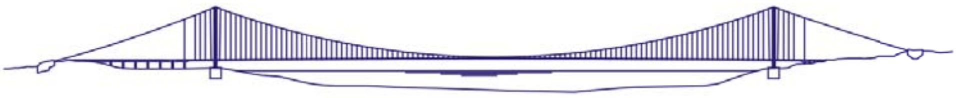
Stretto di Messina

Concessionaria per la progettazione, realizzazione e gestione del collegamento stabile tra la Sicilia e il Continente Organismo di Diritto Pubblico
(Legge n° 1158 del 17 dicembre 1971, modificata dal D.Lgs. n°114 del 24 aprile 2003)

EurolinK

PONTE SULLO STRETTO DI MESSINA



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INDICE

Abbreviations

AC	Alternating Current - corrente alternata
Bridge	Messina Strait Bridge
DC	Direct Current - corrente continua
EN	Europa Norm
PE	Conduttore di protezione
SI	System of Units
Ω	Ohm

1 Introduction

This report describes the preliminary evaluation of the risk of corrosion of embedded or exposed steel caused by stray currents from the electrically powered railway passing the bridge. Together with the evaluation is an assessment og possibility to quantify the magnitude of possible stray currents.

The evaluation is limited to the bridge between and including the terminal structures, and the anchor blocks. Structures outside these areas, as for example the viaduct approach structure on the Sicily side and other underground nearby structures and installations, are excluded owing to lack of data.

The report also proposes methods of monitoring the corrosion risk.

2 Conclusion and recommendation

A model for calculation of node voltages and line currents in a resistance network is developed and may be applied for quantification of the stray currents and identification of possible areas at risk of stray current corrosion, which require particular attention and monitoring.

The assessment of the magnitude of stray currents heavily depends on the quality of the input data, which should be verified. In addition a sensitivity analysis should be performed reflecting design and operating conditions.

It is recommended to include a corrosion monitoring system to detect

- General corrosion in the reinforced concrete structures
- Stray current corrosion

3 Sources of stray currents

The trains running on the railway on the bridge will be electrically powered from dedicated railway substations located on shore in Calabria and in Sicily.

The Italian railways use two traction power systems: traditionally 3 kV DC, and 25 kV AC for new high speed lines.

The traction power is distributed to the trains via an overhead catenary wire system and collected by the train engines by pantographs.

In the DC system, the rails in the railway track are insulated from the ground in order to reduce stray currents, and the traction current will ideally return back to traction substations via the electrically continuous rail system. However, because of unavoidable imperfections of the rail insulation, parts of the return current will find additional return paths, for example through the soil and through the bridge structure.

In AC traction systems the rails are usually not insulated from the ground for safety reasons. Owing to the bi-polar nature of the current the amount of corrosion caused by AC stray currents is much less than corrosion caused DC stray currents of the same magnitude.

The present study is based on the assumption that a 3 kV DC traction system is being applied.

4 Assessment of corrosion risk

The risk of corrosion from stray currents may be assessed by

- identifying the possible stray current paths
- estimating the magnitude of the stray currents

4.1 Identification of possible stray current paths

Stray currents that are escaping from the rails on the bridge and on the terminal structures because of imperfect rail insulation may reach the ground only through the concrete foundations of the towers, the terminal structures and the anchor blocks, and through the terminal structures' connections with the adjoining bridge decks.

