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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INDEX

1 Executive Summary

1.1 Introduction

This report describes the design of the following structural elements for the Terminal Structure:

- Steel frame
- Transverse steel truss
- Longitudinal webs
- Transverse webs
- Concrete deck slab

The design is based on that shown in the Tender Design with this phase introducing the following changes to the Tender Design:

- Overall width increased from to 59708 mm to 69870 mm with the increase equally distributed on the two service lanes to accommodate the Suspended Deck dilation inside the facade of the Terminal Structure
- Outwards sloping 2 % cross fall of the deck

1.2 Scope

This report describes the design of the structural elements of the Terminal Structure, Calabria side.

The Specialist Technical Design Report is summarising the design which is verified in detail in the Design Report - Main Elements (Report CG1002-P-CL-D-P-SV-S8-00000000-01).

1.3 Materials

Plated structural components and hot rolled sections comprising the bracing and truss system are fabricated from Grade S355 ML structural steel.

Structural concrete is of Grade C35/45 and according to EN 206-1, both for concrete and predalles. Maximum aggregate dimension is 25 mm for the concrete deck and 10 mm for the predalles.

Reinforcement are of carbon steel Grade B450C and according to EN 10080.

1.4 Structural Analysis

The Terminal Structure is modelled and analysed by use of a SAP2000 model whilst the global Messina Strait Bridge is analysed in the COWI proprietary analysis program IBDAS (Integrated Bridge Design and Analysis System).

Bearing reactions for selected fixed loads from the IBDAS model have been applied to the SAP 2000 model to reflect the interaction between the Terminal Structure and the Suspended Deck.

Bearing reactions from the adjacent viaduct have likewise been applied to the SAP 2000 model to reflect the interaction between the two structures but since the viaduct bearing configuration was altered at a late stage and since reactions have not been received at the time of writing the viaduct reactions are based on estimates while assuming that the reactions are equivalent to those of the Pantano Viaduct on the Sicily side.

The structural analysis takes into account the construction sequence of the Terminal Structure which relies in prefabricated predalles acting as formwork for the in-situ cast concrete deck slab.

Note that seismic forces are not considered governing for the design of the main deck elements, so design calculations are performed without the seismic load combination.

1.5 General Description

The Terminal Structures are the approach infrastructures connecting the suspension bridge with the existing road and railway network on the two sides.

On the Calabria side the Terminal Structure is linked to the suspension bridge and to a viaduct linking the main land.

The suspension bridge lands on a number of bearings on the Terminal Structure where a trench is provided for the rail girder which extends longer into the Terminal Structure than the roadway.

The viaduct also lands on bearings provided for its geometry and for both the viaduct and the suspension bridge the Terminal Structure is prepared for installation of large expansion joints which at the suspended deck interface accommodate approximately ± 2000 mm.

The Terminal Structure is a composite structure consisting of a concrete deck on a steel box structure. In plan the overall dimensions of the Terminal Structure are 60.870 m and 71.200 m for the width and length respectively whilst the height varies between 2.810 m at the Suspended Deck support and 10.800 m at the facade. The concrete deck slab has a thickness varying between 300 mm and 400 mm including 50 mm of pre-cast concrete elements (also referred to as predalles).

The deck supports 2 railway tracks, 3 roadways (of which one is an emergency lane) and 2 service lanes.

The service lane is located on the outside of the roadway over the entire length of the Suspended Deck and the Terminal Structure. It is the primary access route for inspection and maintenance.

Along the railway is a platform located on either side of the railway girder for evacuation if necessary. The platform is continuous over the entire Terminal Structure length.

The crash barriers are continuous over the entire bridge length and provide a safe barrier for the road traffic. The wind screen on the service lane reduces the wind speed across the bridge.

Both terminal structures have just one span with a cantilevered overhang of 19.600 m at each end. They are connected to the suspended cable system by hanger cables, which - via an opening through the superstructure of the Terminal Structure - are tied-down into the substructure.

Bearings on each substructure support the superstructure vertically and transversely while a number of bearings support the Suspended Deck and the adjacent viaduct.

The Terminal Structure is provided with walkways and hatches to allow structural components to be maintained and inspected.

The Terminal Structure is painted in the outer surface for corrosion protection whilst only a single coat of primer is applied to the inner surfaces which are protected by a dehumidification system

The man components are described in the following where figures illustrate the layout of the Terminal Structure.

Below is shown the general layout in Figure 1-1.

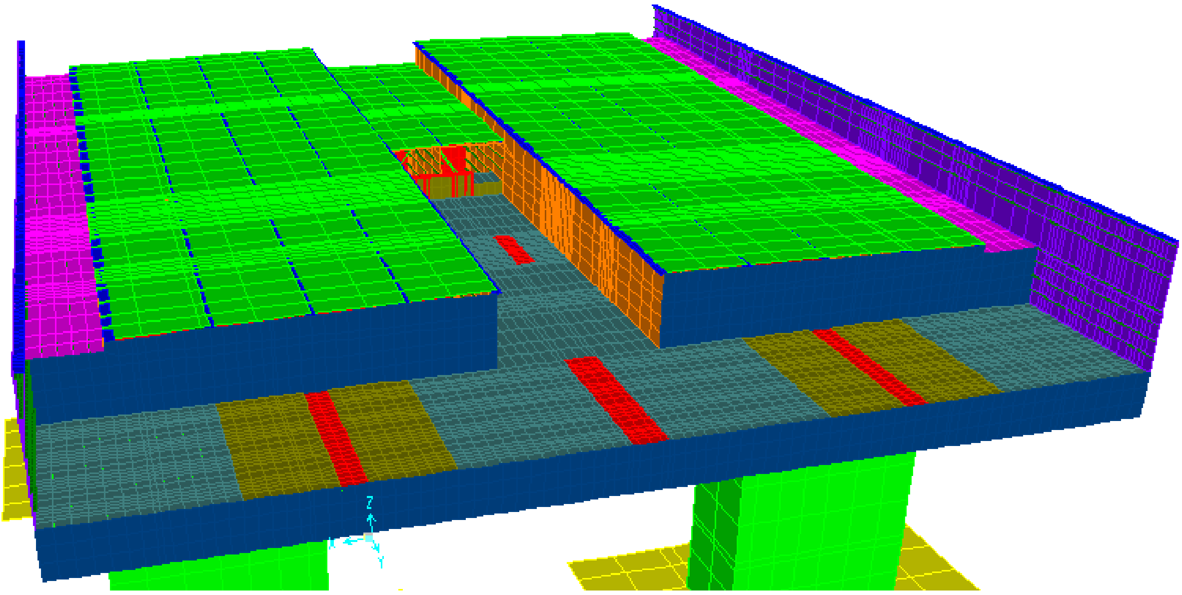

Figure 1-1: Isometric view - Superstructure general layout

1.6 Steel Box

The steel box is composed of an open steel frame with is closed by use of steel plates (typically t = 10 mm) which are provided with appropriate stiffeners to ensure the stability of the plates. The closing steel plates increase in thickness at locations where concentrated loads are present, i.e. typically at the bearings.

The frame is composed of I-shaped profiles (typically IPE600, HE500B and HE600A) which are also applied as half-sections. The half-sections comprise a vertical grid.

At the bottom half-sections are connecting the vertical grid in the transverse direction and the closing steel plates have stiffeners in the longitudinal direction.

At the top the vertical grid is connected by both HEB500-profiles and steel plates (300×40 THK) in the transverse direction and steel plates (500×40 THK) in the longitudinal direction. These top steel elements carry the concrete deck and have shear stud connectors attached.

The layout is shown in Figure 1-2.

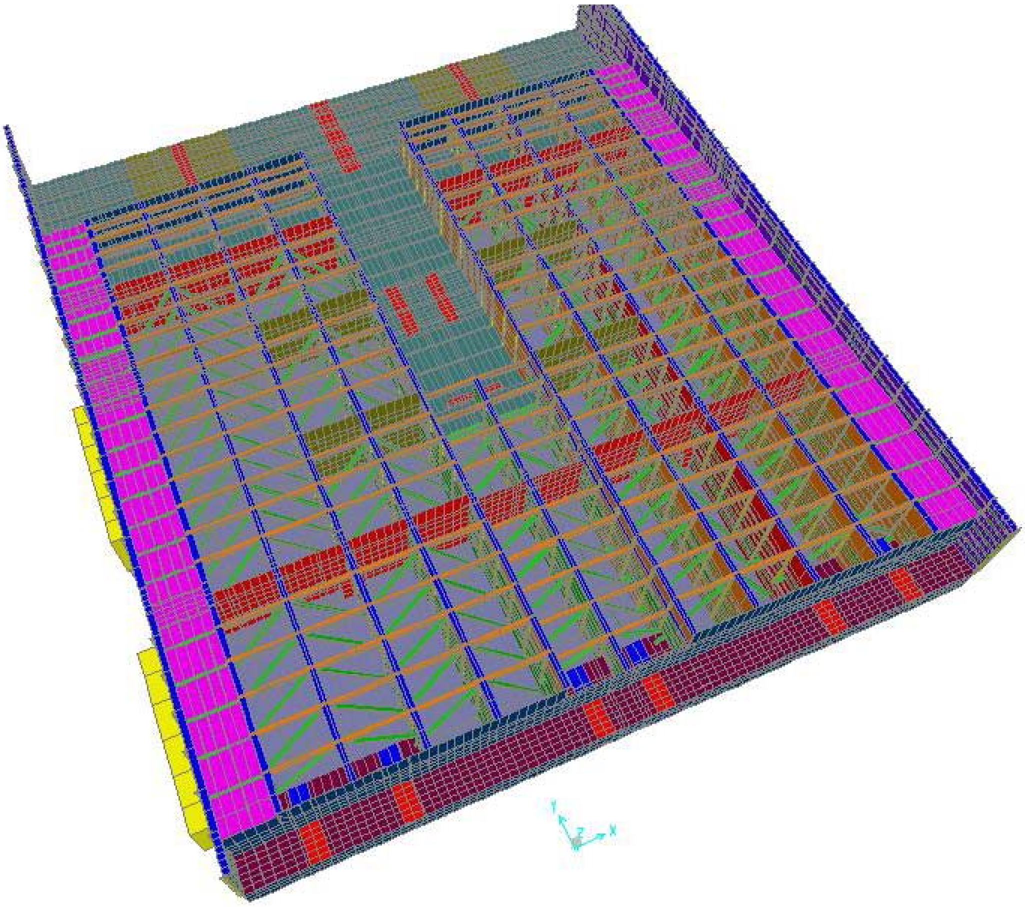

Figure 1-2: Isometric view - Layout of steel box

Initially the steel box carries its own weight including the in-situ cast concrete and composite action is applicable after the concrete has achieved its final strength.

The governing load combinations (Ref. CG1002-P-CL-D-P-SV-S8-00-00-00-00-01 Design Report Main elements) for the steel frame elements is *STR9_5.* The highest utility ratio is 0.40.

1.7 Transverse steel truss

In order to stiffen the steel frame a truss structure in the transverse direction is applied. The truss is composed of HE300B-profiles and is shown in Figure 1-3.

