Iran University of
Science &Technology
School of Railway Engineering

TU Graz
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TECHNIK
LEIDENSCHAFT

Study of Concrete Sleepers in Sandy Areas Aiming to Prevent Corrosion and Breakage

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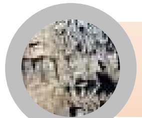
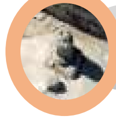
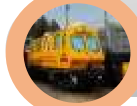
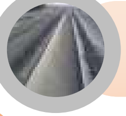
Destructive effects of sand on infrastructure

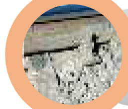

Physical and chemical degradation of concrete Sleeper

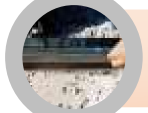

Premature wear of fastening system


Stiffness due to filling up of empty space between ballast dunes

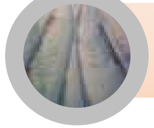

Increase in track maintenance activities and costs


Burying the Infrastructure in the sand


Lack of line stability


Reduction of track gauge and geometry


Rail deflections in


Interrupt switch function due to sand accumulation

1. Desert areas cover more than **30** million hectares of the country.
   - 1-1 **12** Million Hectares of Loose Sand
   - 1-2 **5** Million Hectares of **Active** Loose sand
2. About **600 km** of railway track pass through these areas.
3. Crossing the railway tracks through the areas of sand storm and sedimentation


Low Pollution


Medium Pollution

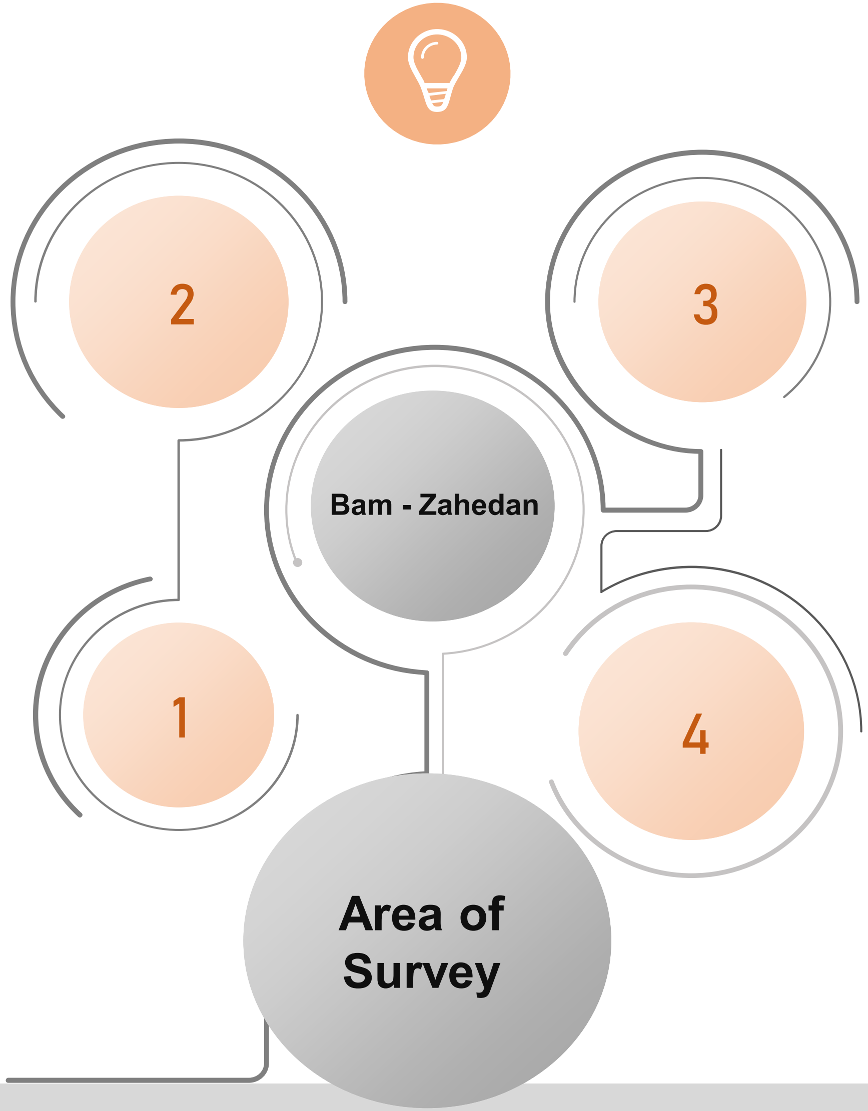

High Pollution


Critical Pollution

Literature

Studies of this track were started a long time ago, about **1982**. The first phases of the project, including studies, mapping, and variants, were done until before the problems were caused by the imposed war. The construction process of the project resumed again in **1991**

In Iran, **11** regions (including: Khorasan, Hormozgan, Kerman, Yazd, Qom, Isfahan, Tehran, northeast 1 and 2), out of **15** areas of the railway tracks are involved in the issue of **Loose Sand**.

