8th ICAAR 1989 KYOTO
8th Internationl Conference
on Alkali-Aggregate Reaction

ALKALI AGGREGATE REACTION IN RAILWAY PRESTRESSED CONCRETE BRIDGES

Hisayoshi Ichihara , Makoto Shimamura and Itsuki Koshiishi

Structure Maintenance Section, EAST JAPAN RAILWAY COMPANY,
1-6-5, Marunouchi, Chiyoda-ku, Tokyo 100, Japan

ABSTRACT

A ten-year-old viaduct on the Joetsu Shinkansen in Niigata, Central Japan, has shown unusual cambering due to alkali-aggregate reaction. The aggregates found in the concrete are clay slate, chert and andesite of local river gravel, and contain 36% of alkali-reactive minerals. The white deposit forming the rims within the aggregate periphery and mortar surface contains approximately 70% of SiO_2. Map-cracking is not a uniform feature in the cambered prestressed concrete girders.

1. INTORODUCTION

The Kamiyamada-Yanagisaku site on the Joetsu Shinkansen in Niigata, Central Japan, consists of an 800m long viaduct with 19 sections of pre-stressed concrete girders. The viaduct was constructed in 1978/79 by the Strabag method, and regular operation over it began in 1982.

After inauguration of service, notable camber was observed on the viaduct girders. At first, the distortion was assumed to be caused by creeping of concrete, but proved to be due to expansive alkali-aggregate reaction thereafter. This paper reports on the investigations of these prestressed concrete girders in relation to alkali-aggregate reaction.

2. OUTLINES OF CONSTRUCTION

(1) Dimensions of the girders (Fig-1)

(2) Concrete mix

Cement: High-early-strength portland cement
Water cement ratio: 36%
Unit weight of cement: 447kg/m³
Design criterion strength σ_{ck}: 400kgf/cm²

(3) Prestressing steel

Strand constitution: 19T12.4
Number of strands: 22/girder
Tensile strength σ_{pu}: 175kgf/mm²
Fastening method: VSL method (wedge fastening)

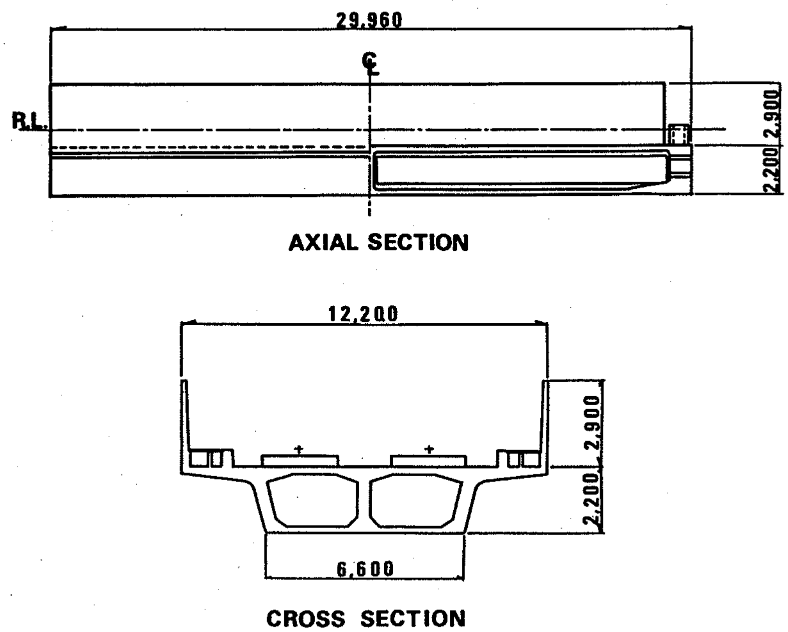

Fig-1 Dimensions of the girders

(4) Support:Rubber block bearing with stainless steel plates 1000*900*56mm

(5) Support anchor: Steel bar ϕ 120mm*1100mm

(6) Construction period: Mar.1978 to Mar.1979
approximately 19 days per girder

(7) Track: Concrete slab track

(8) Environment: Because of snow-melting sprinklers installed, the girder surface is exposed to circulating water in winter.