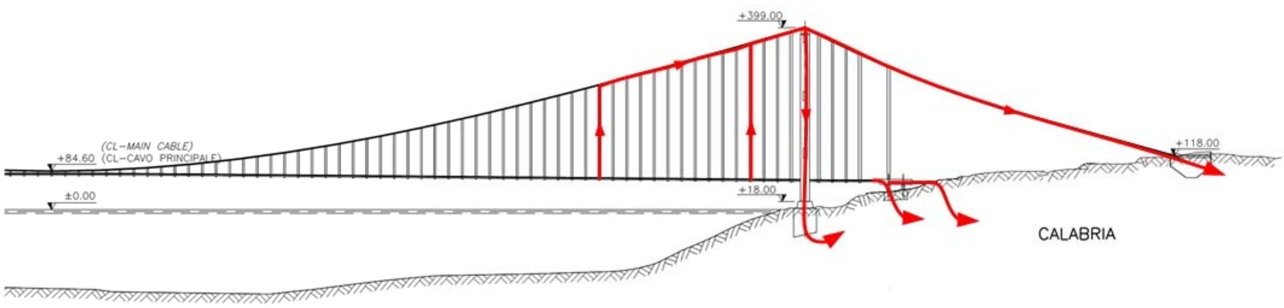

Figure 1: Illustration of possible stray current paths through structure - symmetrical for the Sicily side

Stray currents may also be picked up by the protective conductors and earthed cable screens of the electrical systems and cause overheating. It is recommended that the risk of such cable-borne stray currents are identified and mitigated.

4.1.1 Imperfect rail insulation

The rails on the steel deck of the bridge are planned to be insulated by applying an embedded rail system from Epilon:

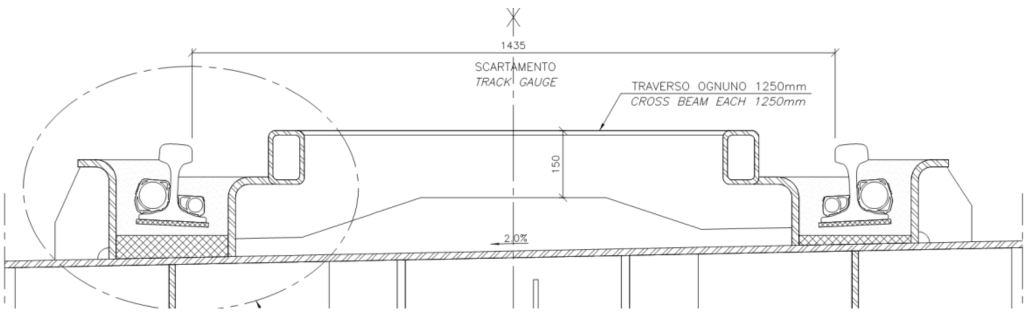

Figure 2: Embedded rails by the Epilon system

The rails are embedded in an insulating material which,according to Epilon's data sheet, should provide a rail insulation better than 5000 Ω.km corresponding to 0.2 x 10^{-3} S/km.

Electrical resistance or conductance	EN 50122-2	fully embedded	~0.2 x 10^{-3} ~5000	S km^{-1} Ω km	stray current protection
Electrical resistance	EN 13146-5	R_{33}	>5	kΩ	signalling insulation rail-rail

Even if this value is for one rail, i.e. that the insulation is 2500 Ω.km corresponding to 0.4×10^{-3} S/km for a two rail track, it is 1250 times better than the maximum value 0.5 S/km recommended by EN 50122-2:

Table 1: Recommended conductance per unit length *G'* for single track sections

Traction system	Open air *S* / km	Tunnel *S* / km
railway	0,5	0,5
Mass transportation system in open formation	0,5	0,1
Mass transportation system in closed formation	2,5	-

NOTE 1: The values given in table 1 are based on two running rails per track.

The length of the bridge between the terminal structures is 3.666 km corresponding to a theoretical insulation better than:

$2 \times 3.666 \times 0.4 \times 10^{-3} =$ 0.0029 S corresponding to 341 Ω for both tracks on the entire steel bridge.

This theoretical resistance value will decrease because of contamination on the surface of the Epilon insulation, for example by braking dust, abraded material from the rails and other dust and/or debris from the surroundings. Despite drain per 30 m, water and moisture will inevitably collect dust on the surface and provide a current path across the insulation.

The actual rail insulation value to be applied in the assessment of the stray currents depends on the amount of contamination and on the frequency of cleaning the rail bed.