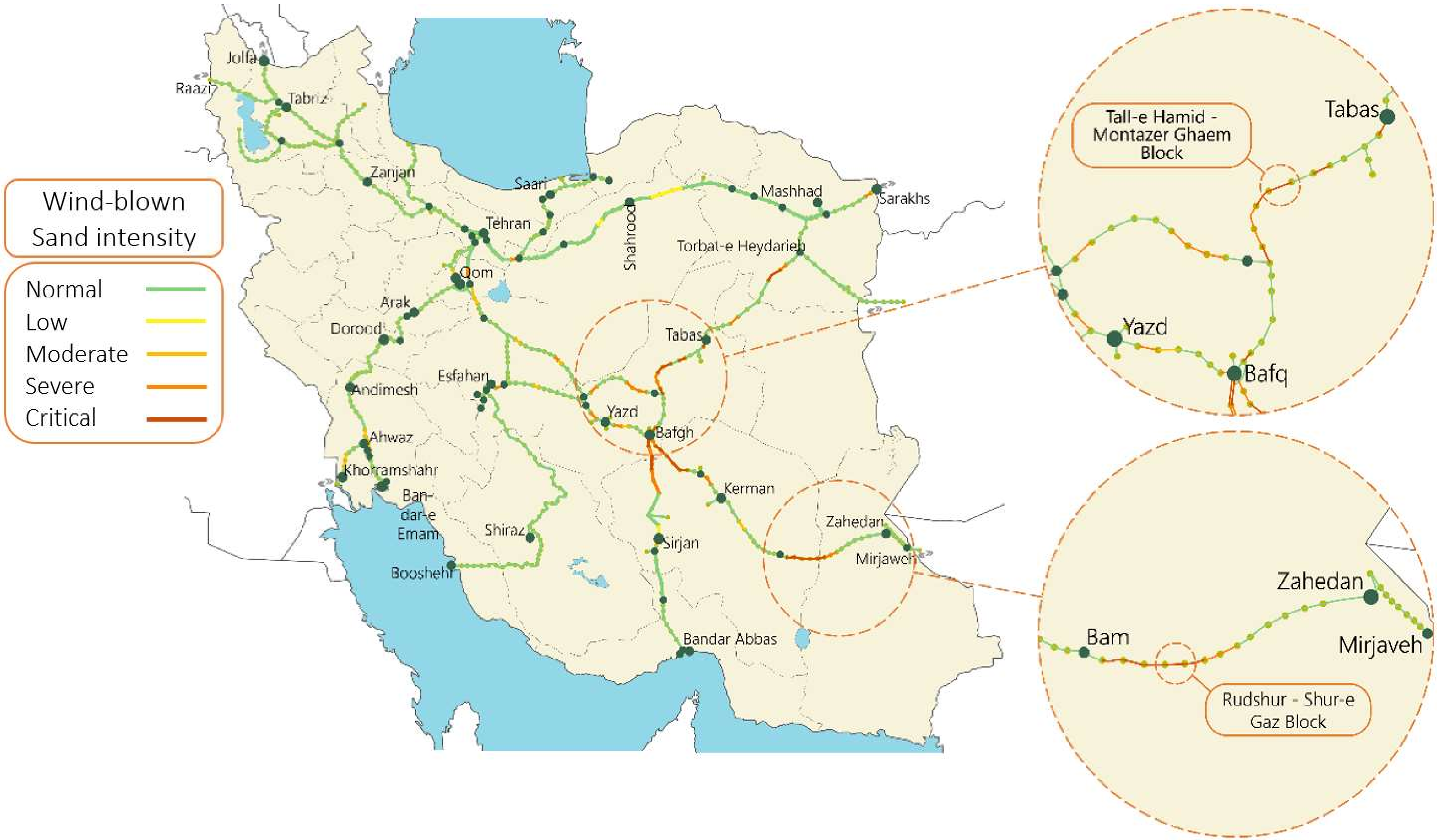


Visited stations:

- Kalat-Mazarab
- Mazarab-Namakzar
- Namakzar-Shur-e-Gaz
- Shur-e-Gaz –Talle Hamid
- Talle Hamid – Montazer Ghaem

- **B70** concrete sleeper made by **CBG**
- **Granite** ballast
- Rail type **UIC60**
- **VOSSLOH** fastening system
- The track is designed for an axle **load of 25** tons and an **operating load of 22.5** tons

Literature



Wind-blown
Sand intensity
Normal
Low
Moderate
Severe
Critical
Jolfa
Raazi
Tabriz
Zanjan
Saari
Tehran
Shahrood
Mashhad
Sarakhs
Torbat-e Heydarieh
Qom
Arak
Dorood
Tabas
Esfahan
Andimesh
Yazd
Bafgh
Ahwaz
Khorramshahr
Ban-
dar-e
Emam
Kerman
Zahedan
Mirjaveh
Shiraz
Sirjan
Booshehr
Bandar Abbas
Tall-e Hamid -
Montazer Ghaem
Block
Tabas
Yazd
Bafq
Zahedan
Bam
Mirjaveh
Rudshur - Shur-e
Gaz Block

	Year	Scholar	Title of Study	Results
1	2011	Mohammadzadeh et al.	Time-dependent reliability analysis of B70 pre-stressed concrete sleeper subject to deterioration	• More vulnerability of the cross section of the sleeper and the onset of corrosion in it from 5.5 years • Improving the reliability of concrete sleeper by increasing its height in the middle cross section of sleeper
2	2015	Tadayon et al.	Investigating the reasons of deterioration and corrosion of sleepers in desert areas	• sleeper failure simply due to corrosion of the reinforcement and rejection of other concrete degradation mechanisms • Exacerbation of failure due to dynamic loads • The amount of primary chloride ions exceeds the allowable limits
3	2016	Research crew	Survey on Zahedan-Bam railway	• Severe corrosion of the steel tendon • Moisture retention and lack of drainage by fine-grained desert soil • The same failure pattern, longitudinal cracks on the side surfaces of the sleeper

Fick's second law:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(D\frac{\partial C}{\partial z}\right)$$

c_s as boundary condition and c_i as initial condition

$$C_{(x,t)} = c_s - (c_s - c_i)erf\left(\frac{x}{\sqrt{4Dt}}\right) \qquad D = D_0\left(\frac{t_0}{t}\right)^m$$

Where:

C is the concentration of matter

D is the diffusion rate → Time, Temperature, Concentration, Environmental Conditions

c_s is the surface chloride concentration

c_i is the initial chloride concentration

t_0 is the measurement time of D_0

t is the time to obtain the diffusion coefficient

m is a constant coefficient called the aging coefficient,

considering C_{cr} as the corrosion threshold content on the left side of the equation and solving for t :

