Prestressed Concrete Sleepers Failure Investigation Case Study

Denis Yurlov[1], Andrey Shishkin[2] , Semion Zhutovsky[2]

[1]*Israel Railways, Lod, Israel*
[2]*Technion Israel Institute of Technology, Haifa, Israel*

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INTRODUCTION

The efficiency of rail transport is crucial to compete with other transportation modes. Thus, over the years railway operators demand increasing rolling stock axle load and speeds. Hence, railway infrastructure improvements are crucial to withstand persistent increasing of bearing capacity expressed in significant dynamic load and cumulative traffic load.
Railway sleepers are key elements in track infrastructure that have been in ongoing development and enhancement. Since initially been introduced, the application of prestressed concrete sleepers steadily increases. Nowadays, concrete sleepers are the major type of sleepers used around the world. However, systematic failures of concrete sleepers are very common in the railway infrastructure. In this paper a case of failure of prestressed monoblock concrete sleepers was investigated. The conducted investigation included field survey and laboratory analysis. The results of the study revealed problems in the durability design and curing process as the main cause of the failure.

RESULTS

Field survey

The field survey included visual inspection and Non-Destructive Testing (NDT).

Visual inspection

The visual inspection of the prestressed concrete sleepers revealed longitudinal cracks between 200 microns and several millimeters that in most cases passed through the prestressing cables. Cracks appeared in a variety of locations and diverse variations. An example of the characteristic longitudinal cracking of the sleepers is shown in Figure 1. Nevertheless, the cracks passed around the prestressing cable zones, reflecting corrosion of the prestressing cables causing development, growth, and opening of these cracks. In addition, on the uninstalled concrete sleepers, cracking was observed as well, illustrating net cracking pattern on its surface as shown in Figure 1 suggesting the failure cause could be either alkali-silica reaction of aggregates or ettringite formation caused by either internal or external sulfate attack.

Figure 1. Characteristic longitudinal cracking on top (left) and side surfaces (center). The net cracking pattern on the surface of a new concrete sleeper (right).

Non Destructive Testing

The NDT was done by Schmidt hammer and Ultrasonic Pulse Velocity (UPV) on several sleepers. These results are graphically summarized in Figure 3 below. The error bars in these figures indicate the confidence interval of 95%, which corresponds to twice Standard Deviation (SD).

The field tests were conducted in different zones of the sleepers as indicated in Figure 2 below, as well as, on different sleepers conditions such as new, partially cracked, and fully cracked sleepers. The results of field testing confirm that mechanical properties of concrete used for sleepers production are satisfactory and therefore the reason for failure most probably is not of mechanical origin.

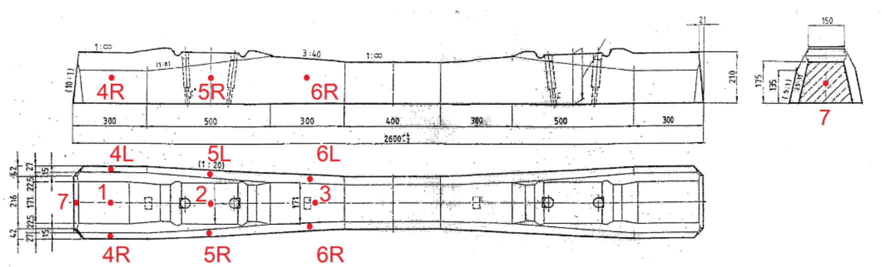

Figure 2. NDT testing points layout

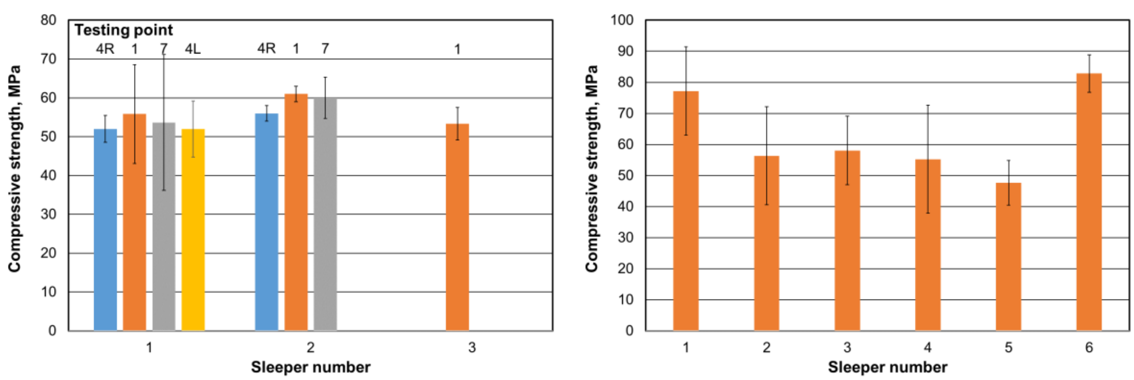

Figure 3. Evaluation of compressive strength based on in situ Schmidt rebound hammer test (left) and UPV measurement (right)

Laboratory study

Compressive strength

Compressive strength testing results of the drilled cores from failed sleeper demonstrate wide distribution but satisfying the manufacturing requirements. Furthermore, generally strength testing results on drilled cores are usually lower than specially casted and cured samples due to the damage introduced during drilling and during the service life of the element.

Mineralogical composition

The mineralogical composition was determined on three different samples taken from three locations of the cracked concrete sleeper. The summary of the composition is given in Table 1 below and an example of the X-ray Diffractogram (XRD), including Rietveld fitting curves, and difference plot are shown in Figure 4 below.

