Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 10 (1976)

Artikel: Development of extremely high strength concrete railway bridges for the Japanese National Railways

Autor: Machida, Fujio

DOI: https://doi.org/10.5169/seals-10478

Development of Extremely High Strength Concrete Railway Bridges for the Japanese National Railways

Développement de béton à très haute résistance pour les ponts ferroviaires des Chemins de Fer Nationaux Japonais

Entwicklung von höchstfestem Beton für Eisenbahnbrücken der japanischen Staatsbahnen

FUJIO MACHIDA
Superintendent
Shimonoseki Construction Division, JNR
Shimonoseki-shi, Japan

1. Introduction

In JNR, longer span concrete bridges have been built to abate train noise. This is because not only concrete bridges are easy to maintain but also longer span bridges are necessary for grade separation and riparian improvement to construct Shinkansen or elevated structures of urban railways.

With the elongation of bridge span, the ratio of the dead load to the whole design load has increased. In Japan, railway lines in many cases pass on the soft ground of alluvial formation, and also the earthquake often occurs. Therefore, the reduction of the bridge weight itself has come to be one of the greatest subjects.

There are two ways of the weight reduction — the adoption of light weight concrete and the adoption of extremely high strength concrete which reduces the section of the member and makes the structure light.

In the case of the light weight concrete, there are several problems in physical characteristics or in regulation of deflection, and it was limited to comparably small spanned elevated structures. Studied was the application of the extremely high strength concrete to long span bridges.

With the water reducing agent of alomatic sulphonic compound, a concrete mix proportion test and a basic characteristic test have been executed to develop the high strength concrete suitable for the ordinary concrete placing method.

2. Physical property of extremely high strength concrete

In JNR, studies on the extremely high strength concrete with compressive strength up to 1, 000 kg/cm^2 have been made since 1970, and the three methods of producing this concrete are as follows:

(1) Water cement ratio reducing method by using water-reducing agency.

(2) Method using artificial aggregate of crinker.

(3) Auto-clave curing method.

Of the above mentioned methods, the method (1) is the most favorable one from the viewpoint of the ordinary facilities and past long experiences of work execution.

With the extremely high strength concrete produced by the method (1), it has been proved that the quality of the aggregate have much effect on the concrete strength and that the optimum ratio of fine aggregate is 30 to 40%. The physical property of hardened concrete has been examined. Furthermore, 5-meter T-section type girders have been tested to get some guidance for work execution.

(1) Studies on mix proportion of concrete

For studying the characteristic of mixed concrete, tests have been made on the following mix proportions;

a. Fine aggregate ratio; 10, 20, 30 and 40%

b. Coarse aggregate; river sand and gravel, and crushed stones

c. Unit cement volume; 500, 700 and 900 kg/m^3

d. Max. size of coarse aggregate; 10 and 20 mm

e. Admixture; with and without admixture

As a result of the tests, it is found that if the ratio of fine aggregate is under 20%, the concrete is rough, especially when unit cement volume is less than 500 kg/cu. meter. Therefore, the optimum ratio of fine aggregate is about 30 to 40% with both the river sand and gravel and the crushed stones.

(2) Compressive strength

With the unit cement volume 700 kg per cu. meter, compressive strength is about 950 - 1, 050 kg/cm^2 with admixture, and about 530 - 760 kg/cm^2 without admixture. With the quick cement the short term compressive strength of concrete is as high as 437 kg/cm^2 at the age of one day. When the ratio of fine aggregate is less than 20% and unit cement volume is 500 kg/m^3, the strength of concrete becomes lower. With the unit cement volume of 700 kg per cu. meter, the crushed stones and river sand and gravel keep high strength regardless of the ratio of fine aggregate, the maximum size of aggregate, whether 10 or 20 mm, showing the same strength.

(3) Modulus of elasticity

Modulus of elasticity of extremely high strength concrete is 3. 0-4. 0 x 10^5 kg/cm^2.

(4) Variety of concrete strength due to the difference of stone quality of aggregate

The results of compressive and bending tests show that effect of the stone quality is as much as 25% of compressive strength. It is therefore impossible to produce the extremely high strength concrete with the aggregate containing weak stones such as serpentine, weathered rock, shale, or limestone. What is necessary is to select the strong aggregate based on the results of accurate tests with stone quality.

(5) Compressive fatigue strength

Compressive fatigue test has been done using a concrete cylinder, 10 cm in diameter and 20 cm long. The upper load limitation of the compressive fatigue test was as 55, 60, 65, 70 and 80% of the static ultimate strength, while the lower load limitation was kept a certain value.

