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

PROGETTO DEFINITIVO

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INDICE

1 Executive summary

The Messina Bridge is a very large and flexible bridge and therefore the loads will result in very large movements of the structure. Transverse wind load on the structure results in up to 9.9m horizontal movement of the bridge girder in the centre point of the main span. At the same position traffic loads results in vertical movements of the bridge girder up to 2.7m. Large movements in the longitudinal direction of the bridge girder result in pronounced wear for the mechanical components and it is therefore important to reduce the movements as much as possible in order to obtain a cost effective design and reduce interference of the traffic due to repair and maintenance as much as possible.

It is furthermore important that the comfort requirements are met for the users of the bridge when passing the bridge by road or rail.

The mechanical components such as bearings and expansion joints for the bridge should as far as possible remain within the range which has proven feasible for other bridges.

The bridge shall be able to survive severe earthquakes and for this purpose it is an advantage if the bridge is flexible in order to limit the forces in the structure. A substantial damping of the structure is also an advantage during a seismic event.

The objective is therefore to introduce a system of devices that limits movement at normal operation conditions but will allow movements of the girder during severe load conditions such as earthquake and will be able to dissipate energy.

The components in the devised system are the following:

- Restraint of the bridge deck at the tower with hydraulic buffers;
- Bearings
- Expansion joints

Restraint of the bridge deck at the tower

Movements are reduced by introducing a system of longitudinal and lateral restraints of the bridge deck at the towers.

Complete fixation of the bridge deck at the towers will create very large forces in the structures and would not be feasible or economical to accommodate.

Total release of the deck will on the other hand introduce excessive movements in the structure which would be very difficult, if not impossible, to accommodate.

The connections to the towers are equipped with hydraulic buffers, which under "normal" working conditions will remain closed and thus act as rigid connections. In the event of an earthquake the buffers will allow movement of the deck while hydraulically limiting the force transferred between the towers and the bridge girder and also reduce the movements of the girder.

In order to reduce the load on the abutments the road way decks are discontinued at the towers and only the railway deck is continuous. The adjacent cross beams are linked by means of two "triangles" of struts connected at the centre, thus forming an elastic hinge. The rotations in the railway deck due to bending relative to a vertical axis are therefore distributed along the railway deck to meet the comfort criteria.

Bearings and expansion joints

Due to the dimensions of the bridge the size of the required bearings and expansion joints will exceed the "standard" dimensions available from suppliers, however the design of these components will be based on existing proven technology. The following should be noted:

- In the tender design seismic isolation was introduced with the use of hydraulic buffers between the the piers and the terminal structure. In the transverse direction this however results in large lateral movements of the terminal superstructure during seismic events which would be difficult to accommodate in the adjacent viaducts. In the Progetto Definitivo the transverse buffers have been replaced by a lateral fixation of the terminal superstructure in form of a horizontal guide located at the centre of the substructure cross beam. In the longitudinal direction the buffers have been replaced by the guided sliding bearings A6 and A7 by request from Italian Railway Authorities. The bearings was in the tender design configured as free sliding bearings.
- In the tender design the roadway expansion joints at the extremities of the suspended deck (E3) were adapted with a fuse box to facilitate the large structural movement at earthquakes. In the present design however a joint with two movable sides have been chosen. Contact

with suppliers has clarified that such a joint can constructed and that it can tolerate ULS movement without damage. Other roadway expansion joints have one movable side;

- The bearings A5, A6, A7, A9, A13 and A14 experience high uplift forces. In the Progetto Definitivo these bearings are designed with an upper and lower bearing structure. The lower structure houses the normal bearing while the upper part has two uplift bearings connected together by a hydraulic system facilitating a constant and equally shared uplift on both uplift bearings.

With the designed concept for lateral and longitudinal restraint of the bridge deck at the towers the movements of the deck are reduced significantly giving a high comfort for the users of the bridge.

The bearings and expansion joints have been designed with the latest most efficient sliding materials allowing for higher contact stresses, thus limiting the size of the components, and providing significantly longer service and lower maintenance costs.

2 Introduction

This report describes the bridge articulation system. The concepts are based on the concepts shown in the tender design and the 80 day submittal, but for some items it is found advantageous to introduce the following modifications to the concept:

- Redesign of the transverse link and buffer arrangement at the transverse support of the suspended deck;
- Two movable sides are introduced at the large roadway expansion joints E3;
- Transverse buffer D3 and longitudinal buffer D4 have been removed at the terminal structures;
- Introduction of horizontal guides located at the centre of the substructure cross beam at the terminal structures;
- Two of the total four bearings supporting the terminal superstructure have been changed from free sliding bearings to guided sliding bearings;
- In bearings with large uplift separate sliding surfaces has been introduced for downward and uplift forces.

2.1 Report Outline

This report is organized into the following sections:

- Section 2 includes this introduction,

  Section 3 provides a list of reference materials, including design specifications, design codes, material specifications and reference drawings.
- Section 4 provides descriptions of the materials that are used for each component.
- Section 5 describes the three limit states that are considered in the design, serviceability, ultimate and structural integrity.
- Section 6 introduces the components in the articulation system.

3 Design References

3.1 Design Specifications

1 CG.10.00-P-RG-D-P-GE-00-00-00-00-00-02 - "Design Basis, Structural, Annex," COWI 2010

2 GCG.F.05.03 "Design Development – Requirements and Guidelines," Stretto di Messina, 2004 October 22.

3 GCG.G.03.02 "Structural Steel Works and Protective 9Coatings," Stretto di Messina, 2004 July 30.

3.2 Design Codes

4 "Norme tecniche per le costruzioni," 2008 (NTC08).

5 EN 1993 Eurocode 3: Design of Steel Structures – Part 1-1: General rules and rules for buildings

6 EN 1993 Eurocode 3: Design of Steel Structures – Part 1-5: Plated structural elements

7 EN 1993 Eurocode 3: Design of Steel Structures – Part 1-8: Design of joints

8 EN 1993 Eurocode 3: Design of Steel Structures – Part 1-9: Fatigue

9 EN 1993 Eurocode 3: Design of Steel Structures – Part 1-10: Selection of steel for fracture toughness and through thickness properties

10 EN 1993 Eurocode 3: Design of Steel Structures – Part 2: Steel Bridges

11 EN 1998 Eurocode 8: Design of structures for earthquake resistance

12 RFI/DIN/IC/PO 002 A: Istruzione Tecnica 44/E

3.3 Material Specifications

13 EN 10025-1:2004 Hot-rolled products of structural steels – Part 1: General delivery conditions.

14 EN 10025-2:2004 Hot-rolled products of structural steels – Part 2: Technical delivery conditions for non-alloy structural steels.

15 EN 10025-3:2004 Hot-rolled products of structural steels – Part 3: Technical delivery conditions for normalized / normalized weldable fine grain structural steels.

16 EN 10025-4:2004 Hot-rolled products of structural steels – Part 4: Technical delivery conditions for thermo mechanical rolled weldable fine grain structural steels.

17 EN 10164:1993 Steel products with improved deformation properties perpendicular to the surface of the product – Technical delivery conditions.

18 EN ISO 898-1:2001 Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1: Bolts, screws and studs (ISO 898-1:1999).

19 EN 20898-2:1994 Mechanical properties of fasteners – Part 2: Nuts with special proof load values – coarse thread (ISO 898-2:1992).

