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INVESTIGATIONS ON CONCRETE RAILWAY TIES SUFFERING FROM ALKALI-SILICA REACTION

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ABSTRACT

This paper investigated the railway ties affected by alkali-silica reaction in Shanghai and Zhengjiang railway stations. All these ties were produced by a plant in Beijing. The results showed that about 30% ties produced in 1980~1981 are damaged when used in the stations, while 61~85% ties manufactured in 1985-1987 were cracked now. It was found that load and wet and dry recycles could enhance the ASR cracking processes. Although compressive strength of concrete cubes cut from severely cracked tires are reduced 25%, static crack load of ties met the standard of class II.

Introduction

During the 1950's and 60's, many ASR damaged structures were hydro-structures such as dams. In recent years, however, concrete structures of other types such as pavements, bridge decks, beams and railroad ties have suffered from ASR damage. In Canada, America and South Africa, there are many deteriorated concrete sleepers due to ASR attack (1). In China, it was also found that railroad ties had severely cracked due to ASR (2). In previous investigations, we found that some concrete ties laid between Nanjing and Shanghai were damaged mainly due to alkali-silica reaction through detailed microstructural researches (3). More detailed field inspections, and the mechanical behavior of the affected ties was reported in this study.

Technological Parameters of Concrete Ties

Two types of concrete ties, No. 76 and 82 were used in Shanghai railway station and only No. 76 was placed in Zhengjiang station. Both types were of prestressed concrete and of size 2500 × 450 × 155 mm, and were reinforced in three dimensions. At distance of 40 and 105

TABLE 1

Concrete Mixture and Designed Strength of the Ties

Type No.	Cement (Kg/m^3)	Alkali content (Kg/m^3)	Sand (Kg/m^3)	Coarse aggregate (Kg/m^3)	Water (Kg/m^3)	Designed Strength (MPa)
76	480	5.4-6.6	672	1296	144	48
82	495	5.6-6.8	940	1271	145	58

mm from the bottom, there were two rows of prestressed steel bars arranged longitudinally and six groups of hoops. There were three hoops more in No. 82 than in No. 76. The coarse aggregates were crushed pebbles of size 5~20 mm from Beijing. The fine aggregate was derived from rivers at Huailai in Hebei province. The alkali reactivity of the aggregates were evaluated by autoclave microbar method (4) and was reported in another document (3). It was found that the coarse aggregates were alkali-silica reactive while the find one was innocent. High alkali ordinary Portland cement used was used with alkali, MgO and SO_3 contents 1.0~1.2% Na_2O equivalent, 3.1~3.7% and 2.95~3.10% respectively. 0.5~0.7% (by weight of cement) of a water reducing admixture containing 25% of sodium sulfate was added in concrete. Concrete mixture and designed strength of the ties are listed in Table 1. The ties were cured in about 80°C stream for about 10 hours.

Field Inspection

A survey was made in August 1988 on 13200 concrete ties placed in Shanghai railroad station. No. 82 and No. 76 ties were used. After 13~27 months in service, 4623 ties showed longitudinal cracks between the rail seats and map cracks at both ends with varying degrees of damage as shown in Fig. 1. In 1995, the number of damaged ties had increased to 9387 and the cracks were increased considerably wider. The extent of damage varied from different lines and locations. In Shanghai, there were three lines in which 85% ties were severely damaged showing map cracking in the middle (FIG. 2) while in Zhengjiang station, a small station near Nanjing, only 30% of the ties (No. 76) showed noticeable cracking.

In the 1988 survey, a few cracked ties placed beneath the station roof were found, and in 1995, the number of the ties was still low. By comparison, ties outside the roof were severely

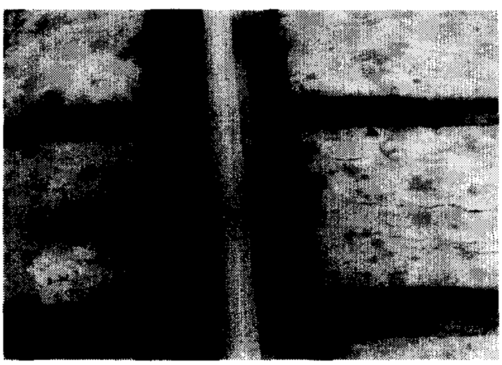

FIG. 1.
Longitudinal cracks between the rail seats with map cracks in the both ends.

