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INVESTIGATION OF DETERIORATED CONCRETE RAILWAY TIES

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ABSTRACT

Some prestressed concrete ties placed on railway from Nanjing to Shanghai show map and longitudinal cracking. Up date to 1995, cracking happened in 9082 ties out of 20945 on 11.9 km railway in Shanghai and more than 85% ties were damaged at Shanghai railway station. Analyses on the affected concrete ties indicate that periclase and ettringite are not involved in the expansion of concrete. The coarse aggregates were alkali-silica reactive and were attacked by alkalis. Alkali-silica reaction is a primary cause for deterioration of the railway ties.

Introduction

Concrete ties on railway from Nanjing to Shanghai are showing longitudinal cracks between the rail seats and map cracks in the ends beyond the rail seat. They are precast prestressed concrete products and laboratory specimens are available. This paper describes field survey and examination of on-line concrete ties as well as laboratory record of specimen same as ties.

Field Survey

A survey was carried out in August, 1988 on 13200 ties placed at Shanghai railway station. 3623 ties were showing serious longitudinal cracks between the rail seats and severe map cracks in the ends beyond the rail seat. Information on cracked ties is shown in Table 1. It is obvious the number of deteriorated ties and their crack width increased with increase of age. Majority of 3 years-old ties, produced in 1985, suffered to some extent cracking, while less than 2 years-old ones were damaged in a small proportion. Another survey conducted in 1995 on the ties at Shanghai railway station and nearby shows that 9802 ties were cracked out of 20945 ties. On three lines at Shanghai station, 85% ties cracked and most of them show severe longitudinal as well as random cracking, as illustrated in Fig. 1 and Fig. 2.

TABLE 1
Quantity and Crack Width of Cracked Ties

Time of production	Number of Surveyed ties	Number of cracked ties		
		<0.3 mm width	0.3-1.0mm width	1.0-1.5mm width
1985	6160	2070	893	244
1986	1760	203	2	0
1987	5280	201	10	0

The railway ties used at Zhengjiang were also deteriorated. Cracked ties are about 30%. They were manufactured in 1980-1981 and in the same type and plant as ties placed in Shanghai.

The ties are reinforced in three dimensions. According to the experience of Great Britain[1], these ties belong to moderately deteriorated if being under general environment. However, railway ties always suffer motive load and impact will accelerate spreading of cracks. Consequently, some ties lost efficacy.

To evaluate expansion, crack width of ties was measured in 5 directions perpendicular to main reinforcement. Calculated expansion from crack width is listed in Table 2. The expansion of tie at two sites is both far larger than limit tensile strain. As a result, the ties were seriously cracked. Table 2 indicates that developing rate of expansion of ties in Shanghai is much higher that of ties in Zhengjiang.

Background Information

The ties were prestressed concrete in 2500 mm long, 450 mm width and 155 mm thickness. Two rows of prestressed reinforcing steel bars were arranged longitudinally at 40mm and 105 mm away from bottom and hooped with 6 groups of steel bars. The thickness of upper unreinforced concrete was in 45-55 mm. They had been made with ordinary Portland cement from Datong, Shanxi province. Alkali, MgO and SO3 contents of the cement were 1.0-1.2% Na2Oequiv., 3.1-3.7% and 2.95-3.10%, respectively. The fine aggregate was derived from rivers at Huailai, Beijing. The coarse aggregates were crushed pebbles in 5-20 mm from Southwest suburb of Beijing. To obtain a good workability, 0.5-0.7% (by weight of cement)

FIG. 1.
Longitudinal cracks of a railway tie.

FIG. 2.
Map cracks of a railway tie.

TABLE 2
Expansion and its Rate of Concrete Ties

Derived site of ties	Shanghai		Zhengjiang	
	Tie 1	Tie 2	Tie 1	Tie 2
Expansion (%)	1.91	2.22	1.40	1.61
Rate of expansion (%/year)	0.239	0.278	0.100	0.115

of a water reducing admixture was added. The admixture was a sodium salt of sulfonated naphthalene-formaldehyde condensate with about 25% of sodium sulfate. Contents of cement, sand, rock and water in 1 m3 concrete were 480 kg, 672 kg, 1296 kg and 144kg, respectively. Ties were cured in about 80°Ê steam for about 10 hours.

Examination of Concrete Cores from Railway Ties

The concrete railway ties were collected and submitted to differential thermal analysis, SEM/EDAX analysis, visual and petrographic examination, evaluation of alkali-reactivity of aggregates and measurement of residual expandability.

Differential Thermal Analysis. Ties were broken and the coarse aggregates were carefully picked up. The residual materials were ground and sieveed. The under-sieve materials, representative of cement pastes, were then analyzed by a differential thermal device. Result is shown in Fig. 3. Mg(OH)2 and ettringite were not detected. This indicates that they were, if existing, in a very small amount. Deterioration of ties may not be attributed to formation of Mg(OH)2 or ettringite.

