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

EUROLINK S.C.p.A.

IMPREGILO S.p.A. (MANDATARIA)
SOCIETÀ ITALIANA PER CONDOTTE D'ACQUA S.p.A. (MANDANTE)
COOPERATIVA MURATORI E CEMENTISTI - C.M.C. DI RAVENNA SOC. COOP. A.R.L. (MANDANTE)
SACYR S.A.U. (MANDANTE)
ISHIKAWAJIMA - HARIMA HEAVY INDUSTRIES CO. LTD (MANDANTE)
A.C.I. S.C.P.A. - CONSORZIO STABILE (MANDANTE)

IL PROGETTISTA	IL CONTRAENTE GENERALE	STRETTO DI MESSINA	STRETTO DI MESSINA
Ing E.M.Veje COWI EurolinK Dott. Ing. E. Pagani Ordine Ingegneri Milano n° 15408	Project Manager (Ing. P.P. Marcheselli)	Direttore Generale e RUP Validazione (Ing. G. Fiammenghi)	Amministratore Delegato (Dott. P. Ciucci)

PS0002_F0

Unità Funzionale	OPERA D'ATTRAVERSAMENTO
Tipo di sistema	SOVRASTRUTTURE
Raggruppamento di opere/attività	ELEMENTI DI CARATTERE GENERALE
Opera - tratto d'opera - parte d'opera	GENERALE
Titolo del documento	Global IBDAS Model Description

CODICE	C	G	1	0	0	0		P		R	G		D		P		S	V		0	0		0	0		0	0		0	0		0	0		0	1		F0

REV	DATA	DESCRIZIONE	REDATTO	VERIFICATO	APPROVATO
F0	20/06/2011	EMISSIONE FINALE	SCC	KLO	KLO / LSJ

NOME DEL FILE: PS0002_F0.docx

INDICE

Table of Appendices

1 Introduction

1.1 Scope

The global IBDAS model of the Messina Strait Bridge established during Tender Design is further developed during Progetto Definitivo in preparation for the subsequent Progetto Esecutivo phase.

The purpose of this report is to present and describe the global IBDAS analysis model as prepared for Progetto Definitivo.

1.2 Report Outline

This report is organized into the following sections:

- Section 1 includes this introduction, describes the development since Tender Design and provides a list of references, including design specifications and design codes
- Section 2 describes the Global IBDAS model
- Section 3 describes the Element stiffness's and added weights to the analysis model
- Section 4 describes the construction phases considered
- Section 5 describes the reference condition of the bridge
- Section 6 describes the loads, load combinations and analysis methods

1.3 Development since Tender Design

The global IBDAS model is improved and further detailed with regard to geometry and loads compared to the Tender Design. The most important improvements and updates are listed below:

- Tower height and cable sag updated due to the requirement by SdM to include the weight of a 40mm typical roadway pavement and steel wrapping wire for the main cables in the calculations

- The Main Cables have been modelled with twin-cables

- The Road and Rail girder cross sections have been modelled according to drawings including stiffeners (previously the stiffeners were implemented as equivalent plate thickness)
- The Girder cross beams have been further detailed to include stiffeners and thus more correct stiffness parameters
- Tower cross beams with curved upper and lower surfaces
- The Tower Section geometry has been updated to reflect the latest design drawings, including correct positioning of longitudinal stiffeners
- The Terminal structure detailing has been improved, to include boxed sections with a good approximation to the geometry shown on the design drawings
- Anchor blocks included
- Revised splay saddle geometry
- Tie-back cables have been modelled and included into the construction stages
- QL live loads for local checks have been implemented according to the new Italian standards
- QL load combinations for local checks have been implemented according to the new Italian standards for all limit states
- Temperature loads and load combinations improved
- Fatigue trains have been included
    - Fatigue trains 1-12 is shown in Annex D in 1991-2:2003 [E09]
    - RFI 1 -6
    - Special Fatigue train consisting of 3 x Freight Train I (fatigue train 5)
- Included soil springs and damping matrices at foundations to include soil-structure interaction
- Hanger replacement and Hanger rupture analysis included
- Analysis for loss of a structural segment included
- Tower TMD's are included in the model

1.4 References

1.4.1 Design Specifications

[1] CG1000-P-RG-D-P-GE-00-00-00-00-00-02 “Design Basis, Structural, Annex”.