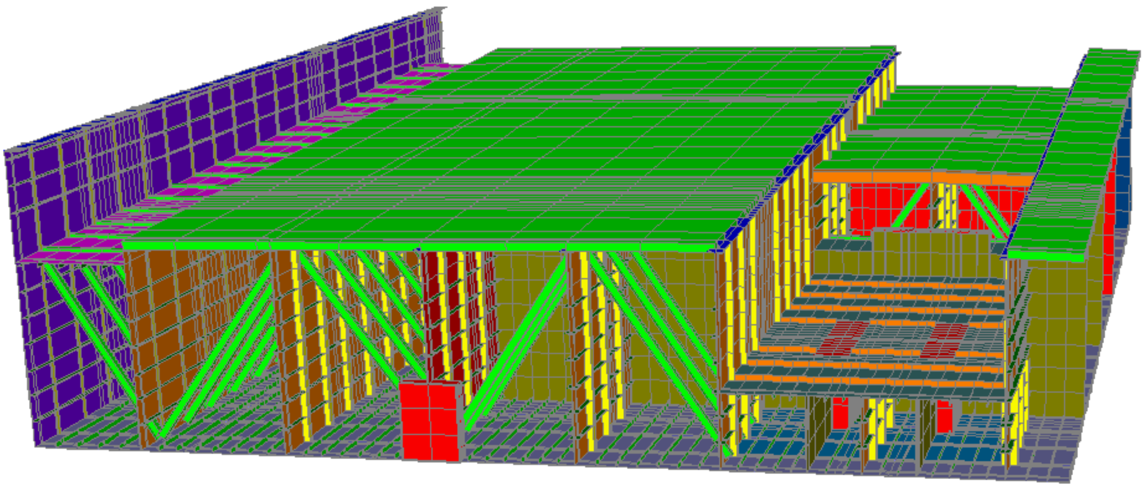

Figure 1-3: Isometric view - Transverse steel truss

The governing load combinations (Ref. CG1002-P-CL-D-P-SV-S8-00-00-00-00-01 Design Report Main elements) for the steel frame elements is *STR2_45*. The highest utility ratio is 0.72.

1.8 Longitudinal webs

11 longitudinal webs run in the entire length inside the Terminal Structure. These are typically of thickness t = 15 mm. However, those longitudinal webs above the bearings which support the superstructure at have an increased thickness of t = 35 mm. The longitudinal webs divide the Terminal Structure into longitudinal compartments and openings are provided in order access transversely through the longitudinal webs.

The longitudinal webs can be seen in the figures above.

The longitudinal webs are stiffened to ensure the plate stability and highest utility ratios are found to be and 0.85.The governing load combinations (Ref. CG1002-P-CL-D-P-SV-S8-00-00-00-00-01 Design Report Main elements) is STR10_61.

1.9 Diaphragms

Heavy diaphragms (t = 40 mm) run across the Terminal Structure above the bearings which support the superstructure. The diaphragms divide the Terminal Structure into transverse compartments and openings are provided in order access longitudinally through the diaphragms.

Supplementary diaphragms (t = 15 mm and 25 mm) are applied on either side of the trench where the suspended deck rail girder extends into the Terminal Structure. However, these diaphragms are limited in the transverse direction.

The diaphragms are can be seen in the figures above.

The diaphragms are stiffened to ensure the plate stability and highest utility ratios are found to be 0.3. The governing load combinations (Ref. CG1002-P-CL-D-P-SV-S8-00-00-00-00-01 Design Report Main elements) is STR10_37.

1.10 Concrete Deck Slab

The mildly reinforced concrete deck slab has a thickness varying between 300 mm and 400 mm including 50 mm of pre-cast elements and with the thicker part towards the rail tracks. This part of the deck has no need for asphalt surfacing and is flush with the roadway surface whereby a constant transverse slope of 2 % is maintained in order to drain the water across the deck without obtrusions. The road surfacing consists of 110 mm asphalt.

The concrete deck cross section is shown in Figure 1-4.

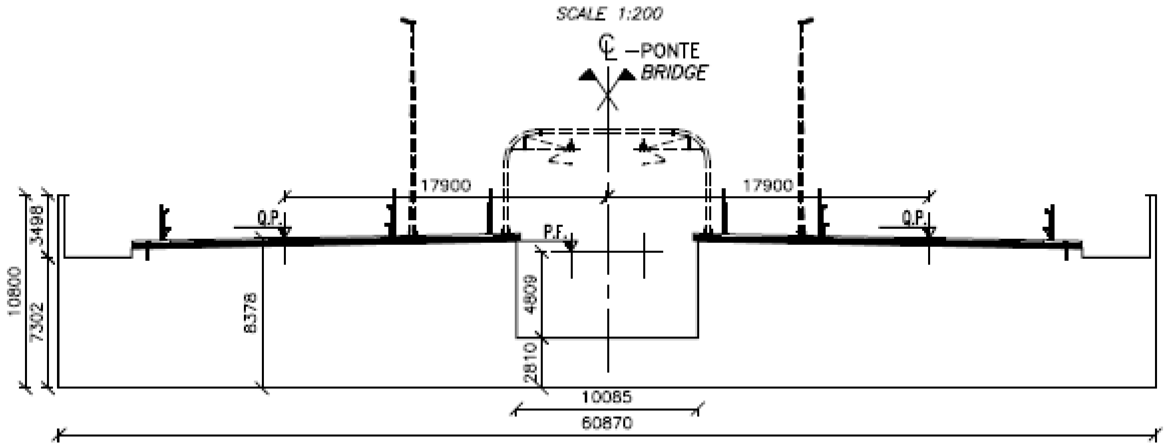

Figure 1-4: Concrete deck cross section

The governing load combinations for the concrete deck are SLU-STR2 for road loads and SLU-FERR-4 for rail loads. Highest utility ratios are found to be 0.81 for SLU-STR2 and 0.8 for FERR-4.

2 Introduction

This report describes the design of the following structural elements for the Terminal Structure:

- Steel box
- Transverse steel truss
- Longitudinal webs
- Diaphragms
- Concrete deck slab

The design is based on that shown in the Tender Design with this phase introducing the following changes to the Tender Design:

- Overall width increased from to 59708 mm to 69870 mm with the increase equally distributed on the two service lanes to accommodate the Suspended Deck dilation inside the facade of the Terminal Structure
- Outwards 2 % sloping cross fall of the deck

2.1 Scope

This report describes the design of the structural elements of the Terminal Structure, Calabria side.

The Specialist Technical Design Report is summarising the design which is verified in detail in the Design Report (Report CG1002-P-CL-D-P-SV-S8-00000000-01).

2.2 Report Outline

This report is organized into the following sections:

- *Section 1* includes the executive summary, which gives a brief description of the report.
- *Section 2* includes an introduction, provides a list of reference materials, including design specifications, design codes, material specifications, reference drawings and complementary reports.

- *Section 3* provides definitions for terms that are commonly used in referencing particular terminal structure components.
- *Section 4* describes the three limit states that are considered in the terminal structure superstructure design, serviceability, ultimate and structural integrity and fatigue;
- *Section 5* describes the materials used in the design and their characteristics;
- *Section 6* provides descriptions of the structural analysis and model used for the terminal structures superstructure design, including specifications for the global and local modelling;
- *Section 7* provides an extract of the design verifications that have been completed for the main structural components.
- *Section 8* summarises the design verifications

2.3 References

2.3.1 Design Specifications

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

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

GCG.G.03.02 “Structural Steel Works and Protective Coatings,” Stretto di Messina, 2004 July 30.

CG.10.00-P-RG-D-P-GE-00-00-00-00-00-02, “Application Manual to Design Basis, Structural, Annex”

CG.10.03-P-CL-D-P-CG-S4-00-00-00-00-01, “Equivalent Stiffness matrices for the Soil-Foundation System”

CG.10.03-P-CL-D-P-CG-S4-00-00-00-00-02, “Equivalent Stiffness and Damping Matrices for the Soil-Foundation System”

2.3.2 Design Codes

NTC-08: DM14.1.2008 - “Norme tecniche per le costruzioni,” 2008 (NTC08).

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

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

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

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

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

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

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

Rete Ferroviaria Italia - Istruzione No. 44F “Verifiche a fatica dei ponti ferroviari”

2.3.3 Material Specifications

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

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

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

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

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

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).

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

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

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

EN ISO 13918:1998 Welding-Studs and ceramic ferrules for arc stud welding-January 1997.

2.3.4 Drawings

Terminal Substructure: Calabria side	
CG1002-P-AX-D-P-ST-F4-VC-00-00-00-03	General layout
CG1002-P-AX-D-P-ST-F4-VC-00-00-00-01	General Arrangement
CG1002-P-BX-D-P-ST-F4-VC-00-00-00-01	Foundation plan and sections
CG1002-P-BX-D-P-ST-F4-VC-00-00-00-02	Concrete Dimensions Piers 1/2
CG1002-P-BX-D-P-ST-F4-VC-00-00-00-03	Concrete Dimensions Piers 2/2
CG1002-P-PX-D-P-ST-F4-VC-00-00-00-01	Reinforcement Foundation Plan 1/2
CG1002-P-WX-D-P-ST-F4-VC-00-00-00-01	Reinforcement Foundation and Sections 1/3
CG1002-P-WX-D-P-ST-F4-VC-00-00-00-02	Reinforcement Foundation and Sections 2/3
CG1002-P-WX-D-P-ST-F4-VC-00-00-00-06	Reinforcement Foundation and Sections 3/3
CG1002-P-WX-D-P-ST-F4-VC-00-00-00-03	Reinforcement - Piers, Sections and Details 1
CG1002-P-WX-D-P-ST-F4-VC-00-00-00-04	Reinforcement - Piers, Sections and Details 2
CG1002-P-WX-D-P-ST-F4-VC-00-00-00-05	Reinforcement - Piers, Sections and Details 3
CG1002-P-AX-D-P-ST-F4-VC-00-00-00-02	Temporary work and jet grouting
Terminal Superstructure: Calabria side	
CG1002-P-AXDPSV-S8-VC-00-00-00-01	Terminal Structures, Calabria / General Arrangement

CG1002-P-AXDPSV-S8-VC-00-00-00-02	Terminal Structures, Calabria / Deck, longitudinal plan and front view
CG1002-P-AX-DP-SV-S8-VC-00-00-00-03	Terminal Structures, Calabria / Steel structures 1
CG1002-P-AX-DP-SV-S8-VC-00-00-00-04	Terminal Structures, Calabria / Steel structures 2
CG1002-P-AX-DP-SV-S8-VC-00-00-00-05	Terminal Structures, Calabria / Steel structures 3
CG1002-P-AX-DP-SV-S8-VC-00-00-00-06	Terminal Structures, Calabria / Steel structures 4
CG1002-P-AX-DP-SV-S8-VC-00-00-00-07	Terminal Structures, Calabria / Steel structures 5
CG1002-P-AX-DP-SV-S8-VC-00-00-00-08	Terminal Structures, Calabria / Steel structures 6
CG1002-P-AX-DP-SV-S8-VC-00-00-00-09	Terminal Structures, Calabria / Steelwork, details 1
CG1002-P-AX-DP-SV-S8-VC-00-00-00-10	Terminal Structures, Calabria / Steelwork, details 2
CG1002-P-AX-DP-SV-S8-VC-00-00-00-11	Terminal Structures, Calabria / Platform, details
CG1002-P-AX-DP-SV-S8-VC-00-00-00-12	Terminal Structures, Calabria / Deck, concrete slab
CG1002-P-AX-DP-SV-S8-VC-00-00-00-13	Terminal Structures, Calabria / Bearing and expansion joints arrangement, plan

2.3.5 Complementary Reports

CG1000-P-RG-D-P-SV-00-00-00-00-00-01, "Global IBDAS Model Description"

COWI Document: A9055-NOT-3-001, “QL Road Traffic Loads”, 20. May 2010

COWI Document: A9055-NOT-3-002, “QL Rail Traffic Loads”, 20. May 2010

COWI Document: A9055-NOT-3-003 “QL Load Combinations”, 20. May 2010

Design report - Bridge Bearings Doc. No.: CG1000-P-CL-D-P-SS-A0-AP-00-00-00-01

Design report - Expansion joints Doc. No.: CG1000-P-CL-D-P-SS-A0-AM-00-00-00-01

Performance Specification - Bridge Bearings Doc. No.: CG1000-P-SP-D-P-SS-A0-AP-00-00-00-01

Performance Specification - Buffers Doc. No.: CG1000-P-SP-D-P-SS-A0-AM-00-00-00-01

Performance Specification - Expansion joints, Railway Doc. No.: CG1000-P-SP-D-P-SS-A0-AM-00-00-00-02

Performance Specification - Expansion joints, Roadway Doc. No.: CG1000-P-SP-D-P-SS-A0-AM-00-00-00-03

3 Nomenclature

The section provides descriptions of terms commonly used throughout the report to refer to various components of the Terminal Structures:

Pier – the vertical elements of the terminal substructure, extending from the top of the concrete foundation slab to the underside of the cross beam.

