sheaths and steel reinforcements would retain their respective positions and directions during and after casting.

The concrete was mixed in a one cubic meter forced-type mixer and placed in the molds using a screw bucket. It was compacted using a relatively large amplitude vibrator inserted into the concrete at close intervals and then the surface was smoothed off immediately.

After steam curing and after confirming that the compressive strength was over 300 kg/cm^2, the members were stripped from the molds and the surface chipped to give a rough finish for later jointing. A temporary prestress of 30 kg/cm^2 was introduced to prevent crack formation during handling, long distance transportation and autoclave curing. The truss members were then cured in an autoclave as shown in Photo 2.

5-3 Autoclave Curing

After concreting, the members were first steam cured at a maximum temperature of 65°C for about 12 hours to shorten the time before stripping and to increase the effectiveness of the subsequent autoclave curing.

The members were cured in an autoclave for 20 hours at a temperature of 180°C and a pressure of 10 atmospheres as shown in Fig. 5. Heating to this temperature was carried out gradually at the rate of 10°C/hour over 15 hours and after curing, the members were allowed to cool gradually at a rate of 4°C/hour over 20 hours to prevent crack formation. The autoclave was 31 meters long and had a diameter of 3 meters.

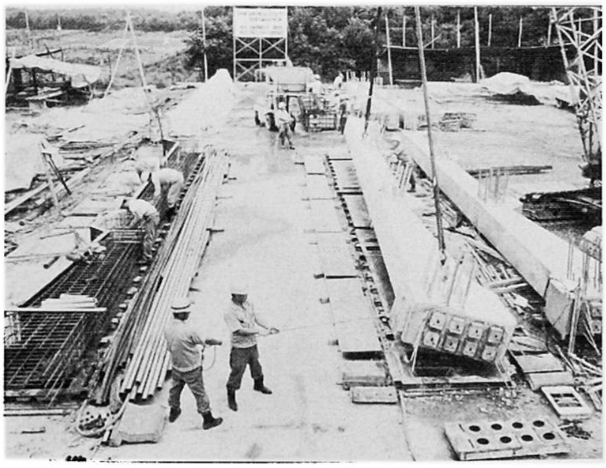

Photo 1 Manufacture of Members

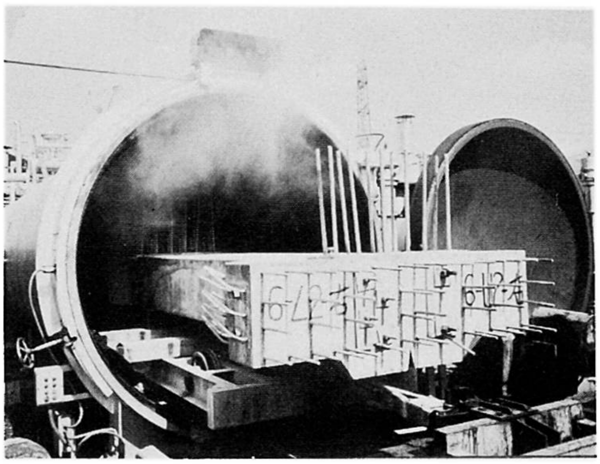

Photo 2 Autoclaving of Members

5-4 Compressive Strength of Concrete

The design compressive strength of the concrete was 800 kg/cm^2, but as a result of adding an additional factor of 1.1, the average strength attained after autoclave curing was 960 kg/cm^2, with a variation factor of 4.6%

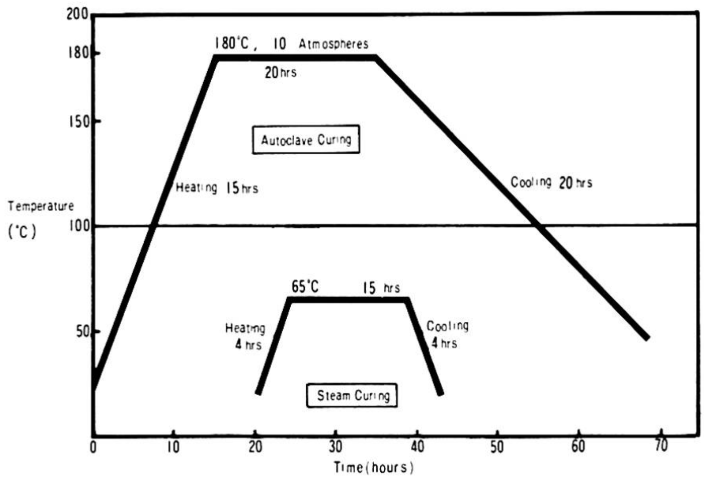

Fig 5. Autoclave Curing Cycle

6. Erection

Various methods were considered for the erection of the trusses, but in view of the site conditions and safety factors involved in the erection of such heavy concrete members, the 'all staging-pull out' method was finally adopted.