Where the rails are crossing expansion joints in the bridge deck, i.e. at the terminal structures, the Epilon embedding system can not be applied. Instead traditional, insulating fixing systems are used. For these short lengths of track, the conductance value 0.5 S/km recommended by EN 50122-2 can be used for the assessment.

4.1.2 Metallic paths through the bridge structure

From the railway bridge girder the stray currents may flow in all parts of the steel bridge construction. The essential current paths identified are shown in the figure below.

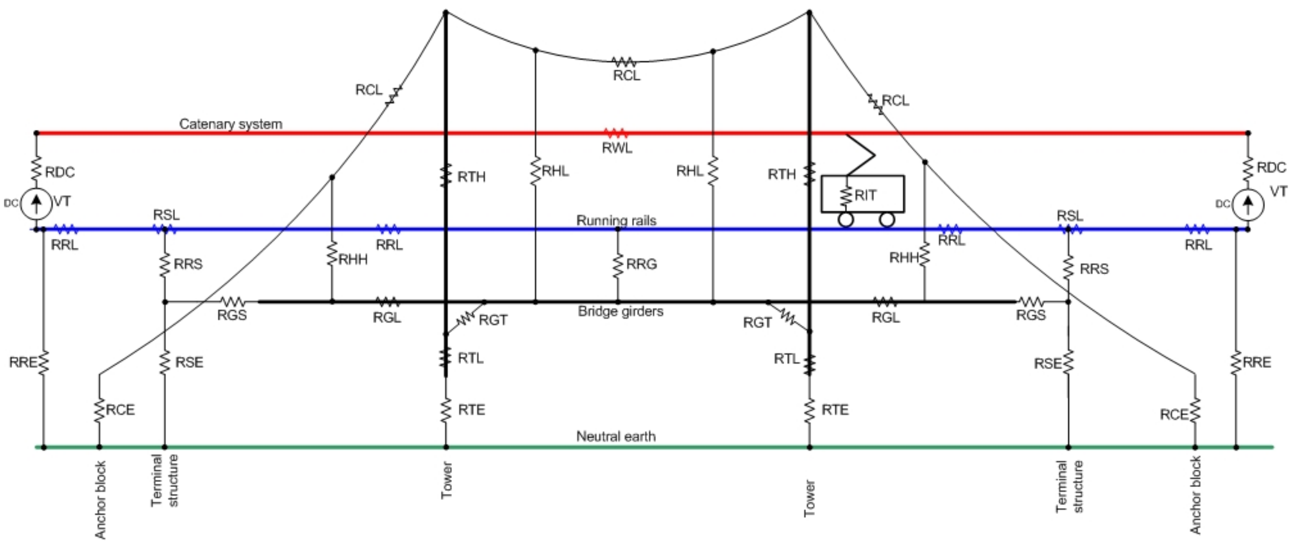

Figure 3: Resistances of essential current paths

From the detailed design drawings and reports the values of pertinent resistances have been identified, calculated or estimated for use in calculations for quantification of the stray currents under ideal conditions. Some of the values i.e. the resistance between track and bridge girder will be lower during operation where humidity builts across the insultation and dust is collected.

4.2 Calculation basis

Resistance values				
	Name	Calcu-lation number	Result	Unit
Resistance Main cables to earth, 4 cables (at each anchor block)	RCE	1	0.05	Ohm
Longitudinal resistance of main cables, 4 cables parallel	RCL	2	4.31E-05	Ohm/km
Internal resistance of traction power rectifier systems	RDC	3	0.1	Ohm
Longitudinal resistance of bridge girder, all girders	RGL	4	1.65E-04	Ohm/km
Resistance between bridge girders and terminal structure	RGS	5	0.5	Ohm
Resistance between bridge girders and towers, one tower	RGT	6	2.30E-05	Ohm
Resistance of hanger cables hangers 1-16 incl.	RHH	7	5.74E-04	Ohm/km
Resistance of hanger cables hangers 17-60 incl.	RHL	7	6.81E-04	Ohm/km