Cross Beam – the transverse beam connecting the piers and that supports the bearings for the superstructure of the Terminal Structure.

Foundation slab - the direct foundation of the piers.

Diaphragm walls - vertical walls to contain the excavation area for the terminal structure foundation.

Longitudinal Webs – the vertical longitudinal plates inside the Terminal Structure connecting the top and bottom.

Diaphragms – the vertical transverse plates inside the Terminal Structure connecting the facades.

Transverse Truss – the transverse steel truss structure inside the Terminal Structure connecting the facades.

Predalles – precast concrete elements used to support the in-situ cast concrete deck.

Jack housing – Space inside the cross beam to host temporary jacking.

Tie-down – hanger cable connecting to the terminal substructure.

U.R. – utility ratio, i.e. the ratio between demand/capacity.

4 Limit States

This section describes the limit states and corresponding performance requirements governing the proportioning of the terminal structure components, in accordance with the project design basis PG0025 and NTC08. The performance of terminal structure components is verified at Serviceability Limit States (1 and 2) Ultimate Limit States and Fatigue Limit States.

4.1 Serviceability Limit States

NTC08 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.

The project design basis PG0025 Section 3.1 specifies the performance requirements for the structure under two levels of serviceability, or normal usage loads. The SLS performance requirements are listed in Table 4-1.

Limit State	***Performance Requirement***
SLS1	*Road and rail runability is guaranteed.* *No structural damage.* *Structure remains elastic and all deformations are reversible.*
SLS2	*As for SLS1 except that only rail runability is guaranteed.*

Table 4-1: SLS performance requirements.

Fatigue related SLS are addressed in Section 4.3.

4.2 Ultimate Limit States

NTC08 Section 2.2.1 defines the following Ultimate Limit States (ULS) that 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.

The project design basis PG0025 Section 3.1 specifies the performance requirements for the structure under ultimate or rare loads. The performance requirements are listed in Table 4-2.

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

Table 4-2: ULS performance requirements.

Fatigue related ULS are addressed in Section 4.3.

4.3 Fatigue Limit States

NTC08 Sections 2.2.1 and 2.2.2 due not distinguish fatigue limit states (FLS) from serviceability and ultimate limits states with similar consequences and performance requirements. However, in NTC08 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. NTC08 Sections 2.2.1 and 2.2.2 define 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).

5 Materials

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

5.1 Concrete and reinforcement

5.1.1 Concrete

All structural concrete for the deck slab to be Grade C35/45 in accordance with EN 206-1:2001. Maximum dimension for aggregates is 25 mm for the slab and 10 mm for the predalles.

5.1.2 Reinforcement

Reinforcement bars shall be made of carbon steel grade B450C quality (hot rolled, ribbed bars of weldable quality and with high ductility), according to EN 10080.

5.2 Structural Steel

Terminal structures are fabricated from Grade S 355 ML structural steels, produced in accordance with EN 10025-4. Mechanical properties are in accordance with NTC08 Section 11.3.4.1.

5.3 High Strength Bolts

High strength structural bolts of Grade 8.8, produced in accordance with EN ISO 898 are used for connections of all non-structural components to the terminal structures. High strength bolts are assumed to have the mechanical properties accordance with NTC08 Section 11.3.4.6.1.

5.4 Shear Studs

Shear studs are manufactured from low carbon steel with a minimum yield point of 350 N/mm^2 and ultimate tensile strength of 450 N/mm^2 and an elongation of 15 %.

5.5 Welding Consumables

The material partial factors (safety coefficients) used to verify welded connections are in accordance with NTC 2008 Section 4.2.8.1.1.

5.6 Stainless Steel

Stainless steel is of grade AISI 316L.

6 Structural Analysis

In the following a description of the modelling of the Terminal Structure is given and in Section 6.2.8 is described how the interaction between the Terminal Structure is applied, i.e. the interface between the global IBDAS model and the semi-local modelling of the Terminal Structure.

6.1 Introduction

The Terminal Structures are modelled and analysed in the developed analysis program SAP 2000 (Structural Analysis Program). This section describes the approach to particular aspects of the structural analysis that affect the terminal structures design.

SAP 2000 is an integrated computerized system for designing of structures and it returns specialized analyses such:

- Eigenfrequency analysis
- Spectral seismic analysis
- Time history analysis (e.g. for seismic time history analysis)

All calculations performed are based on theory of elasticity and are performed as 1st order analysis.

An SAP 2000 model generally consists of the following 4 model items:

1. Structural Model (geometry model), defining the geometry and materials
2. Finite Element Model (or analysis model)
3. Construction Process Model, defining the construction phases
4. Load Model, defining basic loads and load combinations

6.2 Semi- Local FE Model description

This chapter describes the semi-local Finite Element model, build up to study the behavior of the terminal structure and to design the main elements of the structure.

The model, better detailed in the next chapters, is based on the following characteristics:

- A substructure of 2 piers, each doubled cell structures and 1 cross girders
- A deck of composite material, made of a steel box closed on the top by a concrete slab
- The foundation geometry has been modelled

A plot of the SAP 2000 geometry model is shown in the figure below:

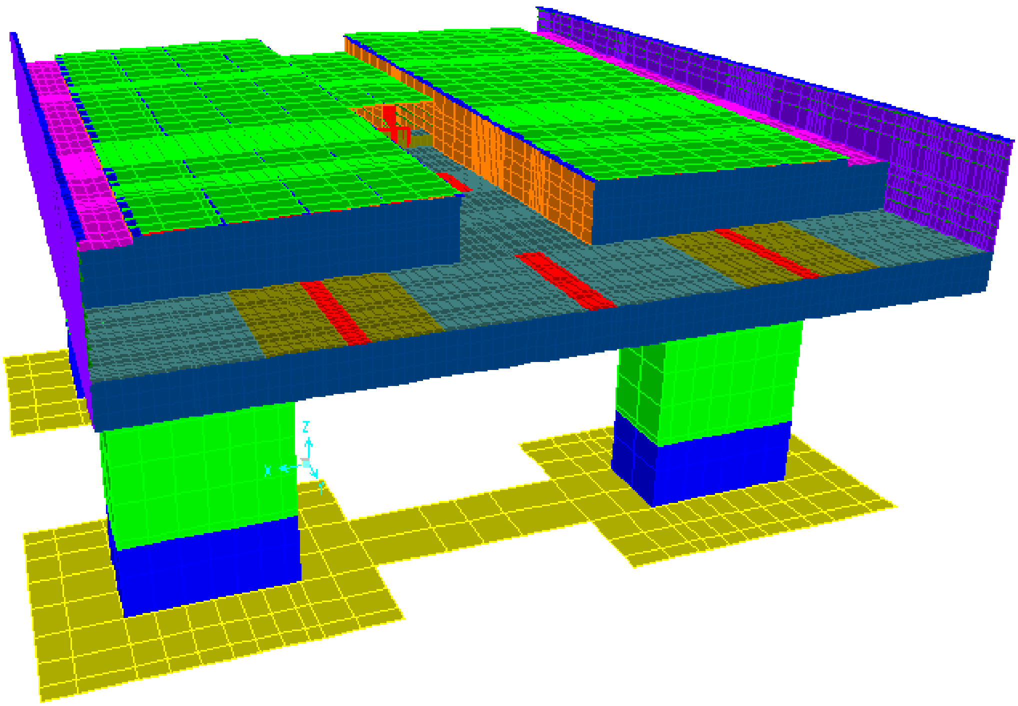

Figure 6-1: 3D Model

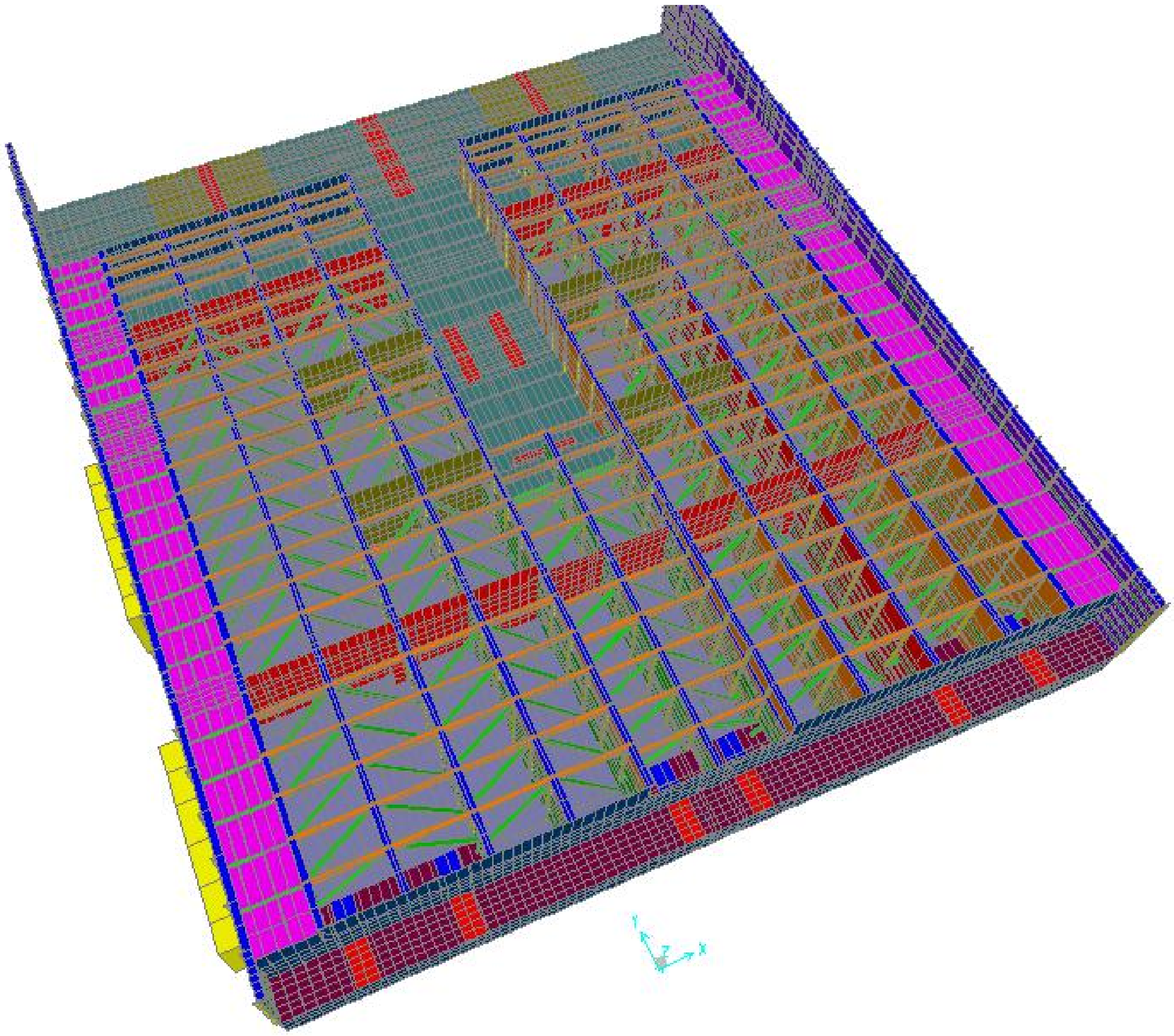

Figure 6-2: 3D Model – top section w/o concrete deck slab

6.2.1 Global Reference System

The global reference system is a right hand system. In this system the nodal coordinates and the stresses are defined. In particular: X axis, the first axis, is on the horizontal plane, orthogonal to the bridge axis, Y axis, the second axis, is aligned along the bridge axis and Z axis, the third axis, is vertical and orientated towards the top.