6-1 Assembly of Members

The precast members were carefully assembled into plane truss blocks on the ground and joined together at the panel points with in-situ 600 kg/cm^2 concrete and then prestress was introduced in the verticals. Measurement after assembly showed an accuracy of within ± 7 mm.

6-2 Preliminary Assembly and Joining of Space Trusses

The assembled plane trusses were raised to the verticle and then lifted up to the erection staging by crane where they were assembled into space truss blocks, being temporarily joined by lateral steel bracings. These space truss blocks were then individually pulled into position along the erection girders.

After arranging the splice reinforcements and inserting the prestressing tendons into the sheaths, the space truss blocks were joined together, three as a time, using 600 kg/cm^2 in-situ concrete and then tension was applied from one direction only, first in the upper chords and then the lower chords, to form a 45 meter span.

The space trusses were positioned with zero camber because there was a calculated camber of 12.8 mm at full dead-load after creep deformation.

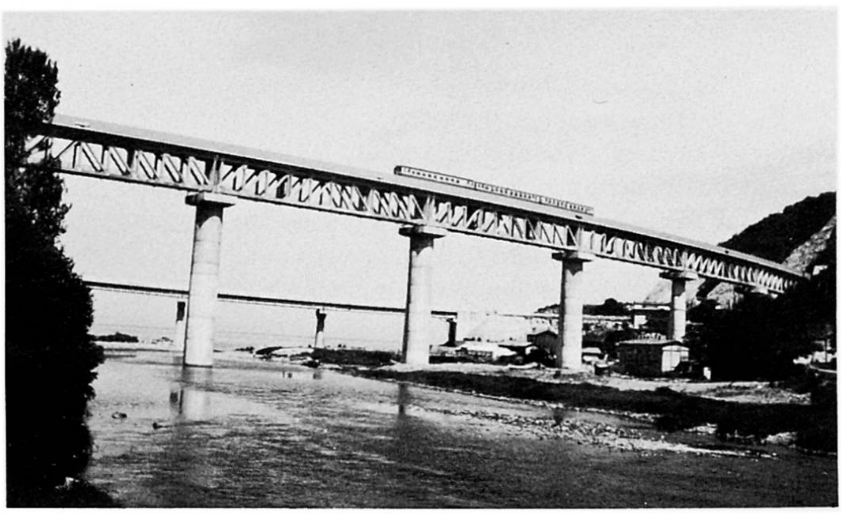

Photo 3 Completed PC Truss Railway Bridge

6-3 Earthquake Proof Walls and Deck Slabs

After the trusses had been secured to the shoes, lateral beams and earthquake proof walls were cast in position and then joined to the trusses using in-situ concrete.

The slabs were precast blocks, 4.5 meters long and 5.8 meters wide and were effectively made into a single continuous deck by the introduction of approximately 10 kg/cm^2 prestress in the longitudinal direction.

SUMMARY

The Akkagawa railway bridge, overall length 305 meters and individual span length 45 meters, is a precast, prestressed concrete bridge in which the Howe truss and extremely high strength concrete have been used. The precast members of the trusses were cured in an autoclave and attained a concrete strength of over 900 kg/cm^2. They were then assembled into space trusses using in-situ concrete and then post-tensioned.

RESUME

Le pont ferroviaire d'Akkagawa, d'une longueur hors-tout de 305 mètres et d'une longueur de travée individuelle de 45 mètres, est un pont en béton précontraint et préfabriqué où des treillis du type Howe et un béton extrêmement résistant ont été utilisés. Les éléments préfabriqués des treillis furent traités dans un four autoclave, et atteignirent une résistance de béton de plus de 900 kg/cm^2. Ils furent ensuite assemblés en treillis en utilisant du béton coulé sur place, puis mis sous précontrainte.

ZUSAMMENFASSUNG

Die 305 m lange Akkagawa Eisenbahnbrücke, eine Fachwerkbrücke nach dem Howe'schen System, besteht aus vorfabrizierten vorgespannten Bauteilen aus höchstfestem Beton. Die Einzelspannweiten betragen 45 m. Die Bauteile wurden nach Betonieren im Autoklav gehärtet, sodass ihre Betonfestigkeit 900 kg/cm^2 überstieg. Diese vorfabrizierten Bauteile wurden auf der Baustelle unter Verwendung von Ortbeton zusammengebaut und vorgespannt.