FIG. 2.
Map cracks between the rail seats in severely cracked ties.

cracked. It was obvious that the damage degree of the ties increased with their service age. It was noted that the tie end near the roof showed some line cracks as shown in Fig. 3, while the outer ends beyond the roof were seriously cracked. The damage for the ties exposed to the sunshine and rain was most noticeable (Fig. 2). In the south part of China the air is quite humid with high groundwater levels, evaporation of water on the upper surface due to the sunshine would force alkali enrichment on the upper layer of ties (6) which may lead to ASR in the ties placed in open air. Therefore, it seems that wet and dry cycles may have accelerate the crack development in the ties. The temperature could be another unfavorable factor.

Most of the unused ties heaped beside tracks (were not shielded from the weather) were not cracked after 7 years but were clearly sound (Fig. 5). However, after they were used in the lines, ASR cracks sometime appeared within 1~2 years. It seems that dynamic load may have been a significant factor in causing the formation and growth of cracks.

For ties that cracks appeared on the upper surface, longitudinal cracks could also usually be observed on the underside of these ties as shown in Fig. 6. The cracks were sometimes to 2 cm deep. Chemical analysis showed the white substance around reactive aggregates was

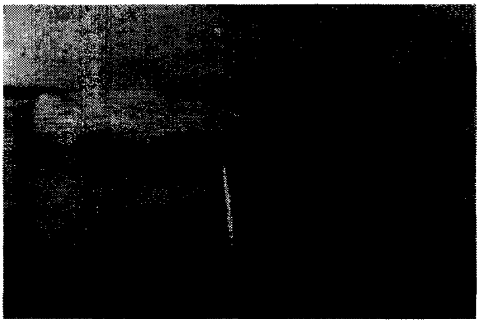

FIG. 3.
Cracks on the ends of a tie near the platform roof.

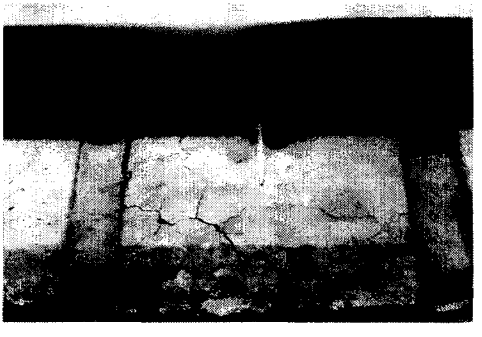

FIG. 4.
Cracks on the ends of a tie far away from the platform roof.

FIG. 5.
Most unused ties heaped up beside tracks did not crack after 7 years.

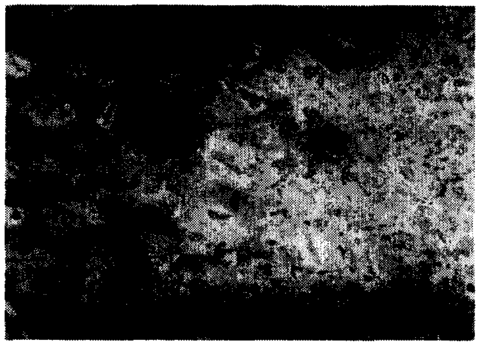

FIG. 6.
Longitudinal cracks on the underside of a tie and white rims around some reactive aggregates.

$CaCO_3$. For severely cracked ties, map cracks may be shown on the underside and bedding cracks on the side walls of the ties as shown in Fig. 7.

After 7~8 years in service under similar circumstance, more Type 76 ties than Type 82 had cracked (Table 2) in spite of more 0.2% Kg/m^3 alkalis containing in type 82 ties. This meant that higher concrete strength and confinement (more hoops used) can to some extent prevent from ASR cracking.