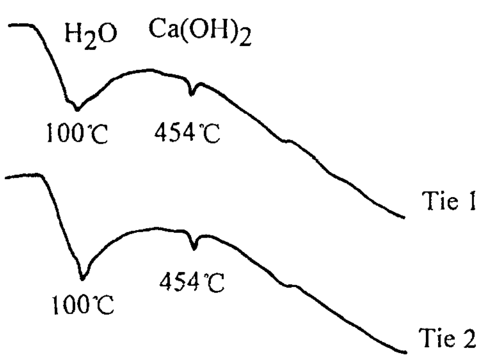

FIG. 3.
Result of differential thermal analysis cement on cement paste in ties.

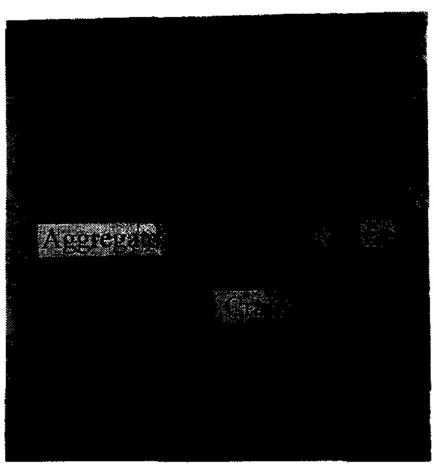

FIG. 4.
Morphology of interface of and aggregate.

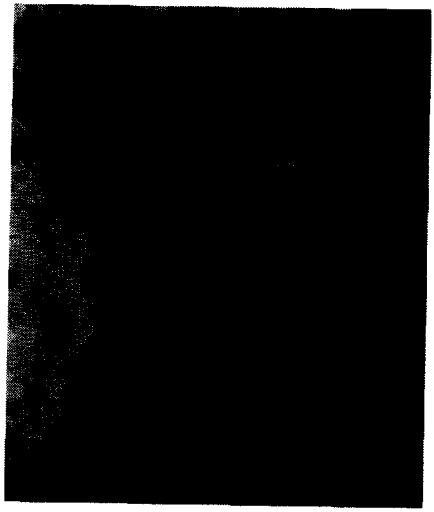

FIG. 5.
Alkali-silica gel.

SEM/EDAX Analysis. New broken face of concrete ties was submitted to SEM/EDAX analysis. Fig. 4 reveals the morphology of interface of cement and coarse aggregate. A crack along with the interface was observed. The aggregate was attacked and eroded, accompanied by formation of gel-like product as shown in Fig. 5, which is enlarged from Fig. 4. DAX analysis shows that the aggregate is enriched in Si and the gel-like product is CaO-SiO2 gel enriched in K(Fig. 6). Ca in the gel is smaller than that in CSH gel. This seems to indicate that the gel was produced by alkali-silica reaction.

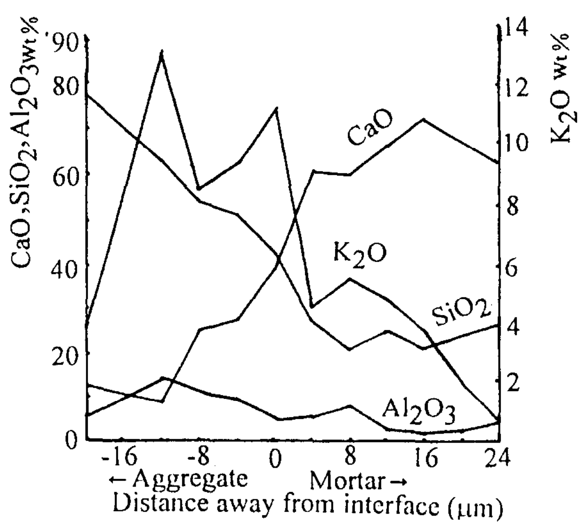

FIG. 6.
EDAX result of interface f cement and aggregate.

FIG. 7.
Specimens from cracked ties.

No significant ettringite was found in cracks, voids or interfaces between aggregates and hardened cement pastes of the damaged concrete ties. The concrete seems not be affected by sulphate attack.

Visual Examination. Visual examination was carried out on specimens cut from ties severely cracked and uncracked on surface. Steel reinforcement in concrete is in good condition. The ties were not affected by corrosion of steel. Ties with severe surfacial cracking also cracked in the inner part and some aggregates were disjoined with mortars (Fig. 7). Ties without surficial cracking show fine cracks in the new broken surface. Bond of cement with aggregate is normal.

Petrographic Examination. Observation on the polished and thin sections of cracked railway ties reveals that some aggregates with reactive silica minerals have been eroded and cracks mainly originated from the coarse aggregates. Coarse aggregates were siliceous dolostone and limestone, granite, tuff and other volcanic rocks. The siliceous dolostone, siliceous

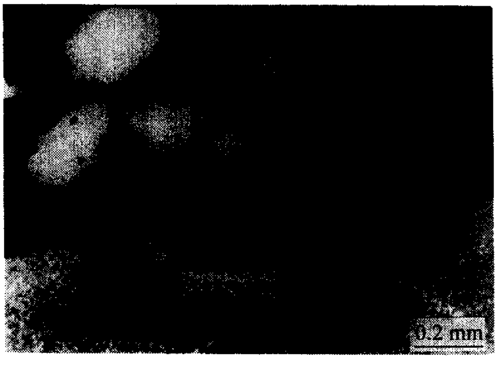

FIG. 8.
Microcrystalline quartz in coarse aggregate.