20 UNI EN 14399:2005-3 High-strength structural bolting assemblies for preloading - Part 3: System HR - Hexagon bolt and nut assemblies

21 EN ISO 14555:1998 Welding-Arc stud welding of metallic materials. May 1995.

22 EN 10293:2005 Steel castings for general engineering uses

3.4 References

3.4.1 Design reports

Design Report - Suspended deck at Towers and Terminal structures	CG1000-P-CL-D-P-SS-A0-00-00-00-00-01
Design Report - Bridge bearings	CG1000-P-CL-D-P-SS-A0-AP-00-00-00-01
Design Report - Expansion Joints	CG1000-P-CL-D-P-SS-A0-AM-00-00-00-01
Performance Specification - Bridge Bearings	CG1000-P-SP-D-P-SS-A0-AP-00-00-00-01
Performance Specification - Buffers	CG1000-P-SP-D-P-SS-A0-AM-00-00-00-01
Performance Specification - Expansion Joints, Railway	CG1000-P-SP-D-P-SS-A0-AM-00-00-00-02
Performance Specification - Expansion Joints, Roadway	CG1000-P-SP-D-P-SS-A0-AM-00-00-00-03

Table 1: Design reports

3.4.2 Drawings

Articulation system - General arrangement	CG1000-P-AX-D-P-SS-A0-00-00-00-00-01
Articulation system - Support of suspended deck at towers	CG1000-P-AX-D-P-SS-A0-00-00-00-00-02
Articulation system - Longitudinal supports	CG1000-P-BX-D-P-SS-A0-00-00-00-00-01
Articulation system - Transverse supports (1)	CG1000-P-BX-D-P-SS-A0-00-00-00-00-02
Articulation system - Transverse supports (2)	CG1000-P-BX-D-P-SS-A0-00-00-00-00-03
Articulation system - Hydraulic systems	CG1000-P-BX-D-P-SS-A0-00-00-00-00-05
Articulation system - Bridge bearings , Overview	CG1000-P-DX-D-P-SS-A0-AP-00-00-00-01
Articulation system - Bridge bearings , Details	CG1000-P-BX-D-P-SS-A0-AP-00-00-00-01
Articulation system - Expansion joints, Overview	CG1000-P-DX-D-P-SS-A0-GE-00-00-00-01
Articulation system - Expansion joints railway (1)	CG1000-P-DX-D-P-SS-A0-GE-00-00-00-02
Articulation system - Expansion joints railway (2)	CG1000-P-DX-D-P-SS-A0-GE-00-00-00-03
Articulation system - Expansion joints railway (3)	CG1000-P-DX-D-P-SS-A0-GE-00-00-00-06
Articulation system - Expansion joints roadway (1)	CG1000-P-DX-D-P-SS-A0-GE-00-00-00-04
Articulation system - Expansion joints roadway (2)	CG1000-P-DX-D-P-SS-A0-GE-00-00-00-05

Table 2: Articulation drawings

4 Materials

The mechanical properties of the articulation construction materials are described in this section.

The design of some of the articulation components are proposed by the manufacturers based on technical specifications provided by COWI. The mechanical properties of components construction materials should be found in the manufacturers' documentation.

4.1 Structural Steel

The structural components are mainly fabricated from Grade S 460 ML structural steels, produced in accordance with [16]. The steels are assumed to have the mechanical properties listed in Table 3, in accordance with [4] Section 11.3.4.1. The steel fabricator has confirmed that the mechanical properties will not vary with material thickness for thicknesses less than 100 mm, as is typical for rolled steel products.

Grade	Yield Strength, f_{yk} (MPa)	Tensile Strength, f_{tk} (MPa)
S 355 ML	355	470
S 460 ML	460	540

Table 3: Structural steel mechanical properties for thicknesses less than 100 mm.

All structural steel is assumed to have the following properties, in accordance with [4] Section 11.3.4.1:

- Elastic modulus: $E = 210{,}000$ MPa
- Poisson's ratio: $\nu = 0.3$
- Shear modulus: $G = 77{,}000$ MPa
- Coefficient of thermal expansion: $\alpha = 12 \times 10^{-6} / °C$
- Density: $\rho = 7{,}850$ kg/m^3

The material partial factors (safety coefficients) used to verify structural steel elements are in accordance with [4] Sections 4.2.4.1.1, 4.2.4.1.4 and are listed in Table 4.

Verification	Partial Factor
Resistance of Class 1, 2, 3 and 4 sections	$\gamma_{M0} = 1.05$
Resistance to instability of members in road and rail bridges	$\gamma_{M1} = 1.10$
Resistance to fracture of sections under tension (weakened by holes)	$\gamma_{M2} = 1.25$
Fatigue resistance (useful fatigue life criterion with significant failure consequences)	$\gamma_{mf} = 1.35$

Table 4: Material partial factors for structural steel.

4.2 High Strength Bolts

High strength structural bolts of Grade 8.8 or Grade 10.9, produced in accordance with [18], are used for all bolted connections and splices. Grade 8.8 bolts are used for connections of all non-structural components to the towers and Grade 10.9 bolts are used for the tower leg construction joint splices (except for the skin plates splices, which are welded). High strength bolts are assumed to have the mechanical properties listed in Table 5, in accordance with [4] Section 11.3.4.6.1.

Grade	Yield Strength, f_{yb} (MPa)	Tensile Strength, f_{tb} (MPa)
8.8	649	800
10.9	900	1000

Table 5: Structural bolt mechanical properties.

The material partial factors (safety coefficients) used to verify bolted connections and splices are in accordance with [4] Section 4.2.8.1.1 and are listed in Table 6.

Verification	Partial Factor
Resistance to bolt shear	$\gamma_{M2} = 1.25$
Resistance to bolt tension	
Resistance to bearing on plates	
ULS slip resistance	$\gamma_{M3} = 1.25$
SLS slip resistance	$\gamma_{M3} = 1.15$
Bolt preload force	$\gamma_{M7} = 1.10$

Table 6: Material partial factors for bolted connections and splices.

4.3 Welding Consumables

Welding consumables shall comply with the requirements of [7] Section 4.2.

Welding procedures shall be specified in a way that the mechanical properties of the thermo-mechanically processed plates are not reduced.

Matching filler materials shall be used in compliance with the mechanical properties of the base material.

The material partial factor, $\gamma_{M2} = 1.25$, used to verify welded connections and splices is in accordance with [4] Section 4.2.8.1.1.

5 Design principles

This section describes the limit states and corresponding performance requirements governing the proportioning of the articulation components, in accordance with [1]. The performance of the articulation components is verified at Serviceability Limit States (1 and 2) Ultimate Limit States, Fatigue Limit States and Structural Integrity Limit States.

The design of some of the components comprised in the Articulation system is proposed by the manufacturers based on technical specifications provided by COWI. Verification of these components in specific limit states should be found in the manufacturer's documentation.

5.1 Serviceability Limit States

In [4] Section 2.2.2 defines the following Serviceability Limit States (SLS) that are to be evaluated in a structural design:

- Local damage that can reduce the durability of the structure.
- Displacement or deformations that could limit the use of the structure, its efficiency and its appearance.
- Displacement or deformations that could compromise the efficiency and appearance of non-structural elements, plants and machinery.
- Vibrations that could compromise the use of the structure.
- Damage caused by fatigue that could compromise durability.
- Corrosion and/or excessive deterioration in materials due to atmospheric exposure.

In [1] Section 3.1 is specified the performance requirements for the structure under two levels of serviceability. The SLS performance requirements are listed in Table 7.

Limit State	Performance Requirement
SLS1	Road and rail runability is guaranteed. No structural damage. The structure remains in an elastic state and all deformations are reversible.
SLS2	As for SLS1 except that only rail runability is guaranteed.

Table 7: SLS performance requirements

The following is verified in SLS for the articulation components.

- Stresses on effective cross-sections in the transverse support at the towers shall be less than the design material yield strength.
- Load, movement and rotation on bearings. Further the accumulated movement shall be acceptable in relation to the chosen overall statical system.
- Movement and rotation in expansion joints. Further the accumulated movement shall be acceptable in relation to the chosen overall statical system.
- Load, movement and rotation on buffers.

5.2 Ultimate Limit States

In [4] Section 2.2.1 it is defined that the following Ultimate Limit States (ULS) are to be evaluated in a structural design:

- Loss of equilibrium of the structure or part of it.
- Excessive displacement or deformation.
- Arrival at the maximum resistance capacity of parts of the structure, joints or foundations.
- Arrival at the maximum resistance capacity of the structure as a whole.
- Arrival at ground collapse mechanisms.
- Failure of frames and joints due to fatigue.
- Failure of frames and joints due to other time-related effects.
- Instability of parts of the structure or structure as a whole.

In [1] Section 3.1 specifies the performance requirements for the structure under ultimate or rare loads. The performance requirements are listed in Table 8.

Limit State	Performance Requirement
ULS	Temporary loss of serviceability allowed. The main structural system maintains its full integrity. Structural damage to secondary components is repairable by means of extraordinary maintenance works.

Table 8: ULS performance requirement

The following is verified in ULS for the articulation components:

- Lateral support at the towers
  - Stresses on effective cross-sections shall be less than the design material yield strength.
  - Slip-resistant bolted connections do not slip.
  - Bolt shear and plate bearing capacities shall be larger than demands for bolted connections that are slip resistant at SLS.
  - Welded connections provide sufficient capacity.
  - Through thickness stresses on plates with welds on either side of the plate thickness shall be less than the allowable stresses for the steel type specified.
- Load, movement and rotation on bearings.
- Movement and rotation in expansion joints.
- Load and movement in buffers

5.3 Fatigue Limit States

In [4] Sections 2.2.1 and 2.2.2 there is no distinction between fatigue limit states (FLS) from serviceability and ultimate limits states with similar consequences and performance requirements. However, in [4] Section 4.2.2.1 and in this report, FLS are distinguished because the loads and load combinations used for verification are different, as are the means by which the elements are verified. In [4] Sections 2.2.1 and 2.2.2 it is defined that the following fatigue related SLS and ULS that are to be evaluated in a structural design:

- Damage caused by fatigue that could compromise durability (SLS).
- Failure of frames and joints due to fatigue (ULS).

