Stretto di Messina

Concessionaria per la progettazione, realizzazione e gestione del collegamento stabile tra la Sicilia e il Continente Organismo di Diritto Pubblico
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Eurolink

PONTE SULLO STRETTO DI MESSINA

PROGETTO DEFINITIVO

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INDICE

1 Executive Summary

This report describes the track superstructure system proposed for the railway on the Messina Bridge.

The railway line crossing the Messina Strait Bridge forms the link between the future high-speed line Salerno-Reggio Calabria and the Sicily lines Messina-Palermo and Messina-Catania, which is a part of the conventional network. In document GCG.F.03.03, article 3.2 it is required that the railway line must concord with the requirements of the category II of the Technical Specifications of Interoperability for High Speed (HS TSI INF - valid for lines specially adapted for high speed) of the order V=200km/h.

The basic parameters for the railway infrastructure are described in the TSI. All requirements are given for lines built with the standard European track gauge of 1435mm.

The specifications for cant, rate of change of cant, cant deficiency, rate of change of cant deficiency and track twist are applicable to lines having this nominal track gauge and are addressed in document CG.10.00-P-1S-D-P-SS-P2-FE-00-00-00-02 - Performance Specifications - Railway system.

For the Messina Bridge the main performance parameters are specified in the Design Basis as follows:

- axle load: max. 250kN
- line speed: 120km/h
- train length: 750m

Track arrangements

The tracks on the suspension bridge are built with continously welded rails (CWR) for the entire length of the bridge. At the transitions to the Terminal Structures at the extremities of the bridge rail expansion joints are provided in the tracks allowing for movements between the tracks on the suspended deck and on the Terminal Structure corresponding to ULS load cases. Between the Terminal Structures and the adjacent viaducts similar rail expansion devices are provided.

The railway lines on the adjacent viaducts are designed by the Landworks Designer (SINA) and it has been informed that the tracks here are ballasted tracks layed on concrete sleepers. For the tracks on the Terminal Structures a un-ballasted slab track system has been specified for direct attachment of the rails to the concrete slab by rail fasteners, type Vossloh or similar.

Rail fastening system on the bridge

An embedded rail fasteming system has been required in the Specifications for the Messina Strait Bridge (ref. F.04.01 para. 4.3.1) and was shown in the tender document issued by SdM October 2004. Several suppliers are available for embedded rail systems, however for this Progetto Definitivo the system Edilon Corkelast Embedded Rail System has been included and will be described in this document.

The Edilon Corkelast ERS is a slab track system (un-ballasted track system) which can be applied on bridge decks and in slab track sections on embankments, in level crossings and in tunnels. The ERS offers low construction height, low self weight and low noise and vibration radiation. Especially the low self weight is important for long span bridges.

On new steel bridges the most common application for the Edilon ERS is the use of steel channels mounted to the main girders or welded directly onto the deck plate. It consists of a rectangular steel channel where the rail is aligned and the free space around the rail is filled with cork rubber providing lateral and vertical support of the rail through bonding between the rail and the rubber and between the rubber and the steel channel. The cork rubber is cast in situ.

Other suppliers are available for embedded rail systems. Both the CDM system and the Bolidt system can be compared with the Edilon system. The embedded rail systems have been developed for tramways and light rail systems. The reference list from the company contains only three references with axelload over 20 ton. The longest installation is in a tunnel in France, where the system have been used in concrete trenches in the tunnel floor.

Verification of steel channels

The Edilon ERS is installed in steel channels integrated in the steel deck of the railway girder.The channels are fabricated from rolled steel plate which are welded to the deck plate by continuous double-sided fillet welds. Check rails have been integrated in the inner channels. The inner channels are interconnected by welded cross beams at regular intervals in order to ensure that possible derailment loads are distributed to both channels.

Loads on the track fastening system are defined in HS TSI INF, section 4.2 with reference to Eurocode EN 1991-2: Traffic loads on bridges and in document CG.10.00-P-RG-D-P-GE-00-00-00-00-00-02 - Design Basis, Structural. These loads, comprising wheel loads, braking and acceleration loads nosing loads and de-railment loads shall be transferred from the rail through the rail fastening system and the steel channels to the railway deck.

3D finite element models have been prepared for the verification of the steel channels and acceptable stresses have been found for both the outer and the inner channel, the integrated check rail and the cross beams. The stability against buckling of the steel channels have been verified and found acceptable. Further, the resistance to fatigue caused by repeated loading of the outer steel channel has been assessed and found adequate.

Protection against de-railment and overturning

The derailment protection is provided through guard rails integrated in the steel channels for the Edilon ERS. The derailment protection comprises continuous rectangular hollow steel sections welded to the inner channels, interconnected at regular intervals.

Along the railway tracks emergency walkways are installed. As an integrated part of the walkways a crash barrier is provided as protection against overturning of rolling stock in form of a continuous rectangular hollow section. As the walkway and thus the crash barrier is supported at regular intervals along the bridge (center distance is 1875mm) the loads from a possible overturning railway vehicle will be distributed on several posts.

The crash barrier has been designed to resist a load of 150kN acting 0.76m above TOR and placed at any position along the walkway. For the detailed design of the walkway and the crash barrier reference is made to doc. CG10.00-P-CL-D-P-SS-R4-00-00-00-00-01 - Design Report - Secondary Structures.

Evacuation of rain water from railway deck

In order to be able to evacuate rain water from the railway deck openings are provided in the steel channels at intervals of 30m allowing the water to flow towards the gullies provided near the edge of the deck. The minimum opening will be 250mm. At these positions the rails will be un-supported over a distance of 300-350mm, which is similar to the unsupported distance in tracks with sleepers.

The opening will further provide sufficient space to facilitate welding of the rail during installation and during future maintenance works.

Installation of embedded rail system

The installation of the steel channels including check rail profiles and cross beams is done at the workshop, where the steel bridge sections are manufactured. Sufficient care shall be given to the positioning of the channels in order to ensure adequate installation tolerances for the track after erection and welding of the bridge girders.

The installation method comprises partially industrialized embedding processes requiring preparation of the bonding surfaces, accurate positioning of the rails and correct conditions for pouring of the Corkelast materials.

Installation and adjustment of the rails is proposed to be done using a top-down method by means of rail installation portals, supporting the rail in the correct position by attaching to the head of the rails. The resilient strips are attached to the underside of the rail. When the rails are in correct position the Edilon Corkelast is poured and hardening will take place. The setting time is approximately 2 hours.

The rate of installation varies naturally with the methods applied. For the Messina Bridge mechanized procedures for placing of rails and pouring of the Corkelast materials will be envisaged and it is expected that a installation rate of approximately 150m track per day can be obtained.

Maintenance and replacement

Maintenance and replacement of the Edilon ERS consists of a number of different activities. In a number of these operations, removal and renewal of the ERS may be required. In case of renewal the old Edilon Corkelast ERS needs to be removed and replaced with new material into the existing steel channel. All maintenance and renewal methods re-establish the performance and durability of the Edilon ERS.

Maintenance work can be done either as preventive maintance or as corrective maintenance.

Track/bridge interaction

Interaction between tracks and bridge, i.e. the consequence of the behaviour of one on the behaviour on the other, occurs because the tracks and the bridge are interlinked through the rail fastening system. The interaction takes form of forces in the rails and in the deck as well as displacements of the various elements of the tracks and the bridge.

The interaction must be taken into account as a serviceability limit state (SLS) for the bridge as well as being an ultimate limit state (ULS) load case for the rails. Forces and displacement will be calculated using the partial safety factors for the loads concerned.

The verification of the track/bridge interaction is be done in accordance with the recommendations in UIC Code 774-3 comprising effects from temperature difference between rail and deck, effects from braking and acceleration of trains and effects from local and global bending of the bridge deck. It has been found that relative movements of the rail due to temperature difference and acceleration/braking of trains are within acceptable limits. Further, it has been found that the additional stresses introduced in the rail due to bending of the bridge deck also are acceptable and in accordance with the requirements in UIC Code 774-3.

The stability of the embedded rail to resist longitudinal stresses caused by uniform temperature differences between the rail and the deck has been assessed. A FEM model has been established modelling a part of the embedded rail including initial deflections of the rail. The elastic support of the rail in lateral and vertical directions are modelled by support springs with stiffness corresponding to values obtained by tests. The stability is found adequate.

Railway expansion joints

The tracks on the suspension bridge are consisting of continously welded rails (CWR) for the entire length of the bridge. In order to allow for relative movements in the longitudinal direction between the suspended bridge and the Terminal Structures rail expansion joints are provided in the tracks Between the Terminal Structures and the adjacent viaducts similar rail expansion devices are provided.

The expansion devices have been designed for the movements calculated for the ULS load cases.

The expansion device comprise rail adjustment switches accommodating the relative longitudinal movements without increasing the track gauge. In the gap between the adjoining structures the rails are supported on a number sledges which are interconnected in order to obtain equal distance between the sledges.

The railway expansion joints are addressed as a part of the Articulation and auxiliary systems and reference is made to document no. CG.10.00-P-RX-D-P-SS-A0-00-00-00-00-01 - Articulation, Specialist Technical Design Report for further information.

Analysis of rail noise

An analysis of the noise from the railway has been carried out. Vibrations in the tracks will be transmitted to the steel structure when a train is passing and the steel box girders will then emit the vibrations as airborne noise.

This structure-borne noise is added to the usual airborne noise from the train's wheels, engine and braking systems. The analysis focus on determining the amount of additional noise transmitted from the bridge structure in comparison to the expected airborne train noise.

It has been found that the noise level from train traffic on the bridge will be dominated by the structure-borne noise, which is expected to be approximately 5 dB higher than the airborne noise.

For positions at lower heights the differences might be larger, because of the edges of the bridge screening the airborne train noise to a higher degree. At positions close to and under the bridge the total noise can be expected to be completely dominated by the structure borne noise.

2 Introduction

2.1 Scope

This report describes the track superstructure system proposed for the railway.

This Specialist Technical Design Report focuses primarily on the fastening system for the railway tracks.

This report is organized into the following sections:

- Section 2 includes this introduction, provides a list of reference materials, including design specifications, design codes, material specifications, reference drawings and complementary reports
- Section 3 provides descriptions of the basic parameters of the infrastructure subsystem corresponding to the essential requirements
- Section 4 describes the fastening system proposed in the design.
- Section 6 describes the proposed testing operations required to obtain approval of the rail fastening system.
- Section 7 describes issues regarding track/bridge interaction.
- Section 8 describes other railway installations.

2.2 References

2.2.1 Design Specifications

GCG.F.04.01 “Engineering – Definitive and Detailed Design: Basis of Design and Expected Performance Levels,” Stretto di Messina, 2004 October 27.

CG.10.00-P-RG-D-P-GE-00-00-00-00-00-02 - Design Basis, Structural

European Union, Directive 96/48/EC - Interoperability of the Trans-European High Speed Rail System, Technical Specification for Interoperability, 2008.

UIC recommendation for design and calculation of ballastless track, UIC 2008

2.2.2 Design Codes

EN 13481 part 1and 5:	Railway applications - Track - Performance requirements for fastening systems
EN 13146 part 1 - 8:	Railway applications - Track - Test methods for fastening systems.
EN 13232 part 1 - 9:	Railway applications - Track - Switches and crossings (expansion devices).
ENV 13803 part 1:	Railway applications - Track alignment design parameters - Track gauges 1435 mm and wider - Part 1 : Plain line
EN 13848 Part 1 - 5:	Railway applications - Track geometry quality

2.2.3 Material Specifications

EN 13232 part 1 - 9:	Railway applications - Track - Switches and crossings (expansion devices).
EN 13674 part 1 :	Railway applications - Track - Rail - Part 1: Vignole railway rails 46kg/m and above
EN 10025 - 4	Hot rolled products of structural steel - Part 4: Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels

2.2.4 Reference documents

CG.10.00-P-1S-D-P-SS-P2-FE-00-00-00-02	Performance Specifications - Railway system
A9055-MEM-6-003	Test requirements for embedded rail system
A9055-NOT-6-002	Analysis of rail noise transmitted from bridge elements

2.2.5 Drawings

CG.10.00-P-BX-D-P-SS-P2-FE-00-00-00-01	Railway system, General Layout
CG.10.00-P-BX-D-P-SS-P2-FE-00-00-00-02	Railway system, Details (1)
CG.10.00-P-BX-D-P-SS-P2-FE-00-00-00-03	Railway system, Details (2)

3 Basic parameters of the infrastructure subsystem

The railway line crossing the Messina Strait Bridge forms the link between the future high-speed line Salerno-Reggio Calabria and the Sicily lines Messina-Palermo and Messina-Catania, which is a part of the conventional network.

In the contract document GCG.E.01.11, article 4.2 it is stated that the railway infrastructure shall be designed and built in compliance with the Technical Specifications of Interoperability (TSI) of the European High Speed (HS TSI) Railway System. Further, in document GCG.F.03.03, article 3.2 it is required that the line must concord with the requirements of the category II of the TSI for High Speed (lines specially adapted for high speed) of the order V=200km/h.

3.1 Technical Specifications of Interoperability (TSI) of the European High Speed (HS) Railway System

The trans-European high speed railway system, to which Directive 2008/57/EC applies and of which the infrastructure and maintenance subsystems are parts, is an integrated system whose coherence must be verified, with the objective of assuring the interoperability of the system in respect of the essential requirements.

Article 5 (4) of the Directive says “the TSIs shall not be an impediment to decisions by the Member States concerning the use of infrastructures for the movement of vehicles not covered by the TSI's”.