$$x = erf^{-1}\left(\frac{c_s - c_{cr}}{c_s - c_i}\right)\sqrt{4Dt}$$

EN 13230

has not determined the amount of allowable initial chloride

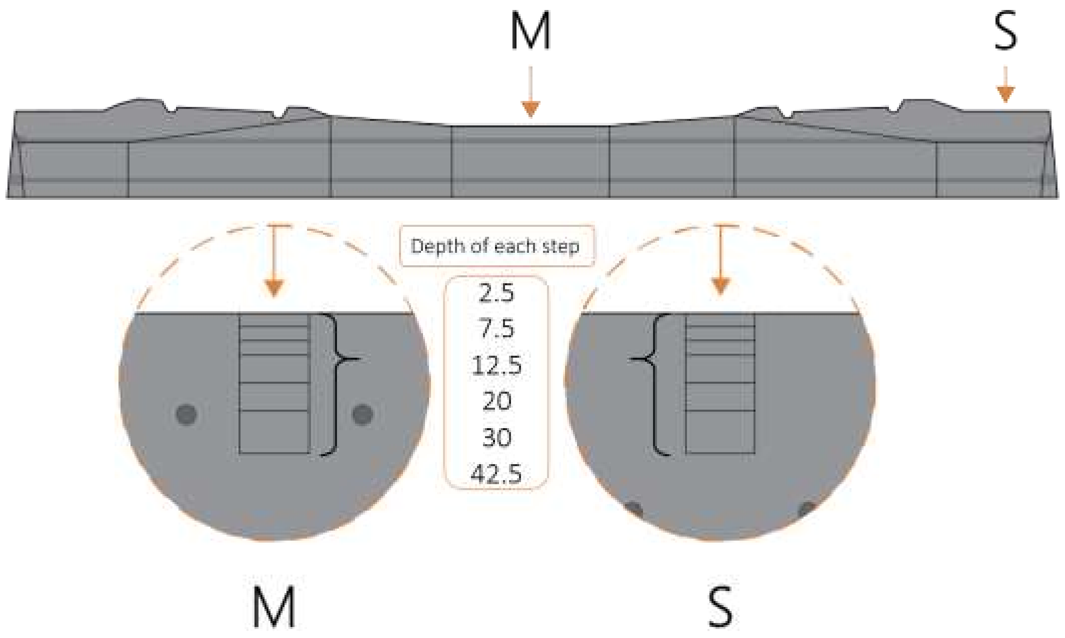
ACI 222

acid-soluble chloride content of 0.08% by weight of cement

EN 206

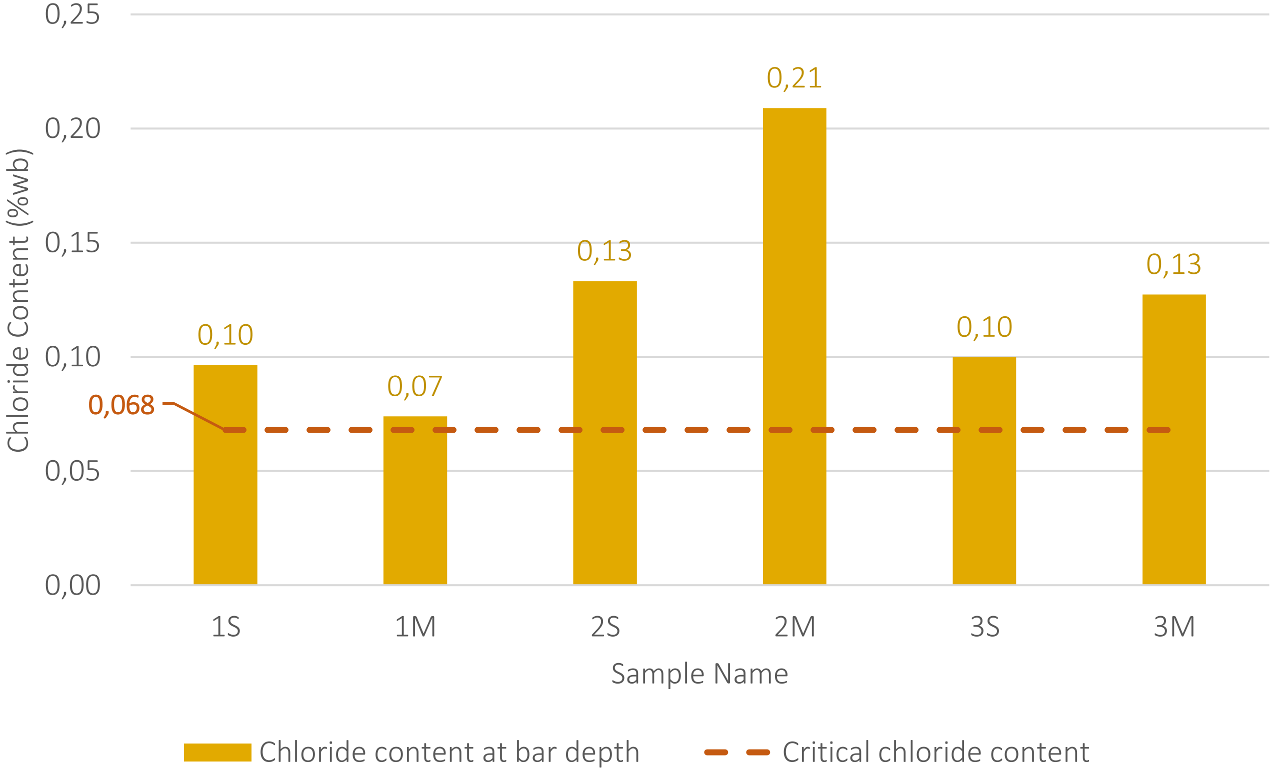
has a maximum total chloride content of 0.1% to 0.2% by weight of cement

Initial Chloride

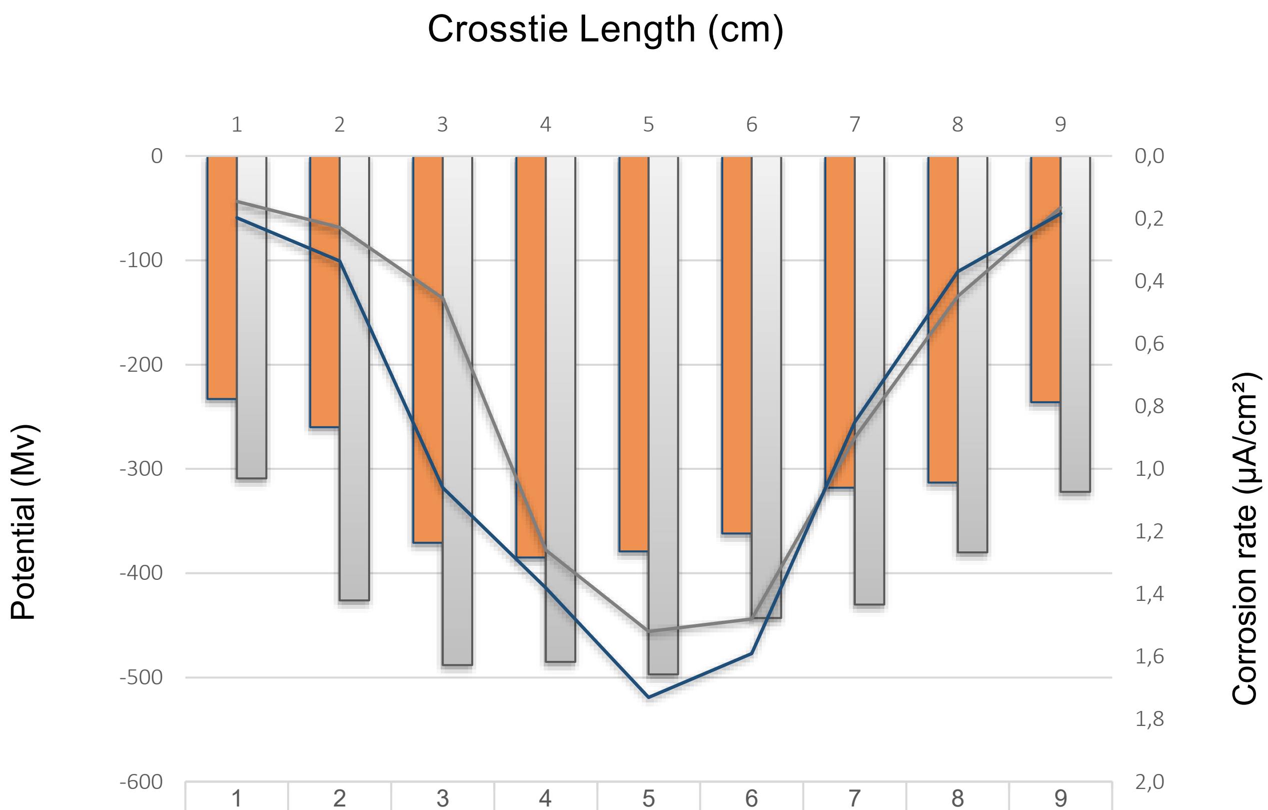


	1S	1M	2S	2M	3S	3M	Average
Chloride diffusion coefficient, $\times 10^{-12}$ m^2/sec	4.41	2.38	3.27	1.23	7.01	1.67	3.63
Surface chloride content, % by weight of concrete	0.34	0.14	0.52	0.42	0.23	0.35	0.33