2 Description of the Global IBDAS model

This section describes the global FE-model established for Progetto Definitivo.

The basis for the modelling of the bridge is the Tender Design and the further development carried out during Progetto Definitivo as presented in the project drawings.

The current model version is 3.3f, which is the model version described in this report.

The present report describes the global model, which is a beam model. Semi-local models using shell elements are also prepared for selected parts of the bridge and these models are described in separate reports. The semi-local models are included in the global model in the sense that for most parts of the bridge the global (beam) model is used but for selected parts a more detailed modelling with diaphragms is used.

The following semi-local models are prepared:

- Shell elements in a part of the tower legs including cross beam and special diaphragms
- Shell model of part of the suspended deck including cross girders

2.1 IBDAS Model Structure

The global model is created using the general computer aided structural design and analysis system IBDAS (Integrated Bridge Design and Analysis System), developed by COWI. IBDAS is based on 3D parametric solid modelling and provides procedures for fully integrated design and analysis of load bearing structures.

A short introduction to IBDAS and the many features available is given in Appendix A.

IBDAS is an integrated computerized system for design of load bearing structures and it contains special facilities for bridge design including specialized analyses such as (but not limited to):

- Automatic determination of extreme bridge live load effects based on influence line calculations
- Eigenfrequency analysis
- Spectral buffeting analysis
- Spectral seismic analysis
- Time history analysis (e.g. for seismic time history analysis)
- Verification according to codes of practice (relevant Codes of practice may be implemented)

All calculations performed are based on theory of elasticity and are performed as 1^{st} order analysis with P-delta effects (geometric stiffness) included. Exceptions from this will be clearly stated.

Construction stage analyses as well as seismic time history analyses are always carried out as 2^{nd} order analyses.

The bridge structure is modelled using the IBDAS standard model "SUSPBR", a model particularly developed for analysis of suspension bridges. The SUSPBR model has been used for analysis and design of several suspension bridges and has been updated continuously and adapted to the Messina Bridge.

An IBDAS model generally consists of the following 4 model items:

1 Structural Model (geometry model), defining the 3D geometry and material data (see Section 2.2 and 2.3)

2 Finite Element Model - or analysis model (see Section 2.4 - 2.8)

3 Construction Process Model, defining the construction phases (see Section 4)

4 Load Model, defining basic loads and load combinations (see Section 6)

2.2 Geometry

The geometry model of the Messina Strait Bridge is described below.

An IBDAS model is to a great extent based on geometry and most of the information needed for the generation of the FE-model is extracted in IBDAS from the geometry model. The geometrical configuration from the geometry model is translated into an analysis (or FE-) model. The geometry model as well as the FE-model is basis for the construction phase modelling.

The following structural elements are included in the model of the Messina Strait Bridge:

- 2 towers, each consisting of 2 legs and 3 cross girders
- Suspended deck consisting of 2 roadway girders and 1 railway girder and all cross girders. Alignment according to alignment drawings also included
- Main cables (twin cables modelled)
- Hangers
- Transverse and longitudinal connections between the suspended deck and the towers
- 2 terminal structures consisting of a composite girder and 2 piers each
- Viaduct spans
- Foundations. The tower foundations geometry has been considered. The pier foundations have not been modelled in detail. Soil springs have been modelled.
- The Anchor Blocks have been considered, including soil springs.

A plot of the IBDAS geometry model is shown in the figure below.