As mentioned previously (3), we found considerable amount of reactive aggregates in severely cracked concrete. The main reactive part was chalcedony and microcrystalline quartz as shown in Fig. 8. In the interface of cement and reactive aggregate particles, large amount of silica gel was observed. Figure 9 shows a typical EDAX result of silica gel found in cracked concrete. However, no abnormal amount of ettringite was found in cement paste. Therefore, the observed cracks in ties was most likely due to alkali-silica reaction rather than delay ettringite formation attack.

Mechanical Behaviors of Concrete Ties

Ties placed in Zhengjiang railway station were selected in the study according to their surface appearance. Ties were grouped into three levels of damage: uncracked, cracked

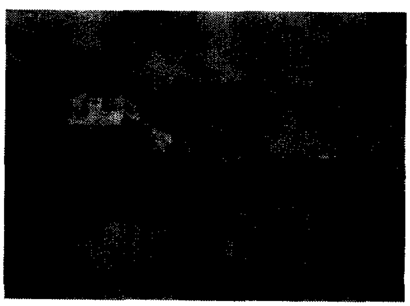

FIG. 7.
Bedding cracks in severely cracked ties.

TABLE 2
Number of the Cracked Ties

Type	Number of ties placed	Number of cracked ties	Percentage
76	6397	4508	70.5
82	4478	2770	61.9

(longitudinal cracks between the rail seats with map cracks in the both ends) and severely cracked (0.5~1 mm wide longitudinal cracks as well as some map cracks). 3~4 concrete ties for each damaging level were collected for the test.

Crack tests were carried out according to Chinese standard TB 1879-87 "Crazing-resistance test method of static load for prestressed concrete ties". The tests were grouped into two parts: static load on the location where the rail is laid (back section crack test); (Fig. 10) and in the middle part of the ties (middle section crack test) (Fig. 11). The expansion of the ties was estimated by measuring the width of cracks. The results of the test are listed in Table 3.

According to the standard, if the tie cracks under a load on the back section +M of a tie are beyond 215 KN or 180 KN, it can be categorized into class I or II respectively. The corresponding values for the middle section are $\geq$ 180 KN or $\geq$ 160 KN for the class I or II. The results (Table 3) show that the average crack loads for three levels of damage meet the requirement of class I. However, two ties cracked at loads of only 200 KN in the back section test. These two ties had to be categorized as class II.

In addition non-destructive tests: ultrasonic and resilience method were performed and compressive strengths of 8 × 8 × 8 cm concrete cubes cut from the ties were also measured (Table 4). Because of ASR cracks, the velocity of ultrasonic conduction was reduced to about 1 Km/s and the resilience changed a little. The fact that ultrasonic velocity of cracked concrete was slightly higher than that of the un-cracked may be due to other influencing factors. Another possible reason is that alkali-silica reaction causes surface cracks which do not greatly affect the strength of reinforced concrete, especially in its early stage. However, if the concrete is heavily cracked, the strength or ultrasonic velocity may reduce a lot. The

FIG. 8.
The texture of a reactive aggregate particle (thin section, crossed polarized light).

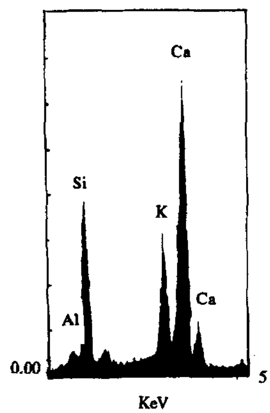

FIG. 9.
EDAX result of the typical silica gel.

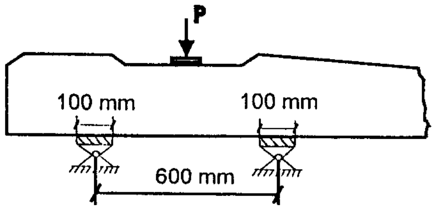

FIG. 10.
Back section crack test (static load on the location where the rail is laid).