3.OBSERVATION OF ANOMALISTIC PHENOMENA

Vertical track irregularity due to the distortion of the girders has been recorded on periodical inspection since about 5 years after construction. At the same time, apparent cracks have grown on the inner wall of the girder boxes. The run of these cracks is track-axial on the roof walls and along the prestressing strands on the side walls of the support portions. The cracks are developing with time, and the maximum width of which is approximately 0.5mm.(Fig-2)

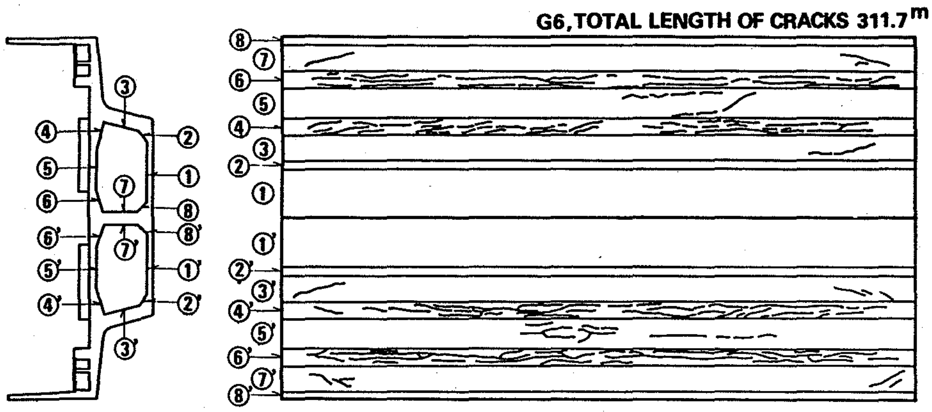

Fig-2 Crack illustration of the inner wall of the girder box

Fig-3 shows the amount of the camber, calculated as the difference between the highest point on the top surface of the girder and the average height at the points directly above the girder supports. The camber has increased at approximately 3.5mm/year up to the present without any sign of ceasing.

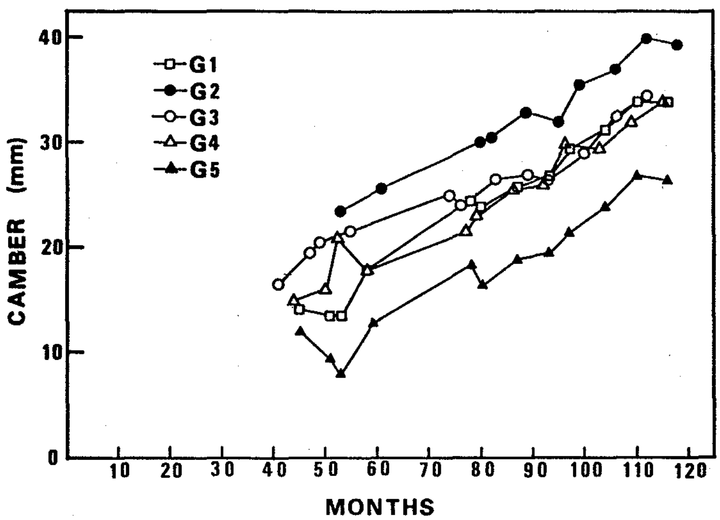

Fig-3 Periodical development of the camber

4.EXPERIMENTS

At first, the cambering of the prestressed concrete girders was assumed to be caused by creeping of concrete. However, judging from the phenomena observed thereafter: map cracking on the viaduct columns of material of possibly similar origin, and unusual continuation of distortion, it was supposed that the cambering of the girders also relates to AAR. Concrete cores were drilled from the girders in Mar.1985 and Oct.1988 and examined as follows:

(1) Outside view of the cores

A transparent-white deposit was found to have formed on the rims within the aggregate periphery and on the mortar surface. The maximum crack depth in the cores reached as much as 7cm.

(2) Polarized microscopy and chemical analysis(ASTM-C289)

The coarse aggregate used in the concrete are clay slate, chert and andesite of local river gravel, which were shown to be harmful to concrete by an ASTM-C289 test, and contain 36% of alkali reactive minerals.
The fine aggregates are composed of particles originated from diorite, schist, sandstone, clay slate, and mineral fragments such as feldspar and quartz. They also contain 17% of alkali reactive minerals.

Table-1 Content of alkali reactive minerals in the aggregate by polarized microscopic observation (%)

	Glass	Quartz	Mica	Total
Coarse aggregate	6	27	3	36
Fine aggregate	1	11	5	17

(3) Scanning electron microscopy and X-ray analysis

The estimated SiO_2 content of the white deposit within the aggregate periphery ranged between 60 and 77%. Chert in the aggregate showed reactivity. (Fig-4,5)

	wt.(%)
Na_2O	10.68
Al_2O_3	1.95
SiO_2	77.71
K_2O	6.87
CaO	2.80

×300
Fig-4 Deposit on the coarse aggregate

	wt.(%)
Na_2O	7.32
Al_2O_3	1.73
SiO_2	60.10
K_2O	7.25
CaO	23.60

×500
Fig-5 Deposit in the mortar

(4) Alkali content measurement

Alkali content in the cement is 1.02% for the equivalent Na_2O: considerably higher than that of general portland cement.