Although the results of the test showed some deviation for the certain stress ratio, the fatigue strength of extremely high-strength concrete is deemed to be about 55% of the static ultimate strength.

(6) Creep

Creep measuring test has been done with four test pieces — two of them for 100 days under the load intensity of 170 kg/cm^2 and the others for 300 days under that of 270 kg/cm^2. The creep coefficient was about 0. 8.

(7) Ultimate strain

Measured were the stress-strain curve and the shape of stress distribution near the failure point.

The strain of extremely high-strength concrete is about 3‰ at the highest stress point, and that of the ordinary concrete is about 2. 5‰. Stress distribution has shown the trapezoid distribution, intermediate between the triangular and rectangular ones.

(8) Durability against freezing and thawing

Test has been done by the method of the ASTM C 200. The comparison between the durabilities of extremely high-strength concrete σ_{28} = 900 kg/cm^2 strong and that of the ordinary concrete with no entrapped air σ_{28} = 330 kg/cm^2 strong was made to show that in case of the ordinary concrete the modulus of the vibro-elasticity became below 50% at 75 cycles and in case of the extremely high-strength concrete, even with no entrained air, the concrete barely weathered at as much as 450 cycles. The extremely high-strength concrete is superior to the ordinary one with comparatively low strength in the durability against freezing and thawing.

3. Concrete placing test

The extremely high-strength concrete was applied firstly to the Ayaragigawa Bridge on the San-yo Shinkansen. Prior to the construction of the bridge, concrete placing test was done to check the workability at the work site.

Concrete mix-proportion was determined to be the design standard strength σ_{ck} = 600 kg/cm^2, with the slump as 8 ± 2 cm, water cement ratio as 31%, sand aggregate ratio 34%, unit cement volume 484 kg per cu. meter, and water reducing agent NL 1400, 0. 9% of the unit cement volume.

The test has been done four times in all with the 5-meter long beams, whose section is the same as that of the Ayaragigawa Bridge and sheath is bent up as the beam end.

The results show that if slump become less than 8 cm, the mobility of concrete turns to be poor, poor consolidation appearing along the upper side of sheaths. When slump becomes more than 16 cm, the segregation of the aggregate happens. Therefore, as a counter-measure, the variation of the surface water of fine aggregate has been kept small, and the placement of frame vibrators reviewed. The diameter of the vibrator was made 35 mm, and the distance between the frame and reinforcement 40 mm, so as to make it easy to insert the rod vibrator. And also the mix-proportion of concrete has been adjusted as follows: slump is as 12 ± 2.5 cm, water cement ratio as 30%, sand aggregation ratio as 40%, unit cement content as 484 kg per cu. meter, water reducing agent as 0.75% of the unit cement weight.

After curing the beams, the compressive strength of concrete of each part of them was estimated by both ultra-sonic nonfailure method and core specimen by boring.

Test results have shown that the compressive strength of 28-day-age is valued as maximum 780 kg/cm^2, minimum 635 kg/cm^2, and mean 753 kg/cm^2, respectively.

4. Application of extremely-high-strength concrete

1) T-section type girder

The extremely-high-strength concrete was firstly applied in Ayaragigawa Bridge constructed, in winter, secondly Kagetsu Bridge in summer, both on the San-yo Shinkansen.

Explain in detail below is the construction of Ayaragigawa Bridge.

Ayaragi River crosses the San-yo Shinkansen in 45 degrees in Shin-Shimonoseki Station.

As the piers were not allowed to stand inside the river, and the crossing angle of the railway with the river was limited to 60 degrees, the span was 49 meters long with the total length of bridge 50 meters. The bridge consists of single track 4T-section girders and double-track 8 T-section girders, totaling 12 girders.

By the use of extremely-high-strength concrete of σ_{ck} = 600 kg/cm^2, it enabled to lower the girder depth, and to reduce the weight of the main girder to less than 150 tons, which was the limit in crane handling. As a result, erection work was easily carried on and completed on schedule.

The girder depth is one 18th of span length, which is strictly specified by the design standards of Shinkansen structures.

(1) The main girders were manufactured in manufacturing yard near the work site.

(2) Concrete plant about 1 km apart from the work site was used.

(3) Concrete placing method

a. Received mixed concrete in bucket from mixing car at the work site, then the bucket was carried to the placing site by gantry crane of 2.5-ton capacity.

b. Two buckets of concrete were placed from bottom of girder to the top of web as lower portion and then placed upper flange as upper portion. Upper portion was placed 30 to 60 minutes after lower portion was placed.

