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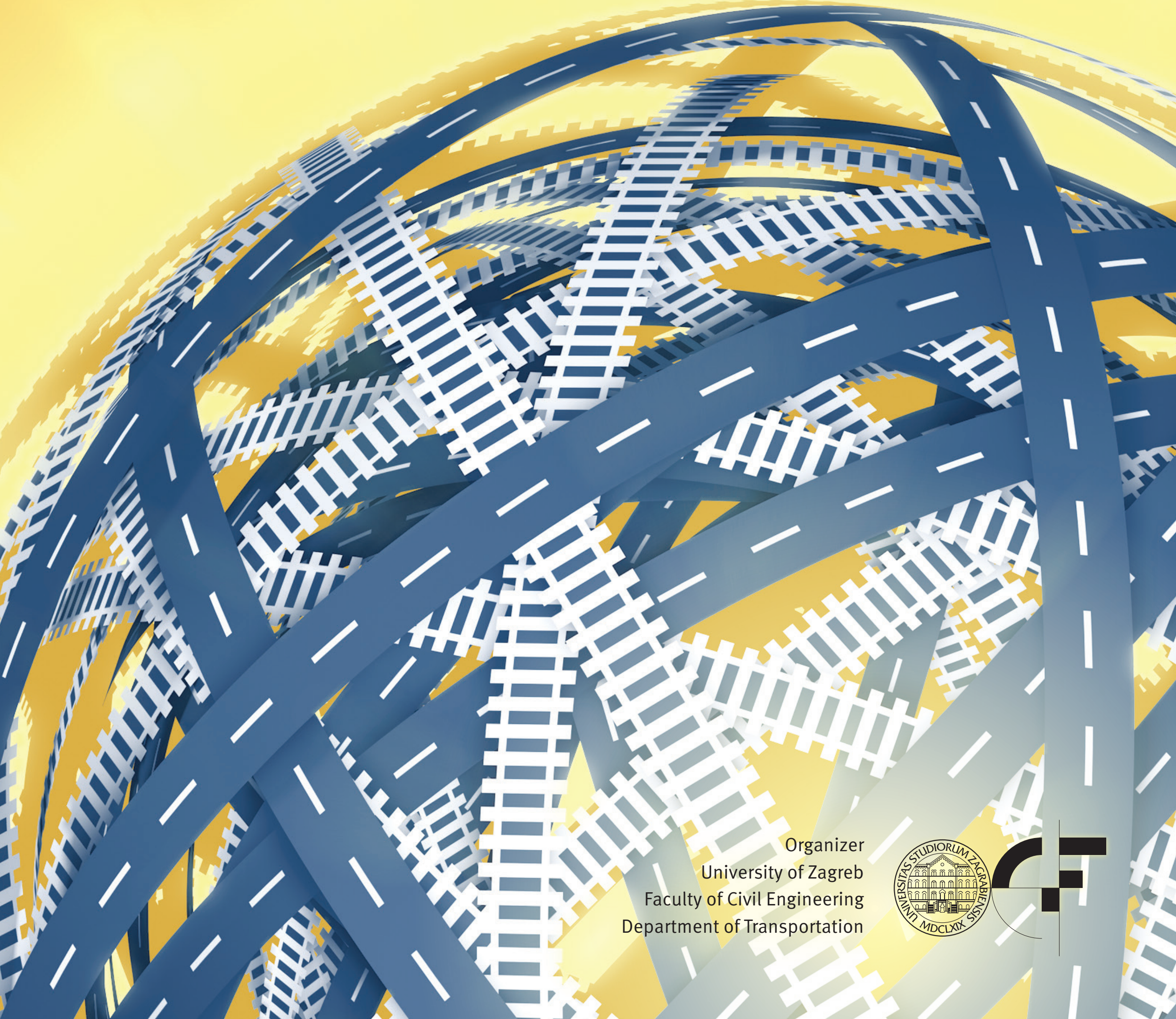
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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CONCRETE MIX DESIGN FOR THE REMEDY OF CORRODED CONCRETE SLEEPERS