FIG. 9.
Chalcedony in coarse aggregate.

limestone and partial volcanic rocks contained microcrystalline quartz and chalcedony(Fig. 8 & 9). Ties also contained a small amount of dolomitic limestones, which are similar in texture as alkali-carbonate reactive Kingston argillaceous dolomitic limestone. Some cracks spread to mortars along the corners or boundaries of siliceous dolostone, siliceous limestone and volcanic rocks. A few of cracks extended from aggregates to mortars. Others were perpendicular to the boundaries of coarse aggregates. Fig. 10 illustrates the cracks in the concrete ties.

The fine aggregates were almost feldspar and crystalline quartz. A very small amount of particles composed of strained quartz and microcrystalline quartz was incorporated in sands.

<u>Evaluation of Alkali-Reactivity of Aggregates.</u> The coarse aggregates were carefully separated from the cracked railway ties. The residual materials were then treated with dilute HCl. Acid insoluble residues were washed with water and dried. These obtained residues were collected as fine aggregates. They were submitted to evaluation of alkali-silica reactivity. Test was carried out by Chinese autoclave method[2]. Table 3 lists the results. Coarse aggre-

FIG. 10.
Cracks in concrete ties.

TABLE 3
Expansion of Micromortar Bars for Evaluating Alkali-Silica Reactivity

Ratio of cement to aggregate	Expansion (%)								
	Coarse aggregate								Fine aggregate
	1	2	3	4	5	6	7	8	
10:1	0.082	0.058	0.126	0.210	0.036	0.049	0.391	0.378	0.039
5:1	0.121	0.091							
2:1	0.213	0.167							

gates 1 and 2 were derived from Zhengjiang railway ties without and with cracks, respectively. Coarse aggregates 3, 4, 5, 6, 7 ,8 and fine aggregate were come from one cracked railway tie placed in Shanghai. Samples 3, 4, 5, 6, 7 and 8 were sorted from a mixture of aggregate according to alkali-reactivity by naked eyes. Most of coarse aggregates caused more than 0.10% expansion, thus they were alkali-silica reactive. Fine aggregate caused a very low expansion. It was nonreactive.

Examination of Laboratory Concrete Specimens. The 15cm°¡15cm°¡15cm concrete specimens, with the same mixes as ties and placed in the laboratory room of the plant, cracked at age of 3-6 years. A crack on one specimen is 8 mm in width. When cured in a moist container, alkali-silica gel was observed to squeeze out through the cracks and coarse aggregates themselves cracked. There is no corrosion of reinforcement, no load, no sulphate attack, no freezing and thawing and no cycle of drying and wetting on the specimens. Concrete specimens heat cured both at 80°Ê and 60°Êshowed same cracking. This indicates that delayed ettringite formation may not be involved in the cracking of concrete ties, or was not essential for the cracking. Therefore, it may be deduced that the concrete was mainly affected by alkali-silica reaction.

Discussion

The alkali content of the concrete ties from cement and water reducing admixture was about 5.2-6.2 kg/m3. This value is far higher than the safe threshold 3.0 kg/m3 for alkali-silica reaction[3]. The railway ties placed out of doors were easy to gain moisture. Thus, the reactive siliceous aggregates may make the ties to suffer distress by alkali-silica reaction. Examination of the ties and laboratory specimens supports this deduction. The ties cracked by alkali-aggregate reaction may be further damaged by the motive load and other factors.

The railway ties were precast units and were treated with heat steam during production. It was suggested that these ties might be deteriorated by secondary ettringite formation[4]. Petrographic examination shows that there was not a large amount of ettringite in the concrete. Therefore, the secondary ettringite formation was not, at least, the main reason of the deterioration. The cracking of concrete specimens in laboratory suffered heat treatment at 60°Ê further confirms this conclusion.

MgO in the cement was lower than 5% limit. Its hydration may not cause unsoundness. Test shows that there are not many Mg(OH)2 in pastes of concrete ties. Sulfate attack is also not a key factor to affect the durability of the ties, as mentioned above.

Conclusion

The siliceous aggregates in the railway ties were potentially alkali-silica reactive. Petrographic examination and SEM/EDAX analysis of the deteriorated concrete revealed the presence of typical features of alkali-silica reaction. Alkali-silica reaction will cause concrete to further expand. The cracking of ties is not, induced by formation of Mg(OH)2 or ettringite. It appears that alkali-silica reaction is a prerequisite for the deterioration of the concrete. The cause for difference between cracking of concrete ties needs to be further investigated.

Some of concrete ties lost efficacy and need to be replaced.

Acknowledgment

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