The following is verified in fatigue limit state for the articulation components:

- Lateral support at the towers
  - Slip-critical bolted connections do not slip under SLS loads.
  - Steel stresses under fatigue loading are less than the endurance limit for the design details used.

5.4 Structural Integrity Limit States

Consideration of Structural Integrity Limit States (SILS) is unique to this project and is a result of the structure's exceptional size and importance. These limit states are not considered in [4] and are described only in the project design basis. In general, the limit states considered are similar to those considered at the ULS, however, the return periods for the applied loads are longer (i.e., higher wind speeds and peak ground accelerations) and the performance criteria are relaxed from those applicable at the ULS. The performance requirements are listed in Table 9.

Limit State	Performance Requirement
SILS	Complete loss of serviceability, even protracted in time, is permitted. The survival of the following elements of the main structural system must be guaranteed: restraint and support system, main cables, saddles.

Table 9: SILS performance requirements

In the structural integrity limit states significant damage is allowed for all the Articulation components, hence they are not verified for this state. The damage can be made good by significant extraordinary maintenance operations, which may involve prolonged closures of the Bridge.

6 Articulation

The Messina Bridge is a very large and flexible bridge and therefore the loads will result in very large movements of the structure. Transverse wind load on the structure results in up to 9.9m horizontal movement of the bridge girder in the centre point of the main span. At the same position traffic loads results in vertical movements of the bridge girder up to 2.7m. Longitudinal movements of the bridge structure without longitudinal restraint of the girder are shown in Table 10.

Longitudinal movements of the bridge structure		**Girder at tower**	**Girder at end**	**Tower at girder level**
SLS1	+/- (m)	4.79	4.80	0.03
SLS2	+/- (m)	4.94	4.94	0.03
ULS	+/- (m)	5.68	5.70	0.05

Table 10: Longitudinal movements of the free bridge structure for various load cases

Large longitudinal movements of the bridge girder results in pronounced wear for the mechanical components, it is therefore important to reduce the movements as much as possible in order to obtain a cost effective design and reduce interference of the traffic due to repair and maintenance as much as possible.

It is furthermore required that the comfort is high for the users of the bridge when passing the bridge by road or rail.

The mechanical components such as bearings and expansion joints for the bridge should as far as possible remain within the range which has proven feasible for other bridges.

The bridge shall be able to survive severe earthquakes and for this purpose it is an advantage if the bridge is flexible in order to limit the forces in the structure. A substantial damping of the structure is also an advantage during a seismic event.

The objective is to introduce a system of devices that prevents movement at normal operation conditions but during severe load conditions such as earthquake will allow movements of the girder and will be able to dissipate energy.

6.1 Longitudinal and lateral restraint of the deck at the tower

Movements are reduced by introducing a system of longitudinal and lateral restraints of the bridge deck at the towers.

Complete fixation of the bridge deck at the towers will create vary large forces in the structures would not be feasible or economical to accommodate.

Total release of the deck will on the other hand introduce excessive movements which would very difficult, if not impossible, to accommodate.

The connections to the towers are equipped with hydraulic buffers, which under "normal" working conditions will remain closed and thus act as rigid connections. In the event of an earthquake the buffers will allow movement of the deck while hydraulically limiting the force transferred between the towers and the bridge girder and also reduce the movements of the girder.

The concept of the system is shown in Figure 6-1, where the longitudinal buffers are marked by D2. The seismic isolator in the connection to the tower is marked by D1

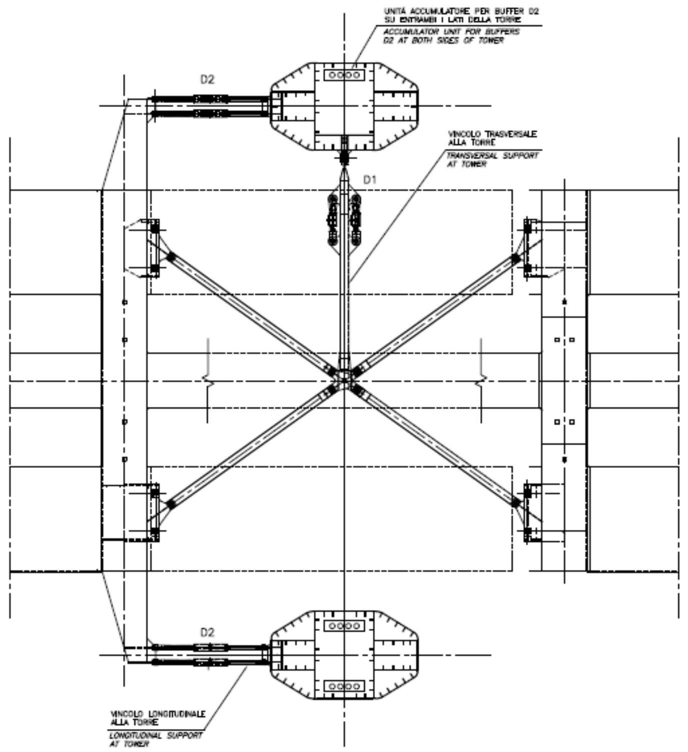

Figure 6-1: Restraint of the deck at the towers

In order to reduce the load on the abutments the road way decks are discontinued at the towers and only the railway deck is continuous. The adjacent cross beams are linked by means of two "triangles" of struts connected at the centre, thus forming an elastic hinge. The rotations in the railway deck due to bending relative to a vertical axis are therefore distributed along the railway deck to meet the comfort criteria, see Figure 6-2

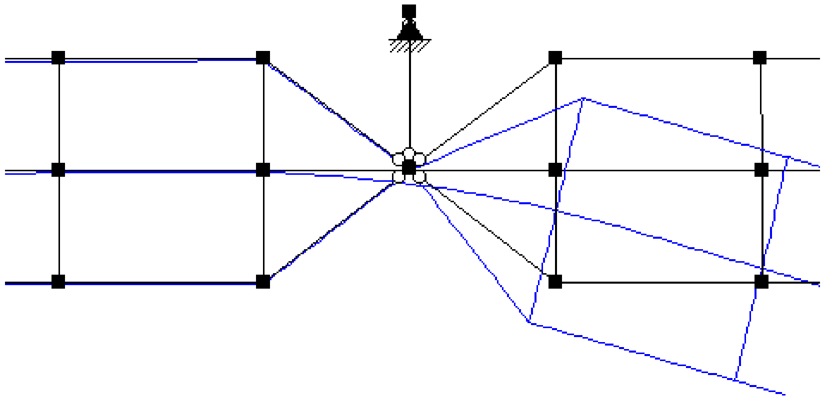

Figure 6-2: Deformation of the bridge girder at the towers due to transverse loads

6.2 Alternative articulation concept at the towers

As the concept for restraining of the deck at the towers is complex alternative solutions have beeb investigated. Especially it would be advantageous if the roadway girders could be made continuous at the towers. In the following two alternative concepts are briefly described:

- **Continuous roadway girders and transverse rigid support at the towers.** This concept was evaluated and it was found that in the case of strong transverse wind loads on the bridge an unfavourable "bottle opener" effect would occur. Due to this effect the forces in the transverse support system at the terminal structure and at the tower would become excessive.
- **Continuous roadway girders and transverse flexible support.** This concept is based on a rigid transverse connection at the terminal structure and a flexible connection at the tower. In the event of strong transversal winds on the bridge girder the transverse forces should be distributed between the support structure at the terminal structure and the flexible connection at the tower. With a suitable flexibility at the tower for distribution of the transverse loads this

concept would however lead to large transversal movements of the bridge girder during strong winds, movements in the order of 2 to 3m could be expected. Furthermore movements of this magnitude could lead to geometrical problems at the railway expansion joint at the terminal structure.

Studies of various alternative concepts including the two above-mentioned concepts showed that the disadvantages of the various solutions outweighed the advantages which could be gained and therefore after careful consideration it was decided to maintain the concept originally shown for the tender design.

6.3 Hydraulic Buffers

The design of the hydraulic buffers is proposed by the manufacturers based on technical performance specifications issued as a part of the Progetto Definitivo.

The technical specifications are in accordance with [1] and [2].