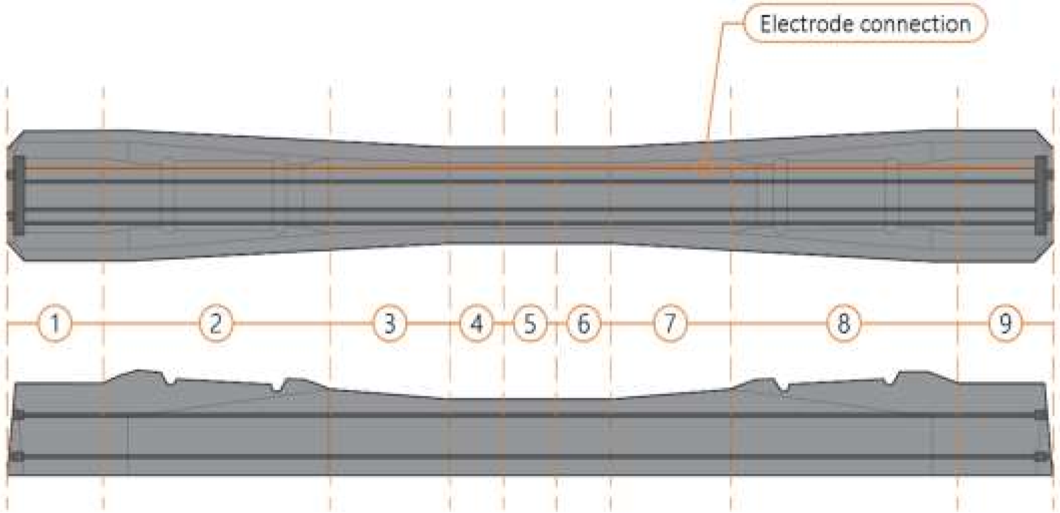
$$C_i = 0.014$$



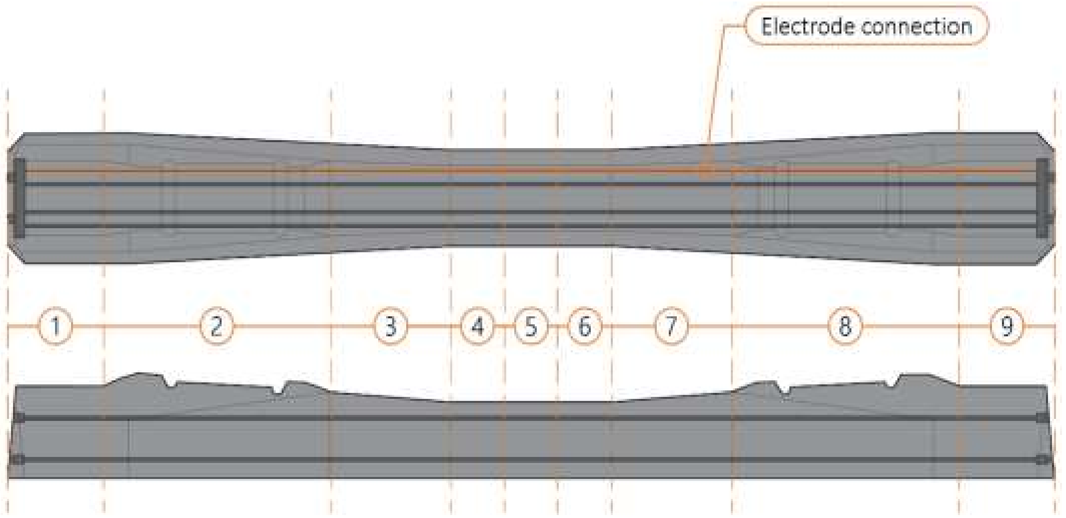
Critical Chloride

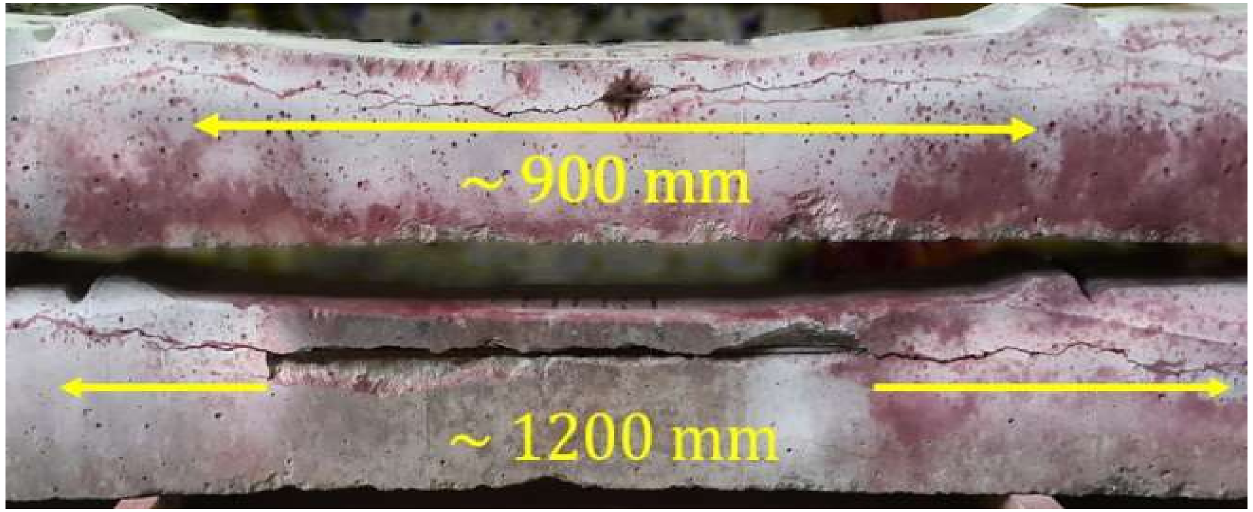


	1	2	3	4	5	6	7	8	9
HPC_Values (1st Sleeper)	-233	-260	-371	-385	-379	-362	-318	-313	-236
HPC_Values (2nd Sleeper)	-309	-426	-488	-485	-497	-443	-430	-380	-322
C_Rate (1st Sleeper)	0,145	0,228	0,454	1,26	1,52	1,48	0,9	0,448	0,165
C_Rate (2nd Sleeper)	0,197	0,336	1,06	1,38	1,73	1,59	0,85	0,369	0,184