Therefore, when designing a new or upgraded high speed line, consideration should be given to other trains, which may be authorised on the line.

The limiting values set out in the present TSI are not intended to be imposed as usual design values. However, the design values must be within the limits set out in the TSI.

The functional and technical specifications of the subsystem and its interfaces, described in sections 4.2 and 4.3 in the TSI, do not impose the use of specific technologies or technical solutions, except where this is strictly necessary for the interoperability of the trans-European high speed rail network. But innovative solutions for interoperability could require new specifications and/or new assessment methods. In order to allow technological innovation, these specifications and assessment methods shall be developed by the process described in sections 6.2.2.

3.1.1 Requirements for Basic Parameters

The basic requirements are described in the paragraphs in the TSI.

All requirements are given for lines built with the standard European track gauge of 1435 mm.

The specifications for cant, rate of change of cant, cant deficiency, rate of change of cant deficiency and track twist are applicable to lines having this nominal track gauge.

Requirements are described for the subsystem under normal service conditions. Consequences, if any, of the execution of works, which may require temporary exceptions as far as the subsystem performance is concerned, are dealt with in section 4.4 in the TSI.

The performance levels of high speed trains can be enhanced by adopting specific systems, such as vehicle body tilting. Special conditions are permitted for running such trains, provided they do not entail restrictions for other trains not equipped with such systems.

Reference is made to document CG.10.00-P-1S-D-P-SS-P2-FE-00-00-00-02 - Performance Specifications - Railway system for assessment of the basic parameters as set out in HS TSI chapter 4.

3.2 Functional and technical specifications of infrastructure subsystem

3.2.1 Categories of Line

The requirements to be met by the Infrastructure Subsystem are specified for each of the following Categories of Line of the trans-European high speed rail system, as relevant.

- Category I: specially built high-speed lines equipped for sppeds generally equal od greater that 250km/h.

- Category II: specially upgraded high-speed lines equipped for speeds of the order of 200km/h.
- Category III: specially upgraded high-speed lines or lines specially built for high speed, which have special features as a result of topographical, relief, environmental or town-planning constraints, on which the speed must be adapted to each case.

All categories of lines shall allow the passage of trains with a length of 400m and a maximum weight of 1000t.

For the Messina Strait bridge the line shall conform to category II above.

The Category of Line for every section of track shall be published in the Register of Infrastructure.

3.2.2 Performance parameters

The performance levels of the categories of lines defined in section 3.2.1 are characterised by following performance parameters:

- Kinematic gauge (free envelope)
- Axle load
- Line speed
- Permissible train length

New and upgraded lines on the trans-European high speed rail system shall be designed to have at least the performance levels set out in section 4.2 of the TSI.

It is permissible to design new and upgraded lines such that they will also accommodate larger gauges, higher axle loads, greater speeds and longer trains than those specified.

The TSI's shall not be an impediment to decisions by the Member States concerning the use of infrastructures for the movement of vehicles not covered by the TSI's.

For the Messina Bridge the main performance parameters are specified in the Design Basis. as follows:

- Kinematic gauge: UIC GC, see below
- Axle load: max. 250kN

- Line speed: 120km/h
- Train length: 750m

Article 5, Point 7 of Directive 2008/57/EC states:

Infrastructure designed to the minimum requirements of the TSI does not provide the capability to meet both maximum speed and maximum axle load in combination. The infrastructure is only capable of being exploited at maximum speed for axle loads less than the maximum set out, and similarly the infrastructure is only capable of being exploited at maximum axle load for speeds less than the maximum.

The free envelope to be used is in general the P.M.O No. 1 - (Gabarit C – Nuovo impianto), but on the bridge, as required by RFI on all railroad bridges, there must be provided additional clearance of 300 mm and 500 mm in the area above the level PF + 700 mm. The resulting free envelope is shown in the figure below.

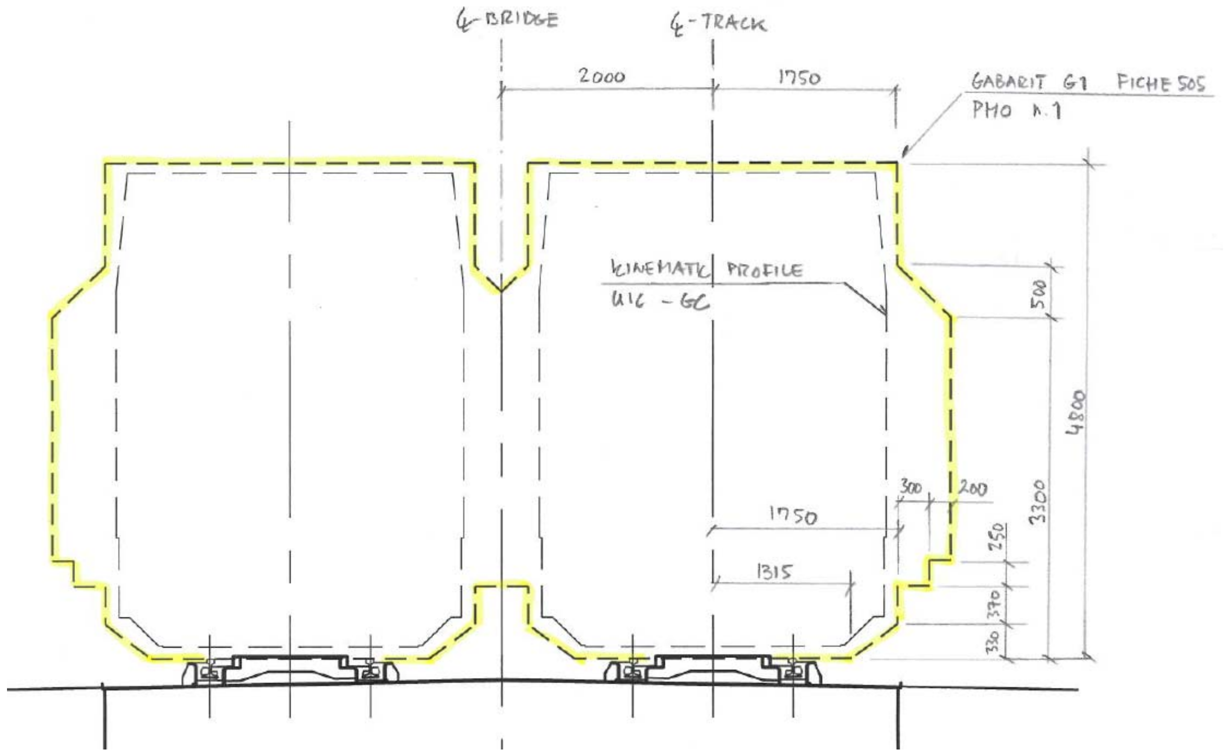


Figure 1 Free envelope on the Bridge

3.2.3 The European TEN net in Italy

3.10

4 Track arrangements

The railway line crossing the Messina Strait Bridge forms the link between the future high-speed line Salerno-Reggio Calabria and the Sicily lines Messina-Palermo and Messina-Catania.

The tracks on the suspension bridge are consisting of continously welded rails (CWR) for the entire length of the bridge. At the transitions to the Terminal Structures at the extremities of the bridge rail expansion joints are provided in the tracks allowing for movements between the tracks on the suspended deck and on the Terminal Structure corresponding to ULS load cases. Between the Terminal Structures and the adjacent viaducts similar rail expansion devices are provided.

The railway lines on the adjacent viaducts are designed by the Landworks Designer (SINA) and it has been informed that the tracks here are ballasted tracks layed on concrete sleepers. For the tracks on the Terminal Structures a un-ballasted slab track system has been specified for direct attachment of the rails to the concrete slab by rail fasteners, type Vossloh or similar.

5 Rail Fastening System on the Bridge

An embedded rail fasteming system has been required in the specifications for the Messina Strait Bridge (ref. F.04.01 para. 4.3.1). Several suppliers are available for embedded rail systems, however for this Progetto Definitivo the system Edilon Corkelast Embedded Rail System (ERS) has been shown and will be described below.

5.1 Description

This embedded rail fastening system was originally shown in the tender document issued by SdM October 2004 and hereafter included in the contractors Tender Design drawings from May 2005.

The Edilon Corkelast ERS is a slab track system (un-ballasted track system) which can be applied on bridge decks and in slab track sections on embankments, in level crossings and in tunnels. The ERS offers low construction height, low self weight and low noise and vibration radiation. Especially the low self weight is important for long span bridges.

On new steel bridges the most common application is the use of steel channels mounted to the main girders and bolted or welded directly onto the deck plate. It consists of a rectangular steel channel where the rail is aligned and the free space around the rail is filled with cork rubber providing vertical and lateral support of the rail through bonding between the rail and the rubber and between the rubber and the steel channel. The cork rubber is cast in situ.

In Appendix 2 is included a general description from Edilon Sedra of the Edilon Corkelast ERS.

5.2 Characteristics of the Edilon ERS

5.2.1 Vertical stiffness

The vertical stiffness is tuned to approximately 1.5mm under nominal axle load. The actual value will be measured in the test program, see Section 6 below.

5.2.2 Uplift resistance

The uplift resistance of the ERS is necessary to withstand the applied live loading without damage to the system. Uplift is defined as a relative vertical displacement of the rail relative the steel channel. Uplift shall be limited to 3mm.

The uplift is provided through bonding of the resin to the rail and steel channels respectively. The bonding is ensured by correct cleaning of the surfaces and application of a special primer to the rail and the steel channel.

5.2.3 Lateral stiffness and stability

The lateral rail head movement of the ERS is limited to 2mm in the outer direction under nominal static single wheel load. This relative displacement of the rail relative to the steel channel is measured 14mm below the TOR.

In EN 13481-5 and EN 13146-4 the load conditions and test methods are specified for the testing of the resistance to repeated loadings and and angular loading. At the nominal loading level these tests can be used to measure the lateral stiffness and stability. The lateral stiffness and stability and the resistance to repeated loading will be measured in the test program, see Section 6 below.

5.2.4 Longitudinal stiffness and maximum rail displacements

For ERS a longitudinal movement of ±7mm relative to the steel channel can be tolerated without damage to the fastening system. The resistance of the fastening system varies between unloaded and loaded tracks. The expected values for the longitudinal stiffness are given below:

	Longitudinal stiffness [kN/mm per m track]	Maximum rail displacement [mm]
ERS unloaded	13	7
ERS loaded	19	7

Table 1 Longitudinal stiffness of ERS

The longitudinal stiffness will be measured in the test program, see Section 6 below.

5.2.5 Electrical insulation

The electrical insulation for ERS fulfil the requirements in EN 13481-5 (> 5Ω) and will be measured as a part of the test program, see Section 6 below.

5.3 Steel channels on railway girder

The ERS is installed in steel channels integrated in the steel deck of the railway girder as shown in the figure below:

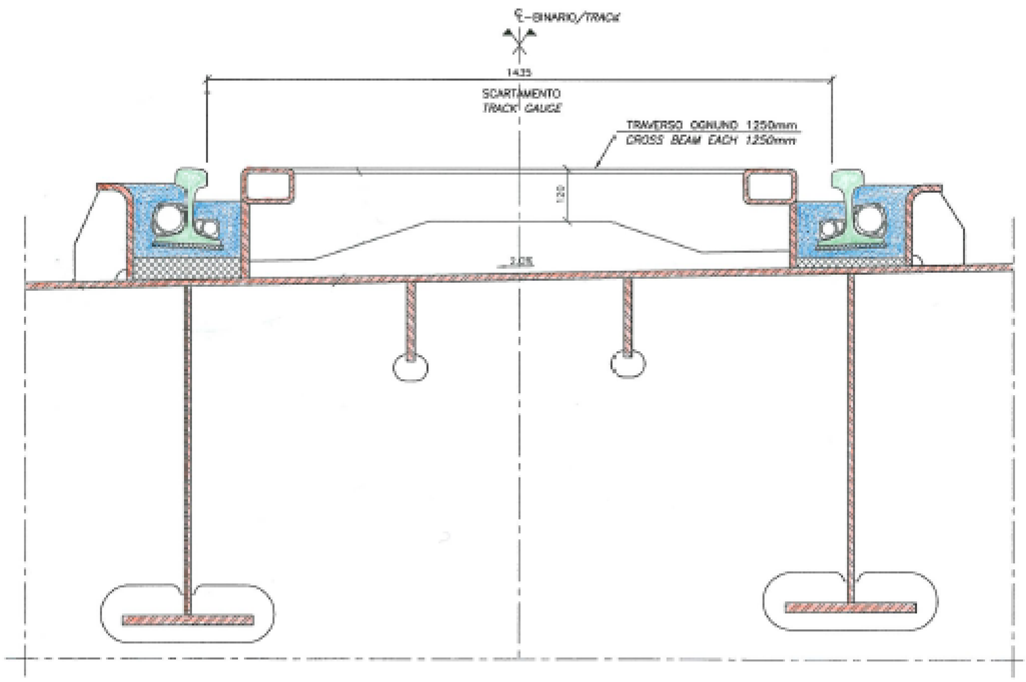


Figure 2 Embedded rail system (ERS) on steel railway girder

The channels are fabricated from rolled steel plate (S460) which are welded to the deck plate by continuous double-sided fillet welds. The check rails comprise a continuous rectangular hollow steel section (S460) welded to the inner channels. The inner channels are interconnected by welded cross beams (S355) at regular intervals in order to ensure that possible derailment loads are distributed to both channels.