The characteristic of buffer D1 and D2 is introduced in the following sections

6.3.1 Characteristics

6.3.1.1 Lateral restraint - buffer D1

The characteristic of buffer D1 is shown in Figure 6-3.

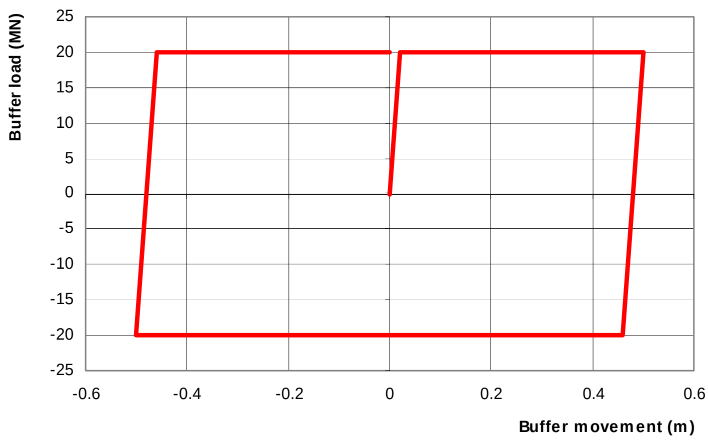

Figure 6-3: Characteristic of buffer D1, total load for 2 hydraulic buffers

A threshold value of 20MN is chosen for the hydraulic buffers. At less magnitude of force no movements of the buffer will occur due to wind loads. Installation of a hydraulic seismic isolator D1 results in a load reduction in the transverse direction from ~60MN to ~20MN in the case of a ULS seismic event.

6.3.1.2 Longitudinal restraint - buffers D2

The characteristic of buffer D2 is shown in Figure 6-4.

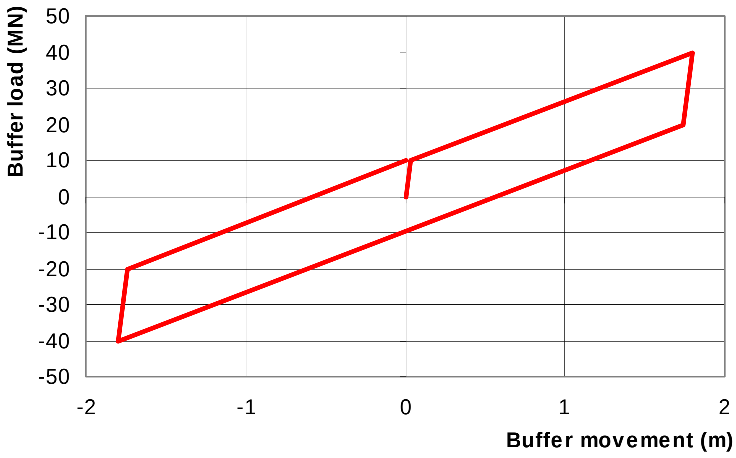

Figure 6-4: Characteristic of buffer D2, total load for 4 hydraulic cylinders

The buffers act as a damper combined with a spring and in the load combination with temperature loading, traffic load on the bridge and earth quake simultaneously the function of the buffer is to reduce the maximum movement of the suspended girder.

To avoid torsional restraint of the deck at the tower the buffers located on the two legs at one tower are connected hydraulically through piping, so that the hydraulic oil can flow freely from one side to the other in case of rotational movements of the deck with regards to a vertical axis. Due to the hydraulic coupling all 8 cylinders will act as one group located at the longitudinal axis of the bridge and the maximum load induced on the tower is 2 times 40MN equals 80MN.

The damping behaviour is provided by means of pressure relief valves restraining the oil flow until a certain threshold value, above which the oil can flow under constant oil pressure. The spring behaviour is provided by means of accumulator tanks located inside the tower legs. The effects of each component and the resulting load-displacement curve for the entire combined system is shown in the figure below.

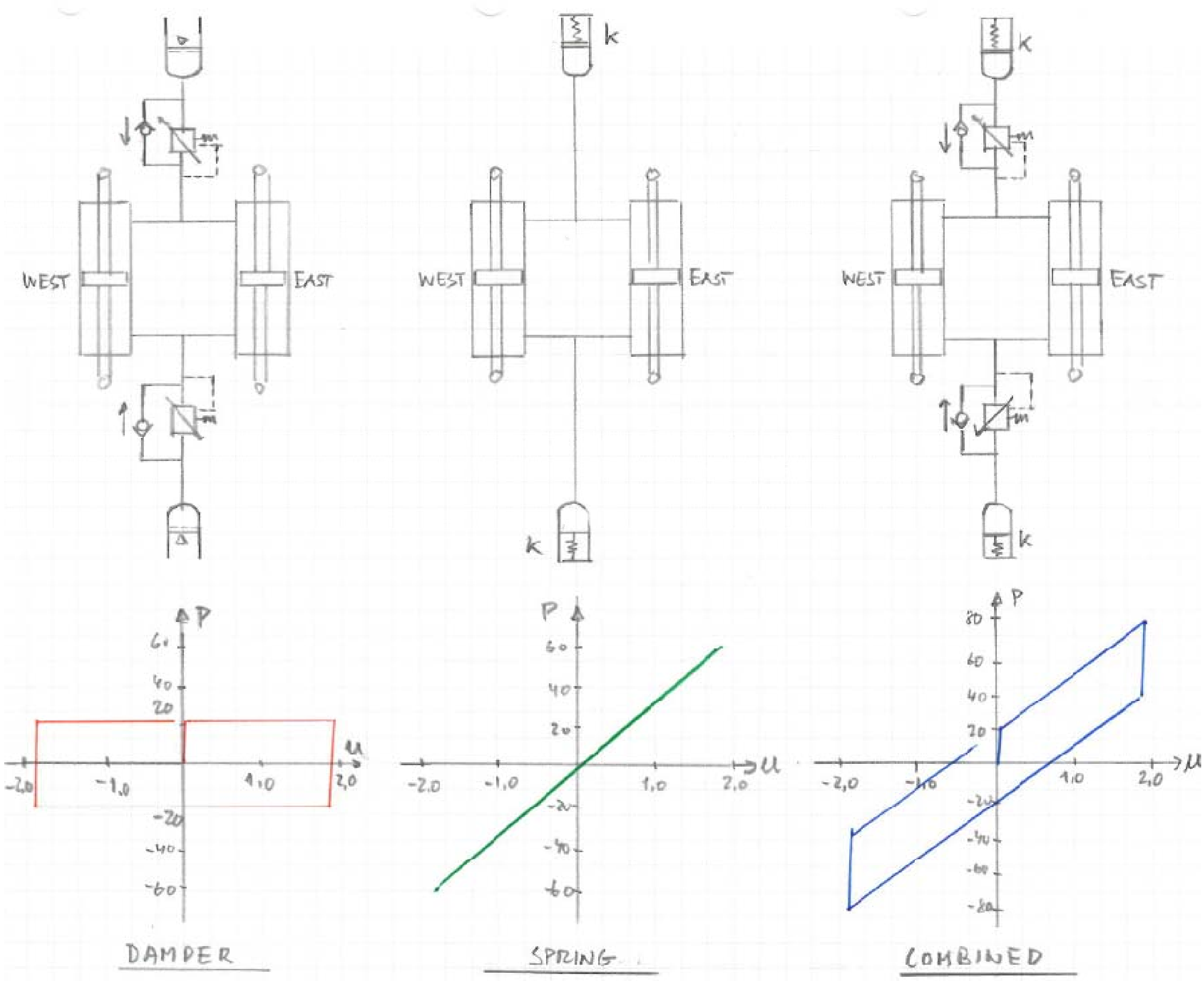

Figure 6-5: Schematic description of system behaviour

The design of the hydraulic circuits required to provide the described buffer characteristic is included in the doc. CG1000-P-CL-D-P-SS-A0-00-00-00-00-01 " Design Report - Suspended deck at Towers and Terminal structures".

In order to obtain very limited movements during frequent traffic conditions the hydraulic system is installed with a threshold value. The threshold value should not be exceeded during the passage of a train and consequently the movements are limited to the movements from local deflexion of the towers and the bridge deck.

In the present design the buffers D2 consist of 4 nos. hydraulic cylinders each in order to remain within acceptable and practical dimensions and to ensure a redundant system.

The threshold value is chosen to 10MN for each group of cylinders connected to each tower leg and the buffer system hence stops any longitudinal movements as long as the force in the buffers at each tower leg is less than 20MN. The 20MN load in the buffer will be exceeded in some load cases; e.g. when there is a temperature change for the bridge girder of ±6^0 C.