The origin of the coordinate system is positioned along the bridge axis, at the beginning of the Terminal Structure (connection with the bridge) with Z = 0 in correspondence of the terrain level.

6.2.2 Geometry

The structural elements of the deck and the substructures are modeled reproducing the exact geometry and position and thereby obtaining the real mechanical characteristics of the structure in terms of mass and stiffness and with very small percentage differences.

Pier foundations have been modeled with shell elements which reproduce their geometry. The insertion plane of the shell is coincident with the medium plane of foundation slab.

The substructures are made up of 4 legs and 2 transverse beams. These elements represent the reinforced concrete piers, with 2-cell shaped section, of the terminal structures. They have all been modeled with shell elements in the medium plane of the various walls, as shown in the figure below:

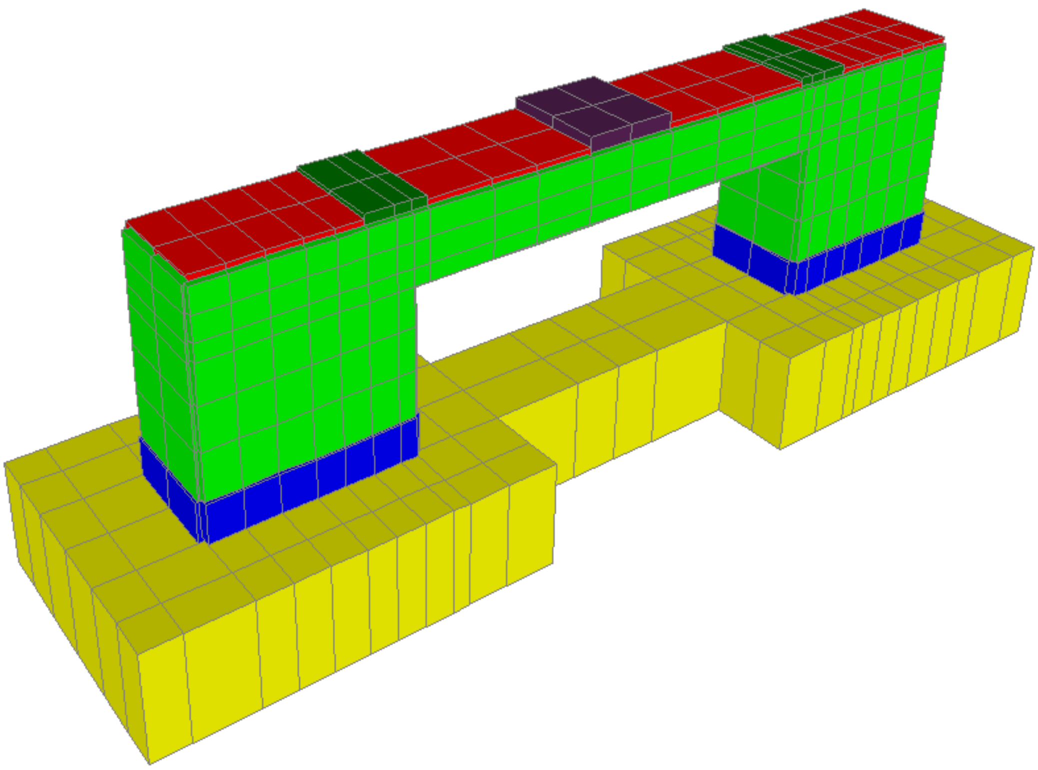

Figure 6-3: Piers middle section

The deck is a composite structure, steel-concrete, and has been modeled with both shell and frame elements.

The upper and inferior stiffeners and the vertical elements have been modeled with shell elements. The longitudinal diaphragm walls (longitudinal webs) inside the deck structure and the welded stiffener plates of the transverse diaphragm walls (transverse webs) have also been modeled with shell elements. The thickness of the plates is the same of the real plates in order to correctly reproduce the inertial characteristics.

The elements which constitute the transverse diaphragms made up of complete profiles sections or of part of them have been inserted in the model as frame elements having the real section.

The concrete deck slab is modeled with shell elements positioned in the medium plane of the slab.

In the FE-model fields are defined on the surfacing allowing automatic definition of lanes to be used for the application of road and rail live loading.

Shell elements representing the concrete slab are connected to the steel box by link elements. These elements connect rigidly the nodes of the slab to the corresponding nodes on the superior webs of the beams. Over these beams the predalles are placed and then the concrete is poured. The rigid links model the actions of the shear studs in the concrete slab.

A view of the elements described above is given in the following figure which represents just a portion of the superstructure.

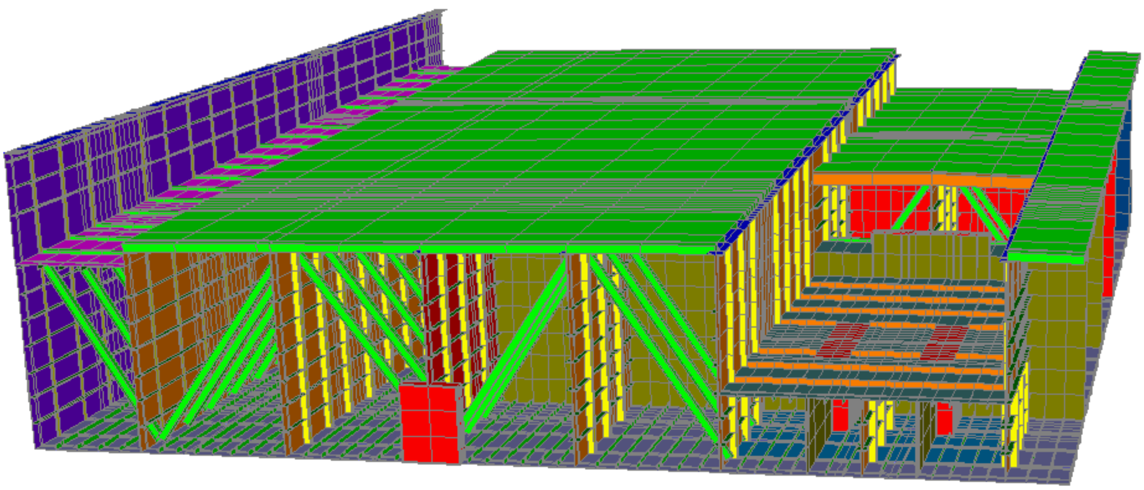

Figure 6-4: Deck view – portion

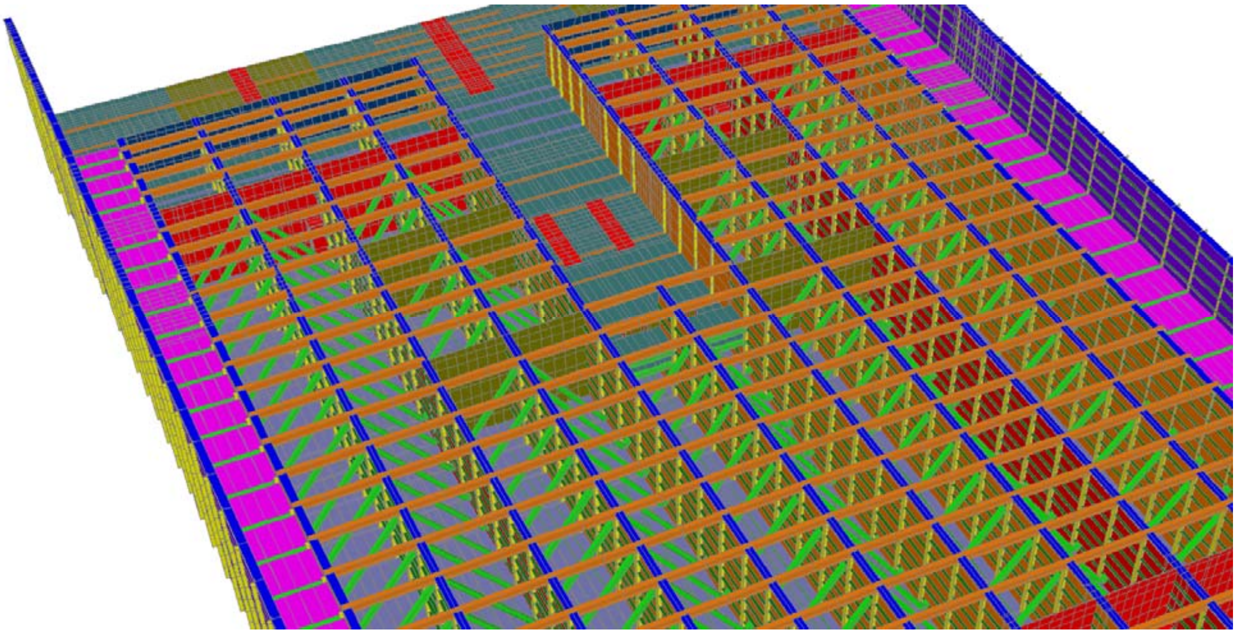

Figure 6-5: 3D Model top view enlargement, concrete deck slab not shown

6.2.3 Material and Basic assumptions

The following materials are used in the SAP 2000 model:

Structural Steel:	Density: E-modulus:	77.0 kN/m^3 210,000 N/mm^2
Concrete Piers:	Density: Strength (cylinder) E-modulus:	25.0 kN/m^3 40 N/mm^2 35,220 N/mm^2
Concrete Foundations:	Density: Strength (cylinder) E-modulus:	25.0 kN/m^3 32 N/mm^2 33,346 N/mm^2
Concrete Deck:	Density: Strength (cylinder) E-modulus:	25.0 kN/m^3 35 N/mm^2 34,077 N/mm^2

The coefficient of thermal expansion is taken as:

$$\alpha_{steel} = 12 \cdot 10^{-6} \text{ per } ^{o}C$$

$$\alpha_{concrete} = 10 \cdot 10^{-6} \text{ per } ^{o}C$$

6.2.4 Node and Element numbering

The Finite Element Model is made up by the elements described in the following table:

Element	*Number*
Joints	46810
Frames	6081
Shells	47144
Links	764

Table 6-1: Model Elements

6.2.5 Boundary and support Conditions

Elements representing the boundary conditions of the terminal structure can be subdivided into 2 categories:

- Elements representing bearings between superstructure and substructure
- Elements representing soil-foundation interface

Bearing devices are modeled with links having characteristics able to realize the given boundary condition. 3 different types of links have been defined, depending on which degree of freedom has been fixed or set as free, in order to represent the real degrees of the bearing system.