5.3.1 Loads on channels

The design criteria are defined in the document CG.10.00-P-RG-D-P-GE-00-00-00-00-00-02 - Design Basis, Structural. The design loads on the railway structures are the following:

- Vertical loads: see Figure 3 below
- Longitudinal - traction: 33(kN/m) x L(m), max. 1000kN
- Longitudinal - braking: 20(kN/m) x L(m), max. 6000kN (LM71, SW/0)
  35(kN/m) x L (m) (SW/0)
- Nosing: 100kN, applied at the top of the rail

The loads above shall be multiplied with α=1.1.

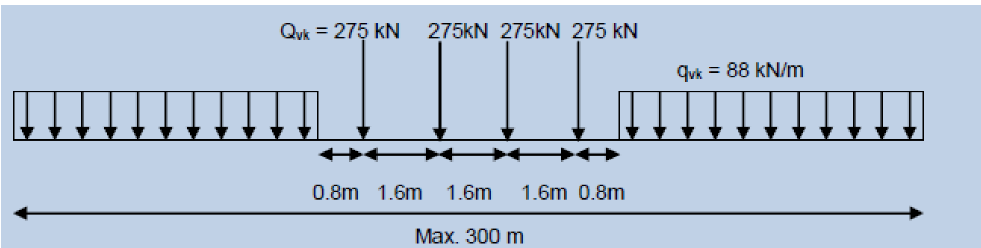


Figure 3 Load model 71 including α=1.1

Loads on the track fastening system are defined in HS TSI INF, section 4.2 with reference to Eurocode EN 1991-2: Traffic loads on bridges.

The loads acting on the channels are shown in the figure below.

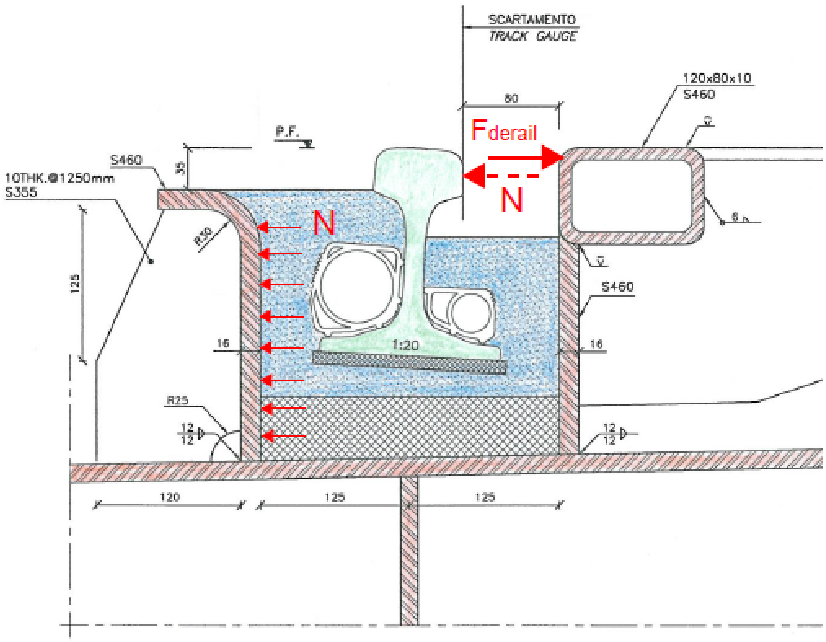


Figure 4 **Loads on channels**

Outer channel:

The nosing force acting on the rail will be transferred through the rail and Corkelast material to the outer channel. Even though the load acting on the rail is concentrated to the point of contact the load will be distributed over a larger area of the channel due to the stiffness of the rail and the elastomeric material. In order to assess the load introduction onto the outer channel a simplified FEM model has been prepared introducing a pair of lateral nosing loads with a distance of 1600mm acting laterally to the rail, which is supported by springs with a stiffness corresponding to the stiffness of the Corkelast (18kN/mm·m, see section 7.2). The resulting reactions from the Corkelast is shown in the figure below.

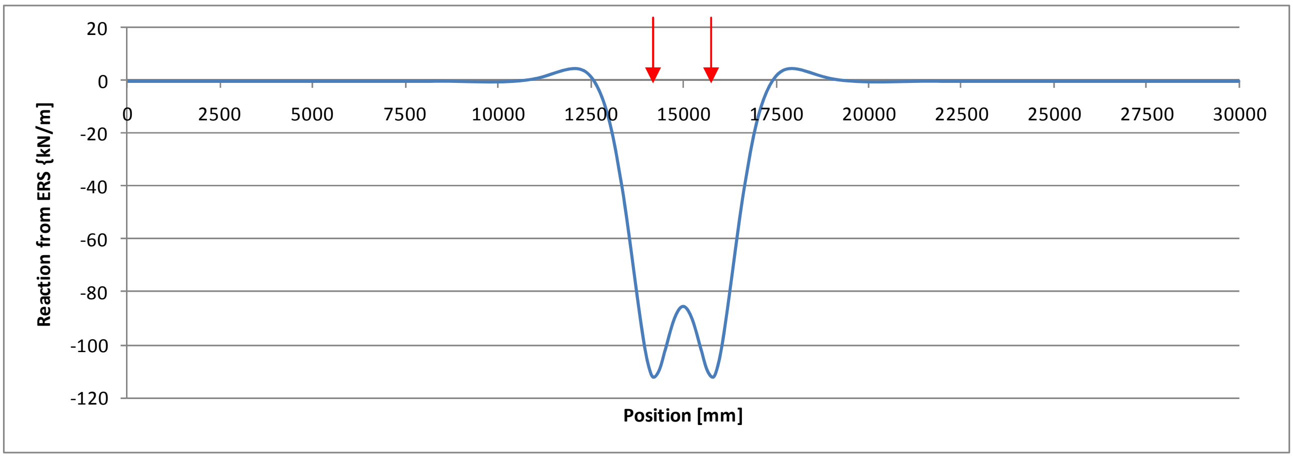


Figure 5 Calculated reactions from the ERS

From the figure above it is found that the distributed length in the longitudinal direction conservatively can be estimated to minimum 1000mm. In the verification of the outer channel, however, the nosing load is assumed to be distributed over an area of 100mm x 200mm.

The nosing load is coexisting with the vertical load from the wheel and is spaced 1600mm along the rail. The applied static nosing load is:

$N = \alpha \cdot \gamma_f \cdot 100kN$, where $\alpha = 1.1$ and $\gamma_f = 1.4$

=> $N = 154kN$

The nosing load will always be coexisting with the vertical wheel load. As the Corkelast is bonded to the steel deck plate the minimum coefficient of friction between the Corkelast and the deck plate can be assumed to be μ = 0.5-0.7. Conservatively, the nosing load applied to the outer channel is set to:

$N = 154kN - 0.5 \cdot 1.1 \cdot 125kN = 85kN$

Inner channel:

Derailment protection has been integrated in the inner channel structure in the form of a continuous steel profile acting as check rail. Horizontal derailment loads have been applied to the check rail spaced 1600mm along the rail. The lateral loads have been distributed in the longitudinal direction over a length of 300mm taking into account the extent of the wheel in contact with the check rail profile. Further, stresses due to global actions calculated by the global FEM model have been introduced.

The following loads have been applied:

F_{derail} = 175kN (distributed over a length of 300mm)

5.3.2 Verification of stresses in channels

For the verification of the steel channels local 3D models for outer and inner channels have been established using the software ROBOT. The structures have been modelled using shell elements.

The loads described in 5.3.1 have been applied and superimposed with stresses due to global actions on the bridge calculated using the global IBDAS model. Combined v.Mises stresses have be calculated.

Outer channel:

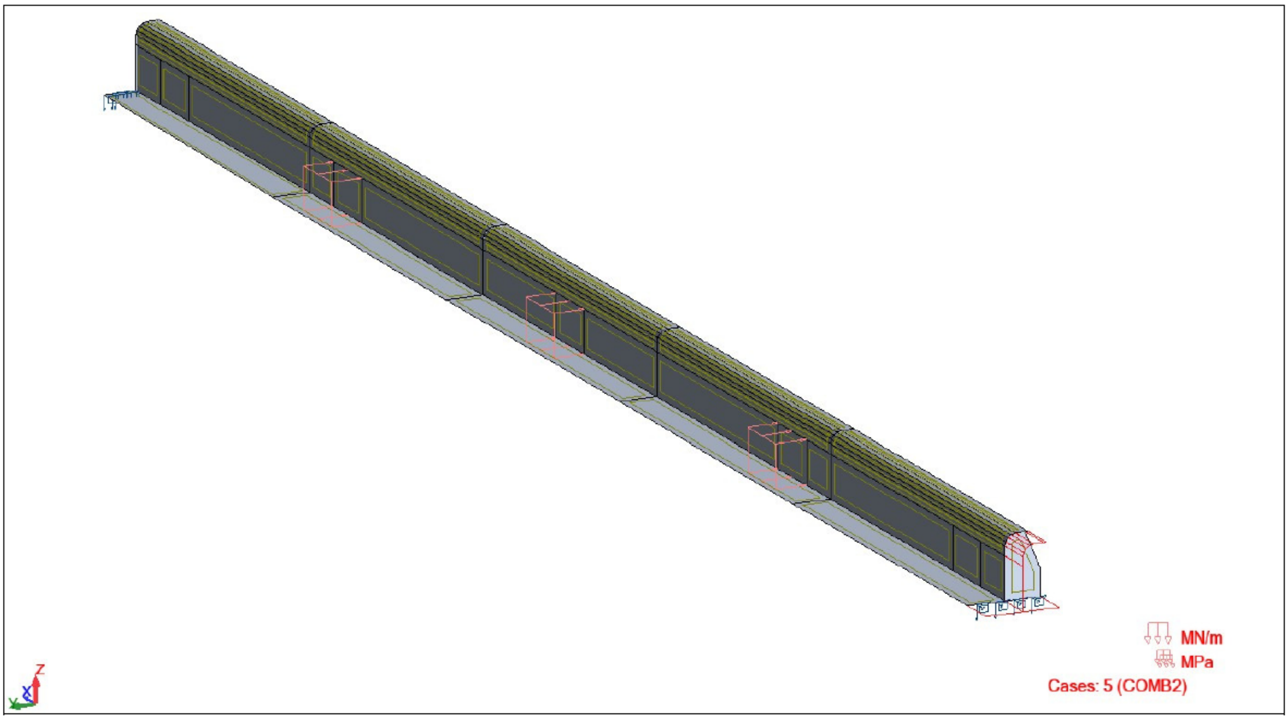
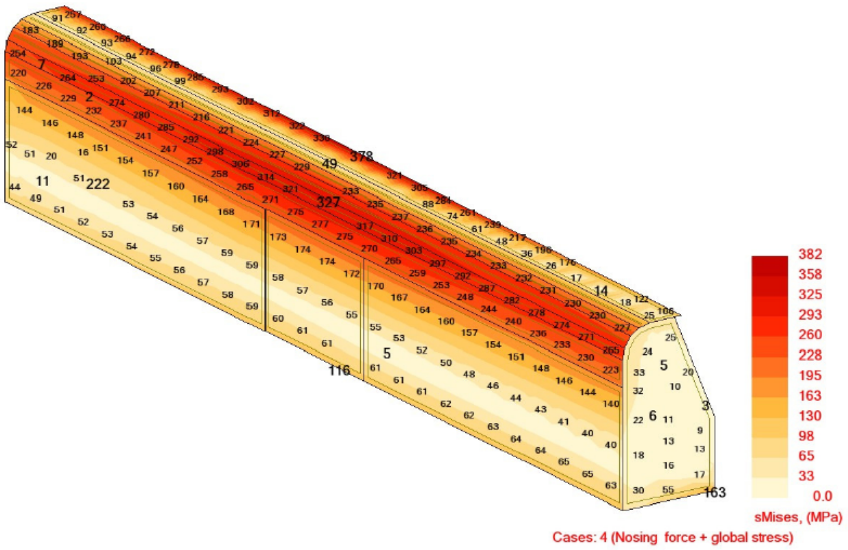


Figure 6 Outer channel - 3D model



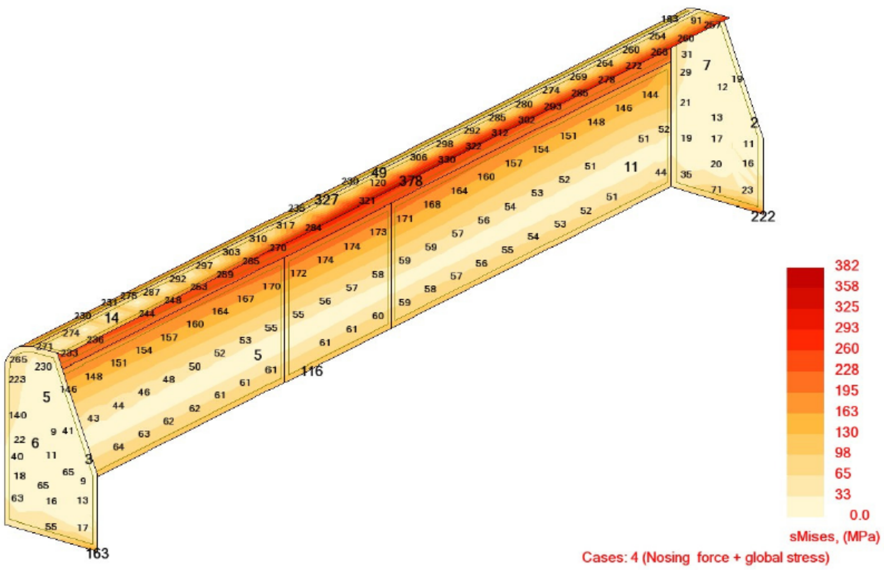


Figure 7 Calculated stresses in outer channel

The maximum combined peak stress is found at the top edge of the flange at the position of the load and is found locally to be approximately 327MPa. At the connection of the channel to the deck plate the calculated stress amounts to 115MPa.