In order to illustrate the function of the buffers the response of the bridge during an ULS seismic event is shown in the following figures. Figure 6-6 illustrates the movements at the girder end with and without buffers for the same load case combined with a time history of a seismic event.

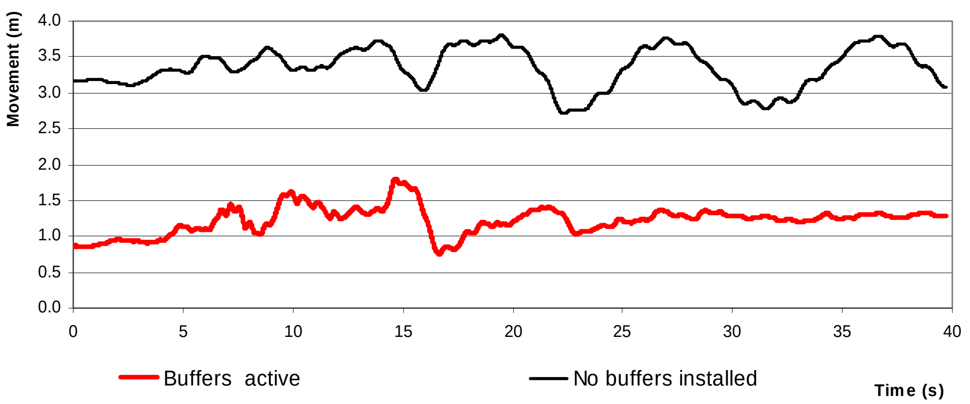

Figure 6-6: Time history calculation. Temperature load, traffic load and seismic time history. Movements at girder end with and without buffers

The movement of the bridge girder at one of the expansion joints at the terminal structures with no buffers installed for a freight train type 6 passing the bridge at 100 km/hour is shown as a function of time in Figure 6-7.

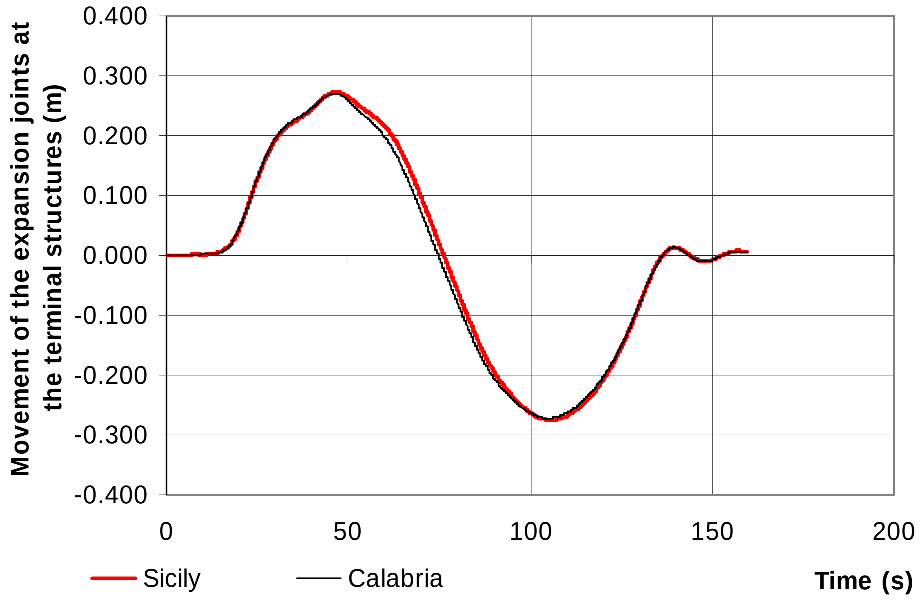

Figure 6-7: Time history analysis. Movement at the expansion joints for the passage of a train. No buffers installed. One train type 6 running at 100km/h over the bridge

The accumulated expansion joint movements for train traffic are shown in Table 11.

Accumulated longitudinal movement for train passage	**Train weight**	**One train passage**	**No of train passages pr track pr year**	**Movements pr year**
Train type	(t)	(m)		(m)
1. I.C.	687	0.605	7300	8830
2. E.C.	474	0.417	3650	3044
3. EXPR	930	0.819	5475	8968
4. DIR	545	0.480	10950	10512
5. ETR 500	624	0.549	3650	4008
6. TEC	1312	1.155	5475	12647
7. Merci	1424	1.254	3650	9154
8. Transporte acciaio	1630	1.435	1825	5238
9. Merci misto	976	0.859	1825	3135
TOTAL			43800	65536

Table 11: Expansion joint movements due to train loads

The above-mentioned movements would result in excessive wear of the mechanical components and a reasonable life time would be practically impossible to achieve. This would result in excessive maintenance costs for the mechanical components.

With the suggested buffers installed the movement of the bridge girder at one of the expansion joints at the terminal structures for a freight train type 6 passing the bridge at 100km/hour is shown as a function of time in Figure 6-8.

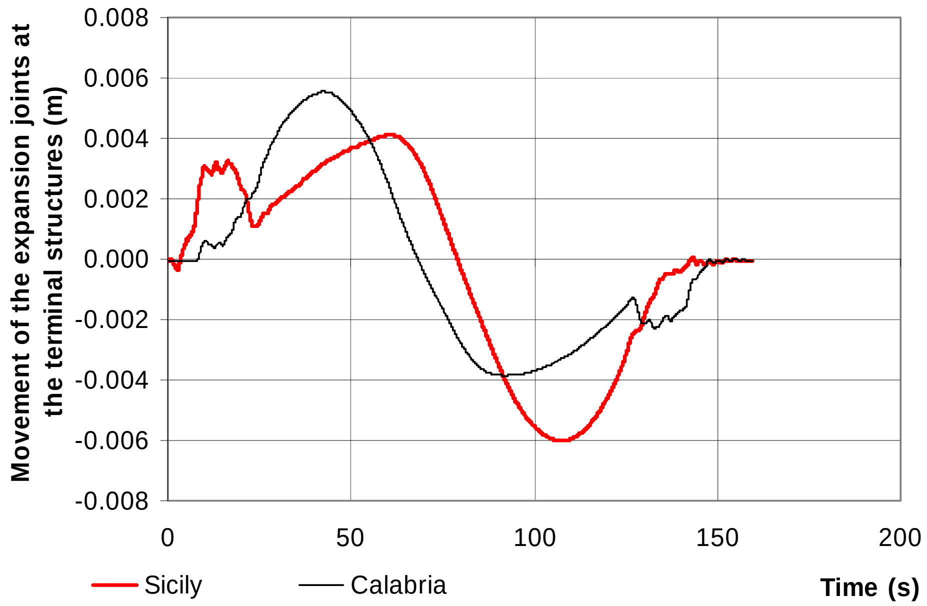

Figure 6-8: Time history analysis. Movement of the bridge girder at the expansion joints with buffers installed. One train type 6 running at 100km/h over the bridge.

The calculated accumulated movements for train passage with the modified articulation system are shown in Table 12.

Accumulated longitudinal movement for train passage	**Train weight**	**One train passage**	**No of train passages pr track pr year**	**Movements pr year**
Train type	(t)	(m)		(m)
1. I.C.	687	0.015	7300	222
2. E.C.	474	0.011	3650	76
3. EXPR	930	0.021	5475	226
4. DIR	545	0.012	10950	164
5. ETR 500	624	0.014	3650	100
6. TEC	1312	0.029	5475	318
7. Merci	1424	0.022	3650	230
8. Transporte acciaio	1630	0.036	1825	132
9. Merci misto	976	0.022	1825	78
TOTAL			43800	1646

Table 12: Expansion joint movement due to train load for the modified articulation system with hydraulic buffers

Introduction of the longitudinal restraining system has thus resulted in a reduction of the accumulated movement from 65536m to 1646m. With this concept a long life time of the mechanical components is secured and comprehensive reductions of maintenance costs are achieved.

6.3.2 Buffer layout

The longitudinal buffers are 14.7 m long. Consequently the buffer will have a high self weight and higher costs will be associated to strengthen the buffer in such a way to avoid deformations of its components.

Due to the big relative movement between the girder at the towers and the tower itself a relative long buffer however are necessary to minimize the rotation at the fastenings.

In the transverse link at the transverse support the two buffers in the tender design experience the same problem of deformation due to the long transverse link. In Progetto Definitivo the layout of the transverse link has been changed to prevent this problem.

6.4 Bearings

The design of the bearings is proposed by the manufacturer based on technical performance specifications issued as a part of the Progetto Definitivo. Standard solutions have been used where applicable.