Load from a train, represented by the resistance of the load	RIT	8	2	Ohm
Resistance between tracks and earth, outside bridge 1 track	RRE	9	2	Ohm.km
Resistance between tracks and bridge girder 1 track	RRG	10	2500	Ohm.km
Longitudinal resistance of tracks, 1 track, 2 rails	RRL	11	0.01145	Ohm/km
Resistance track to terminal structure, 1 track	RRS	12	6.35	Ohm
Resistance to earth of terminal structure (same at Sicily and Calabria)	RSE	13	0.161	Ohm
Longitudinal resistance of tracks, 1 track, 2 rails at terminal structure	RSL	14	0.00155	Ohm
Longitudinal resistance of terminal structure (Same at Sicily and Calabria)	RSR	15	3.75E-06	Ohm
Resistance towers to earth, one tower	RTE	16	0.09	Ohm
Resistance of tower steel construction, above deck level, one tower	RTH	17	4.7E-06	Ohm
Resistance of tower steel construction, below deck level, one tower	RTL	18	1.9E-07	Ohm
Longitudinal resistance of catenary wire system, one system	RWL	19	0.037	Ohm/km

Table 1: Resistance values for calculation model

5 Quantification of results

A model for calculation of node voltages and line currents in a resistance network is developed and may be applied for quantification of the stray currents and identification of possible areas at risk of stray current corrosion, which require particular attention and monitoring.

The assessment of the magnitude of stray currents heavily depends on the quality of the input data, which should be verified.

Among the most essential data to be verified are:

- Traction system voltage
- Distance to the traction power substations
- Type of locomotives
- Frequency of train traffic
- Specific resistance of the soil

The resistance values given in Table 1 are preliminary and have been assessed/calculated as shown in chapter 7.

6 Proposed monitoring systems

6.1 Stray current corrosion monitoring

The mounting of the rails on the bridge in an insulating compound will by itself limit the magnitude of stray currents. The rail insulation may, however, occasionally fail or be shunted by debris or other foreign matter. Therefore it is strongly recommended that a corrosion monitoring system is designed for the Messina Strait Bridge including monitoring for detecting

- Corrosion as a result of stray currents
- Potential gradients to and from the bridge structures

It is also recommended that the voltage between rail and stray current mesh is monitored on a continuous basis, for example by statistical evaluation of the rail potential relative to the bridge structure.

The structures exposed to stray current corrosion are the reinforced concrete structures in contact with soil, i.e. the foundations for the towers and for the terminal structures, and the anchor blocks.

As the outside of these structures are practically inaccessible after construction, preparations for stray current monitoring should be established before backfilling.

The preparations should as a minimum comprise:

Provision of electrical continuity of the reinforcement bars

6.2 General corrosion and updating service life models

In addition to stray current corrosion monitoring it is strongly recommended that corrosion monitoring sensors are installed in the critical and most exposed sections of the structures. This will allow for the necessary performance verification and updating of the service life of the new structures. This will also become a validation of the design assumptions.

Today data acquisition units are commercially available, from where monitoring data can be transmitted via wireless communication to a central computer based monitor installation in the bridge service centre, for further evaluation by the bridge operating and maintenance personnel.

6.3 Monitoring sensors

The following type of monitoring is recommended:

- Corrosion monitoring sensors comprising of black steel electrodes, counter electrodes, reinforcement connections, reference electrodes and temperature sensors cast into the concrete structures at the time of construction
- Sense electrodes comprising steel electrodes located flush mounted on the external side of the foundations and anchor blocks
- Corrosion coupons cast into the concrete.

If calculations or simulations indicate very small risks of stray current corrosion, a fully fledged data acquisition system may not be initially needed. In such case the corrosion sensors should be connected to a position where regular manual data collection can take place, and where a central data acquisition system may be connected in the future, should the manual data indicate increased risk of corrosion.