The static analysis has been performed considering instead of the longitudinal buffers a fixed connection.

A scheme of the bearing devices is shown in the figure below while a scheme of the assigned degrees of freedom of the links in the model is shown in the table below:

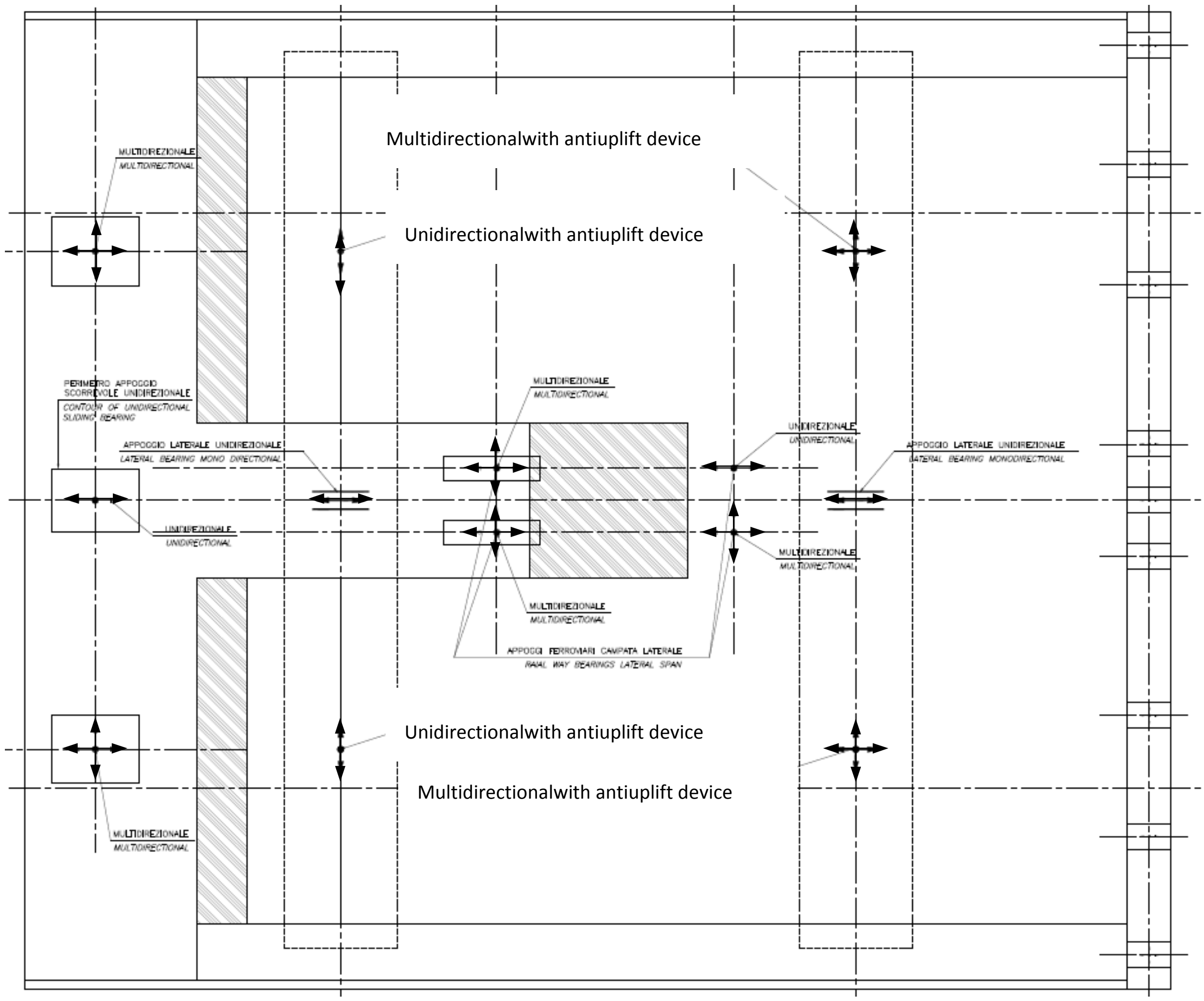

Figure 6-6: Support Conditions: Deck Supports

Bearings	***Links characteristics***					
	UX	***UY***	***UZ***	***RX***	***RY***	***RZ***
Unidirectional	*Free*	*Free*	*Fixed*	*Free*	*Free*	*Free*
Lateral bearing monodirectional	*Fixed*	*Free*	*Free*	*Free*	*Free*	*Free*
Antiuplift device	*Free*	*Fixed*	*Free*	*Free*	*Free*	*Free*

Table 6-2: Links characteristics

Soil-foundation interface is modeled applying linear spring elements to the points representing the nodes of foundation shell elements. The stiffness of the springs has been deducted by using the following stiffness matrix:

	X [kN/m]	Y [kN/m]	Z [kN/m]	r_X [kNm]	r_Y [kNm]	r_Z [kNm]
X [kN/m]	5.3 E+07	0	0	0	1.6 E+08	0
Y [kN/m]	0	5.6 E+07	0	1.7 E+08	0	0
Z [kN/m]	0	0	5.6 E+07	0	0	0
r_X [kNm]	0	1.7E+08	0	3.0 E+10	0	0
r_Y [kNm]	1.6 E+08	0	0	0	3.9 E+11	0
r_Z [kNm]	0	0	0	0	0	5.6 E+11

Table 6-3: Stiffness matrix of soil

Reference for these stiffness matrices for soil is made to the following reports:

- CG.10.03-P-CL-D-P-CG-S4-00-00-00-00-01 “Equivalent Stiffness matrices for the Soil-Foundation System”
- CG.10.03-P-CL-D-P-CG-S4-00-00-00-00-02 “Equivalent Stiffness and Damping Matrices for the Soil-Foundation System”

6.2.6 Interface Global – Semi-Local Model

The model of the Terminal Structure contains also the position of the bearings between the Terminal Structure and the Suspended Deck. The bearing positions have been inserted in the model and in the FE-Model the positions of the specific shells representing the bearings between the Terminal Structure and the Suspended Deck have been defined at specific nodes. At those nodes the bearing reactions from the Suspended Deck are applied.

The bearing reactions from the Suspended Deck are derived from the global IBDAS model where bearing reaction output has been produced for dead load and selected fixed load cases. The output has then been applied to the semi-local SAP 2000 model of the Terminal Structure whilst observing the load cases in question, i.e. ULS, SLS, etc.

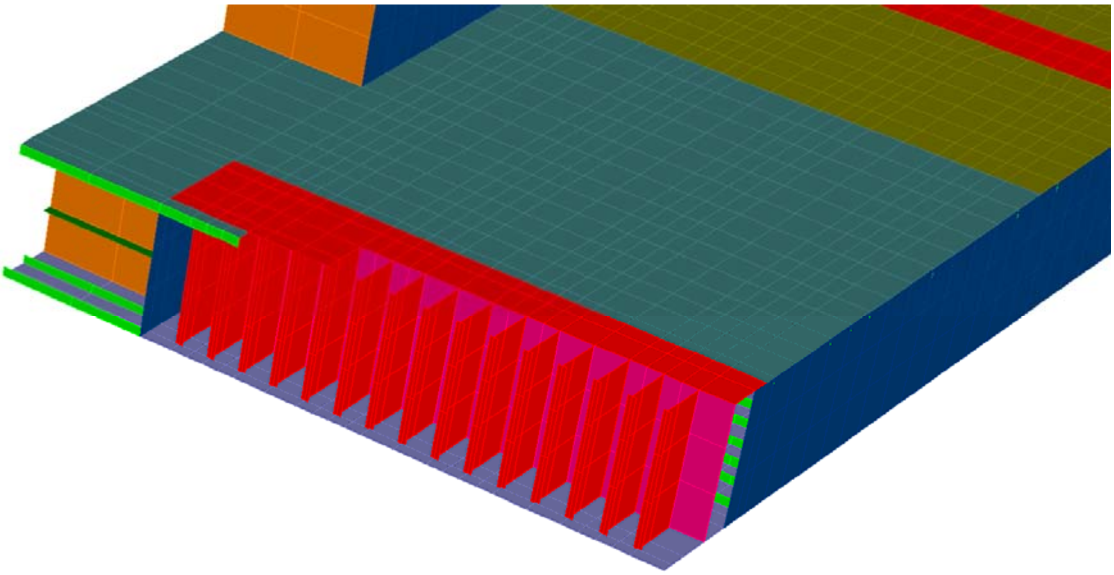

Figure 6-7: Interface Terminal Structure and Suspended Deck - Modelling of the roadway bearing

The position and the numbering of the nodes is represented in the figure below:

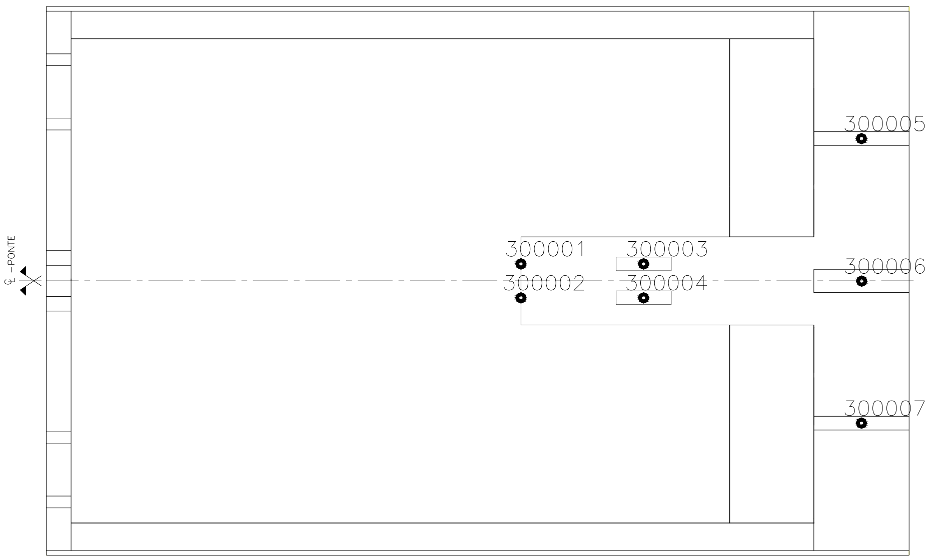

Figure 6-8: Interface Terminal Structure and Suspended Deck - Nodes at bearings

The same procedure has been used for the bearing reactions coming from the viaduct, Calabria side. However, due to the viaduct bearing configuration being altered at a late stage and since reactions have not been received at the time of writing the viaduct reactions are based on estimates while assuming that the reactions are equivalent to those of the Pantano Viaduct on the Sicily side.

The approaching viaducts are approximately of the same size with the Calabria viaduct slightly wider than the Pantano viaduct. However, the difference is not considered significant.

The loads from the adjacent structures are determinate thanks to the analysis made on the IBDAS global model, ref. is made to CG1000-P-RG-D-P-SV-00-00-00-00-00-01, "Global IBDAS Model Description".

Global Ibdas model input is not attached to this report (many pages), it can be made available on request.