The nosing load is the maximum static load to be applied for the design of the steel channel. The fatigue resistance has been assessed below and will be verified during the testing of the embedded rail system.

As a part of the tests carried out at Politecnico di Milano the stresses in the outer channel has been measured using strain gauges for combinations of vertical and lateral loads. The maximum stress is found for V=200kN and L=100kN at the inner side of the rail containment plate app. 6.5mm above the weld to the deck plate. Here the stress is measured to 60MPa, which is considerably less that theoretically calculated. This is considered to be due to the nature of the embedded rail system, where a large part of the lateral loads is transferred to the sides and the bottom of the confinement through shear in the resin. A preliminary report of the tests results is included in Appendix 6.

Inner channels and cross beams:

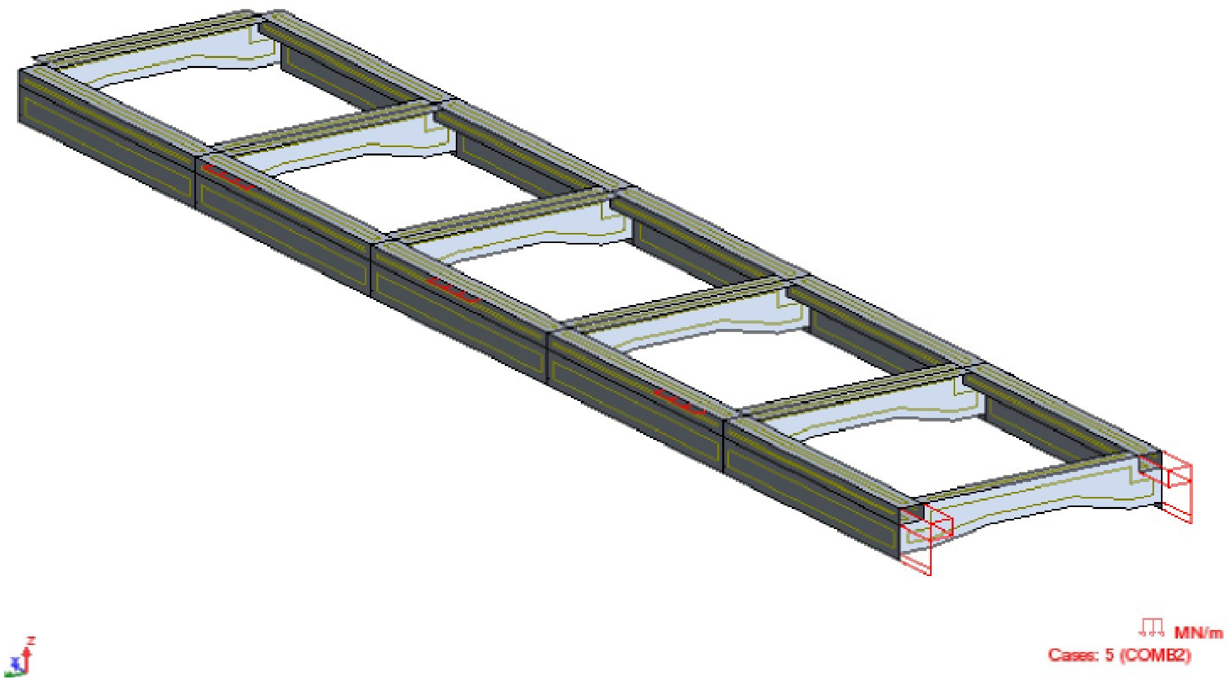


Figure 8 Inner channels and cross beam, 3D model

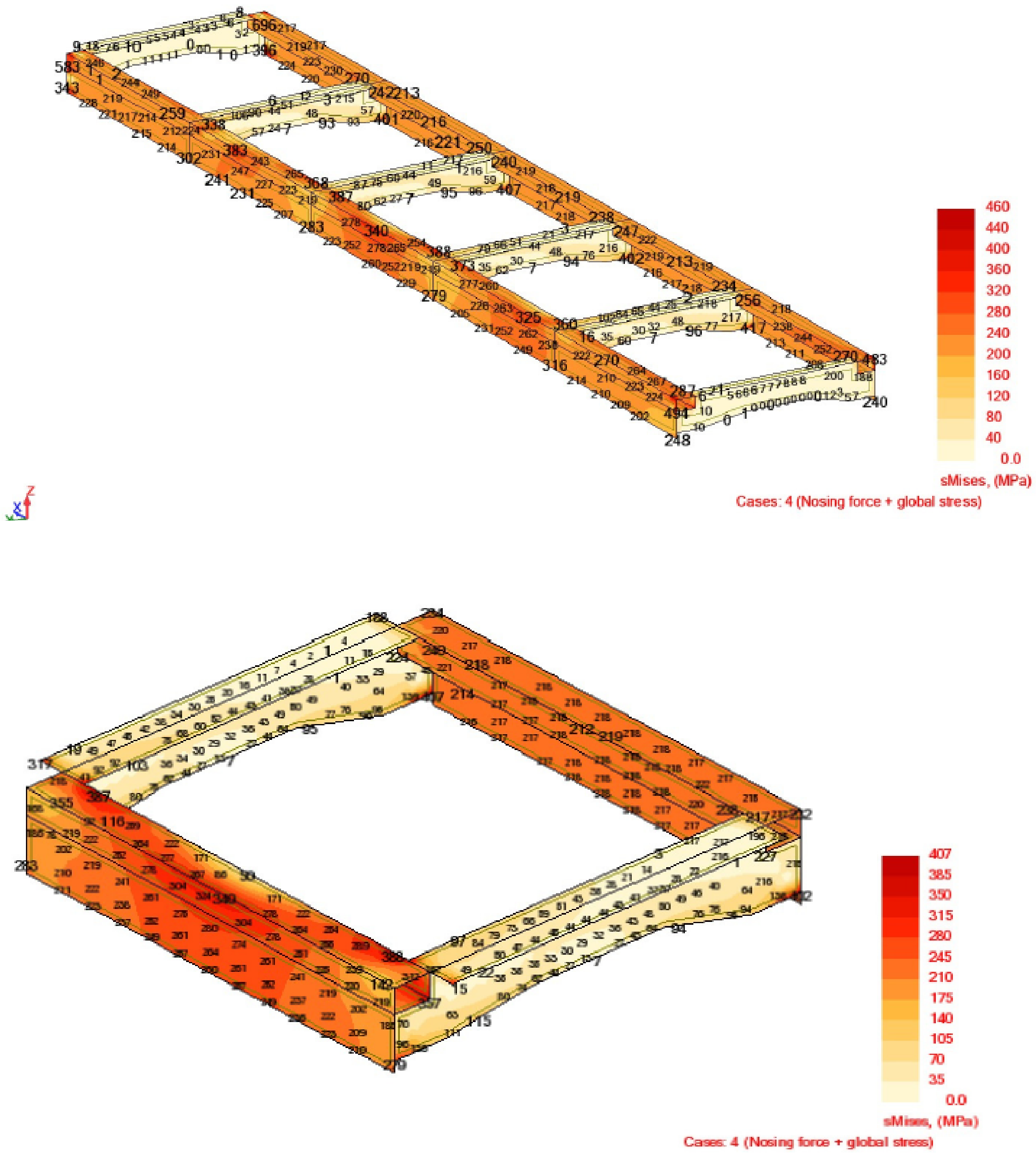


Figure 9 Calculated stresses in inner channel and cross beam

The maximum combined stresses are found locally at the top of the check rail profile and is locally found to be 340MPa. At the bottom of the opposite channel local hot spots have been found where yielding may occur, which however is found to be acceptable due to the very limited area subject to these stresses.

The stresses in the cross beams are found to be relatively low for this load case and well below the acceptable limit.

5.3.3 Stability of steel channels for global stresses in the bridge deck

As the steel channels are integrated parts of the railway girder stresses will be introduced in the steel channels due to global loads and deflections of the bridge deck. The level of stresses in the steel channels will be similar to the stress level in the deck plate of the railway girder.

In order to verify the resistance against buckling of the steel channels under compression the following conservative assessment has been made. Only the upper part of the channels have been included in the model, thus disregarding the longitudinal support at the vertical channel plates. The assumed cross sections are shown in the figure below. The buckling length corresponds to the distance between the stiffeners, i.e 1250mm.

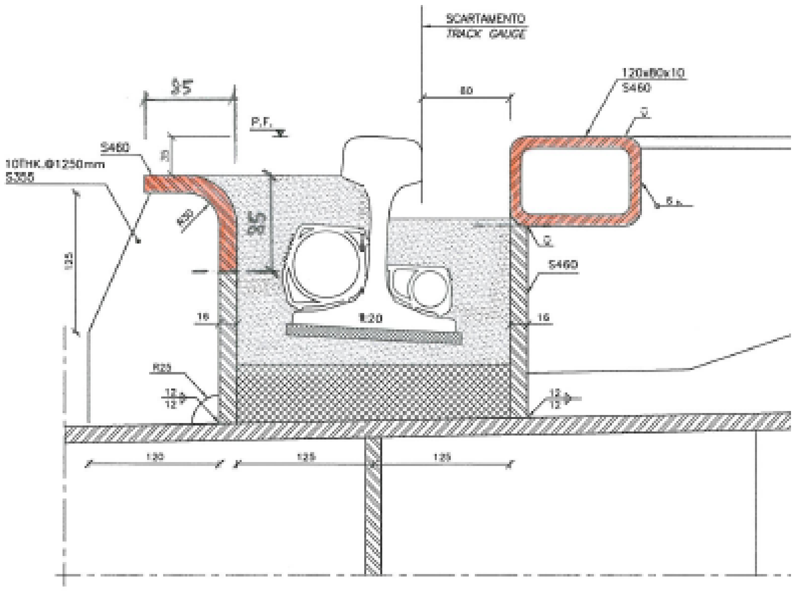


Figure 10 Buckling resistance of the steel channels

Using this conservative approach it is found that critical buckling stress is 0.76 · fyd = 350MPa for the outer channel and 0.92 · fyd = 424MPa for the inner channel.

From the global FEM model the maximum calculated compression stresses in the rail containment channels of the railway girder are found to be 230MPa resulting in utilization ratios of 0.66 and 0.54 for the outer and inner channels respectively. The stability against buckling of the rail containment profiles is thus considered to be adequate.

5.3.4 Fatigue assessment of steel channels

The outer channel may be prone to fatigue due to repeated application of the nosing load from the train wheels. The nosing load will introduce bending in the outer channel varying from 0 to the calculated fatigue stress. Tension will be found at the inner side of the channel plate. The bending stress due to static nosing loads has been calculated above to 235MPa.

The HS TSI INF, section 4.2 with reference to Eurocode EN 1991-2: Traffic loads on bridges only specifies the static nosing loads. For this assessment it is assumed that the corresponding fatigue load is 30% of the static load. The assessment is based on fatigue category 80 with γ_{Mf} = 1.35 and γ_{Ff} = 1.0. The fatigue stress range is thus:

$$\Delta\sigma = 0.3 \cdot 235\text{MPa} / 1.4 = 50.4\text{MPa}$$

The verification criteria is according to EN 1993-1-9, section 8:

$$\frac{\gamma_{Ff} \cdot \Delta\sigma}{\Delta\sigma_{c}/\gamma_{Ff}} \leq 1.0$$

The utilisation ratio for the outer steel channel is thus

$$\frac{1.0 \cdot 50.4}{80/1.35} = 0.85$$

The inner channels are only subject to loads due to derailment of trains and are thus not considered to be prone for fatigue.

For the verification of the fatigue resistance of the steel railway deck, reference is made to document CG1000-P-CL-D-P-SV-I3-00-00-00-04 "Design Report - Fatigue Assessment of Suspended Deck".

5.3.5 Corrosion protection

Trough a number of projects in Denmark in the 1990's the concept of extra surface protection has been developed. Based on a combination of identifications tests, mechanical testing and desk studies, good performance, durability and easy maintenance has been achieved mainly by coating of the surfaces.

For the Messina Bridge the corrosion protection of the railway deck will be provided by application of a water proofing membrane. Reference is made to document CG10.00-P-RX-D-P-SS-P2-00-00-00-00-01 - Technical Specification - Roadway and railway surfacing. In the channels however the surfaces are protected by application of a primer specified for the Edilon ERS.

5.4 Derailment protection and protection against overturning

The derailment protection is, as mentioned above, provided through check rails integrated in the steel channels for the Edilon ERS. The derailment protection comprises continuous rectangular hollow steel sections welded to the inner channels, interconnected at regular intervals.

Two different types of derailment protection can in principle be applied. Check rails, which are rails located in close distance to the running rails, are used:

- to prevent a vehicle from derailing in zones where it would be in danger of striking a structure with consequential personal injury or property damage, or
- to prevent a vehicle from derailing where it is in danger of toppling over the side of an overbridge.

Guard rails located at a distance between 130mm and 300mm from the running rail restrain derailed vehicles from deviating from the general track alignment and are normally installed in accordance with the guidelines below:

- where the nearer running rail is closer than 3.5m from the unprotected support of an overhead or adjacent structure;
- on all open deck bridges (i.e. unballasted) with a span in excess of 6m;
- at any other location, where, in the event of a derailment, it is necessary to restrain derailed vehicles from deviating from the general track alignment.