This test reveals the concentration of Hydrocalumite and Ettringite. Hydrocalumite, also known as Friedel's salt, is chloride salt that is formed when chlorides come into contact with cement paste. According to the international standards [1,2,3], chlorides are thoroughly excluded from concrete composition.

The presence of ettringite in the concrete sleeper suggests delayed ettringite formation since it's likely to exist only either in fresh concrete, or at a very early age then ettringite quickly transformed to monosulfate. One of the explanations of presence of ettringite in the sleeper is high curing temperature [4], i.e. exceeding 80 °C. In this case ettringite crystals could form in the concrete at later ages after hardening while expanding. Since the concrete can not resist the expansive formation of ettringite the net cracking pattern is formed (Figure 1, right above).

Chemical composition

The chemical composition of the cracked concrete sleeper is summarized in Table 2 below. The XDR and the Inductively-Coupled Plasma (IPC) spectroscopy analysis were done from the same location in the sleeper. Note that with the ICP method chloride content cannot be determined. The chemical decomposition did not demonstrate any abnormality.

Table 1. Mineral composition by XRD, % wt.

	Dolomite	**Calcite**	**Quartz**	**Portlandite**	**Ettringite**	**Brucite**	**Hydrocalumite**	**Gypsum**	**Other**
Crack	56.4	16.9	23.6	0.6	1.5	0.0	1.0	0.0	0.0
Surface	30.5	37.7	28.3	0.3	0.0	0.0	0.0	0.0	3.2
Center	76.0	7.7	4.9	0.8	0.3	0.1	3.4	0.6	6.2

Table 2. Chemical composition by ICP, % wt.

	SiO_2	**CaO**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**SO_3**	**K_2O**	**Mn_2O_3**	**Na_2O**	**P_2O_5**	**TiO_2**	**V_2O_5**	**ZnO**	**LOI**
Crack	37.7	19.7	1.1	0.6	6.7	1.9	0.1	0.0	0.1	0.2	0.8	0.0	0.0	31.1
Surface	45.0	19.5	1.6	1.1	3.4	1.9	0.4	0.0	0.1	0.4	1.2	0.0	0.0	25.3
Center	29.7	21.7	0.9	0.4	9.0	2.0	0.1	0.0	0.1	0.1	0.7	0.1	0.0	35.2

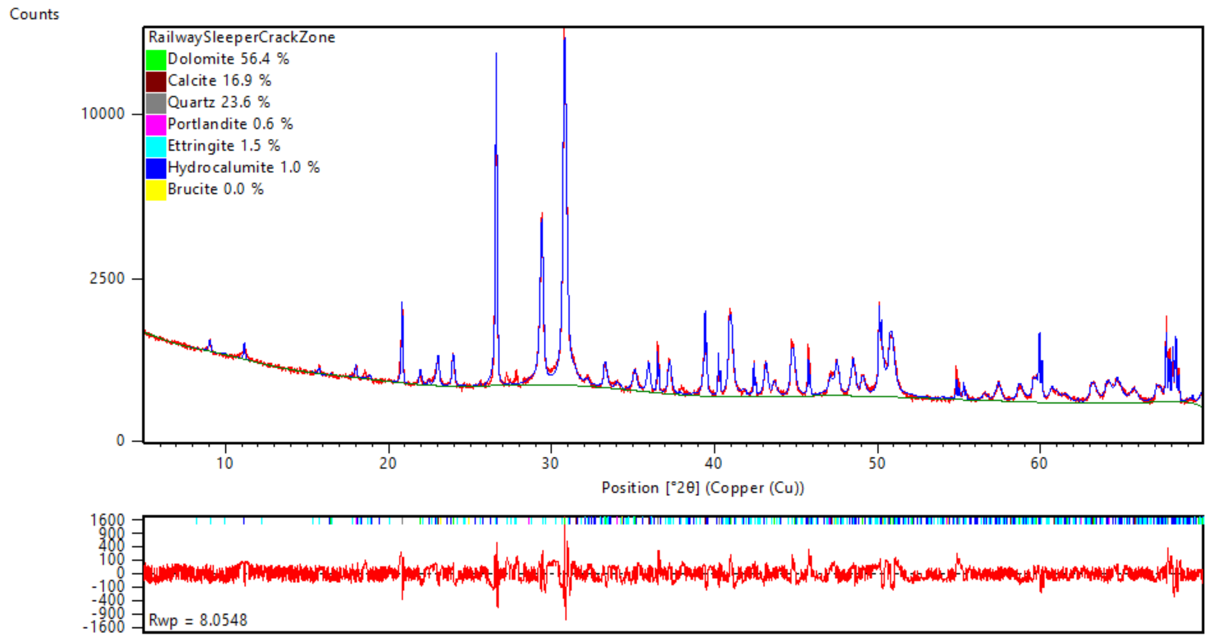

Figure 4. XRD diffractogram of concrete from crack, edge and center zone of sleeper

CONCLUSIONS

According to the results of the study, the failure of prestressed concrete sleepers was due to corrosion and expansion of prestressing cables. The determined reason for that was by chloride attack, which probably was accelerated by sulfate attack that resulted in delayed ettringite formation. Moreover, accumulated high dynamic traffic load accelerated sleepers' failure. Severe cracking of concrete sleepers was observed on the inspected sites. Although the strength of concrete material as high, the integrity and load-bearing capacity of concrete sleepers are significantly degraded by cracking. Currently, it is not clear how to determine the residual bearing capacity of cracked concrete sleepers and criteria for the proactive replacement are not well-defined. Further research and testing are needed to clarify these aspects that are of primary importance to the railway authority.

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