The technical performance specifications are in accordance with [1] and [2].

6.4.1 Terminal Structure

The bearing layout at the terminal structuresis illustrated in Figure 6-9 and Figure 6-10.

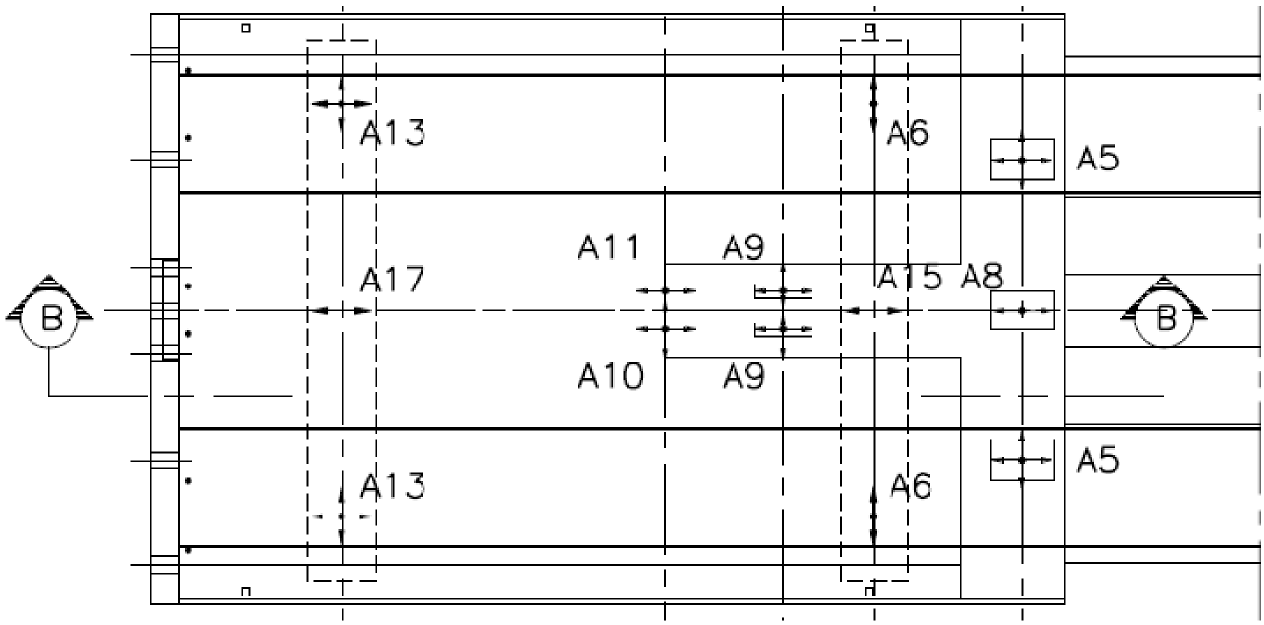

Figure 6-9: Bearing layout at terminal structure on Sicilia side

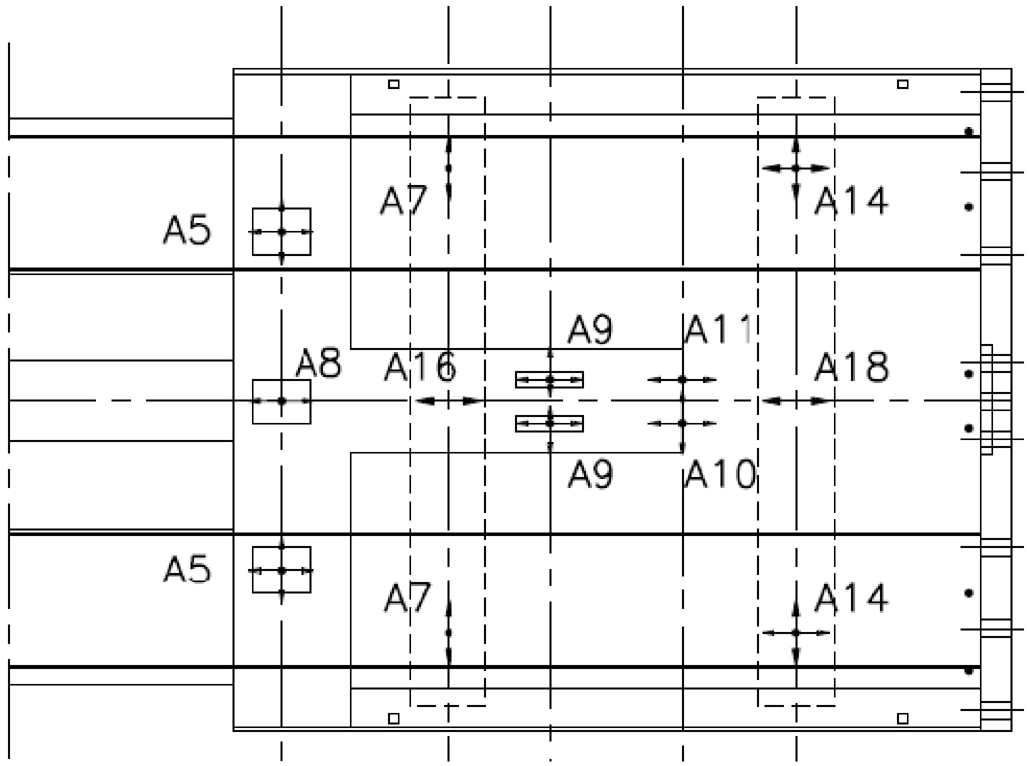

Figure 6-10: Bearing layout at terminal structure on Calabria side

The terminal superstructures is supported by free sliding bearings and guided sliding bearings placed on the terminal substructures cross beams. The bearings are secured against uplift

In the tender design seismic isolation was introduced with the use of hydraulic buffers between the the piers and the terminal structure.

In the transverse direction this however results in large lateral movements of the terminal superstructure during seismic events which would be difficult to accommodate in the adjacent viaducts. In the Progetto Definitivo the transverse buffers have been replaced by a lateral fixation of the terminal superstructure in form of a horizontal guide located at the centre of the substructure cross beam.

In the longitudinal direction the buffers have been replaced by the guided sliding bearings A6 and A7 by request from Italian Railway Authorities. The bearings was in the tender design configured as free sliding bearings.

At both ends of the suspended structure the railway girder is protruding into the terminal superstructure. The extension of the railway girder is supported vertically at the beginning and at the end of the spline girder by the bearings A9, A10 and A11 which are free sliding.

Two further free sliding bearings for vertical loads, A5, are found at the crossbeam connecting the rail and road girders at the terminal structure.

In the transverse direction the railway and road girder is guided by bearings A11 and A8.

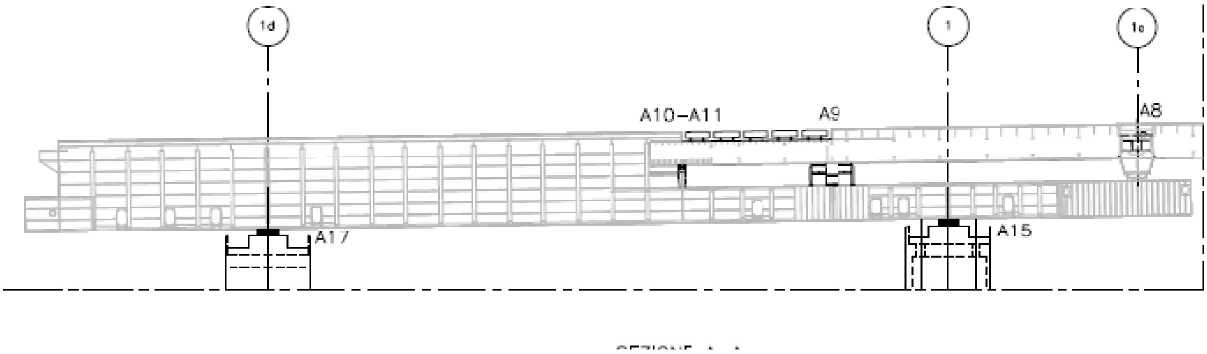

Figure 6-11: Bearing layout at terminal structure on Sicilia side - side view (section B-B in Figure 6-9)

The bearings A5, A6, A7, A9, A13 and A14 experience high uplift forces. In the Progetto Definitivo these bearings are designed with an upper and lower bearing structure. The lower structure houses the normal bearing while the upper part has two uplift bearings connected together by a hydraulic system facilitating a constant and equally shared uplift on both uplift bearings.