For the Messina Bridge check rails have been provided over the entire length of the bridge as required by the Railway Authorities and are installed in accordance with the requirements below:

- Check rails shall be laid in pairs with the ends of the check rails perpendicular to the track.
- The top of the check rail shall be at the level of the adjacent running rail surface (±5mm).
- Check rails shall be fastened preferably every sleeper or every fastening interval on slab track, but shall be fastened at least every alternative sleeper or fastening interval.
- Joints in check rails shall be made in accordance with the requirements for running rails (Rails and rail joints).

Along the railway tracks emergency walkways are provided. As an integrated part of the walkways a crash barrier is provided as protection against overturning of rolling stock in form of a continuous rectangular hollow section. As the walkway and thus the crash barrier is supported at regular intervals along the bridge (center distance is 1875mm) the loads from a possible overturning railway vehicle will be distributed on several posts.

The crash barrier has been designed to resist a lateral load of 150kN acting 0.65m above TOR in combination with a coexistant vertical load of 100kN and placed at any position along the walkway. For the detailed design of the walkway and the crash barrier reference is made to doc. CG10.00-P-CL-D-P-SS-R4-00-00-00-00-01 - Design Report - Secondary Structures.

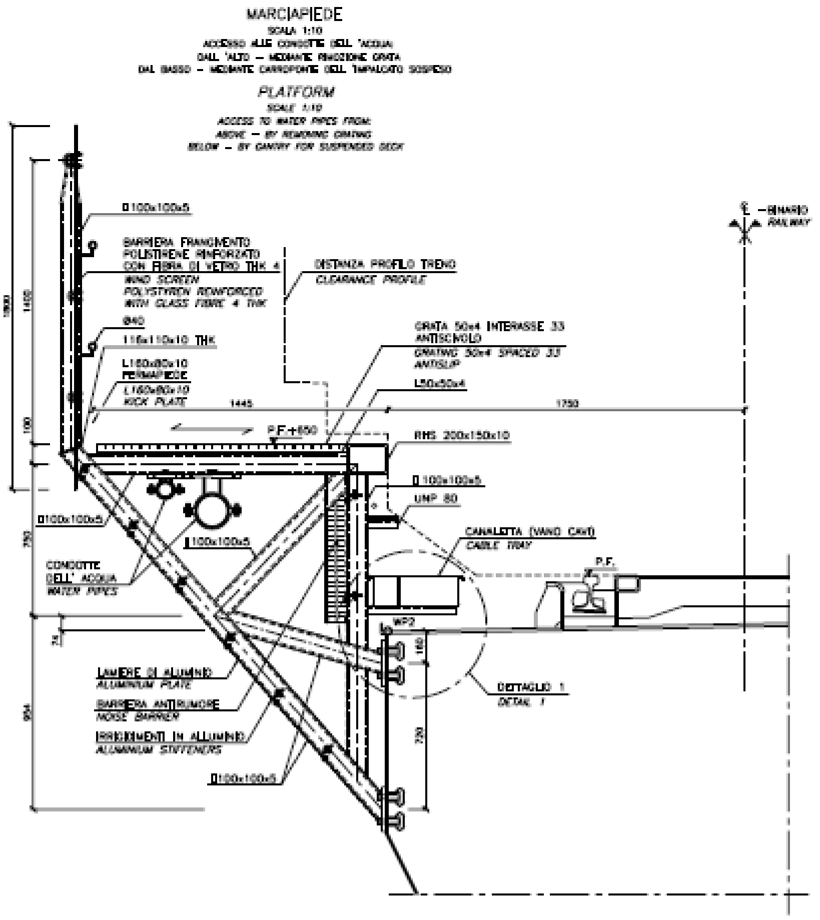


Figure 11 **Emergency walkway and crash barrier**

5.5 Drainage of rain water from the railway deck

In order to be able to evacuate rain water from the railway deck openings are provided in the steel channels at intervals of 10m allowing the water to flow towards the gullies provided near the edge of the deck. At these positions the rails will be un-supported over a distance of 300-350mm.

The opening will further provide sufficient space to facilitate welding of the rail during installation and during future maintenance works.

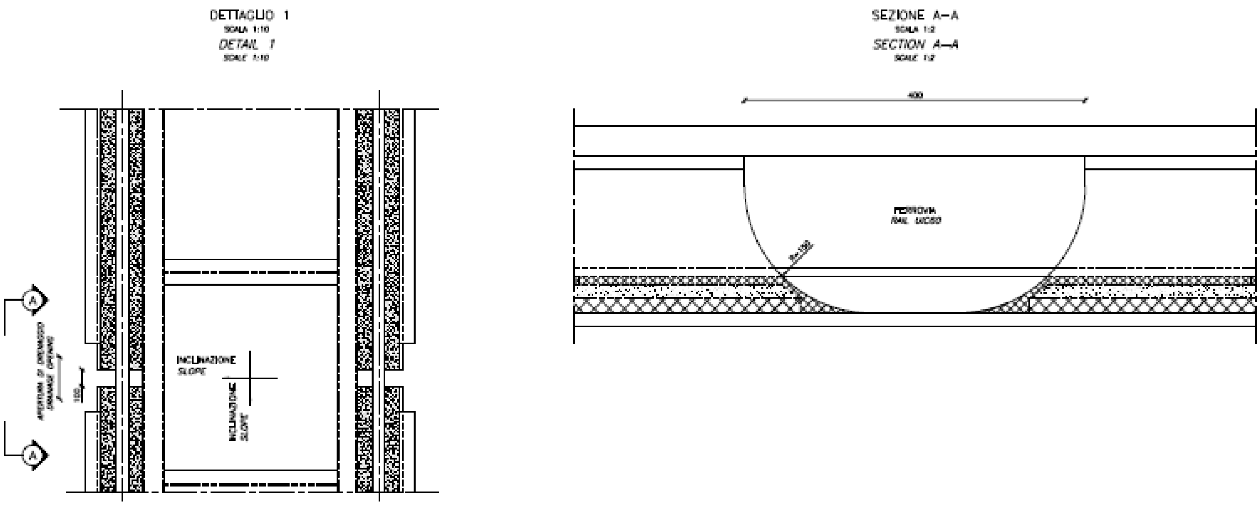


Figure 12 Drainage openings in steel channels

It is noted that the check rails will be continuous at the positions of the drainage openings.

5.6 Installation of the Edilon ERS

The construction sequence for the steel deck and rail system is foreseen as follows:

1. Fabrication of steel deck sections including the rail containments
2. Erection of steel deck sections on site
3. Welding of steel deck sections into one continuous deck girder
4. Installation and positioning of continuously welded rails (CWR) using top-down method and installation portals. Lateral allowance for positioning of rail inside the containments is ±25mm.
5. Casting of resin

The geometrical control of the fabrication and during installation is important; however some geometrical defects can be compensated before the in-situ casting of the resin. The adjustment of the rails should be carried under controlled temperature conditions to ensure that no relative deformations between the steel deck and the rail are present during casting of the resin.

The installation of the steel channels including guard rail profiles and cross beams is done at the workshop, where the steel bridge sections are manufactured. Sufficient care shall be given to the positioning of the channels in order to ensure adequate installation tolerances for the track after erection and welding of the bridge girders.

The installation method comprises partially industrialized embedding processes requiring preparation of the bonding surfaces, accurate positioning of the rails and correct conditions for pouring of the Corkelast materials.

The installation commences by pouring of the polymer leveling layer inside the bottom of the channels. The leveling layer eliminates any inaccuracies in the steel surface and provides a leveled surface on which the rails can be supported.

Figure 13 Installation of rails using top-down procedure

Installation and adjustment of the rails is proposed to be done using a top-down method by means of rail portals. The resilient strips are attached to the underside of the rail. When the rails are in correct position the Edilon Corkelast is poured and hardening will take place. The setting time is approximately 2 hours.

Figure 14 Pouring of Edilon Corkelast

The rate of installation varies naturally with the methods applied. For the Messina Bridge mechanized procedures for placing of rails and pouring of the Corkelast materials will be envisaged and it is expected that a installation rate of approximately 150m track per day can be obtained.

5.7 Maintenance and replacement

Maintenance and replacement of the Edilon ERS consists of a number of different activities. In a number of these operations, removal and renewal of the ERS may be required. In case of renewal the old Edilon Corkelast ERS needs to be removed and replaced with new material into the existing steel channel. All maintenance and renewal methods re-establish the performance and durability of the Edilon ERS.

Maintenance work can be done either as preventive maintance or as corrective maintenance.

Preventive maintenance:

The purpose of this type of maintenance is to conserve the lifetime of the system and to prevent corrective maintenance. Therefore only lighte and simple maintenance methods are used like:

- Cleaning the groove around the rail
- Grinding and re-shaping of rails
- Cleaning of drainage points

Corrective maintenance and renewal:

In case of excessive wear and/or damages repair or replacement of the ERS may be required. Naturally, heavier and more intrusive methods will be applied for this type of maintenance operations. The following types of operations could be envisaged:

- Correction of the ERS surface
- Surface welding of rail heads
- Replacement of the complete ERS
- Renew rail due to excessive wear
- Re-alignment of the ERS

In Appendix 3 is included detailed descritions of the applicable maintenance and renewal procedures.

6 Testing

Reference is made to document A9055-MEM-6-003 describing the proposed test program for the embedded rail system. The document is attached in Appendix 4.

7 Track/bridge interaction

Interaction between tracks and bridge, i.e. the consequence of the behaviour of one on the behaviour on the other, occurs because the tracks and the bridge are interlinked through the rail fastening system. The interaction takes form of forces in the rails and in the deck as well as displacements of the various elements of the tracks and the bridge.

The interaction must be taken into account as a serviceability limit state (SLS) for the bridge as well as being an ultimate limit state (ULS) load case for the rails. Forces and displacement will be calculated using the partial safety factors for the loads concerned.

The verification of the track/bridge interaction is be done in accordance with the recommendations in UIC Code 774-3.

7.1 Effects of differential temperature

Temperature differences between the rail and the structures surrounding the rails may result in relative movements and can cause additional stresses in rails and in the structures. For the Messina Bridge, where the deck structures and the rails all are in steel, it is expected that the temperature differences between the deck and the rails will be small due to the similar thermal behaviour and exposure to temperature of the materials.

In UIC 744-3 however it is recommended that the track/bridge interaction shall be verified for the,in this case rather unlikely event of a temperature difference of 20°C.

Thermal expansion/retraction of the rail due to differential temperatures will be restrained by the longitudinal resistance of the ERS. The restraining force per rail can be calculated as follows:

$R_{ERS} = ½ \cdot K \cdot \Delta L \cdot L$, where

K = longitudinal resistance, see Table 1 (kN/mm per m track)

ΔL = thermal expansion of the rail (mm)

L = length of rail section (m)

This restraining force will introduce an elastic compression in the rail due to the bonding between the rail, the rubber material and the steel channel, thus reducing the resulting movement of the rail.

To simulate the behaviour or the ERS and estimate relative movements and stresses built up into the rail a simplified beam model has been prepared using the software ROBOT. A continuous rail over one half of the suspended bridge is supported in the longitudinal direction by spring supports simulating the stiffness of the ERS. Even though the ERS will provide a continuous elastic support springs are located every 30m. To simulate the behaviour of the supports more correctly in the areas close to the end of the rail however the distance between the supports is here reduced to 10m. The model is shown in the Figure below.