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Abstract

The paper describes the main objectives and conclusions of concrete sleepers affected from salty soil and sulphates also to provide technical examination of the problem, as well estimation and technical proposals of concrete sleepers which are affected by sulphates along the existing railway line 18-41 km, which is under the maintenance of Almobty Company for Contracting. However, in order to proceed with any final technical evaluation and what more a decision to be taken, chemical analysis of the subsoil is mandatory. For this purpose, rail line should be disconnected and the ballast removed. Afterwards geotechnical analysis should follow with bore sample of 2 to 5 meters deep, as well as surface sample, as per test specifications. The same procedure should be followed every 100 meters in the effected line. Our estimation is that additional samples of the same nature should be obtained from the wider area, not only the linear zone. The chemical analysis will provide specific factors to the problem such as the formation of the contaminant as well as the means of soil circulation is it in the form of underground water, fumes or others. Also Geomembranes and geo synthetic should be used to prevent the migration of fluids from one location to another; for example, lining landfills to stop leachate polluting groundwater, controlling groundwater entering tunnels or creating attenuation ponds within development. The problem analysis should follow two basic directions in the quest for solution: a) remedy of ground characteristics, b) remedy of existing rail superstructure (concrete sleepers and fastening system).

Keywords: railway infrastructure, higher speed, safety, environment.

1 Executive Summary

As per SRO (Saudi Railway Organization) request, a visit was performed at site at siding 2 and soil samples was taken for chemical analysis, after the soil analysis, a report was issued with various recommendations that could be adopted, such as the placement of water barriers membranes beneath the track bed, the use of sealants to already placed sleepers, the substitution of the corroded sleepers with new sleepers manufactured with a special concrete mix design etc. Due to the quick deterioration in the concrete sleepers, Almobty was requested to provide a solution to the problem for the foregoing areas limited to the use of concrete sleepers with improved quality and enhanced chloride and sulphate resistant properties. Almobty informed SRO that to proceed with the solution a geotechnical study would have to be performed and upon receipt of the investigation report, a special concrete mix design can be provided by the researcher. Almobty conducted a site visit at Siding 2 along with a special third party for geotechnical studies under the supervision of researchers. The railway line of the area in question is about 22 km long. It should be pointed out that all our remarks regarding all site visits with the manifested corrosion problem of the sleepers, are based solely on visual inspection, filed observations and geotechnical studies. Regarding the site visits the following were observed, all elements of the track line, the sleepers, the fasteners and the rails themselves seem to have been affected by corrosion to a variable extent and thus the sources of corrosive agents must be identified and the causes of corrosion should be safely and reliably concluded based on concrete data gained from field and geotechnical investigation. It is noteworthy that the deterioration of concrete sleepers observed at selected sites present different morphological features, a fact leading us to draw the conclusion that different set of conditions prevail in these different locations and most likely different corrosive mechanisms are accountable for the deterioration of the concrete sleepers. The identified features of deteriorated sleeper elements at the aforementioned sites can be summarized to the followings:

- Quite a few concrete sleepers are marked by fresh open longitudinal cracks which are clearly not associated with the action of any external environmental corrosive factors but are obviously generated by mechanical fatigue and overstressing.
- Concrete sleepers aggressed by corrosion with cracks and spalled off concrete chunks with visible corrosion trace marks of the reinforcement bars presumably by chloride penetration. No visible marks of sulphate attach were seen on the concrete spalls. The most likely source of chlorides it is surmised to be the uprising moisture due to capillary phenomena of a shallow salivated ground water table as it can be concluded from field observations of the broader area. Yet the windblown sand which is in direct contact with the track elements may not be excluded as a possible source of chlorides but this only can be safely indicated by the soil analyses of chemical and mineralogical composition.

Figure 1 Cracked and Corroded Concrete Sleepers (km 19, 25, 31 & 37)

Table 1 Existing Mix Design for concrete sleepers

Sulphate Resisting Portland Cement, Class 52.5 N (as per EN 197-1, low alkali (‹ 0.60%) and C3A ‹ 3.5%).	430 kg
1” Aggregate	252 kg
3/4” Aggregate	360 kg
3/8” Aggregate	360 kg
Washed Sand	576 kg
White Sand	252 kg
Water	170 kg
**Source: SRO Sleeper supplier specifications*	

The following should be noted:

- Aggregates meets EN 12620
- Water reducing admixture could be used in quantity 4.5 lit/m3 approximately.
- Tie has been designed as per SRO specification.
- Pre-stressing has been done as per EN 10138.
- Curing in the oven is of high importance and relevant procedure must be followed.