Corrosion probability based on potential difference	
Levels of potential difference (mv)	**Possibility of rebar corrosion**
Lower than -500	visible evidence of corrosion
-350 to -500	95%
-200 to -350	50%
Higher than -200	5%

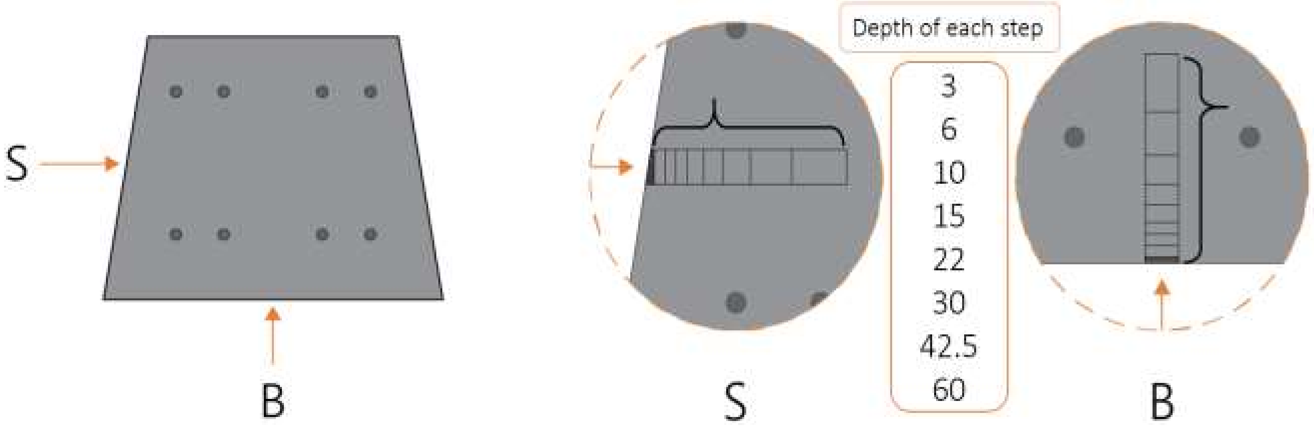




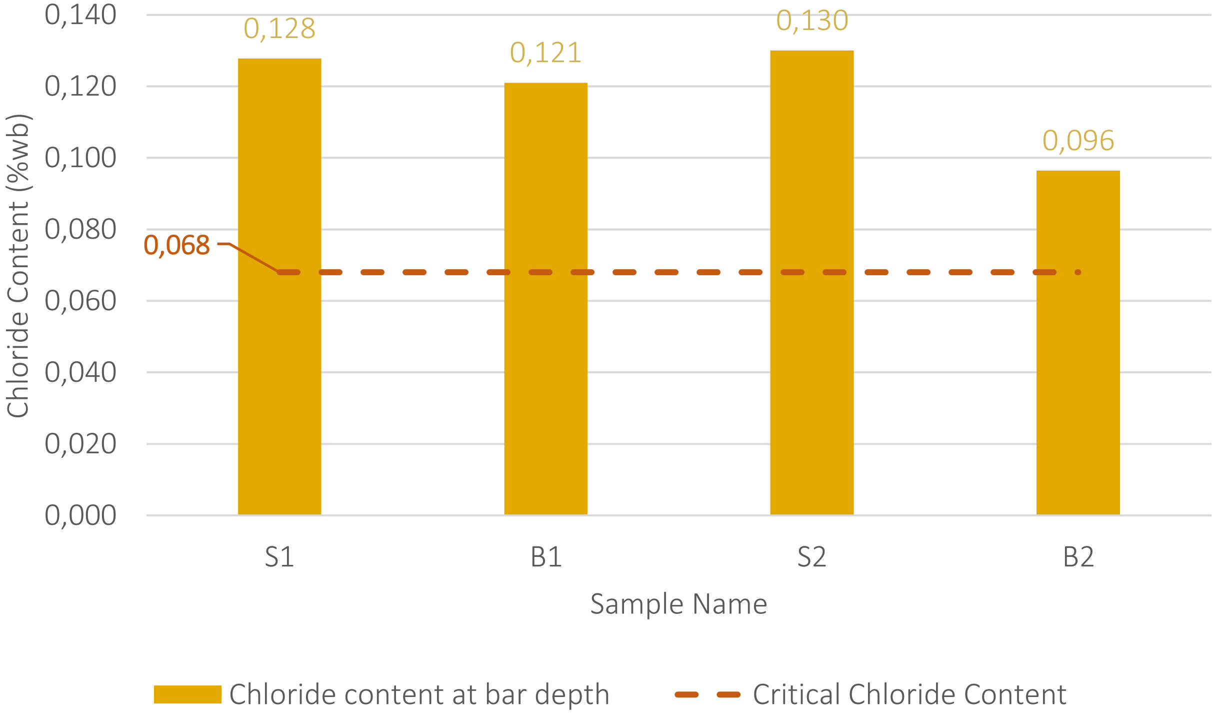
Description of sample	Critical chloride content, % by weight of concrete	Source
Concrete sleepers from the Iranian desert	0.068	This study
Marine Structures surrounding the Persian Gulf	0.05	Shekarchi et al. (2008)
Concrete containing 0%–35% fly ash	0.07	Chalee et al. (2009)
Concrete containing 0%–35% fly ash	0.028-0.041	Cheung and Kyle (1996)
A pier in the Persian Gulf	0.073	Shekarchi et al. (2011)
Normal concrete	0.06	Lambert et al. (1991)