7 Estimation of resistance values for calculation model

The resistance values given in Table 1 are calculated on the below basis.

	General parameters:						
	Specific resistance of steel, typical	175	Ω/km/mm^2				
	Specific resistance of copper, typical	18.5	Ω/km/mm^2				
	Specific resistance of the soil (stony and rocky ground) (ρ)	20	Ω.m				
Calc. no.							
1	**Resistance Main cables to earth, 2 cables (at each anchor block)**						
	Volume of 1 anchor block foundation						
	Length - with addition for corrugated bottom	100	m				
	Width addition for corrugated bottom	100	m				

	Buried height	50	m				
	Volume of one anchor block	500000	m^3				
	$R = 0.2\frac{\rho}{\sqrt[3]{V}}$ Resistance	0.05	ohm				
2	**Longitudinal resistance of main cables, 2 cables parallel**	Mainspan	Sicily	Cal.			
	Number of wires in one cable	44323	45847	45339			
	Wire diameter (mm)	5.4	5.4	5.4			
	Wire cross section (mm^2)	22.90221044	22.90221	22.90221			
	Total cross section one cable (mm^2)	1015095	1049998	1038363			
	Total cross section four cables (m^2)	4060380	4199992	4153452			
	Resistance 4 cables (ohm/km)	4.31E-05	4.17E-05	4.21E-05			
3	**Impedance of traction current substations**						
	Transformer impedance Z% is the primary voltage in % of the nominal voltage required to produce						
	the nominal secondary current on a secondary short-circuit.						
	Z%	5	%				
	Transformer size	5000	kVA				
	Primary nominal voltage	20000	V				
	Secondary nominal voltage	3000	V L-L				
	Secondary nominal current	962	A				
	Phase to Phase Impedance Voltage			150	V		
	Phase to Neutral Impedance Voltage			86.60	V		
	Impedance to produce	962	A at	86.60	V =	0.0900	Ohm / phase line
	Rectifier efficiency according to ABB	99.50%		at 2000A (assumed)			
	Nominal output power at	1500	A	3000	V	4500	kW
	Nominal input power at	1500	A output			4522.6	kW
	Secondary line current in 3-phase transformer @	3000	V L-L =	1732.1	V L-N	870.4	A
	Loss in transformer @	870.4	A			204.5	kW
	Total loss @	1500	A			227.2	kW
	Resistance of rectifiers + transformer	$R=P/I^2$	0.1010	Ohm, rounded		0.10	Ohm
4	**Longitudinal resistance of bridge girder, all girders**						

	Steel cross section of all girders	1060000	mm^2				
	Resistance	0.000165094	Ω/km				
5	**Resistance between bridge girders and terminal structure**						
	This is not possible to quantify because of the expansion systems						
	We estimate	0.5	ohm				
6	**Resistance between bridge girders and towers, one tower**						
	Electrical connection by 4 buffers						
	Diameter approx	500	mm				
	Thickness of piston pipe material, estimated	20	mm				
	Material cross section of one buffer, approx.	31416	mm^2				
	Length of one buffer	0.0165	km				
	Resistance of one buffer	9.2E-05	Ohm				
	Resistance of 4 buffers	2.3E-05	Ohm				
7	**Resistance of hanger cables**	total cross section of hanger cables		Resi-stance ohm/ km			
	Hangers 1-5	304648	mm^2	0.000574			
	Hangers 6-16	312036	mm^2	0.000561			
	Hangers 17-27	263076	mm^2	0.000665			
	Hangers 28-38	255684	mm^2	0.000684			
	Hangers 39-49	255684	mm^2	0.000684			
	Hangers 50-60	255684	mm^2	0.000684			
	Average hanger 1-16	305000	mm^2	0.000574			
	Average hanger 17-60	257000	mm^2	0.000681			
8	**Load from a train, represented by the resistance of the load**						
	A typical Italian locomotive E632 has a nominal power, P, of	4700000	W				
	Nominal voltage, V	3000	V				
	Current: P / V	1567	A				
	Resistance R: V^2/P	1.91	Ω, say	2	Ω		
9	**Resistance between tracks and earth, outside bridge 1 track**						
	According to EN 50122-2, section 5.2, the track insolation should be						
	better than:	0.50	S/km	per track			
	Converted to resistance	2.00	Ω.km	per track			