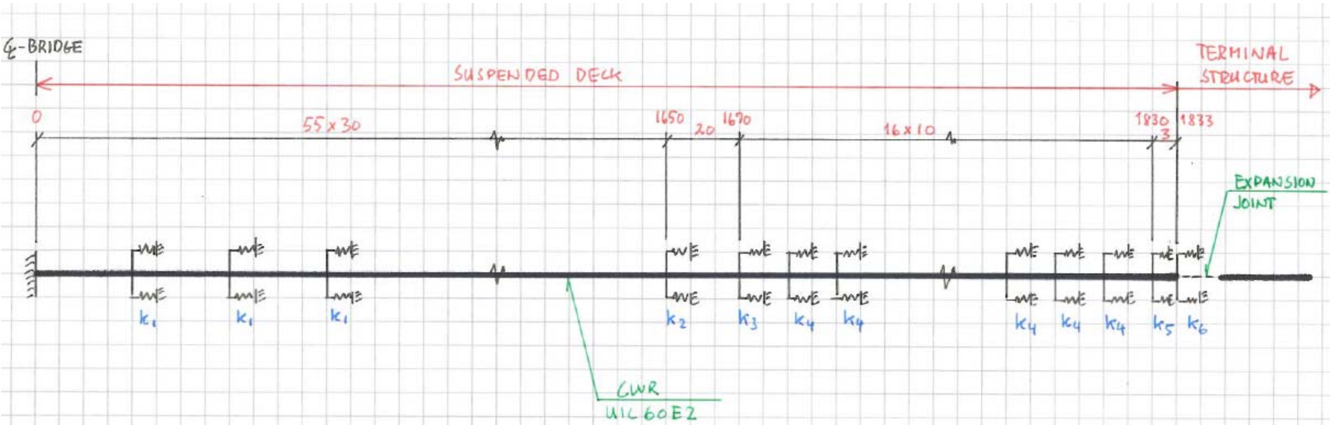


Figure 15 **Calculation of movements and stresses, simplified computer model**

The spring stiffness is calculated based on the unloaded stiffness of the ERS from Table 1 corresponding to 30m of rail.

$$K = \frac{1}{2} \cdot 13\text{kN/m}\cdot\text{mm} \cdot 30\text{m} = 195\text{kN/mm}.$$

The relative movements of the rail caused by a uniform temperature difference of +20°C have been calculated and are shown in the figure Figure 16 below:

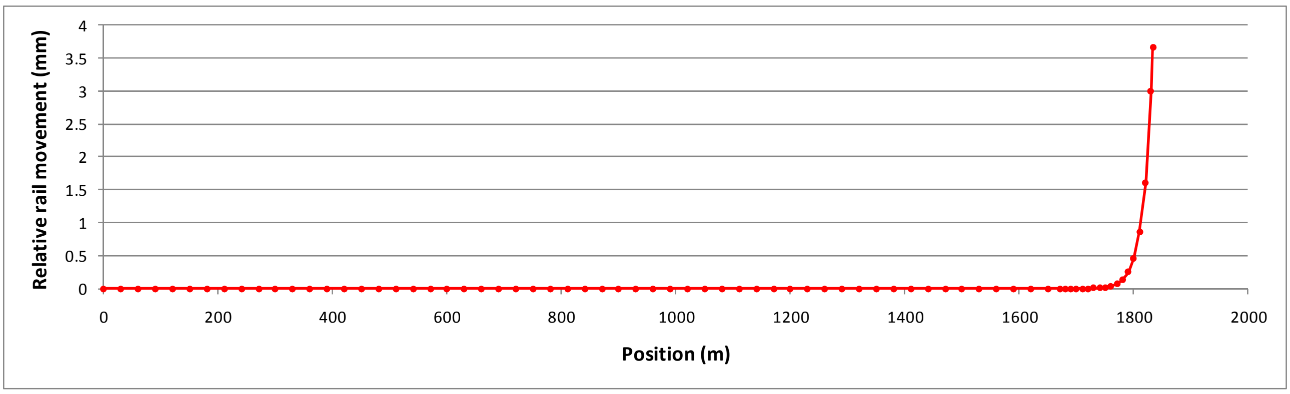


Figure 16 **Relative movement in the rail for ΔT = 20°C**

From the figure above it is seen that the rail will be fixed in the ERS over almost the entire length except for the last approximately 110m, where relative movements occur. At the extremity of the rail the maximum relative movement of 3.7mm is found, which is considered to be acceptable.

Fixation of the rail by the ERS will introduce axial stresses in the rail. At complete fixation the stress can be calculated as follows:

$$\sigma_A = \alpha \cdot \Delta T \cdot E = 1.2 \cdot 10^{-5}\ °C^{-1} \cdot 20°C \cdot 2.1 \cdot 10^{-5} MPa = 50.4 MPa$$

Below is shown the calculated stresses along the rail, confirming that the rail in fact is completely fixed over most of the length.

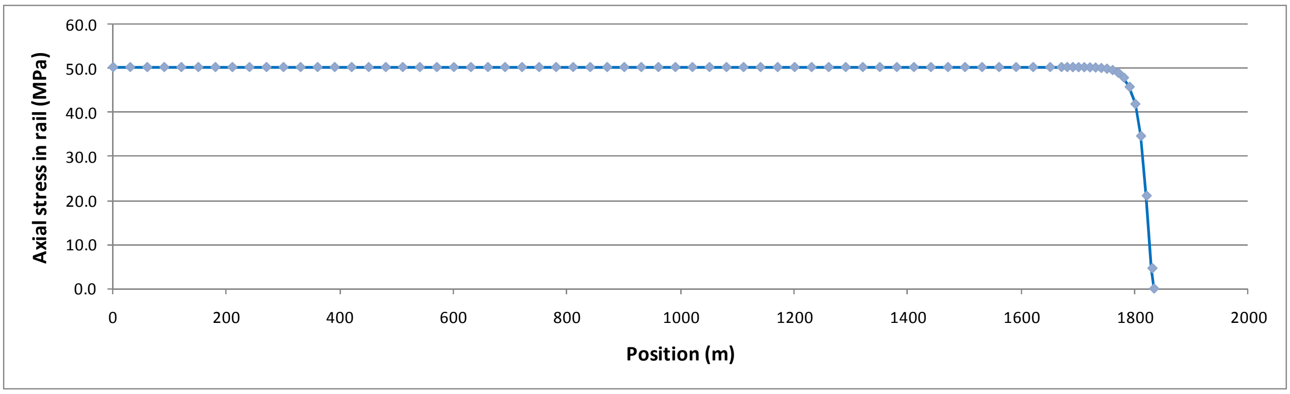


Figure 17 Axial stresses in the rail for ΔT = 20°C

7.2 Verification of rail stability

The stability of the rail under compression imposed by the differential temperatures between the rail and the steel deck as described above has been assessed. The elastic support of the rail in lateral and vertical directions provided by the ERS has been included in a FEM model in ROBOT comprising a 30m long section of the rail. The rail is supported in the axial direction at both ends and an initial vertical deformation of the rail corresponding to 10mm over a length of 10m is included in the model. The initial geometry is shown below.

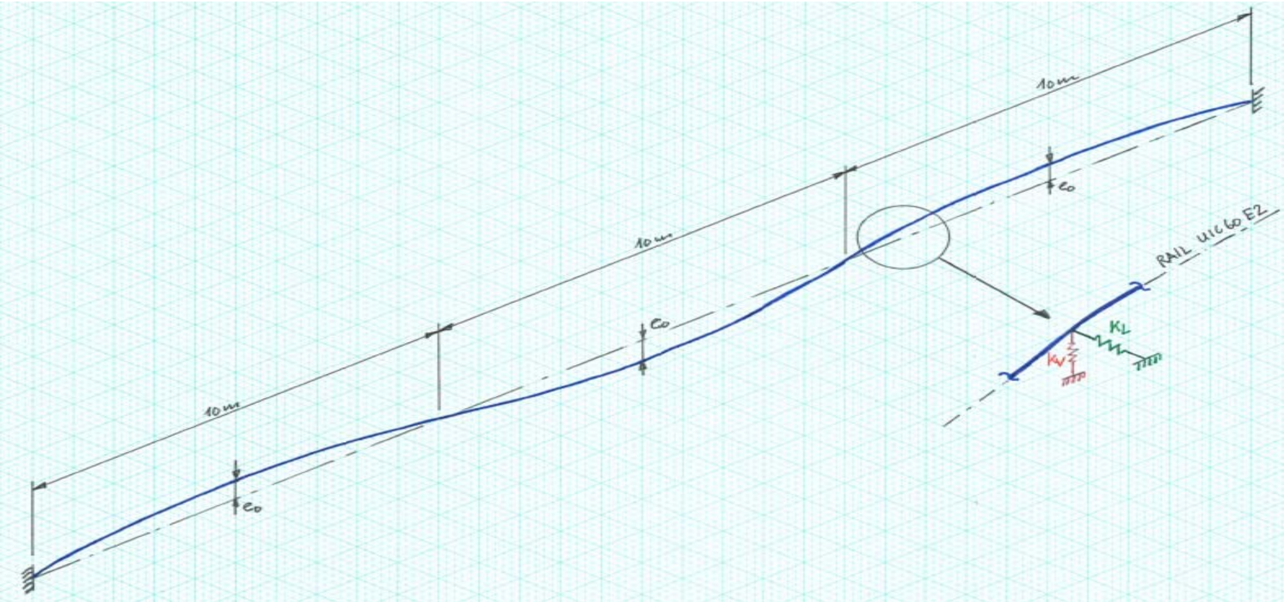


Figure 18 Stabillity of rail, FEM model

The stiffness of the ERS included in the FEM model are based on test results obtained on similar rail configurations by the supplier:

$k_{LATERAL}$ = 18.0 kN/m·mm
$k_{VERTICAL.\ DOWN}$ = 48.0 kN/m·mm
$k_{VERTICAL.\ UP}$ = 20.0 kN/m·mm

In the FEM model the vertical support stiffness in both directions is conservatively set to $K_{VERTICAL}$ = 20.0 kN/m·mm. The model is subject to increased uniform temperature introducing axial loads in the rail. Axial stresses due to global deflection of the bridge has been included by adding uniform stress in the rail.

Load case LC1 describes the "pure" uniform temperature load case ΔT=20°C without any contributions from global effect. The load cases LC2 and LC3 correspond to uniform temperature in addition to superimposed axial stresses due to global effects as follows:

LC1: ΔT=20°C
LC2: ΔT=20°C + 50MPa (~ΔT=40°C)
LC3: ΔT=20°C + 100MPa (~ΔT=60°C)

The deflections and reactions on the ERS based on a 1st order linear analysis are shown in the figures below.

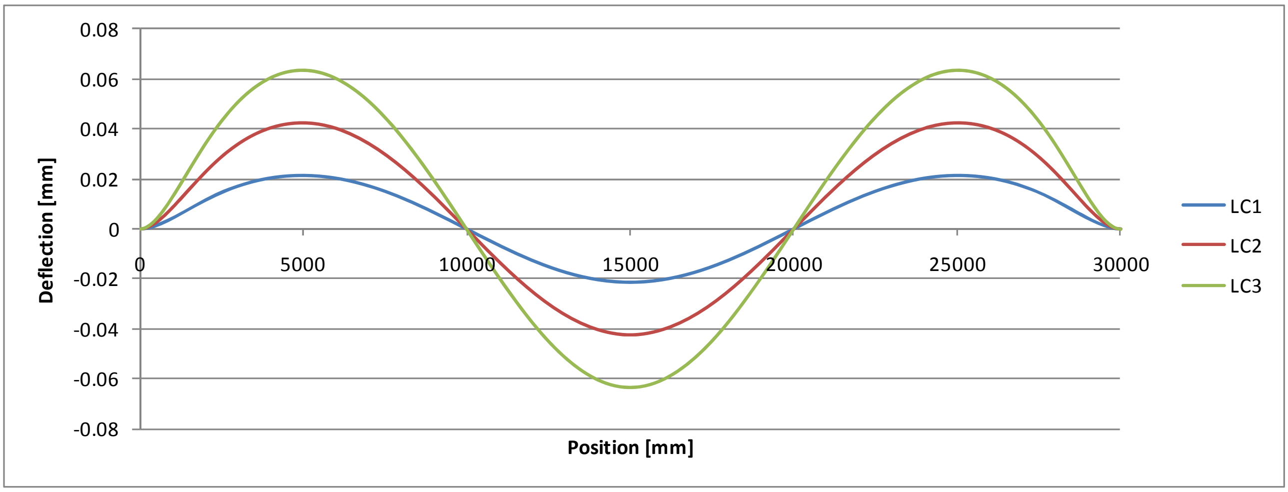


Figure 19 Deflections in z-direction

The calculated deflections of the rail are very small for all three load cases indicating that the stability of the rail is adequate. For verification of the rail stability a linear buckling analysis has been carried out in ROBOT. The critical axial load is found to be 9.3MN corresponding to 1210MPa. As the ultimate tensile stress of the rail (grade R260) is 880MPa, failure in the rail will occur before instability is reached.

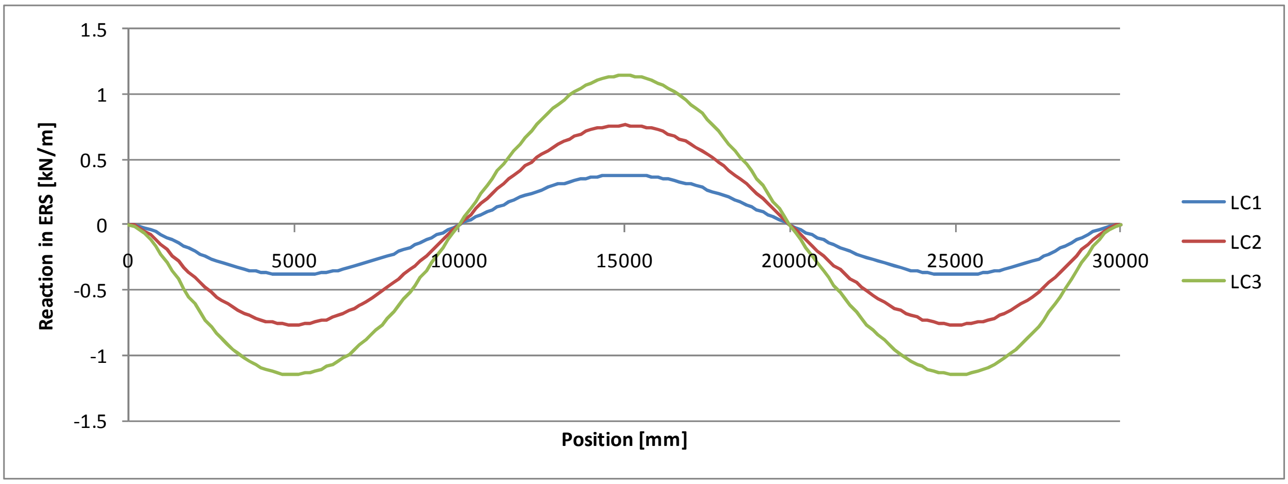


Figure 20 Reactions in ERS

From the figure above it is found that the maximum reaction on the ERS to prevent uplift of the rail is 1.15kN/m (LC3). Assuming a minimum bonding capacity for EDILON ERS with EDILON Corkelast VA60 of 0.8MPa (informed by the supplier) the total bonding capacity is 0.8MPa · 0.250m · 1.0m = 200kN/m and the resistance against uplift of the rail is considered to be adequate. During the testing at Politecnico di Milano the actual uflift resistance will be measured.