2 Geotechnical study

Portland cement when hydrated forms calcium, potassium and sodium hydroxides that are released during the curing reaction providing a high pH environment (≈ 12.5) surrounding the steel. At this pH value, the steel is passive and will not corrode unless the passive film is attacked and destroyed. While several factors can cause the disruption of the passive film, chloride ions are one of the most common attacks and are a primary cause of corrosion of steel in concrete. In addition, the presence of carbon dioxide will neutralize the hydroxides, reduce the pH, and cause the corrosion of steel. [1]

2.1 Carbon dioxide caused problems

Carbon dioxide will react with the hydroxides in the pore solutions to form carbonates, plus water causing the pH to decrease to about 8.3 and the steel to start corroding. The rate of penetration of the carbon dioxide into the hardened concrete depends upon according [7]:
- The partial pressure of CO_2.
- Concrete permeability.
- Cement type.
- Cement content.
- Environmental humidity.

Carbonation caused damage could be prevented by:
- Increasing concrete cover depth over the steel.
- Increasing density of the concrete.
- Using higher amounts of cement in the concrete.

2.2 Chloride caused problems

Chloride ions in concrete can be present due to several factors. The main causes can be 1 (the diffusion/penetration through the concrete from surrounding environment, 2) mixing with the concrete inadvertently as part of the water or aggregate, and 3) using additives as calcium chloride which is a set-accelerator. With the presence of chloride ions at the steel level, the passive conditions are disrupted and corrosion can occur. [2]
Steel corrodes by the anodic reaction which involves iron going to the ferrous ion. There must be a simultaneous cathodic reaction and in Portland cement concrete, it is the reduction of oxygen.

$$\begin{aligned} Fe &\rightarrow Fe^{+++} 2e \text{ – Anodic} \\ \tfrac{1}{2} O_2 + H_2O + 2e &\rightarrow 2OH \text{ – Cathodic} \end{aligned} \tag{1}$$

Oxygen must be available for the corrosion reaction to proceed. When oxygen is readily available the following factors control the rate of the overall corrosion reaction:
- Chloride concentration.
- Potential profiles.
- Concrete mix characteristics control.

2.3 Chloride concentration

The FHWA states that when the chloride concentration in a bridge deck is 0.15% based in cement concrete there is no danger of corrosion at that time and the concrete can be left intact. When concrete contains 0.3% chloride, the concrete below the top mat or the entire deck must be replaced. Report states that it is known that corrosion probably will occur when the concentration reaches 0.35 – 1% chloride ion by weight based on cement, Table 2. The American Concrete Institute has developed standards on chloride levels permissible in the concrete mix used for various reinforced concrete structures,

Table 2 Chloride corrosion concentration

Structure	CL – % By weight based on cement weight
Prestressed	0.06%
Reinforced structure wet exposed to CL – in environment	0.10%
Reinforced structure wet no CL – in environment	0.15%
Above ground dry	No limit for corrosion purposes 2% Ca Cl_2 limit for accelerated set
**Source: FHWA (Federal Highway Authority USA)*	

2.4 Potential profiles

The detection of the presence of high potential areas of corroding steel in concrete can be accomplished by measuring the potential of the steel with respect to a reference electrode. The copper/copper sulphate reference electrode ($Cu/CuSO_4$) is commonly used.
ASTM standard states that a steel potential numerically greater than -0.35v w.r.t Cu_2CuSO_4 will have greater than 90% probability of corrosion in that area. A potential that is numerically less than -0.20v w.r.t $Cu/CuSO_4$ indicates that the steel has a 90% probability to not be in a corroding condition. There is some uncertainty concerning the presence of corrosion when the potential values fall between -0.20v and -0.35v. [8]
The presence of the Chloride ions will force a shift in the electrode potentials from the passive values of +0.100vto -0.100v w.r.t $Cu/CuSO_4$ to the values that are indicative of active corrosion and that are greater than -0.35v.
Chloride ions penetrate into concrete structures in a non-uniform pattern due to non-uniform contact with the structure and to non-uniform concrete properties. As such, potential mapping of reinforced concrete structures usually results in wide ranges of potential varying greatly between 100 mv and 500 mv across the structure. These potential gradients and differences lead to a galvanic type of accelerated corrosion caused by the appreciable corrosion currents that are developed between the different structural parts with different potentials.