6.3 Stiffness, Masses and Weights

6.3.1 Cross-sectional properties

The detailed modelling of the deck structure given by the shell elements and the insertion of the longitudinal stiffening plates are able to reproduce the real inertial and mechanical characteristics of the deck transversal section.

6.3.2 Masses and Weights

In the SAP model masses and self weights of primary structural elements are calculated automatically by the program tank to the possibility to assign the value of the mass to the materials used in the various sections.

6.4 Construction stages

Constructions stages have been taken into account for the design of the Terminal Structure. In particular construction loads have been considered in accordance with the following stages:

- Stage 1: Concrete is poured and supported by predalles on the steel construction
- Stage 2: Composite action for live load
- Stage 3: Long term analysis to calculate the stresses due to concrete creep

Initially the steel box carries its own weight including the in-situ cast concrete and composite action is applicable after the concrete has achieved its final strength.

During the 1st stage, also the self-weight of the adjacent structures, the bridge on one side and the access viaducts on the other side. The loads are considered to be transferred thought the bearing.

During the 3rd stage, in the SAP model a reduced elastic modulus has been applied to the concrete, in order to take into account effects due to viscosity. For this scope a reduction factor of 3.1 has been used. To simulate creep effects an additional temperature load condition has been applied.

Separate construction analysis stages in SAP2000 have been implemented.

6.5 Loads

The SAP 2000 model operates with the following types of loads:

- Basic loads defined as 1.0 times the characteristic load.
- Simple load combinations
- Complex load combinations
- Fixed loads and load combinations

Loads are generally defined in the global (right hand) coordinate system.

The basic loads defined are:

- Permanent Loads (Structural weight PP, non-structural components PN)
- Variable man-generated actions (QL)
- Wind Loads (static and dynamic) (VV)
- Temperature Loads (VT)
- Seismic Loads (VS)

The Permanent Loads include all gravity loads such as dead load, super imposed dead load (deck surfacing and "other loads").

Dead load is calculated automatically by SAP 2000 based on the geometry model (and loads defined and included in the construction process model). Weight of the basic materials can be seen in section 6.2.3 of this report.

6.5.1 Permanent load (PP and PN)

Permanent and semi permanent actions are divided into structural self weight (PP) and non-structural self weight (PN), as detailed below:

- **PP**: the structural weight is calculated for all structural components. Increments of weights due to elements which are not present in the model (such as coating and connections) are taken into account using a 10% incremental factor.
- **PN**: the weight of non-structural components includes the weight of any road surfacing, railway trackbed, protections, parapets and wind shields, technological equipment and services, which must be guaranteed along the crossing; scenarios in which any of these weights are removed during the service life of the structure, for the purposes of routine and extraordinary maintenance, has been considered.

On the FE model, in addition to the above mentioned loads, permanent loads, resulting from the Messina main bridge and from the Pantano viaduct, have been inserted in correspondence of the nodes at the bearing positions.
The forces at the interface bridge-terminal structures have been calculated with the global IBDAS model and have been applied as nodal forces.

6.5.2 Variable man-generated actions (QL)

Variable man-generated actions for local sizing (QL) have been implemented according to the following documents:

1) Doc. No. A9055-NOT-3-002, “QL Rail Traffic Loads”
2) Doc. No. A9055-NOT-3-001, “QL Road Traffic Loads”

The highway and railway loads have been disposed along the structure in such a way as to produce the most adverse load effect. Once the design sections have been identified, the position of the load which induces the maximum stresses in the sections is determinate using the influence lines calculated on the global IBDAS model of the bridge.

Once the positions of the rail loads and road loads maximising the stresses in the design section have been individuated, the corresponding actions are reported on the model of the terminal structures, in two different ways:

- Loads are applied on the bearings at the interface between bridge and terminal superstructure and at the interface betweeen Pantano viaduct and terminal supserstructure, calculated with the IBDAS model for the particualar load case.
- A part of the running loads is applied on the terminal structure itself (depending on the maximising position).

Applied loads are here below described.

6.5.2.1 Road load

Road loads have been applied accordingly to NTC 08 requirements.
The carriageway area includes all areas that can be incorporated permanently or temporarily for use by vehicular traffic. Thereby the total carriageway area of one road deck of 11.95 m2/m has been loaded. 3 load lanes, 3 m wide have been considered together with a remaining lane of 2.95 m for each carriage way.
2 load schemes have been considered:

The load arrangement defined in the following table (load scheme 1) has been applied on both carriageways. The dynamic factor is included in the characteristic lane loads.

The load length is limited to maximum 300m.

Location	Tandem system - TS	UDL system
	Axle load Qik (kN)	qik (kN/m^2)
Notional lane number 1	300	9
Notional lane number 2	200	2.5
Notional lane number 3	100	2.5
Remaining area	0	2.5

Table: Load model 1

In the following figure the application of Load scheme 1 is illustrated:

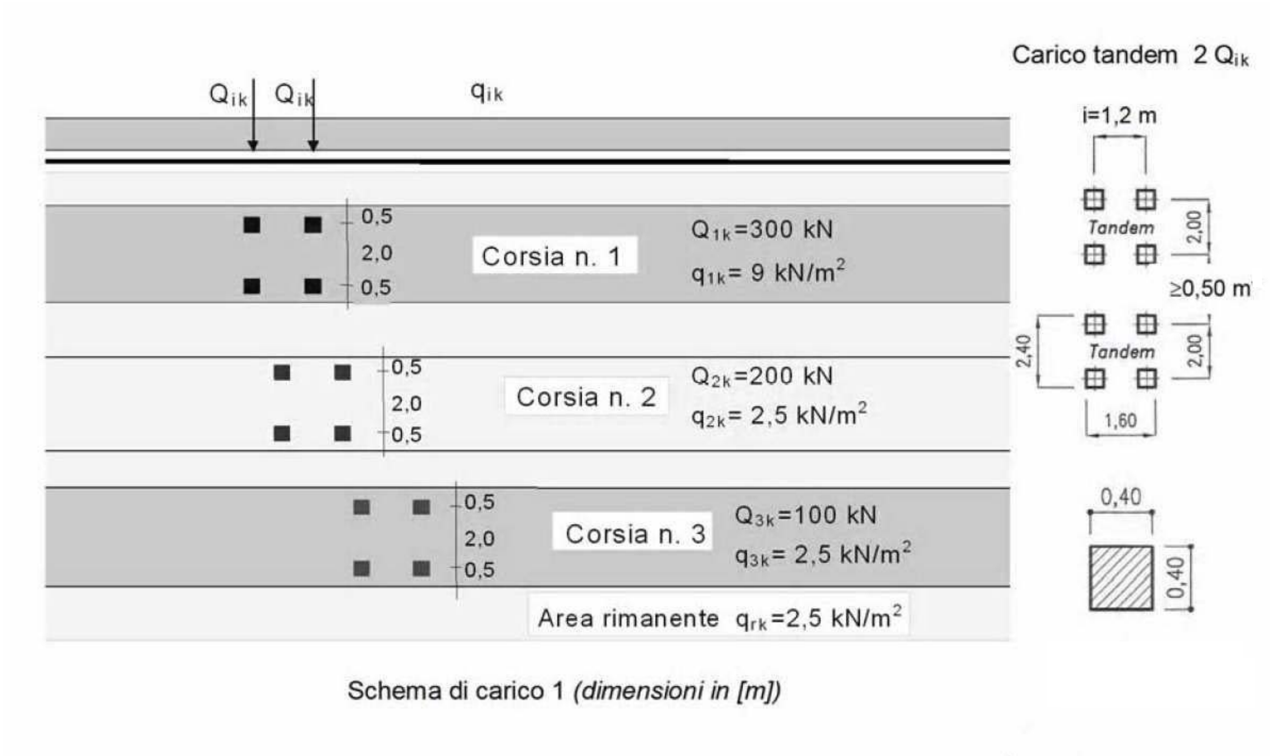

Figure 6-9: Application of Load model 1

Load model 2 consists of a single axle load of: Qk = 400kN

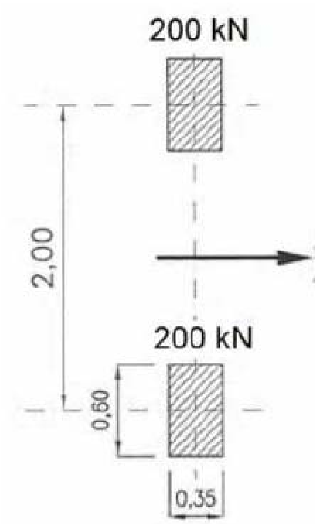

Figure 6-10: Application of model 2 (schema di carico 2)

Once the alignments of shells representing the lanes have been identified, the tandem system loads have been applied diffusing them uniformly on the shell in correspondence on the shell itself. To the above mentioned loads the following loads longitudinal braking or acceleration force shall be applied in lane number 1 are added as follows:

$Q_{Lk} = 360 + 2.7 \cdot L$

$180\ kN \leq QLk \leq 900\ kN$

where L is the actual loaded length under consideration.
The force is assumed to act in the longitudinal direction of the carriageway, parallel with and at the level of the carriageway surface. The force is uniformly distributed over the loaded length.

6.5.2.2 Rail load

In the model 2 shell alignments representing the train binary have been identified and the train loads represented by the load models LM71, SW/0 or SW/2 have been applied on these shells.

Load model 71 represents the static effect of vertical loading due to normal rail traffic.

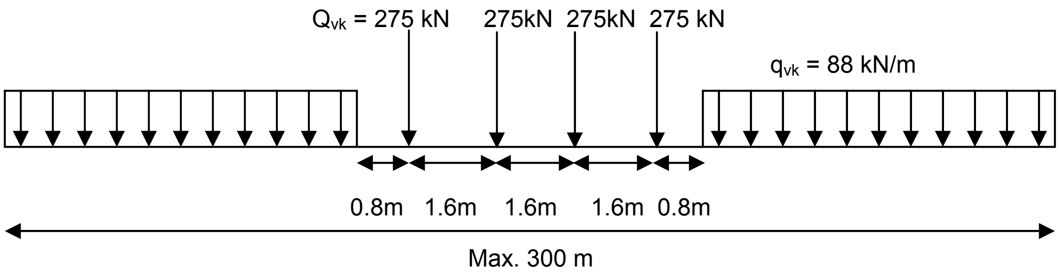

Figure 6-11: Load model 71 with α=1.10

Load model 71 loading has been applied to one or both tracks simultaneously.
The load has been placed in the most adverse position for the element and the uniform part of the LM71 can be applied segmented on the girder in order to increase the load effects of the element under design. α=1.10 for LM71.

Load model SW/0 represents the static effect of vertical loading due to normal rail traffic and SW/2 the static effect of vertical loading due to heavy rail traffic.

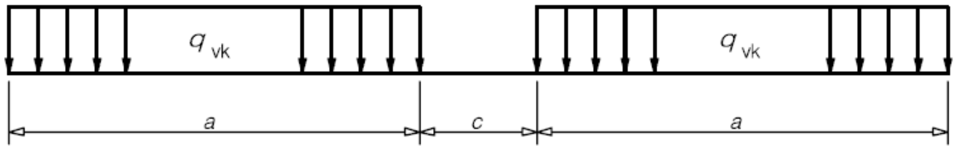

Figure 6-12: Load model SW/0 and SW/2

Load Model	α·qvk [kN/m]	a [m]	c [m]
SW/0	146	15.0	5.3
SW/2	150	25.0	7.0

Load model SW/0 and SW/2 including α=1.10 for SW/0 and α=1.00 for SW/2.
Within a track only one SW/0 or SW/2 shall be applied.