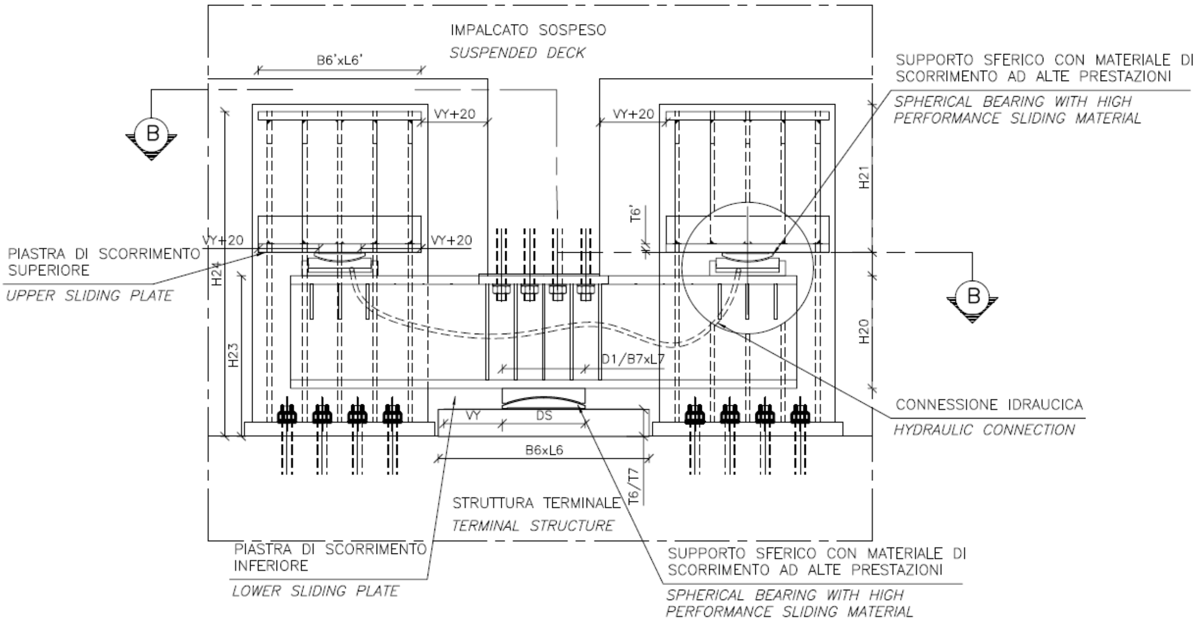

Figure 6-12: Uplift bearing

The uplift bearings will be prestressed through the hydraulic system after installation of bearings and uplift devises. The set-up will be executed by aid of a simple hydraulic pump that will be connected to the hydraulic system.

The hydraulic system secures a constant prestressed condition between the upper and the lower bearing structure. Further the system allows for a subsequent height adjustment/compensation in case of settlement or earthquake.

6.4.2 Drop-in Spans at Towers

At the towers drop-in spans are placed in the road girders. The drop-in spans are placed on 4 bearings each. The layout is shown in Figure 6-13.

Bearings A2 and A4 are free. Bearing A3 is fixed while the drop-in spans are guided in the transverse direction by bearing A1.

According to calculations uplift can be expected in bearings A1-A4 and they are installed with uplift protection.

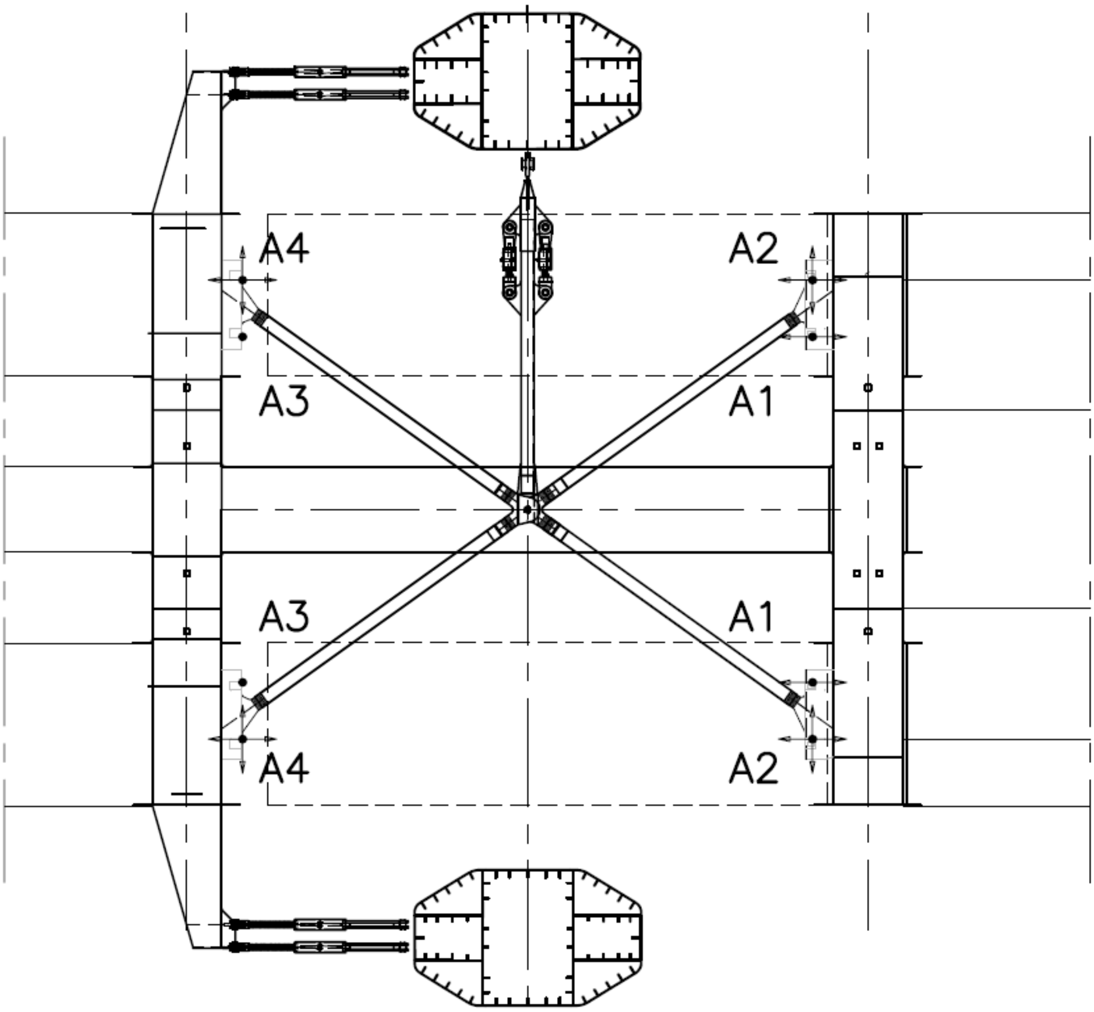

Figure 6-13: Bearing layout at drop-in spans on Sicilia side

6.5 Expansion Joints

The design of the expansion joints is proposed by the manufacturer based on technical performance specifications issued as a part of the Progetto Definitivo.

The technical specifications are in accordance with [1] and [2].

Road expansion joints are installed at the drop-in spans and at the terminal structures. Rail expansion joints are installed at the terminal structures.

6.5.1 Roadway expansion joint

The roadway expansion joints are of a modular type.

In the tender design the roadway expansion joints at the extremities of the suspended deck (E3) were adapted with a fuse box to facilitate the large structural movement at earthquakes.

In the present design however a joint with two movable sides have been chosen. Contact with suppliers has clarified that such a joint can constructed and that it can tolerate ULS movement without damage.