2.5 Moisture content

The effect of moisture on the corrosion rate is an indirect one. The corrosion reaction rate is dependent upon the resistivity of the environment surrounding the reinforcing steel. If the resistivity of the environment is high then the corrosion rate will be lower since the current flow will be reduced by the higher circuit resistance. Table 3 lists the resistivity values for concrete with various levels of moisture content. The dry concrete has sufficient resistivity that is capable of preventing corrosion. The corrosion should not be a problem as long as the concrete remains dry.

Table 3 Resistivity of Concrete

Water saturated	13-15% H_2O	103 – 104 ohm-cm
Laboratory dry	3-5% H_2O	105 – 106 ohm-cm
Baked-dry	‹ 1%H_2O	108 – 109 ohm-cm
**Source: ASTM (American Society for Testing and Materials)*		

2.6 Concrete mix factors

The concrete mix design has a direct effect on the corrosion damage caused by the diffusion of the chloride ions mainly by limiting the permeability of the concrete mix. The higher the chloride ion permeability the higher the corrosion risk. The major factors that affect the concrete permeability include the water to cement ratio and the cement content in the mix. Concrete mix designs with higher cement contents and lower water cement ratios will be better for resisting damage due to chloride caused corrosion.
The type of cement will also change the corrosive behaviour of embedded steel. As mentioned earlier, chloride ions will react with the tricalcium aluminate (C3A) and will be removed from the pore solution. As such, cements with high C3A contents will provide a more protective environment than cements with lower C3A contents will provide a more protective environment than cements with lower C3A contents. Type 1 cement should protect steel from chloride caused corrosion to a greater extent than type 2 or type 5 cements since the C3A content of type 1 is higher than the other two.

2.7 Methodology

The following activities were carried out in this project:
• Visual inspection of damaged and new sleeper.
• Soil sampling from 2m & 5m depth at sleeper sides.
• Soil resistivity measurements were carried out for the soil samples.
• PH and Chloride analysis of the soil samples.
• Dust sampling from the sides and the middle of the sleeper.
• PH and Chloride analysis of the soil samples.
• Potential measurement and potential mapping of the sleeper.
• Comparison of the results with international standards.

2.8 Observations

During the course of the work the following was observed:

2.8.1 Upon visual inspection
• Concrete damage started at the sides of the sleepers and propagated towards the centre (see fig. 1).
• Sever corrosion is recorded on the anchor plate and nearby rebar’s (see fig. 2).

2.8.2 Upon sampling
• Filling material (non-shrinkable grout) for the bolts anchor holes was easy to chip.
• The soil around the sleepers was damp (see fig. 2)

2.8.3 Upon chemical testing
• Fall of alkalinity from pH 12 to pH 8 at the side of the sleeper. (see table 5)
• Increase of chloride level in the concrete to 0.34% against concrete.
• Stability of the pH at the middle of the sleeper.
• Lower chloride level at the middle of the sleeper.

2.8.4 Upon electrical testing
• Potentials >-ve than -550mV where recorded at the sides of the sleeper.
• Potential profile is recorded on the side of the sleeper. (sides strong & middle weak)
• Low soil resistivity is recorded.

Table 4 Chemical Analysis of soil

Sample ID	PH	Total Chloride as Cl (%)	Total Sulphate as SO_3 (%)
S # 01, km 19, 2 m	8.7	0.11	1.36
S # 02, km 25, 4 m	9.1	0.08	1.53
S # 03, km 31, 3 m	9.9	0.02	0.15
S # 04, km 37, 5 m	8.6	0.01	0.17

Table 5 Chemical Analysis of concrete

Sample ID	PH	Total Chloride as Cl (%)	Total Sulphate as SO_3 (%)
S # 01, Original Concrete, Shallow, 1 cm	8.8	0.34	0.56
S # 02, Original Concrete, Deep, 2 cm	8.2	0.09	0.54
S # 03,Concrete, Centre 10 mm Deep	12.6	0.12	0.73
S # 04,Concrete, Centre 40 mm Deep	12.3	0.07	0.67

2.9 Interpretation

The anchor bolts holes although filled with non-shrinkable grout, provide access to carbon dioxide, Chloride, Humidity and Oxygen. Carbon dioxide and Chlorides will decrease the pH of the concrete porous solution. At decrease pH, rebar's will lose their passivity (Iron oxide film which is stable at pH of +12 will break down at lower pH and expose metal underneath to corrode). This reinforcement corrosion process would result in corrosion products that occupy greater space than the original steel and will apply stress on the concrete causing it to crack and provide further access to salts, carbon dioxide, oxygen and humidity which accelerate the corrosion process. Eventually concrete will spall and integrity will be lost (see table 5).