In the FEM model only loads models LM71 e SW/2 have been inserted as the load model SW/0 has been considered not governing and not dimensioning for assessment purposes on the deck elements.

A simply supported beam model of the terminal structure, Sicily side, has been used to evaluate the forces induced by the 3 train load models (LM71, SW/2 and SW/0). It has been found that SW/0 gives smaller forces, compared to LM71 and SW/2.
The results of the above described analyses are here reported:

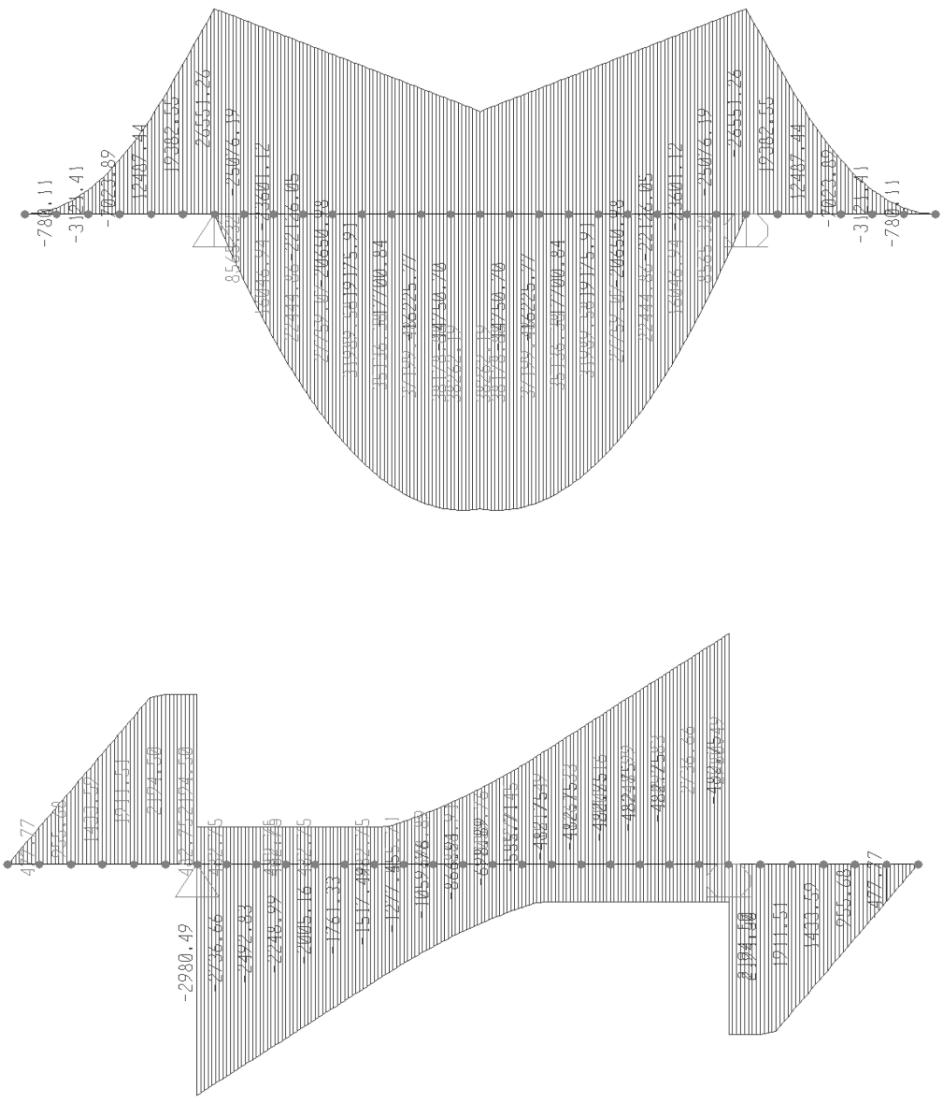

Figure 6-13: Forces induced by Load model SW/0

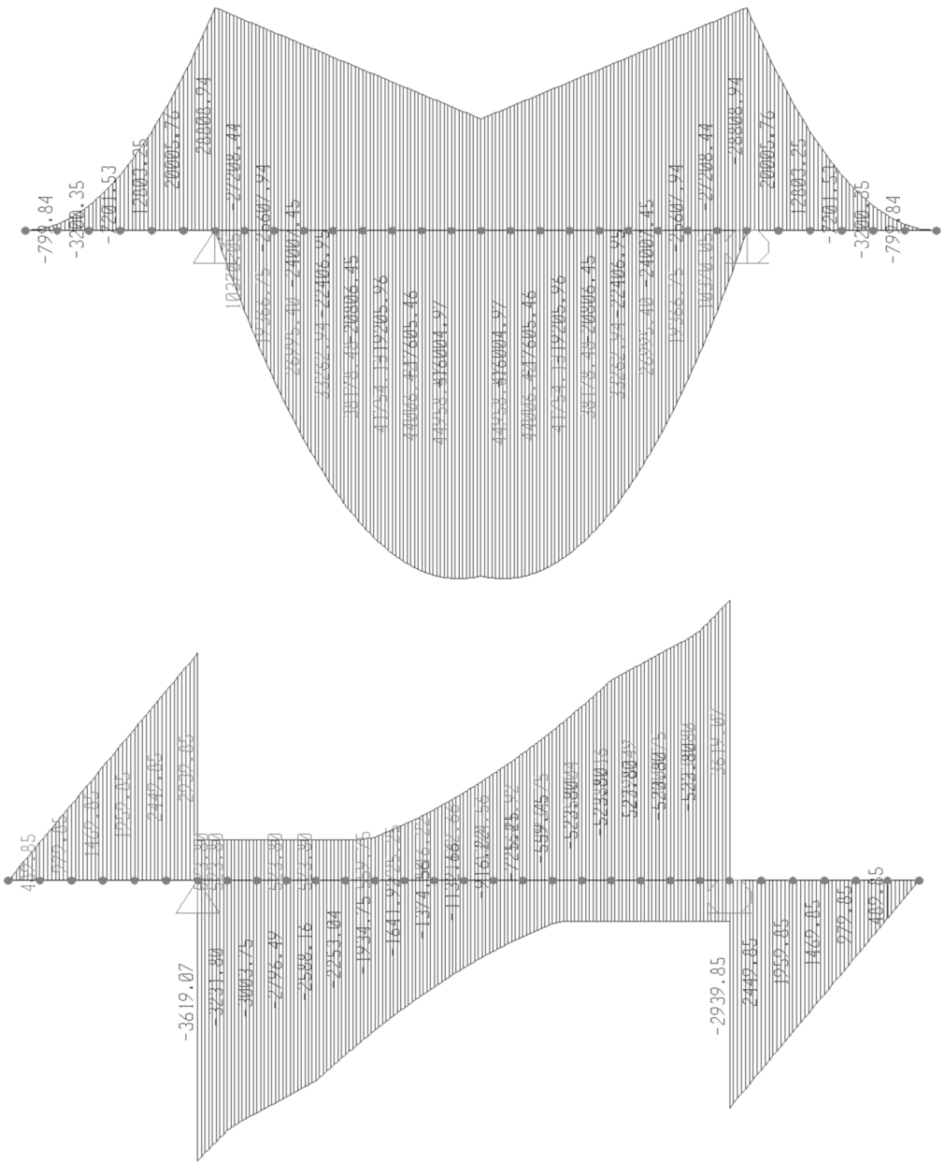

Figure 6-14: Forces induced by Load model SW/2

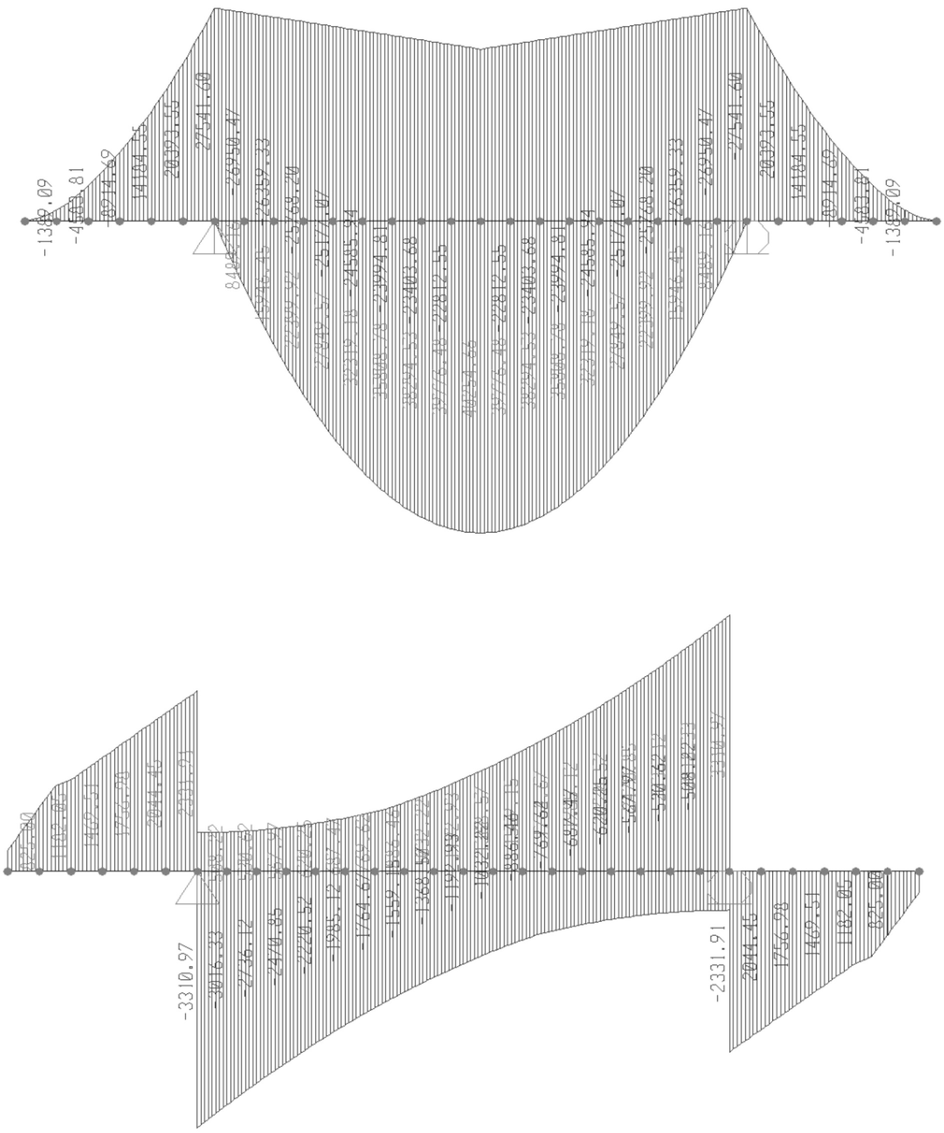

Figure 6-15: Forces induced by Load model LM71

Resulting forces from the train load models have been amplified with dynamic coefficient Φ = 1.06, calculated with dynamic analyses performer in the global IBDAS mdoel.

Traction and braking forces have been applied at top of rails in longitudinal direction, uniformly distributed over the influence length Lab. The traction and braking forces have been combined with the corresponding verticals loads. Braking in one track has been combined with simultaneous traction in the other track.

It is assumed that the two tracks have permitted direction of travel in opposite directions, i.e. braking or traction in both tracks can not occur.