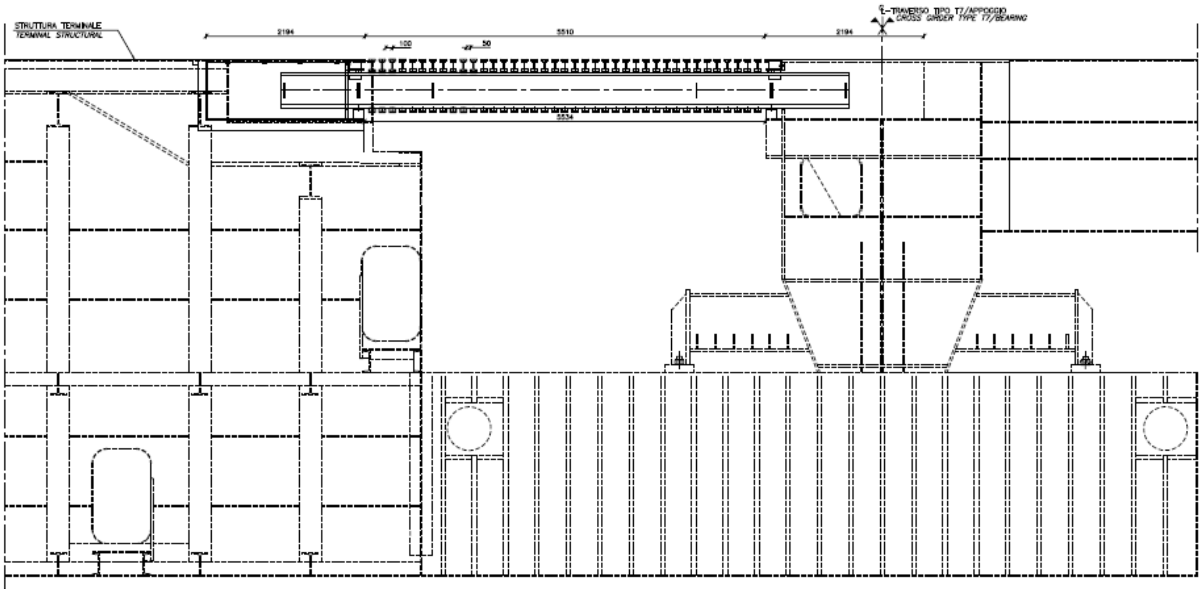

Figure 6-14: Roadway expansion joint E3

Other roadway expansion joints have one movable side.

6.5.2 Railway Expansion Joints

The railway expansion joints are longitudinally moveable stock rails type which facilitates large longitudinal and rotational movements.

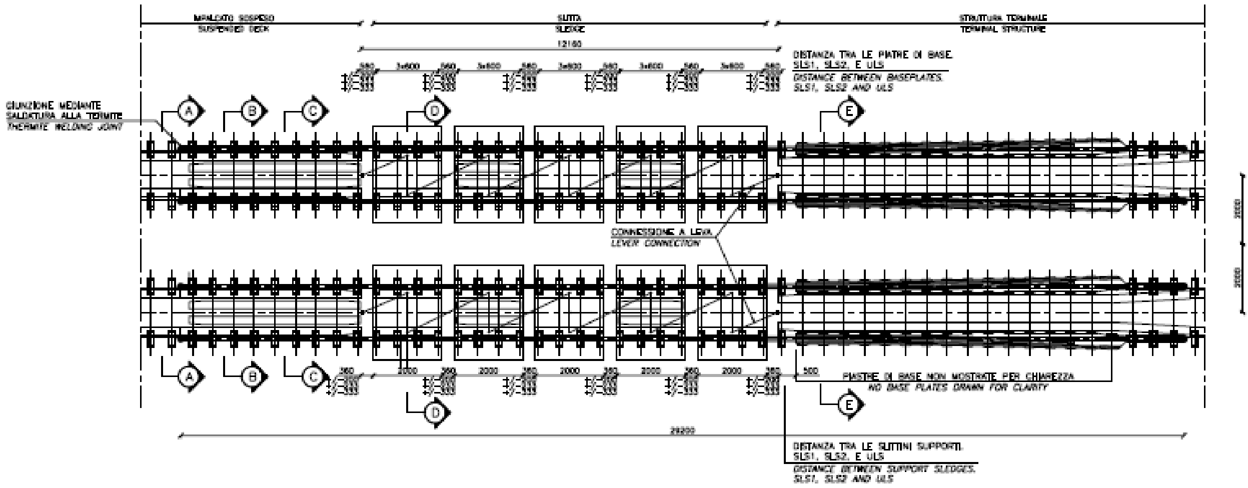

Figure 6-15: Railway expansion joint E4

The expansion joint has the following features:

- The stock rails move longitudinally in two symmetrically arranged cast troughs with integrated switches;
- Wheel transition like that in a switch device of a turnout;
- No gauge widening;
- No check rails required;
- Use of sledges between abutment and the bridge for expansion and contraction.

The design with the sledge is illustrated in Figure 6-16.

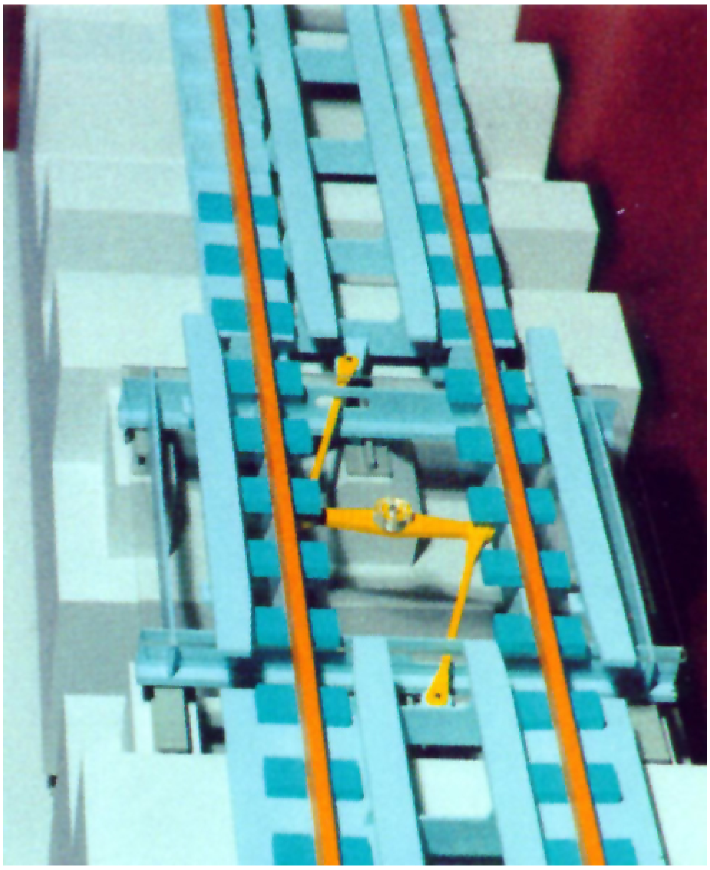

Figure 6-16: Design with sledge

An equal spacing between the sledges is achieved by a lever connection (parts in yellow on the picture of the model) underneath the sledges. The first and last levers are connected either to the terminal station or bridge structure, the levers in-between are connected to each sledge. A turnable arm is fixed under each sledge linking the levers.

The rail movement joint is attached to the supporting structure of the bridge by means of a flexible spline girder. Arising angular deviations are elastically accommodated in vertical and horizontal directions and thus the sensible area of the length modifications in the rails is kept free of deformations.

The connection between the spline girder and the sledges is illustratred in Figure 6-17

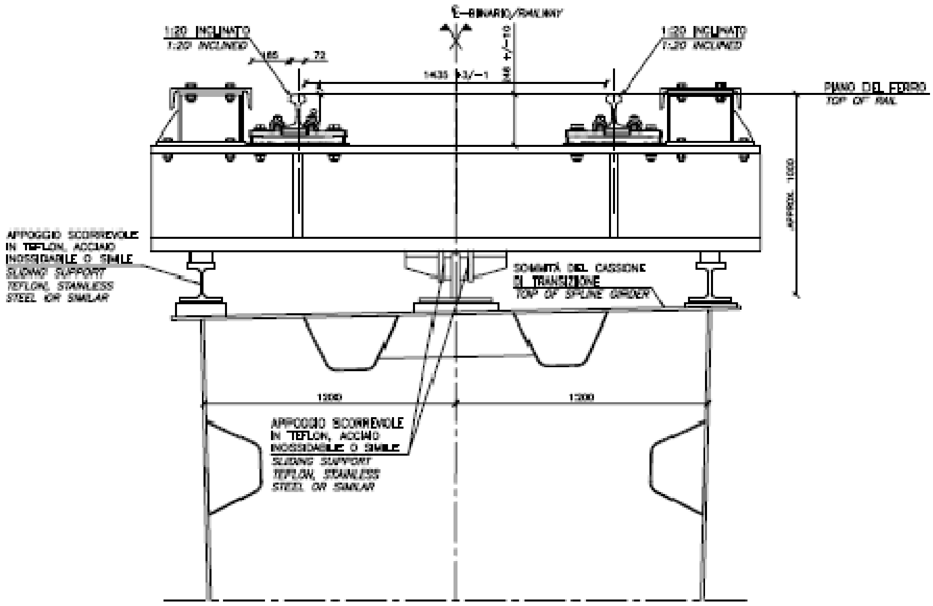

Figure 6-17: Section D-D in Figure 6-15