Figure 2 Severe corrosion on anchor plate & rebar, on anchor plate

3 Conclusions

The following conclusions were derived from geotechnical study;

- Chloride content of the concrete is higher than the permissible levels on the sides of the sleepers while within limits in the centre sections of the sleepers.
- The Alkalinity of the concrete has been reduced.
- The potential mapping exercise has resulted in indicating high risk of corrosion on the sides of the sleepers and the existence of potential gradients on the sides as well.

It is indicative that the deterioration of the concrete of the sleepers is due to electrochemical corrosion of the steel reinforcement. As per the FHWA, when the rebar corrosion is electrochemical in nature, cathodic protection is the most effective way to stop the rebar corrosion and concrete deterioration. Concrete is a material which is basically exposed to the environment and can be affected somehow by the following environmental factors:

- Temperature (High, Low, Frost).
- Relative Humidity.
- Humidification – Drying.
- Seawater.
- Winds.
- Precipitation.
- Sea, Coastal, Ocean (Airborne Chlorides).
- Mineral Salts in groundwater and soil.

The effect in question probably belongs to either one of the last two categories namely to the occurrence of mineral salts in the groundwater and/or the soil and possibly the airborne chlorides as well due to the proximity of the site to the seacoast. Concrete corrosion provides a high risk of reinforcement corrosion which may affect the durability of any concrete elements, due to the combined action of chlorides and carbonation and affection according to international standards and recommendations. All the aggressions to concrete may induce serious problems and pose high risks to the steel reinforcement and subsequently to the durability of the concrete element and the durability of the concrete sleepers. Apparently the inspected concrete sleepers due to their long time exposure to mineral salts contained either in the groundwater or the soil, have been a subject to serve corrosion and expansion and thereby cracks were generated and developed on them. New Sleepers installed with proposed new mix design and they are continuously in observation from September 2015 as it shown in below pictures (see fig.3).

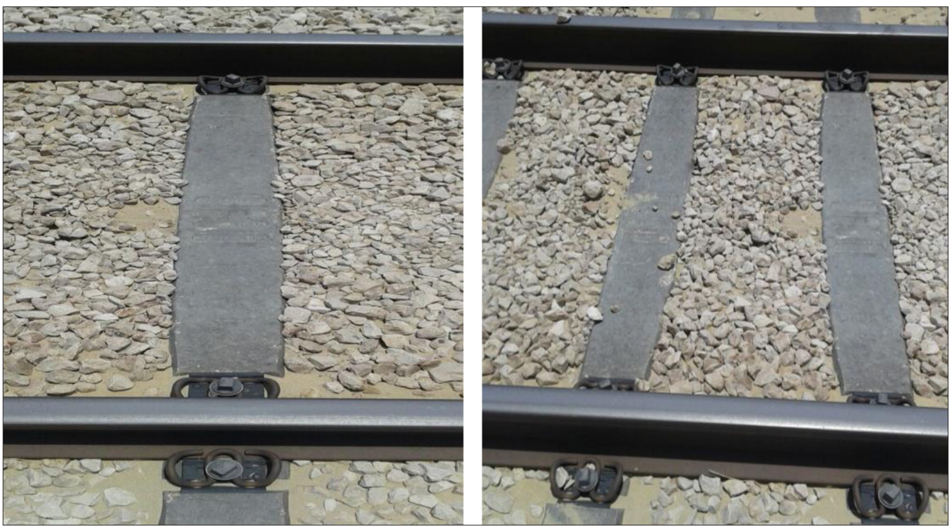

Figure 3 New Installed concrete sleepers (see table 6 mix design)

4 Recommendations

- Use better quality, denser and less permeable repair grout.
- Follow strictly the manufacturer recommendations for the grout application.
- Apply strict quality control on chloride contents of the concrete mix.
- Install Galvanic Cathodic Protection System for the sleepers as per the appended Cathodic Protection system layout, Figure 4.