Traction force is:

Q_{lak} = 33 [kN/m] L [m] ≤ 1000 [kN]

for Load Model 71 and SW/2

Braking force is:

Q_{lbk} = 20 [kN/m] L [m] ≤ 6000 [kN]

for Load Model 71

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.

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

α = 1.1 for LM 71

α = □1.0 for SW/2

Nosing force has been applied at top of rails in transversal direction.

Q_{sk} = 100 kN acting horizontally, at the top of the rails, perpendicular to the centre-line of the track. The nosing force specified above has been multiplied by the α factor.

6.5.3 Wind Loading

Wind loading is implemented according to the Design Criteria PG0025, section 5.3.

6.5.3.1 Static wind

The static mean wind is implemented with a vertical profile as described in the Design Criteria PG0025.

6.5.4 Temperature Loads

Temperature Loads are implemented according to the Criteria PG0025, section 5.3.

The coefficients of thermal expansion are defined in section 6.2.3 of this report.

6.5.5 Seismic Loads

Seismic load is implemented according to the Design Criteria PG0025, section 5.3.2

Complete Quadratic Combination (CQC) is used for combining the effects from different modes.

On the semi-local model of the terminal structure the seismic analyses have not been implemented: the stresses due to the seismic actions on the governing sections of the structure have been calculated with the FE global IBDAS model.

6.6 Load Combinations

The deck components are verified for the load combinations listed in the design basis (PG0025) Section 6.8. The combinations and associated partial factors for each load component are presented in Table 22 and Table 23, Table 24 and Table 25, respectively for SLS, ULS and SILS. The partial factor μ can take the value of 0.95 or 1.15 for steel components or 0.95 or 1.25 for concrete components, depending on where the dead load causes a relieving or adverse effect. A hyphen in a cell under a load component column indicates that the load component is not included in the combination represented by the row.

The combinations implemented for local sizing (QL) of structural elements is according to document A9055-NOT-3-003.

The tables containing the used load combinations are reported in Appendix 3 of report PF0158.

6.7 Modal Analysis

Modal analysis of the terminal structure is not part of this report. Dynamic behaviour of the structure has been analyzed by COWI with IBDAS global model. Reference is made to the report : CG1000-P-RG-D-P-SV-00-00-00-00-00-01, "Global IBDAS Model Description"

6.8 Seismic Analysis

6.8.1 Response Spectrum Analysis

Seismic analysis of the terminal substructure has been performed with the global IBDAS model. Seismic loads acting in the terminal structures have been inserted in SAP 2000 semi-local model as resulting loads on the bearing points, as described in section 6.2.8. For the seismic analysis reference is made to the report CG1000-P-RG-D-P-SV-00-00-00-00-00-01, "Global IBDAS Model Description".

6.9 Results from the calculation

In the calculation, in order to verify the structural elements, transversal sections (section cuts) have been defined. They are made up of groups of shells and joints and are the sections where the program calculates directly the stresses needed in the verification.

By default the positive local 1, 2 and 3 axes of the section cut correspond to the global X, Y and Z axis, respectively.

Section cut forces are reported at a single point in the local coordinate system defined for the section cut. Six different force components are reported at that single point.

They are:

- **F1:** A force in the section cut local 1-axis direction.
- **F2:** A force in the section cut local 2-axis direction.
- **F3:** A force in the section cut local 3-axis direction.
- **M1:** A moment about the section cut local 1-axis.
- **M2:** A moment about the section cut local 2-axis.
- **M3:** A moment about the section cut local 3-axis.

Section cut forces are reported as forces acting on the objects that make up the group that defines the section cut. An example of this is described below. Positive section forces act in the same direction as the positive section cut local axis. The sense of positive moments can be determined using the right-hand rule.

7 Verification

This section summarizes the governing load combinations and the design verifications that have been completed for the terminal structure components. Design principles are described as necessary to clarify the effects of the governing load combinations and the verification results, however, the General Design Principles (CG.10.00-P-RG-D-P-SV-S8-00-00-00-00-01) should be consulted for more detailed descriptions and bases for the verification procedures.

Longitudinal and transversal elements capacity is governed by first yield point at any cross section as there is insufficient ductility available for plastic behaviour. Verification of the longitudinal elements are performed for ULS.

Displacement or deformations that could limit the use of the structure under SLS load combination for steel deck have been calculated.

The concrete slab is made by a concrete cast upon a concrete predalles; the effects due the dead load of the concrete cast are considered entirely taken by the concrete predalles. All the effects due to variable man-generated actions, as the traffic loads are supported by the concrete slab for its complete thickness.

SLS loading during the casting stage have been studied for the predalles and cracking has been studied for the concrete slab. The crack limit is assumed w = 0.3 mm for SLS Frequent.

The steel elements that compose the entire deck of the terminal structure have been verified for the following cases:

- Resistance of cross-sections to general stresses,
- Resistance of members to instability assessed by member checks,
- Resistance of plated structures subjected to out of plane loading to instability.

As specified by the design basis, the fatigue safety checks are done for an unlimited life of all the components analyzed and they concern only those parts of the steel deck that are most affected by the man-generated loading, as the road and rails traffic.

The parts analyzed for the fatigue effects need to be identified with a detail class in order to make the safety checks, according to NTC 08. These parts are:

- The welding on the cruciform joint between the top transversal steel element HE500B and the transversal rib of the vertical panel made with a ½ HE 600A
- The welding on the cruciform joint between the transversal rib of the vertical panel made by a ½ HE 600A and the transversal rib of the bottom panel made with a ½ IPE 600.
- The welding of the transversal rib of the vertical panel made by an ½ HE 600A and the panel itself.
- The welding of the transversal rib of the bottom panel made by an ½ IPE 600 and the panel itself.
- The welding between the vertical panel and the ½ IPE 600 as the detail 8 of section B-B of the drawing CG1002 P BX D P SV S8 VS 00 00 00 01.
- The welding on the corner between the bottom panel with ½ IPE 600 and the vertical panel with a plate 20 thk.
- The welding on the bottom panel and the plate 180 x 20 thk

The unlimited life safety checks has been made, accordingly to the above described principles, verifying that the maximum stress range defined as $\Delta\sigma=(\sigma_{max}- \sigma_{min})$ are minor then the admitted stress range for the verified details.

7.1 Steel box

The steel frame is composed of I-shaped profiles (typically IPE600, HE500B and HE600A) which are also applied as only half their section. I-shaped profiles are applied longitudinally and transversely at the top and bottom of the frame whilst half-sections comprise a vertical grid which also stiffens the plates. The I-profiles at the top have shear studs applied for casting of the concrete deck slab.

The frame is closed by steel plates welded onto the steel frame and the steel plates are provided with stiffeners to ensure the stability of the plates.

Initially the steel frame carries its own weight including the in-situ cast concrete and composite action is applicable after the concrete has achieved its final strength.

The governing load combinations (Ref. CG1002-P-CL-D-P-SV-S8-00-00-00-00-01 Design Report Main elements) for the steel frame elements is *STR9_5.* The highest utility ratio is 0.40.

7.2 Transverse steel truss

In order to stiffen the steel frame a truss structure in the transverse direction is applied. The truss is composed of HE300B-profiles.

The governing load combinations (Ref. CG1002-P-CL-D-P-SV-S8-00-00-00-00-01 Design Report Main elements) for the steel frame elements is *STR2_45*. The highest utility ratio is 0.72.

7.3 Longitudinal webs

Heavy longitudinal webs (t = 40 mm) run in the entire length of the Terminal Structure and above the bearings. The longitudinal webs divide the Terminal Structure into cells and are openings are provided in order access through the longitudinal webs.

The longitudinal webs are stiffened to ensure the plate stability and highest utility ratios are found to be and 0.85.The governing load combinations (Ref. CG1002-P-CL-D-P-SV-S8-00-00-00-00-01 Design Report Main elements) is STR10_61.

7.4 Diaphragms

Heavy diaphragms (t = 40 mm) run across the Terminal Structure and above the bearings. The diaphragms divide the Terminal Structure into cells and are openings are provided in order access through the diaphragms.

The diaphragms are stiffened to ensure the plate stability and highest utility ratios are found to be 0.3. The governing load combinations (Ref. CG1002-P-CL-D-P-SV-S8-00-00-00-00-01 Design Report Main elements) is STR10_37.

7.5 Concrete Deck Slab

The mildly reinforced concrete deck slab has a thickness varying between 300 mm and 400 mm including 50 mm of predalles and with the thicker part towards the rail tracks. This part of the deck has no need for asphalt surfacing and a constant transverse slope of 2 % is maintained in order to drain the water across the deck without obtrusions. The road surfacing consists of 110 mm asphalt.

The governing load combinations for the concrete deck are SLU-STR2 for road loads and SLU-FERR-4 for rail loads. Highest utility ratios are found to be 0.81 for SLU-STR2 and 0.8 for FERR-4.

7.6 Maximum Displacements

To evaluate the displacements of the superstructure of the two terminals structures, four models are used, two for each side.

One model represents the concrete cast stage. In this stage the entire steel structure is build-up and the concrete has been casted onto the concrete predalles but doesn't resist to any load. So the concrete cast is only considered as a load and doesn't give any strength to the structure.

The other model represents the next stage, so the stage where all other loads act. The entire structure, including the concrete deck, collaborates with its whole strength. All the variable actions are taken into account. The loads have been combined with the SLS combination factors.

The displacements found are:

Stages	***Sea side***	***Land side***
Stage 1 (Self-weight)	-0.050 m.	-0.090 m.
Stage 2 (Variable loads)	-0.0098 m.	- 0.026 m.

Table 7-1: Deck maximum displacements

7.6.1 Deck: deflection verification

For all structure configurations loaded with the classified characteristic vertical loading in accordance with EN 1991-2, 6.3.2 (and where required classified SW/0 and SW/2 in accordance with EN 1991-2, 6.3.3) the maximum total vertical deflection measured along any track due to rail traffic actions should not exceed L/600.

In the middle span of the Terminal foundation we find the following values:

Terminal structure	Max. Calculated deflection	Max. Allowable deflection
CALABRIA	0.0287 m	0.0583 m

Table 7-2: Deck deflection

7.7 Fatigue

The relevant stresses transmitted by the weld depend on the type of weld. For fillet welds the stresses that may cause a failure are the caused by the sliding forces between the two parts.

For fatigue verifications of both details directly loaded by road traffic loads and by rail traffic loads, detail 2b (Ref. to CG1002-P-CL-D-P-SV-S8-00000000-01, section 9.4.2) is the most affected by fatigue loads.

For this detail the admitted delta tension is: $\Delta\sigma_d = 0.737\ \Delta\sigma_c = 0.737 \cdot 56 = 41.27$ MPa.
With the calculation it is found:

$\Delta\sigma_d = 1.15 \cdot\ \Delta\sigma = 17.5$ MPa   for road traffic loads
$\Delta\sigma_d = 1.35 \cdot\ \Delta\sigma = 14.4$ MPa   for rail traffic loads

Maximum resulting delta tension on the bottom plate is $\Delta\sigma_d = (\sigma_{max} - \sigma_{min}) = 11.59$ MPa.

8 Summary

The Terminal Structure comprises a closed box structure built up by a steel frame with internal longitudinal and transverse webs and a transverse truss stiffening system. A mildly reinforced concrete slab constitutes the deck.

The governing load combinations are typical ULS load combinations named STR10_61 for the steel components whereas the concrete deck slab is governed by SLU, load combination STR2.

Utilization ratios are found to vary from 0.4 for the diaphragms and 0.85 for the longitudinal webs and around 0.8 for the concrete slab.