Concrete volume was 41 cu. meters for the lower portion and 17 cu. meters for the upper, totaling 58 cu. meters. Concrete placing was finished in about 5 - 6 hours, so the rate of placement was 10 cu. meters per hour.

c. Change of slump was comperably small because the transportation time was as short as 5 to 20 minutes. When concrete arrived much quicker than usual, the slump at the work site was sometimes a little larger than the slump at the plant.

d. Consolidation

8 bar vibrators (diameter 35 mm, 12, 000 rpm) and 12 frame vibrators (1/4 HP, 345 rpm) were set zigzag at 3-meter intervals, 60 cm high and 140 cm high respectively from the bottom. Especially at the bent up part of sheaths, consolidation work were executed by injecting the bar vibrators between the frames and the reinforcement.

(4) Curing

As it was winter, all beams were covered by sheet to keep the temperature inside between 10 and 15°C. The maximum temperature showed 50°C in 15 hours after concrete placing. The temperature difference between the atmosphere and inside the sheet was 40°. The upper face of beam flange was covered curing mats.

(5) Compressive strength

Concrete cylinders each 10 cm in diameter and 20 cm long, were used as concrete specimen for compressive strength test. The compressive strength at the age of 28 days by standard curing was 659 kg/cm^2, where the number of specimen were 39, and standard variation 25. 9 kg/cm^2, that is to say, coefficient of variation 3. 9%, and entrapped air 0. 8% at mean value.

(6) Erection

After beams were moved side-ways, they were transported to the erection site by truck, and then hanged and erected by two cranes of 127-ton capacity.

2) Prestressed concrete through truss bridge

A concrete through truss bridge was built crossing over the prefectural road to construct a line to the Rolling-stock Base from Hiroshima Station.

The bridge being in the urban area near the Station, there was strong need to reduce train noise. The through type had to be adopted because of road clearance below the bridge. From these reasons, it was quite advantageous to adopt the through truss.

(a) Experimental studies

(1) For the study of panel point portion, fatigue strength test, photo elastic test and concrete placing test were executed.

(2) Static load bearing test was conducted on the model truss, whose scale was about one third of truss bridge and composed of three panels, 8. 1

meters of span length, to confirm ultimate strength of truss structure.

(b) Design of the Iwahana through truss bridge

(1) General structure

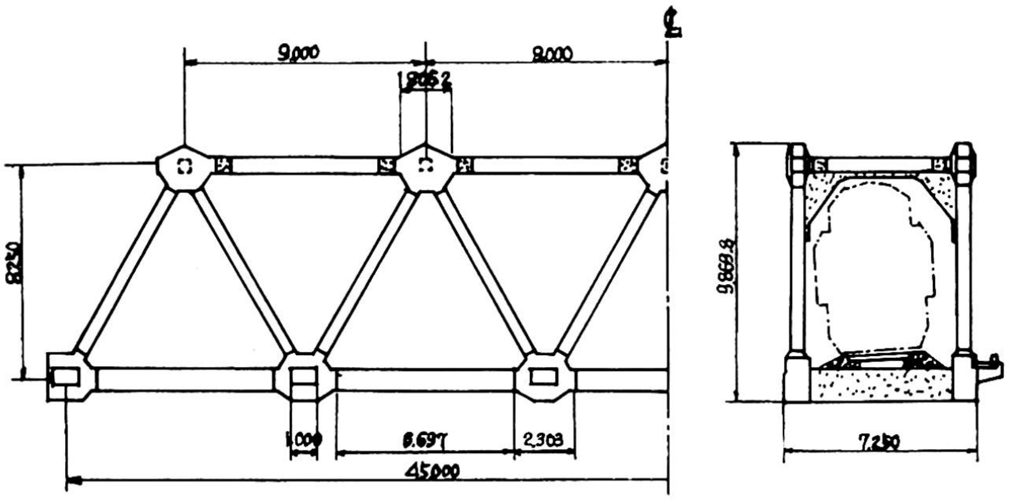
i) From many types of truss, Waren truss type was adopted because the number of the chords is small.

ii) Floor structure

The composite structure embodying slab and lower chord is effective for earthquake proof and reduction of concrete volume. However, the structural analysis is complex and concrete volume placed at work site becomes large. Therefore, non composite structure, whose stress distribution is easy to estimate, was adopted. Floor slab of hollow type was manufactured at concrete plant with the concrete of design standard strength 500 kg/cm^2.

iii) Partition of member of the truss

Precast members were divided as follows:
panel points, upper and lower chords, diagonals, cross beam, upper cross beam for each panel. Although the concrete joint was adopted at upper chord for the purpose of absorbing the errors in manufacturing and construction work, resin joint was generally used at other parts.