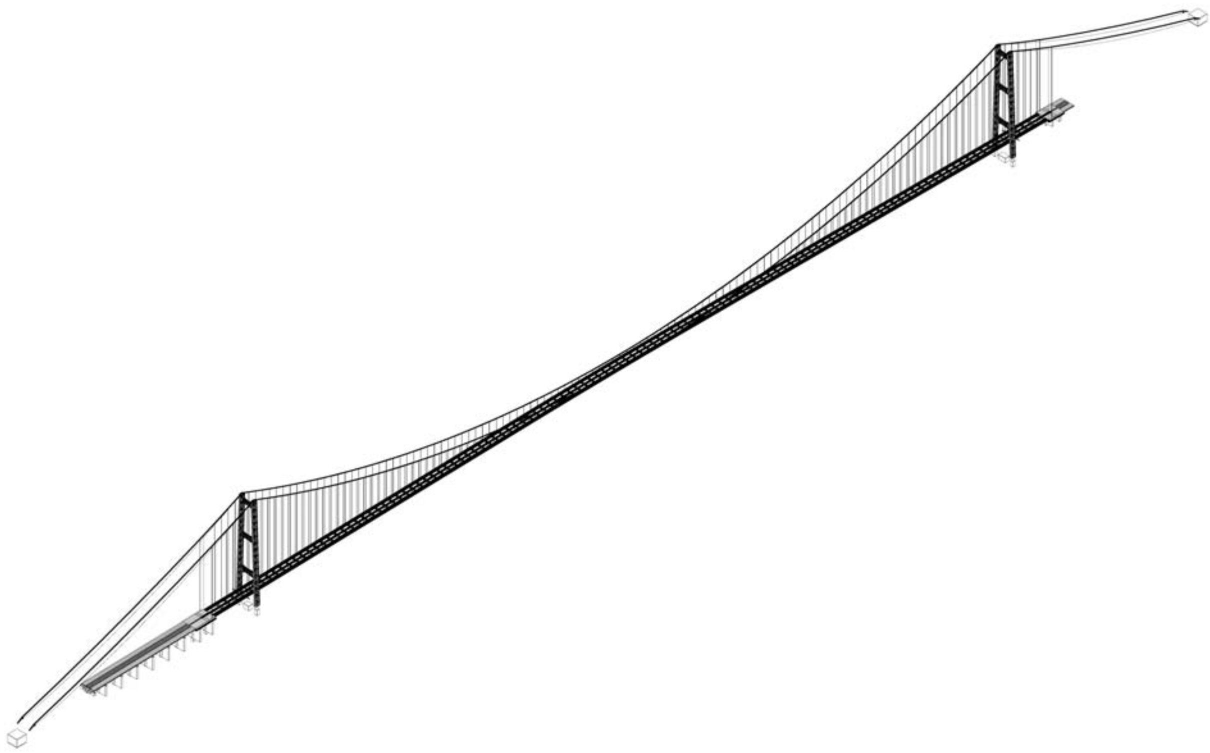


Figure 2.1: Messina Strait Bridge, geometry model (isometric view).

Most of the main members of the entire bridge are modelled with an approximate geometry, so that the masses and structural characteristics are correct within few percent of the actual values.

The structural modelling of the above elements is done in separate sub models, which are assembled to create the global bridge model.

The different structural elements are explained in more detail in the following, which shows pictures from the model established during the Progetto Definitivo design period.

2.2.1 Towers

The towers are modelled from top of the foundation.

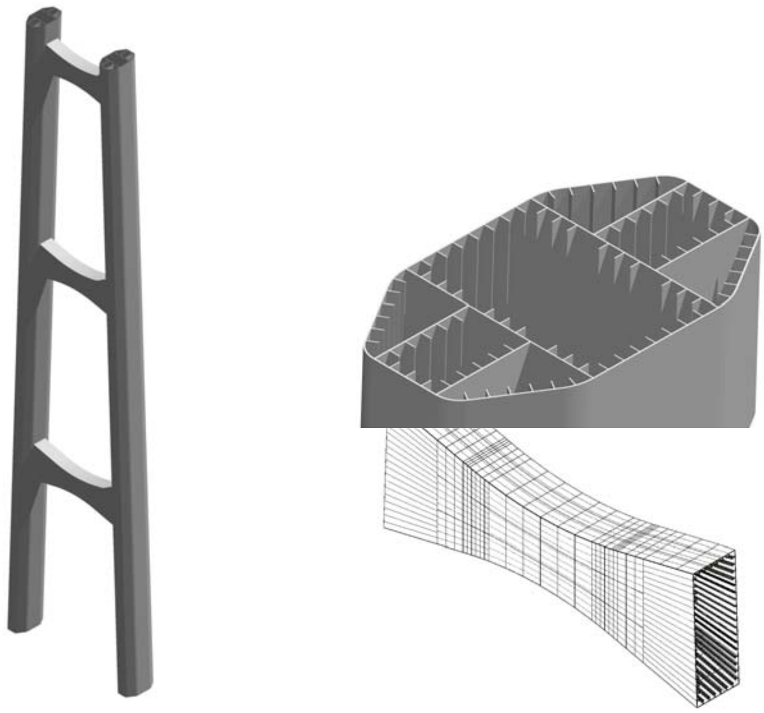


Figure 2.2: Messina Strait Bridge, geometry model and cross section of the Tower and Cross girders.