10	**Resistance between tracks and bridge girder 1 track**						
	According to Edilon data sheet, the resistance of one rail is	5000.00	Ω.km				
	The resistance of one track = two rails is	2500.00	Ω.km				
11	**Longitudinal resistance of tracks, 1 track, 2 rails**						
	One track comprise 2 rails UIC 60						
	Weight/m of one rail	60	kg/m				
	Weight/cm	600	g/cm				
	Density	7.85	g/cm^3				
	Cross section:	76.43312102	cm^2				
	Cross section:	7643.312102	mm^2				
	Specific resistance	175	$\Omega/km/mm^2$				
	Resistance of one rail	2.29E-02	ohm/km				
	Resistance of one track	0.0114	ohm/km				
12	**Resistance track to terminal structure, 1 track**						
	Length of terminal structure	0.09	km				
	resistance of plain track, 2 rails	22.22222	ohm				
	Because of 2 extra guide rails and extra steel dust we decrease this by	250	%				
	Resulting resistance	6.35	ohm				
13	**Resistance to earth of terminal structure (same at Sicily and Calabria)**						
	Resistance of foundations to earth						
	One corner block, width	18	m				
	One corner block, Length	25	m				
	One corner block, area	450	m^2				
	Connection block, length	18	m				
	Connection block, width	8	m				
	Connection block, area	144	m^2				
	4 corner blocks and two connections	2088	m^2				
	Buried depth	7	m				
	Buried volume	14616	m^3				
	Resistance	0.16	ohm				
	Copper down conductors, each	50	mm^2				
	Number of down conductors	16					
	Total copper cross section	800	mm^2				
	Length of down conductors	0.048	km				
	Resistance of down conductors	0.00111	ohm				
	Total resistance	0.161	ohm				
14	Longitudinal resistance of tracks, 1 track, 2 rails at terminal structure						
	Length of terminal structure, average	0.09	km				

	Resistance of 1 track over this length	0.001030313	ohm				
	Add for expansion joint	50	%				
	Total resistance	0.00155	ohm				
15	**Longitudinal resistance of terminal structure (Same at Sicily and Calabria)**						
	Steel cross section						
	Average height	6.8	m				
	Number of longitudinal bulkheads	13					
	Width	60.8	m				
	Length of steel cross section	210	m				
	Thichness of bulkhead plates average	20	mm				
	Steel cross section	4200000	mm^2				
	Length of terminal structure, average	0.09	km				
	Resistance	0.00000375	ohm				
16	**Tower foundations**	RTE					
	Volume of 1 tower foundation						
	Diameter	55	m				
	Buried height	17	m				
	Volume of two circular foundations (V)	80778	m^3				
	$R = 0.2\frac{\rho}{\sqrt[3]{V}}$ Resistance	0.09	ohm				
17	**Resistance of tower steel construction, above deck level, one tower**						
	length of steel in one cross section	126	m				
	Steel thickness, average	50	mm				
	Steel area in cross section	6300000	mm^2				
	Resistance, per km, one leg	2.77778E-05	ohm/km				
	Resistance, per km, two legs	1.38889E-05	ohm/km				
17	**Resistance of tower steel construction, above deck level, one tower**						
	Height	0.341	km				
	Resistance	4.73611E-06	ohm				
18	**Resistance of tower steel construction, above deck level, one tower**						
	Height	0.04	km				
	Resistance	1.89444E-07	ohm				
18	**Resistance of catenary wire**						
	One catenary system with contact wire and catenary wire						
	Approx. Cu cross section	500	mm^2				
	Resistance	3.70E-02	ohm/km				