Table-2 Alkali content of the cores

Content in concrete (%)		Content in cement (%)		
Na_2O	K_2O	Na_2O	K_2O	Equivalent Na_2O
0.11	0.12	0.59	0.65	1.02

(5) Characteristics of the concrete

The results of examinations for compression strength, elasticity, unit weight, and propagation velocity of supersonic waves are given in Table-3. Modulus of elasticity and compression strength of the examined samples are 40～60 and 60 ～90% of the criteria, respectively. Propagation velocity of supersonic waves is a little less than 4km/sec. Neutralized concrete reaches a depth of 4mm to 11mm from the surface.

Table-3 Characteristics of the concrete

No. of the core	No.1	No.2	No.3
Compression strength (kgf/cm^2)	251	354	330
Unit weight (g/cm^3)	2.27	2.22	2.28
Static modulus of elasticity ($\times 10^4 kgf/cm^2$)	17.3	14.6	17.8
Dynamic modulus of elasticity ($\times 10^4 kgf/cm^2$)	27.2	24.8	26.9
Propagation velocity of supersonic waves (km/s)	4.25	3.84	3.93

Notes / Sampling portions No.1:Lower slab, No.2,3:Mid-wall

(6) Expansion measurement

Fig-6 shows the results of the expansion test in which newly drilled cores are exposed in the air under temperature 20℃, relative humidity 100% for the first 3 months, and then 40℃, R.H.100%. Expansion strain of the cores drilled in Mar.1985 is 0.07 ～0.09% at the end of the first 3 months, and the final strain of the 18 months is 0.17 ～0.26%. The cores drilled in Oct.1988, which are now under examination, show rather greater strain: 0.06～0.14% for the first 3 months(20℃,R.H.100%).

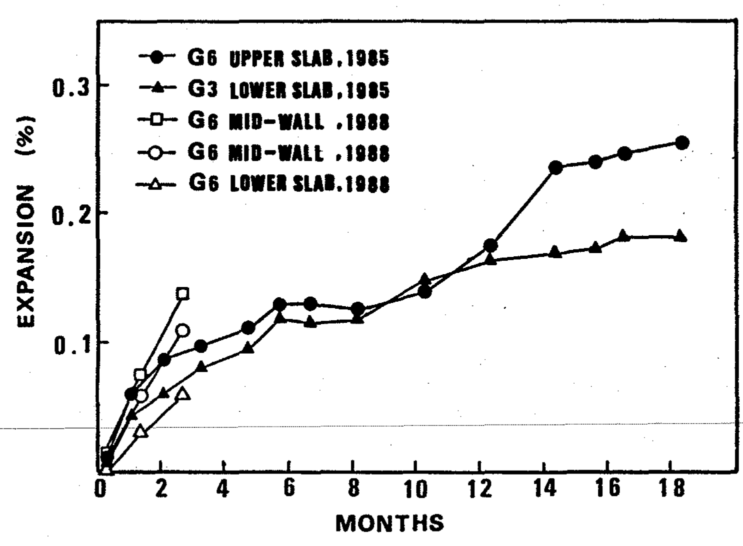

Fig-6 Expansion measurement

5. DISCUSSION

The observed anomalistic phenomena on the girders and the results of the above experiments suggest the following:

(1) The cambering of the girders has been generated by expansive alkali aggregate reaction. This phenomenon is derived mainly from the differential expansion of the upper slab where AAR tends to occur severer than the lower parts because of the abundant water supply and the smaller restraint of the reinforcing steel, and partly from the increase of the tensile stress that acts upon the steel strands due to a whole sectional expansion of the girders.

(2) The strain of the upper slab concrete of the girders at present, which is estimated upon a hypothesis that the total camber is due to the differential expansion of the girder above mentiond : ε=0.02 ~0.04% is smaller than the final expansion strain of the cores : ε=0.17 ~0.26% experimentally measured, so that the cambering will continue hereafter.

(3) AAR tends to cause linear cracking, instead of map cracking, because of the restraint due to prestressing against axial expansion.

6. COUNTERMEASURES

Epoxy injection into the cracks, water repellent treatment with silane on the outside and water-tight cement coating have been carried out for the purpose of AAR suppression.

In order to compensate for the track irregularity on the girders within the permissible limit for the Shinkansen: 7mm/10m, rail fastenings were replaced with special devices which can be adjusted up to 70mm.

7. FINAL COMMENTS

New information has been obtained from in situ and experimental records from Kamiyamada-Yanagisaku viaduct concerning the properties of AAR under prestressing, about which there is little available literatuer.

The measurement of the structure will be continued hereafter in order to ascertain the effects of the countermeasures.

8. ACKNOWLEGEMENTS

This work was supported by Dr.Hidenobu Tatematu and Mr.Jun Takata of Railway Technical Research Institute, and Dr.Tadayoshi Ishibashi of East Japan Railway Company. The authors would like to thank them for the support. The assistance of the members of the Structure Inspection Center in Niigata of East Japan Railway Company is also appreciated.