$C_{cr} = 0.068$

Surface Chloride

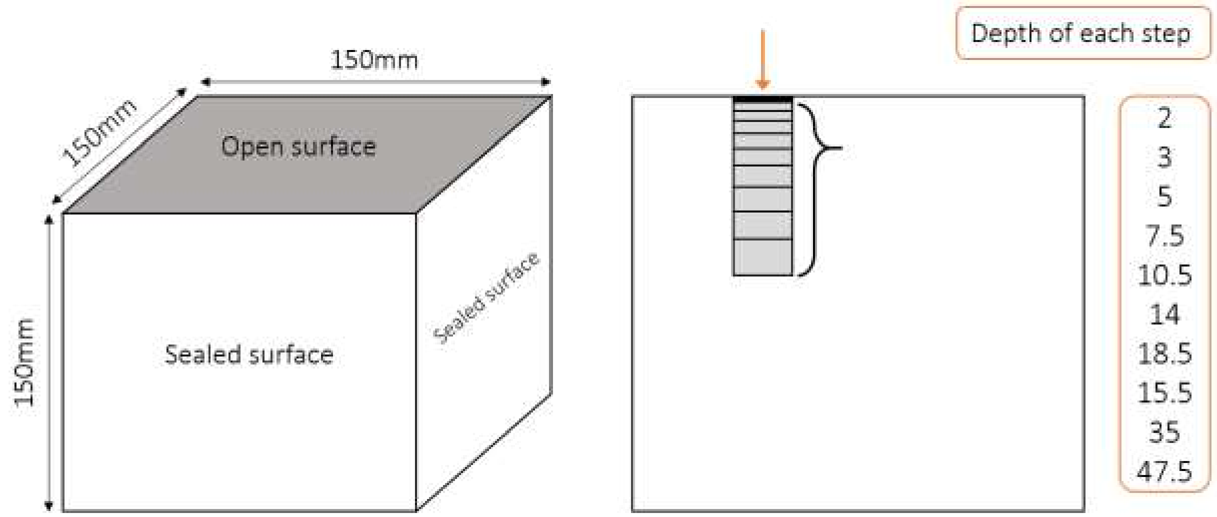


	Sleeper 1		Sleeper 2		
	S1	B1	S2	B2	Average
Chloride diffusion coefficient, × 10^{-12} m²/sec	4.04	3.49	3.61	3.48	3.77
Surface chloride content, % by weight of concrete	0.21	0.32	0.21	0.33	0.27



$$C_s = 0.27$$

Diffusion Rate



3D View 2D View

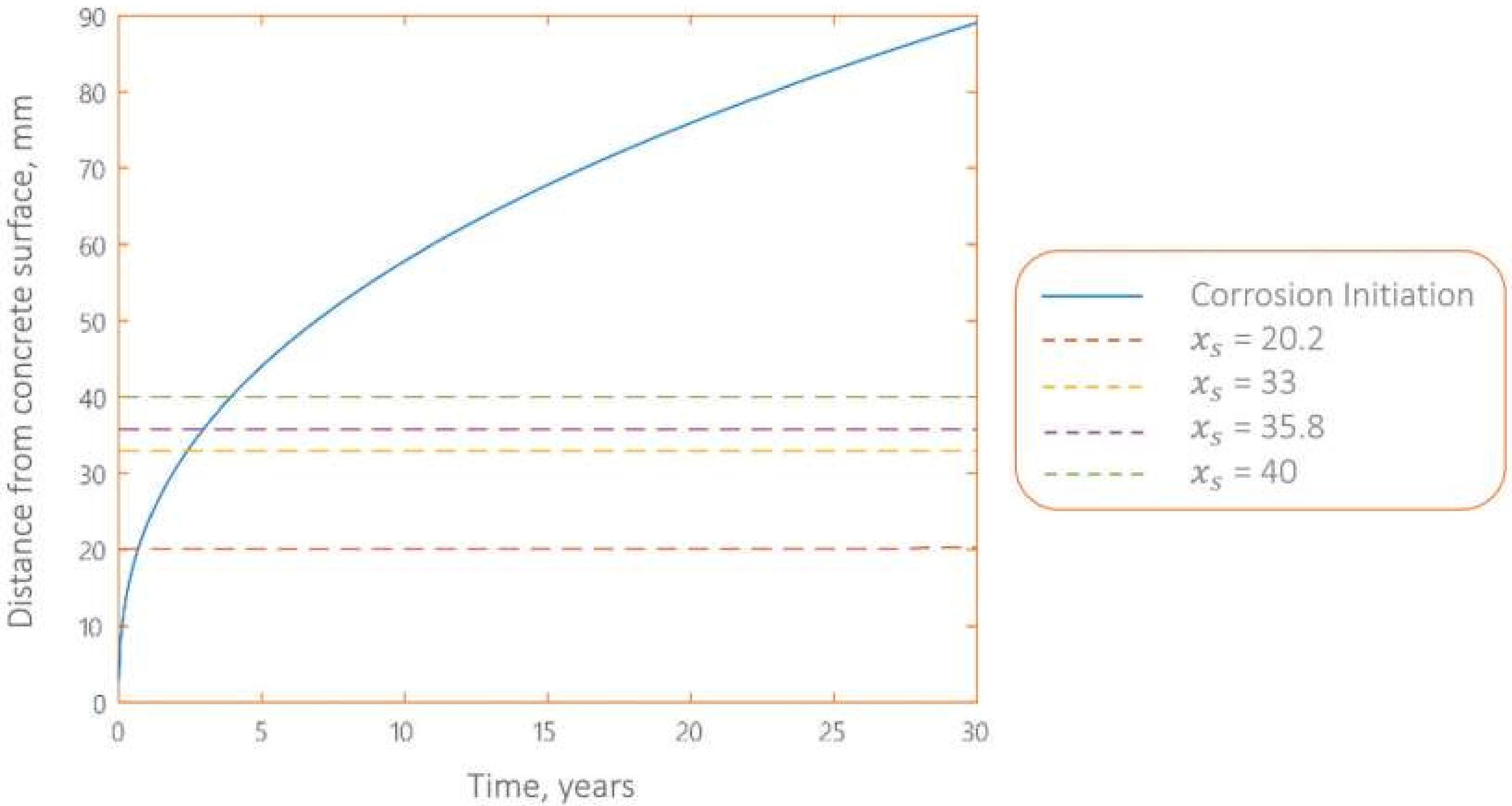
	Sample 1	Sample 2	Average
Chloride diffusion coefficient, × 10^{-12} m^2/sec	7.53	7.78	7.622
Surface chloride content, % by weight of concrete	0.90	0.94	0.92

$$D = D_0 \left(\frac{t_0}{t}\right)^m \longrightarrow D = 7.622 \left(\frac{0.25}{t}\right)^m$$

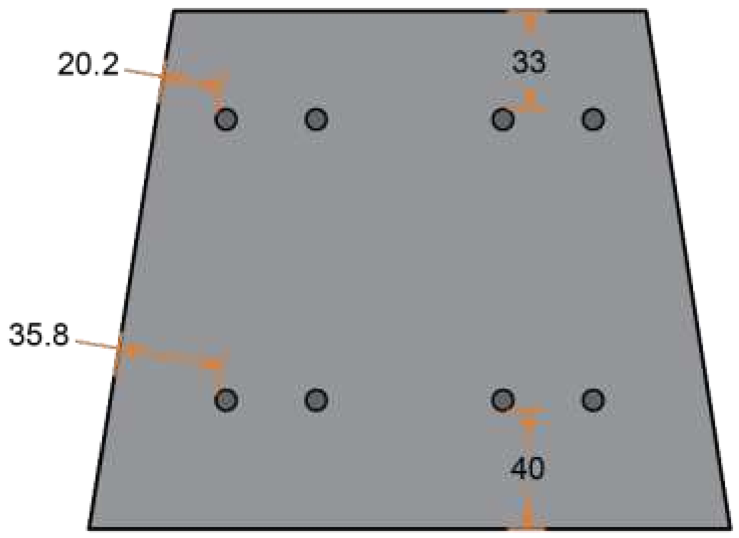
$$x = erf^{-1}\left(\frac{c_s - c_{cr}}{c_s - c_i}\right)\sqrt{4Dt} \quad , D = 7.622\left(\frac{0.25}{t}\right)^m$$

$$C_s = 1.76\sqrt{181.88\, t^{0.8}}$$

✓ $C_s = 0.27$ ✓ $C_{cr} = 0.068$ ✓ $C_i = 0.014$



Values for x_s



01

The cause of early and immediate cracking of concrete sleepers in desert areas is the corrosion of pre-stressed wires due to chloride ion penetration from the environment to the concrete structure.