The tower legs are modelled geometrically correct with all the longitudinal steel, as shown in the above figure. Diaphragms, bolts and miscellaneous utilities are added as weight per meter along the tower legs.

The cross beams are modelled considering the longitudinal steel, as shown in the above figure. Diaphragms are added as weight per meter along the cross beams.

The tower saddles are modelled with the same geometry as the tower legs, but with added weight to achieve the correct total weight.

2.2.2 Suspended Deck

The suspended deck consists of 3 individual longitudinal girders connected by cross girders.

The model includes the correct alignment according to the alignment drawing.

All the longitudinal steel skin of the girders including stiffeners is modelled with their exact geometry and plate thicknesses. The diaphragms are not modelled but their weight is added as weight per meter along the girders.

Local elements such as additional stiffeners and plates near hanger anchorages are not included in the global model but the weight is added. The weight of paint and welds are included as uniform distributed weight along the girders.

The hanger cross girders are modelled with the exact outer geometry and longitudinal stiffeners. The plate thicknesses (sides, bottom and top) are selected as representative thicknesses found near the centre of the cross beams, and are constant along the length. The diaphragms are not modelled. The weight has been adjusted by adding the weight difference between the analysis and design model as weight per meter along the girders.

Plots of the longitudinal steel girders and the cross girder are shown in the figures below. The plot shows the contour which is used by IBDAS for calculation of element properties (stiffness, mass etc.).

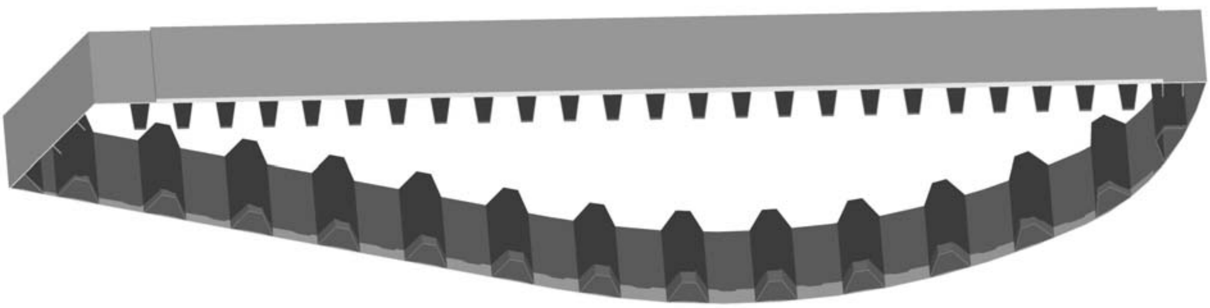


Figure 2.3: Typical cross-section of the suspended deck (road way)