7.3 Effect of braking and acceleration of trains

Braking and acceleration (traction) forces are defined in the Design Basis as follows:

Traction force:

$Q_{lak} = 33\ [kN/m]\ L\ [m] \leq 1000\ [kN]$

for Load Model 71, SW/0 and SW/2

Braking force:

$Q_{lbk} = 20\ [kN/m]\ L\ [m] \leq 6000\ [kN]$

for Load Model 71 and SW/0

$Q_{lbk} = 35\ [kN/m]\ L\ [m]$

for load model SW/2

Where

L is the influence length in m of the load effects of the element considered.

For load model SW/0 and SW/2 only those parts of the structure which are loaded shall be taken into account.

The traction and braking loads specified above shall be multiplied by a factor:

$\alpha = 1.1$ *for LM 71*

$\alpha = 1.1$ *for SW/0*

$\alpha = 1.0$ *for SW/2*

The braking and accelerations forces shall be transferred from the rail through the rubber material to the steel channels and thus to the steel deck. The theoretical values for the longitudinal stiffness of the ERS are given in Table 1. Based on these values the corresponding longitudinal relative movement of the rail can be calculated:

$u_{acceleration}$ = 1.1 · 33kN/m / 0.5 · 19kN/mm m = 3.8mm

$u_{braking}$ = 1.1 · 20kN/m / 0.5 · 19kN/mm m = 2.3mm (LM71 and SW/0)

1.0 · 35kN/m / 0.5 · 19kN/mm m = 3.7mm (SW/2)

The calculated relative movements are below the limits indicated in Table 1 and are thus considered to be acceptable.

7.4 Effects of global and local bending of the bridge deck

Deflection of the bridge girder will occur due to traffic loads, wind loads etc. and may introduce additional stresses in the rails and in the deck structures. From the results of the global IBDAS model calculations an envelope of section forces in the railway girder has been provided. Further, passing trains will introduce local bending of the deck plate, which also may introduce stresses in the rails. In order to assess these additional stresses it has conservatively been assumed that the rails are rigidly connected to the steel deck without taking into account the spring support provided by the embedded rail system.

In UIC 774-3 the additional stresses in the rail due to bending of the deck are limited for stability reasons to 92MPa in tension and 72MPa in compression for ballasted tracks on concrete sleepers. Similar requirements are found in EN 1991-2. For the embedded rail system with continuous lateral support of the rail these limits are considered to be conservative.

The global effects on the rail introduced by deflection of the bridge girder have been calculated by applying the load combinations defined in Table 23 A in the Design Basis. The load combinations include environmental loads such as wind and temperature as well as traffic loads on the road girders and on the rail girder. Based on these load combinations an envelope of the maximum section forces in the railway girder has been extracted. Assuming that the rails are rígidly connected to the railway girder the corresponding stresses in the rails can be calculated. This assumption is considered to be conservative as the rail to some extend is elasticly supported by the embedded rail system and the calculated stresses may thus be considered to be "to the high side".

***Table 23 A:** Combinations corresponding to Serviceability Limit States (SLS) Characteristic considering the QL load.*

	PP	PN	QL							VV	VT	VR	VS
			Road			Rail							
			LM1	LM2	Brake	LM71, SW/0, SW/2, HLSM(3)	Un-loaded	Brake & Acc	Nos-ing				
1	1.00	1.00	1.00	-	-	0.80	-	0/ 0.40	0/ 0.80	0.60	0.60	0.60	-
2	1.00	1.00	1.00	-	-	0.40/ 0.80	-	0.80	0/ 0.40	0.60	0.60	0.60	-
3	1.00	1.00	-	1.00	-	0.80	-	0 /0.40	0 /0.80	0.60	0.60	0.60	-
4	1.00	1.00	-	1.00	-	0.40/ 0.80	-	0.80	0/ 0.40	0.60	0.60	0.60	-
5	1.00	1.00	0.75(TS) 0.40(UDL)	-	1.00	0.80	-	0/ 0.40	0/ 0.80	0.60	0.60	0.60	-
6	1.00	1.00	0.75(TS) 0.40(UDL)	-	1.00	0.40/ 0.80	-	0.80	0/ 0.40	0.60	0.60	0.60	-
7	1.00	1.00	-	0.75	1.00	0.80	-	0/ 0.40	0/ 0.80	0.60	0.60	0.60	-
8	1.00	1.00	-	0.75	1.00	0.40/ 0.80	-	0.80	0/ 0.40	0.60	0.60	0.60	-
9	1.00	1.00	0.75(TS) 0.40(UDL)	-	-	1.00	-	0/0.50	0/ 1.00	0.60	0.60	0.60	-
10	1.00	1.00	0.75(TS) 0.40(UDL)	-	-	-	1.00	-	1.00	0.60	0.60	0.60	-
11	1.00	1.00	0.75(TS) 0.40(UDL)	-	-	0.50/ 1.00	-	1.00	0/ 0.50	0.60	0.60	0.60	-
12(2)	1.00	1.00	0.75(TS) 0.40(UDL)	-	-	0.60	-	0.60	0.60	0.60	0.60	0.60	-
13	1.00	1.00	0.75(TS) 0.40(UDL)	-	-	-	-	-	-	1.00	0.60	0.60	-
14	1.00	1.00	0.75(TS) 0.40(UDL)	-	-	0.80	-	0/ 0.40	0/ 0.80	0.60	1.00	0.60	-
15	1.00	1.00	0.75(TS) 0.40(UDL)	-	-	0.40/ 0.80	-	0.80	0/ 0.40	0.60	1.00	0.60	-
16	1.00	1.00	0.75(TS) 0.40(UDL)	-	-	0.80	-	0/ 0.40	0/ 0.80	0.60	0.60	1.00	-
17	1.00	1.00	0.75(TS) 0.40(UDL)	-	-	0.40/ 0.80	-	0.80	0/ 0.40	0.60	0.60	1.00	-
18	1.00	1.00	0.2	-	-	0.30(1)	-	-	-	-	0.60	-	1.00

(1) Only one track need to be loaded and load model SW/2 can be neglected.
(2) Load case is only to be applied for investigating cracking of concrete.
(3) Apply load groups as indicated in table 23A-1

The calculated stresses caused by global deflection of the bridge girder are shown in the Figure below.

Geometry:

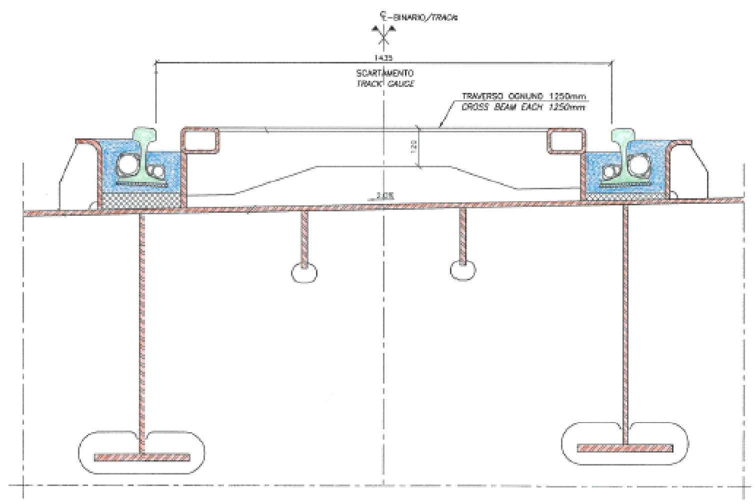
Distance	2000	mm
Gauge	1435	mm
Rail head	72	mm
Rail height	172	mm
Z0-rail	80.92	mm
H-girder	2285	mm
Z0-girder	1395	mm
TOR	199	mm

Position rails:

	y (m)	z (m)
Outer rail	2.754	0.833
Inner rail	1.247	0.833

Section properties:

A	0.438	m2
Iy	0.363	m4
Iz	2.368	m4
A-rail	0.008	m2
L-embed	0.498	m



Elimination	y/n	n	n	n	Outer rail						Inner rail					
Case	Criteria	Ns	My	Mz	σN	σMy	σMz(+)	σMz(-)	σ-comb		σN	σMy	σMz(+)	σMz(-)	σ-comb	
		[MN]	[MNm]	[MNm]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
6650	min NS	-9.372	0.310	0.208	-21.42	0.71	0.24	-0.24	-20.47	-20.95	-21.42	0.71	0.11	-0.11	-20.60	-20.82
6650	max NS	7.744	-3.557	0.152	17.70	-8.16	0.18	-0.18	9.71	9.36	17.70	-8.16	0.08	-0.08	9.62	9.46
6650	min MY	-2.048	-21.992	4.703	-4.68	-50.47	5.47	-5.47	-49.68	-60.62	-4.68	-50.47	2.48	-2.48	-52.67	-57.62
6650	max MY	-2.875	45.592	-2.735	-6.57	104.62	-3.18	3.18	94.87	101.23	-6.57	104.62	-1.44	1.44	96.61	99.49
6650	min MZ	-0.589	-2.137	-38.123	-1.35	-4.90	-44.32	44.32	-50.57	38.07	-1.35	-4.90	-20.07	20.07	-26.32	13.82
6650	max MZ	-0.590	-2.136	38.121	-1.35	-4.90	44.32	-44.32	38.07	-50.57	-1.35	-4.90	20.06	-20.06	13.81	-26.31
6650	min VY	-0.686	1.000	-24.209	-1.57	2.29	-28.15	28.15	-27.42	28.87	-1.57	2.29	-12.74	12.74	-12.02	13.47
6650	max VY	-0.685	1.000	24.209	-1.57	2.29	28.15	-28.15	28.88	-27.42	-1.57	2.29	12.74	-12.74	13.47	-12.01
6650	min VZ	-3.486	-10.882	7.505	-7.97	-24.97	8.73	-8.73	-24.21	-41.66	-7.97	-24.97	3.95	-3.95	-28.99	-36.89
6650	max VZ	-2.654	-6.592	-22.429	-6.07	-15.13	-26.08	26.08	-47.27	4.88	-6.07	-15.13	-11.81	11.81	-33.00	-9.39
6650	min MT	-1.787	-0.937	23.889	-4.08	-2.15	27.77	-27.77	21.54	-34.01	-4.08	-2.15	12.57	-12.57	6.34	-18.81
6650	max MT	-1.787	-0.937	-23.914	-4.08	-2.15	-27.80	27.80	-34.04	21.57	-4.08	-2.15	-12.59	12.59	-18.82	6.35
								MAX	101.23					**MAX**	99.49	
								MIN	-60.62					**MIN**	-57.62	

Figure 21 Calculation of stresses in the rail due to global bending

It has been found that the additional tension stresses in the rail due to deflection of the bridge girder slightly exceeds the limit included in UIC 774-3, which however is considered to be acceptable due to the conservative assumptions made for the calculation. The additional compression stresses are found to be below the limit.

7.5 Combination of effects

The relative movements of the rail have been estimated for a differential temperature between the rail and the steel bridge girder of 20°C and for braking and acceleration loads as specified in the

TSI and the Design Basis. As the differential load case is considered to be rather unlikely to occur it would not be correct to add the full effects of both load cases.

The following load case has thus been considered:

$$1.0 \cdot \text{braking} + 0.5 \cdot \text{difftemp}.$$

The resulting relative movement of the rail for this load case is thus:

$$1.0 \cdot 3.8\text{mm} + 0.5 \cdot 3.7\text{mm} = 5.7\text{mm} < 7\text{mm (ref. Table 1)}$$

8 Railway expansion joints

The tracks on the suspension bridge are consisting of continously welded rails (CWR) for the entire length of the bridge. In order to allow for relative movements in the longitudinal direction between the suspended bridge and the Terminal Structures rail expansion joints are provided in the tracks Between the Terminal Structures and the adjacent viaducts similar rail expansion devices are provided.

The expansion devices have been designed for the movements calculated for the ULS load cases.

The expansion device comprise rail adjustment switches accommodating the relative longitudinal movements without increasing the track gauge. In the gap between the adjoining structures the rails are supported on a number sledges which are interconnected in order to obtain equal distance between the sledges.

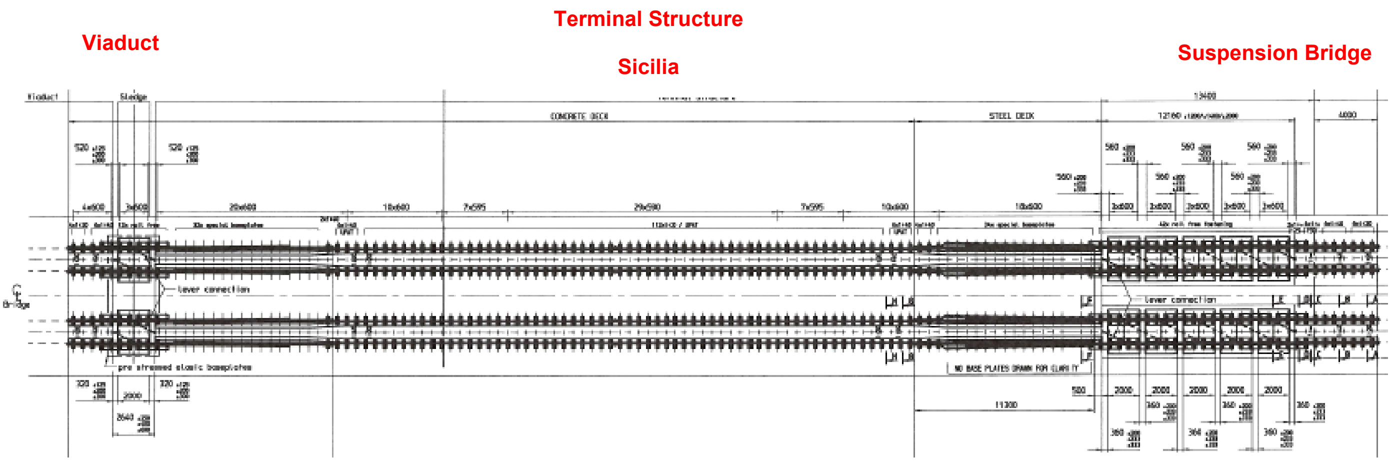


Figure 22 **Layout - Railway expansion joint**

The railway expansion joints are addressed as a part of the Articulation and auxiliary systems and reference is made to document no. CG.10.00-P-RX-D-P-SS-A0-00-00-00-00-01 - Articulation, Specialist Technical Design Report for further information.