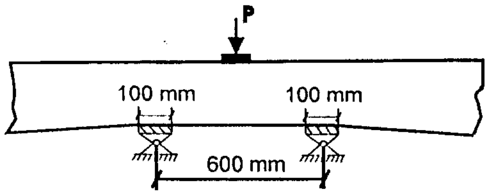

FIG. 11.
Middle section crack test (static load on the middle of the back surface).

equivalent strength or a 15 × 15 × 15 cm cube deduced from that of 8 × 8 × 8 cube was about 36 MPa. It is about 25% under the design strength. The decrease in flexural strength may be greater (7). In this case, the expansion of the ties was about 1.6%. Because of the three dimensional reinforcement by the steel, the static load of the ties changed a little and still met the criteria of the class I. However, the crackive load of one tie in both the cracked and the severely cracked group was only 2/3 of the design strength. According to the manual for repair of railway lines, if the width of circular and longitude cracks is beyond 0.5 mm and the length of the latter reaches 1.25 m, the tie should be rehabilitated. Besides, vertical cracks alone fasten bolts may significant influence the fixing of tracks. Inspection in Shanghai railway station showed such cracks occurred in 2.4% of the total ties. Rehabilitation is needed. Therefore, deleterious ASR had significantly reduced the service life of the ties.

Conclusions

After inspection of the concrete railway ties affected by ASR, it was found about 30% ties produced in 1980~1981 were damaged, while 61~85% ties manufactured in 1985-1987 were cracked now. It was also found that loading and wet and dry cycles could enhance the ASR cracking processes. Although compressive strength of concrete cubes cut from severely

TABLE 3
The Result of the Statistic Load Crack Test

Degree of Damage			Uncracked	Cracked	Severely cracked	Maximum	Minimum
Estimated Expansion (%)			0	0.51	1.61		
Middle Section -M (FIG. 11)	Deflection (mm)		4.24	4.40	4.46	6.01	3.98
	Crack occurrence	Deflection (mm)	2.29	2.00	1.70	2.57	1.64
		Load (KN)	235	240	230	240	200
	Deformation	Width of cracks (mm)	3.0	2.3	2.5		
		Load (KN)	360	372	356	408	335
Back Section +M (FIG.10)	Deflection (mm)		6.18	6.37	6.54		
	Crack occurrence	Deflection (mm)	4.52	4.28	4.30	7.78	2.56
		Load (KN)	240	250	233	300	200
	Deformation	Width of cracks (mm)	1.9	2.1	1.3		
		Load (KN)	436	451	404	464	395

TABLE 4
Test Results of the Concrete Ties

Degree of damage	Compressive strength (8x8x8 cm) MPa	Ultrasonic test		Resilience			Depth of carbonation (mm)
		Velocity (Km/s)	Deviation (Km/s)	Average	Minimum	Derivation	
Un-cracked	----	4.83	0.027	57.1	55.5	0.76	0.5
cracked	39.8	5.12	0.080	56.3	55.3	0.86	1.0
severely cracked	----	3.99	0.99	53.1	51.6	1.46	1.0

cracked tires reduced to 25%, static crack load of ties met the standard of class II. However, it is suggested that it should be replaced for the severely cracked ties.

References

1. Tang Mingshu, Concrete and Cement Products (in Chinese) pp. 4-6, (1992).
2. Tang Mingshu, Porc. 9th Int. Conf. on Alkali-Aggregate Reaction in Concrete, London, vol. 1, pp. 654-657, (1992)
3. Jin Qinhua, Deng Min and Han Sufeng, Investigation of Deteriorated Concrete Railway Ties, (1996) (to be published in Cement and Concrete Research).
4. CECS 48-93, Registered in France in AFNOR P 18-588. Rapid Test Method for Determining the Alkali Reactivity of Sands and Rocks, China Engineering Construction Standardization Socity, Beijing, (1993).
5. Hobbs, D. W., Alkali-Silica Reaction, Thomas Telfurd, London, pp. 155-176, (1988)
6. Xu Zhongzi and Hooton, R. D., Cement and Concrete Research, Vol. 33 pp. 951-961 (1993).
7. Rigden, S. R. et al, Magazine of Concrete Research, Vol. 47, No. 170, Mar., pp. 11-12, (1995).