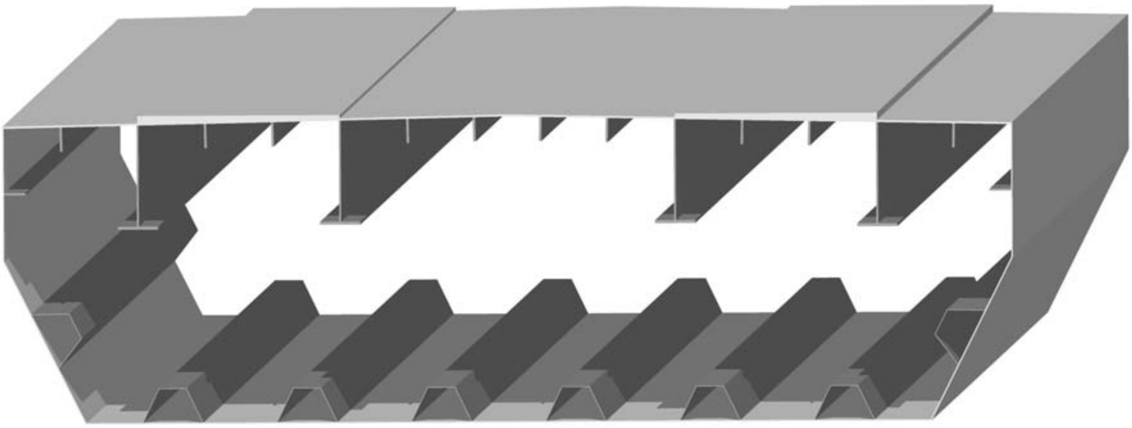


Figure 2.4: Typical cross-section of the suspended deck (rail way)

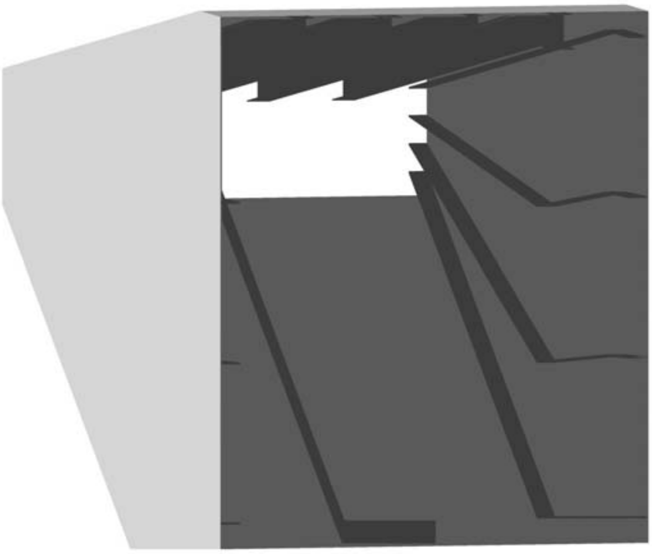


Figure 2.5: Typical cross-section of hanger cross beam

2.2.3 Roadway Surfacing and Railway Tracks

Surfacing is included in the geometry model by using a non-structural material definition. The use of a non-structural material for the surfacing ensures the introduction of the proper weight and load distribution for local roadway loads without introducing a corresponding stiffness, i.e. the surfacing is not included in stiffness calculations but it is included in mass calculations.

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

For the railway girder, the tracks are modelled in the same way as the road lanes but the tracks are modelled with horizontal top surface corresponding to top of rails, which enables correct point of attack for loading, which is also used for comfort analyses. The weight of the surfacing layer has been set to 0 and the weight of the rails and their fixations is added separately as an external load with PN status.

2.2.4 Cables and Hangers

The main cables are modelled as cable elements following a cable curve with sag as indicated on the drawings and hanger forces corresponding to the weight of the girders. The two-cable setup has been modelled according to the drawings.

The hangers are modelled as one hanger per location with a cross-sectional area corresponding to the sum of the hanger areas at the corresponding location on the bridge. The hangers are modelled from anchorage points in girder to end point at the main cables. Cable clamps and anchorages are added as weight to the main cables and deck.