Profile

Concrete placed at the site

Fig. Iwahana PC Truss Bridge

(c) Manufacturing of members

The precast members were manufactured at the Okayama concrete plant of OKK corporation about 160 kilometers away from the work site.

To manufacture members such as lower chords, diagonals and chords, plane truss dimension at real scale was made at first. Then the frame were built up between block panel points, and then high strength concrete was placed. Thus it was possible to make good connection at each end face of the precast member. The upper chords and the cross beams were separately manufactured because of concrete joint.

(d) Erection

Erecting work was executed with the scaffolding at the work site as follows:

(1) Lower chords and lower panel points were connected in all length of span.

(2) Connecting middle cross beams.

(3) End cross beams were concrete-placed at work site.

(4) Laying of slabs.

(5) The diagonals of each panel were fablicated temporarily on the ground using hanging apparatus.

(6) Temporary diagonals fablicated in (5) were placed on the scaffolding and set.

(7) The upper panel points were set and the cables of the diagonal chords were tensioned.

(8) Upper cross beams and upper chords were set at the due place using hanging apparatus.

(9) Concrete for joints of the upper cross beams and upper chord members were placed.

5. Observation

The span length of concrete railway bridge will be come longer along with the development of high-strength concrete to solve the environmental problems of such projects as riparion improvement, highway widening and grade separation.

In addition, there are strong needs to shorten the construction periods and to abate the noise during construction, and the precast method proves in bridge construction.

The extremely-high-strength concrete is quite effective to reduce dead weight of concrete bridge of long span.

For instance, in the case of 60-meter span length, the dead load can be reduced by 14% by using $\sigma_{ck} = 600\ kg/cm^2$ concrete and about 29% by using $\sigma_{ck} = 800\ kg/cm^2$.

In the case of the continuous bridge by precast concrete block method with the center span of 100 meters and each side span of 60 meters with standard design strength σ_{ck} = 400 kg/cm^2, concrete volume is estimated at 4,000 cu meters, and pier reaction about 4,000 tons, and with the standard design strength σ_{ck} = 800 kg/cm^2, concrete volume is estimated at 3,400 cu meters, and pier reaction 3,000 tons.

Hence, it can be said that prestressed concrete truss is much economical.

Necessary for further development of prestressed concrete bridge are not only the enlargement of span length but also the development of panel and slab structures, taking into considering erection methods. Necessary for further development of prestressed concrete bridges.

In JNR, prestressed concrete through truss with the span length of 72 m, now planned for track additioning of the Nippo Line in Kyushu and also deck truss with the 45-m long span in the construction work for the Tohoku Shinkansen.

SUMMARY

On the Japanese National Railways, longer concrete bridges are increasingly used to reduce train noise. Studies on ultra high-strength concrete, especially that using aromatic sulpho compounds water reducing agent, have been made. Mix proportion tests and tests for basic characteristics of concrete have also been carried out. PC T-section girders were used in the construction of the Ayaragigawa Bridge, and PC through trusses on the Iwahana Bridge.

RESUME

Récemment, aux Chemins de Fer Nationaux du Japon, on a adopté des poutres en béton de plus en plus longues dans le but de réduire le bruit des trains. Des études sur le béton précontraint à très haute résistance ont été effectuées en utilisant un agent aromatique sulfuré réduisant l'eau à utiliser. Les expériences ont été réalisées avec des mélanges de proportions différentes afin d'étudier les caractéristiques fondamentales de ce béton. Des applications ont été faites, sur le Pont Ayaragi avec des poutres en béton précontraint de sections en T, et sur le Pont Iwahana.

ZUSAMMENFASSUNG

Seit kurzem werden von den Japanischen Staatsbahnen immer häufiger lange Brücken gebaut, um den Lärm der fahrenden Züge zu vermindern. Um diesen Forderungen nachzukommen, werden jetzt bei den JNR Versuche mit höchstfestem Beton insbesondere unter Zusatz von aromatischen, Anmachwasser sparenden Lösungsmitteln durchgeführt. In den Versuchen wurden die Eigenschaften verschiedenartig zusammengesetzten Betons geprüft. Höchstfeste Betone fanden Anwendung im Brückenbau bei den Brücken über den Fluss Aiyaragi und über den Iwahana.