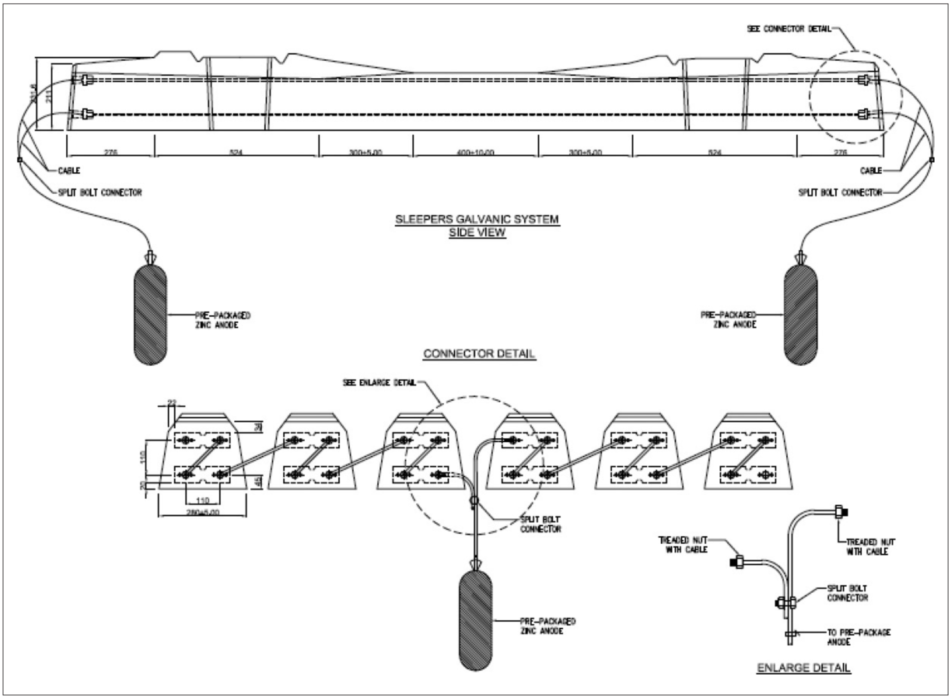

Figure 4 Sleepers galvanic system side view (Source: SAF Sleepers / Al-Mobty Company for Contracting)

All visited areas regard to existing railway line in full service. On that account it is recognized that some of our proposed recommendations cited in initial report that we presented to the client such as the placement geotextile beneath the track bed and the use of sealants to already placed sleepers may be practically infeasible to be implemented, due to inadequate line blockage. So the solution to the problem for the foregoing areas should be sought and limited to the use of concrete sleepers with improved quality and enhanced chloride and sulphates resistant properties (see Table 6). Based on the above our recommendations for the mix design for aggression resistant sleepers is as follows:

Table 6 Recommended mix design for concrete sleepers

Design – C 65 Type V (SRC)	
Cement Type – V	480.0 kg
1” Coarse Aggregate (32%)	352.2 kg
3/4” Coarse Aggregate (35%)	385.2 kg
3/8” Coarse Aggregate (33%)	363.2 kg
Washed Sand (50%)	311.1 kg

Design – C 65 Type V (SRC)	
White Sand (50%)	311.1 kg
Water	181.8 kg
Admixture – Sika (Viscocrete 20HE)	4.80 Ltr.
**Source: SAF Sleepers / Al-Mobty Company for Contracting*	

Note:
1) Weight of Coarse, Fine Aggregate and Water to be adjusted during batching for moisture.
2) To reduce the water and to improve the compressive strength, M/s. Sika product Sika (Viscocrete 20HE) can be added in a mix @ 1.0 liter 100Kg of cement

Also geotextile/geosynthetc can be an alternative solution for the remedy of corroded concrete sleepers, geotextile has been utilized widely around the world in for soil insulation and facilitation of drainage. The international experience allows us to define exact specifications on the insulation demands, load bearing capacities, performance in specific maintenance activities such as tamping and ballast cleaning. All the above mentioned requirements are well within the specifications of modern materials. In general, excess or uncontrolled water within soils can weaken them, causing numerous problems. The Management of water behind retaining walls and civil engineering structures, beneath railways, inside tunnels or within slopes, is one of the most important aspects influencing the long term performance of the structure, especially in railways action must be taken.
• Separation and filtering of two distinct soils or layers and preventing cross-contamination
• Protecting membranes or other vulnerable structures
• Improving the bearing capacity of weak soils.
• As is in our case, it can prevent the infiltration of salty soil moisture in the rail structure.

There are a wide range of products that is supported by several manufactures/firms capability to develop and produce specific textiles to suit individual projects and needs.

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