9 Other railway installations

9.1 Catenary system

The catenary system including support portals is designed by the landworks designer SINA, however provisions must be made on the bridge to facilitate the installation.

Catenary portals are placed at every cross beam along the bridge deck which are provided with a typical distance of 30m. At the section at the towers the distance here between the cross beams is 60m and additional brackets will be arranged on the sides of the rail way girder for the installation of the catenary portals.

The catenary portals will be included in drawing CG10.00-P-AX-D-P-SS-R4-00-00-00-00-05, however for the design verification of the portals reference is made to the design documents issued by SINA.

9.2 Traffic management incl. signals

The traffic management system is designed by the landworks designer SINA. Reference is made to relevant documents issued by SINA.

10 Analysis of rail noise

An analysis of the noise from the railway has been carried out. Vibrations in the tracks will be transmitted to the steel structure when a train is passing and the large steel box girders will then emit the vibrations as airborne noise.

This structure-borne noise is added to the usual airborne noise from the train's wheels, engine and braking systems. The analysis focus on determining the amount of additional noise transmitted from the bridge structure in comparison to the expected airborne train noise.

Description of the analysis and the results are described in document A9055-NOT-6-002 and is attached in Appendix 5.

From the results it can be seen, that the noise level from train traffic on the bridge will be dominated by the structure-borne noise, which is expected to be approximately 5 dB higher than the airborne noise.

For positions at lower heights the differences might be larger, because of the edges of the bridge screening the airborne train noise to a higher degree. At positions close to and under the bridge the total noise can be expected to be completely dominated by the structure borne noise.

11 Appendices

11.1 Appendix 1: List of standards

EUROPEAN RAILWAY AGENCY

Interoperability Unit

Applicable standards in HS Infrastructure subsystem TSI (2008/217/EC)

Reference:	ERA/Interoperability/JCP/hpi/2008/210
Version:	1.0
Date:	November 13, 2008
Status:	Approved
Author:	

ERA 1.0 Page 1/8

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Interoperability Unit

Standards or other documents referred to in the HS infrastructure TSI (and therefore mandatory)

TSI Sections	Characteristics	Mandatory standards or other documents
4.2.9 4.2.9.2	Equivalent conicity Design values.	prEN 13715.- Railway applications – Wheelsets and bogies – Wheels – Tread profile EN 15302:2006 - Railway applications - Method for determining the equivalent conicity
4.2.13 4.2.13.1 c)	Track Resistance Lines of category 1 *Longitudinal forces due to interaction between structures and track*	EN1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges - clause 6.5.4
4.2.14 4.2.14.1	Traffic load on structures Vertical loads	EN1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges - paragraphs 6.3.2 (2), 6.3.3 (3); paragraphs 6.3.2 (3) and 6.3.3 (5) ; paragraphs 6.4.3 (1) and 6.4.5.2 (2) EN 1990: 2002/ - annex A2
4.2.14 4.2.14.2	Traffic load on structures Dynamic analysis	EN1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges - section 6.4.4; paragraphs 6.4.6.1.1 (3), (4), (5) and (6); paragraph 6.4.6.2 (1) ; paragraph 6.4.6.5 (3) EN 1990: 2002/ annex A2
4.2.14 4.2.14.3	Traffic load on structures Centrifugal forces	EN1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges - paragraph 6.5.1 (4)
4.2.14 4.2.14.4	Traffic load on structures Nosing forces	EN1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges - paragraphs 6.5.2 (2) and (3).

Reference: ERA/Interoperability/JCP/hpi/2008/210
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4.2.14 4.2.14.5	Traffic load on structures Actions due to traction and braking (Longitudinal loads)	EN1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges - paragraphs 6.5.3 (2), (4), (5) and (6) ; paragraph 6.5.3 (6).
4.2.14 4.2.14.6	Traffic load on structures Longitudinal forces due to interaction between structures and track	EN1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges -clause 6.5.4.
4.2.14 4.2.14.7	Traffic load on structures Aerodynamic actions from passing trains on line side structures	EN1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges -section 6.6.
4.2.14 4.2.14.8	Traffic load on structures Application of the requirements of EN 1991-2:2003	EN1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges + national application documents
5.3.1 5.3.1.1 a)	The rail Railhead profile Plain line	EN13674- 1:2003– Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above – Annex A
5.3.1 5.3.1.1 b)	The rail Railhead profile Switches and crossings	EN13674-2: 2003- Railway applications - Track - Rail - Part 2: switch and crossing rails used in conjunction with flat-bottom symmetrical railway rails 46 kg/m and above – Annex A
5.3.1 5.3.1.3 a)	The rail Steel grade Plain line	EN13674- 1:2003– Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above – Chapter 5

Reference: ERA/Interoperability/JCP/hpi/2008/210
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5.3.1 5.3.1.3 b)	The rail Steel grade Switches and crossings	EN13674-2:2003Railway applications - Track - Rail - Part 2: switch and crossing rails used in conjunction with flat-bottom symmetrical railway rails 46 kg/m and above – Chapter 5
5.3.2 a)	The rail fastening system Minimum Resistance to rail longitudinal slip	EN 13481-2:2002 - Railway applications – Track - Performance requirements for fastening systems - Part 2: Fastening systems for concrete sleepers
5.3.2. b)	The rail fastening system Resistance to repeated loading	EN 13481-2:2002 - Railway applications – Track - Performance requirements for fastening systems - Part 2: Fastening systems for concrete sleepers
5.3.2. d)	The rail fastening system Minimum electric resistance	EN 13146-5- Railway applications – Track – Test methods for fastening systems – Part 5: Determination of electrical resistance
6.2.5 6.2.5.2	Technical solutions given presumption of conformity at design phase Assessment of equivalent conicity	EN 13674-1: 2003Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above – rail sections 60 E 1 and 60 E 2
6.2.6 6.2.6.2	Particular requirements for conformity assessment Assessment of minimum value of mean track gauge	EN 13848-1:2003 - Railway applications/Track - Track geometry quality - Part1: Characterization of track geometry- section 4.2.2

EUROPEAN RAILWAY AGENCY

Interoperability Unit

Standards or other documents not referred to in the HS infrastructure TSI (and therefore voluntary)

TSI Sections	Characteristics	Relevant standards or other documents
5.3.1.2	Design linear mass	EN13674-1:2003+A1:2007 – Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above
		EN13674-2:2006 Railway applications - Track - Rail - Part 2: switch and crossing rails used in conjunction with flat-bottom symmetrical railway rails 46 kg/m and above.
5.3.2. a)	The rail fastening system Minimum resistance to rail longitudinal slip	EN13146-1: 2002 - Railway applications - Track - Test Methods for Fastening Systems - Part 1: Determination of longitudinal rail restraint
5.3.2. b)	The rail fastening system Resistance to repeated loading	EN13146-4: 2002+ A1: 2006 - Railway applications - Track - Test Methods for Fastening Systems - Part 4: Effect of repeated loading
5.3.2. c)	The rail fastening system Dynamic stiffness of the rail pad on concrete sleepers	EN13481-2:2002 +A1: 2006 Railway applications – Track - Performance requirements for fastening systems - Part 2: Fastening systems for concrete sleepers
5.3.3	Mass and dimensions	EN13230-1:2002 - Railway applications - Track - Concrete bearers and sleepers - Part 1: General Requirements (Revision under process – published next year)
4.2.2	Nominal track gauge/	EN13848-1: 2003 – Railway applications - Track - Track geometry quality – Part 1:Characterisation of track geometry (+ Amdt A1/2008)
4.2.6	Minimum radius of curvature	EN 13803-1: 2006 - Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 1: Characterisation of track geometry
		EN 13803-2: 2006+ AC2007 - Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 2: Switches and crossings and comparable alignment design situations with abrupt changes of the curvature
4.2.7	Track cant	ENV 13803-1: 2002 - Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 1: Characterisation of track geometry

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		EN 13803-2:2006 + AC 2007- Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 2: Switches and crossings and comparable alignment design situations with abrupt changes of the curvature
		EN 14363: 2005 Railway application – Testing for the acceptance of running characteristics of railway vehicles – Testing of running behaviour and stationary tests
4.2.8 -	Cant deficiency	ENV 13803-1: 2002- Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 1: Characterisation of track geometry
		EN 13803-2:2006/ AC 2007 - Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 2: Switches and crossings and comparable alignment design situations with abrupt changes of the curvature
		EN 14363: 2005 Railway application – Testing for the acceptance of running characteristics of railway vehicles – Testing of running behaviour and stationary tests
4.2.9.2	Equivalent Conicity Design values	EN 15302: 2008. - Railway applications –Method for determining the equivalent conicity
4.2.9.3. 4.2.9.3.1	In service values Minimum values of mean track gauge	EN13848-1: 2003+A1 2008 – Railway applications - Track - Track geometry quality – Part 1:Characterisation of track geometry
		EN13848-5: 2008– Railway applications - Track - Track geometry quality – Part 5: Geometric quality levels
4.2.10	Track geometrical quality and limits on isolated defects	EN13848-1: 2003/ A1 2008 – Railway applications - Track - Track geometry quality – Part 1:Characterisation of track geometry
		EN13848-5: 2008/– Railway applications - Track - Track geometry quality – Part 5: Geometric quality levels
4.2.12	Switches and crossings	EN 13232-2:2003 - Railway applications – Track – Switches and crossings – Part 2: Requirements for geometric design
		EN 13232-9:2006 - Railway applications – Track – Switches and crossings – Part 9: Layouts
		EN 13803-2:2006/ AC 2007 - Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 2: Switches and crossings and comparable alignment design situations with abrupt changes of the curvature
4.2.12 4.2.12.1	Switches and crossings Means of detection and locking	EN 13232-4: 2005/ - Railway applications – Track – Switches and crossings – Part 4: Actuation locking an detection

Reference: ERA/Interoperability/JCP/hpi/2008/210
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4.2.12 4.2.12.2	Switches and crossings Use of swing nose	prEN13232-7:2006/ - Railway applications - Track - Switches and crossings - Part 7: Crossings with movable parts
4.2.12 4.2.12.3	Switches and crossings Geometrical characteristics	EN 13232-2:2003 - Railway applications – Track – Switches and crossings – Part 2: Requirements for geometric design
		EN 13232-4:2005/ - Railway applications – Track – Switches and crossings – Part 4: Actuation locking an detection
		EN13232-5: 2005 - Railway applications - Track - Switches and crossings - Part 5: Switches
		EN13232-6:2005/ - Railway applications - Track - Switches and crossings - Part 6: Fixed common and obtuse crossings
		EN 13232-7:2006/ - Railway applications - Track - Switches and crossings - Part 7: Crossings with movable parts
		EN 13232-9:2006 - Railway applications – Track – Switches and crossings – Part 9: Layouts
4.2.13	Track resistance	prENV 13803-1:2002 - Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 1: Characterisation of track geometry
		EN 13803-2:2006/AC 2007 - Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 2: Switches and crossings and comparable alignment design situations with abrupt changes of the curvature
		EN 14363: 2005 Railway application – Testing for the acceptance of running characteristics of railway vehicles – Testing of running behaviour and stationary tests
4.2.16	Maximum pressure variations in tunnels	EN14067-5:2005/ - Railway applications - Aerodynamics - Part 5: Requirements and test procedures for aerodynamics in tunnel
4.2.17	Effect of crosswinds	prEN 14067-6: 2006- Railway applications - Aerodynamics - Part 6: Cross wind effects on railway operation (In preparation in TC 256 WG6)
4.4.3	Protection of workers against aerodynamic effects	EN14067-4:2005/prA1 2008 - Railway applications - Aerodynamics - Part 4: Requirements and test procedures for aerodynamics on open track
4.5	Maintenance rules	EN13848-1: 2003/AC2007 – Railway applications - Track - Track geometry quality – Part 1:Characterisation of track geometry
		EN 13232-9:2006 - Railway applications – Track – Switches and crossings – Part 9: Layouts
		ENV 13803-1:2002 - Railway applications - Track alignment design parameters –Track gauges 1435 and wider - Part 1: Characterisation of track geometry

11.2 Appendix 2: Edilon Corkelast Embedded Rail System Guideline for Bridge Design

11.3 Appendix 3: Edilon Corkelast Embedded Rail System Maintenance and renewal

11.4 Appendix 4: Testing of embedded rail system Doc. no. A9055-MEM-6-003

11.5 Appendix 5: Analysis of rail noise Doc. no. A9055-NOT-6-002

11.6 Appendix 6: Test results, Intermediate report Doc. no. A9055-MEM-6-007