02

Cracking and deterioration in concrete begin as a result of pre-stressed wires deterioration from the upper layer in the midspan of the B70 concrete sleeper and extends around

03

By developing the model and applying the coefficients, it is found that corrosion at the most critical section and nearest steel tendon to the surface, begins approximately 8.5 months after exposure.

04

The decrease in the chloride diffusion coefficient has a significant effect on the delay in corrosion initiation.

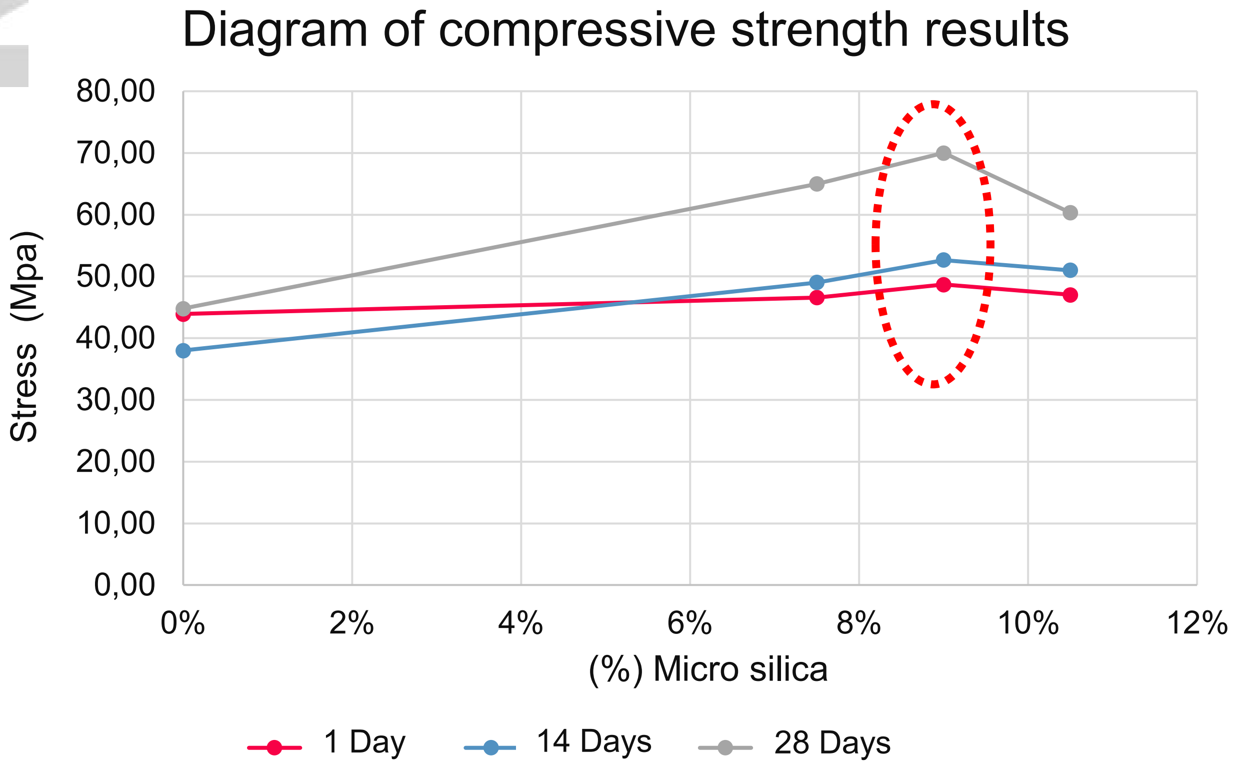
05

By decreasing the diffusion coefficient from **3.5** $(10^{-12}\frac{m^2}{s})$ to **0.5** $(10^{-12}\frac{m^2}{s})$, the onset of corrosion is delayed from **8.5** months to about **6** years for the first steel wire, with a **20.2** mm concrete cover. This reduction can be achieved by modifying the mixing design and adding cementitious supplementary materials such as silica fume.

06

The increasing concrete cover is recognized as an essential factor affecting the time of corrosion initiation. Increasing the concrete cover from **20** to **35** mm delays the corrosion initiation from **8.5** months to **2** years and **8.5** months. Although this factor alone is not sufficient, if combined with the reduction of the chloride diffusion coefficient, as a practical and reliable solution, it can improve the durability of concrete sleepers in terms of chloride-ion penetration and steel corrosion.

%0 %7.5 %9 %10.5



- The usage of micro silica decreased the flow up to 1.5 times the current flux.
- Due to the low water-to-cement ratio the reference sample showed relatively high resistance against the flux.

Sleepers in desert areas → Concrete ✓ / Prestressing wires

1. Infiltration coatings
2. Chemical vapor deposition coating
3. Galvanized coating
4. Epoxy Coated Rebar (ECR)
5. Hard chrome coatings
6. Electroless nickel-phosphorus coatings
7. Fantachrome plating coatings
8. Polyurea coatings
9. Dichromate coatings

✓ **Galvanized**, **ECR**, **Hard chrome,** and **Polyurea** coatings were chosen for further investigation.

(Salt-Spray)

According to **ASTM B117-18**: 120 hours of testing

Hard Chrome

Polyurea

Galvanized

?

(ECR)

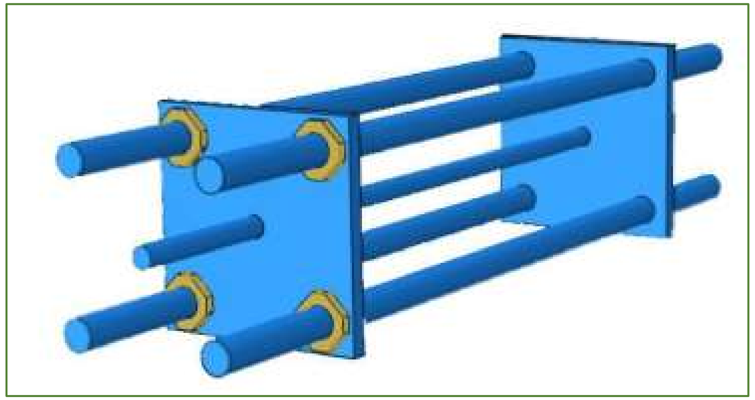
1 Samples in Normal Condition

700 hours of salt spraying

Sample NO.	Name	249 hour	384 hour	700 hour
1	**Hard chrome**	Corrosion in **2** points	**%5** of Corrosion	About **%80** of corrosion
2	**Galvanized plating**	Corrosion in **2 -3** spots	Several red points	Not specific change
3	**Al-rich (ECR)**	**%90** of Corrosion	%100 of corrosion	Completely corroded
4	**Zn-rich (ECR)**	intact	intact	intact
5	**Galvanized Spray**	Almost intact with white swelling	Some red spots detected	-

2 Samples in prestress Condition

700 hours of salt spraying



	24 hour	72 hour	144 hour	264 hour	700 hour
			Increasing	Increasing	Increasing the volume

Reference Sample

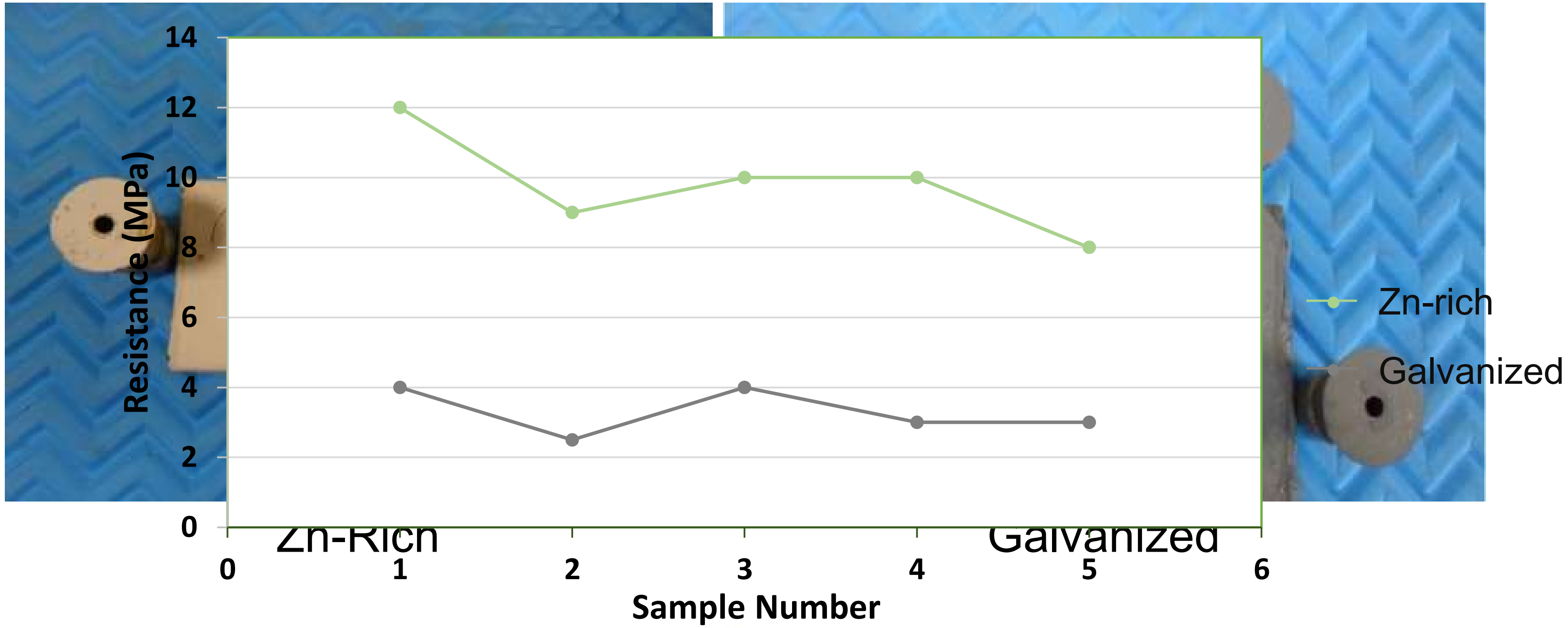
Zn-Rich

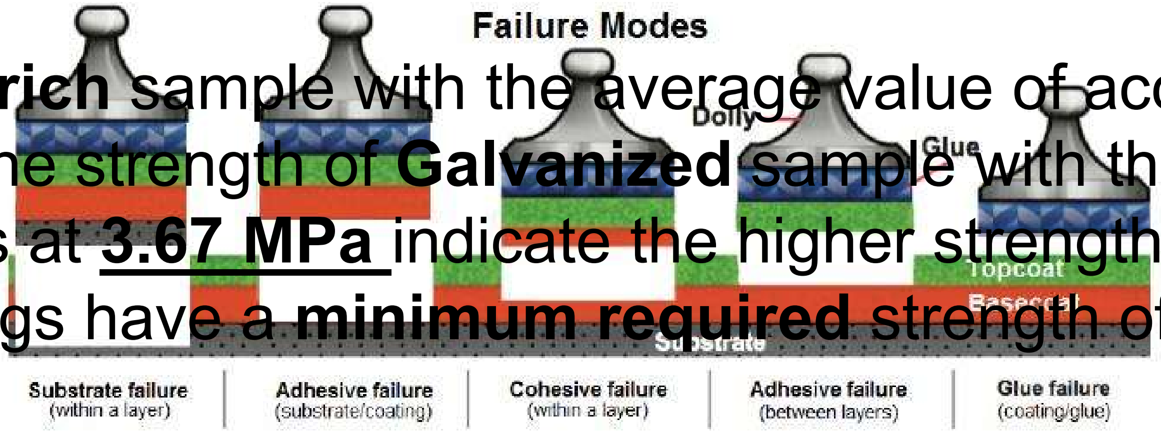
Galvanized Spray ✓

Galvanized Plating

3 Pull off Test

ASTM D4541





The strength values in **Zn-rich** sample with the average value of acceptable samples at **10 MPa** versus the strength of **Galvanized** sample with the average values of acceptable samples at **3.67 MPa** indicate the higher strength of **Zn-rich** coating. However, both coatings have a **minimum required** strength of **3.45 MPa**.

Coating for bars

4 Scratch Resistance Test

Zn-rich:

No scratches under the effect of concrete fall and acceptable

Galvanized:

Scratching and tearing that can be controlled by modifying the height of the concrete fall

Conclusion

1. Final selection of **9% Micro silica** as additive of Pozzolan to concrete mixing plan to reduce chlorine ion penetration and increase the compressive strength of concrete based on **RCPT** and **compressive strength tests.**

2. Selection of **Galvanized spray** and **Zn-rich** coating as a cost-effective and corrosion-resistant coating based on **pull-off** tests and **scratch resistance** and **spray salt**

3. According to the experiments, using Micro silica delays the corrosion initiation for about **2** years, and using any of the selected coatings increases the service life of the sleeper to normal sleepers' service lifetime (up to **50** years).

Thanks For Watching

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