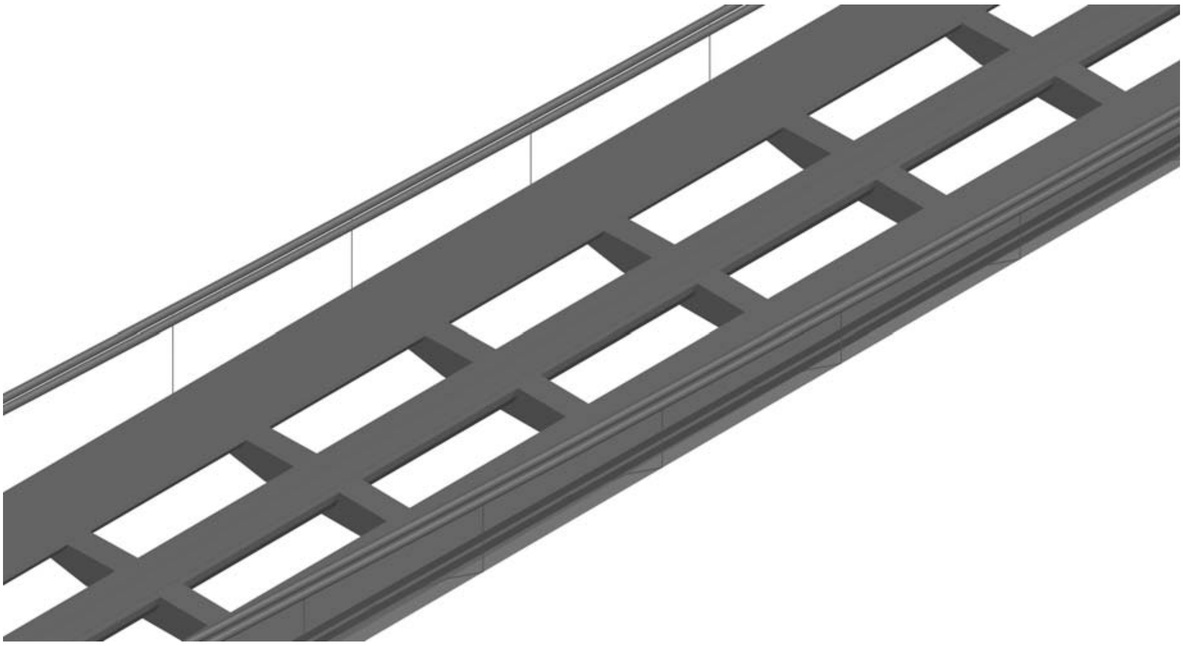


Figure 2.6: Messina Strait Bridge, view of geometry at centre of main span.

2.2.5 Terminal Structures

The terminal structures and approach spans are modelled with slightly less detail than the other elements as they are primarily used to get the correct boundary conditions for the remainder of the bridge, but are also used to estimate bearing forces and used for verification of the terminal structures.

The girders are modelled with beam elements. The longitudinal walls and stiffeners have been included in the model. The transverse and vertical stiffeners and the diaphragms have not been modelled but there weight has been added as weight per meter along the structure. In Figure 2.7 a cross section near the viaduct on the Sicily side is shown and the full geometry of the terminal structure (Sicily) is shown in Figure 2.8.

The piers are modelled with beam elements. As the stiffness of the terminal structure piers only has minor impact on the relative movements in the bearings for non-seismic loads and the seismic design is governing for the piers it is chosen to use a reduced E-modulus of the Terminal Structure Piers taking cracking of the concrete into account. This E-modulus is used for all load cases thus reducing the number of model variants within each model version.

The foundations have been modelled with a rigid beam positioned at the centre between the piers, where soil springs are defined, which is described later in this report.

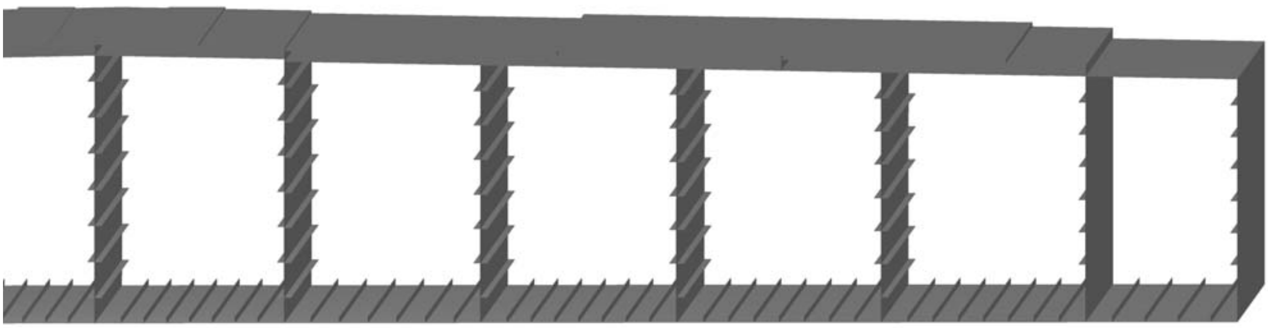


Figure 2.7: Cross section of terminal structure (Sicily)

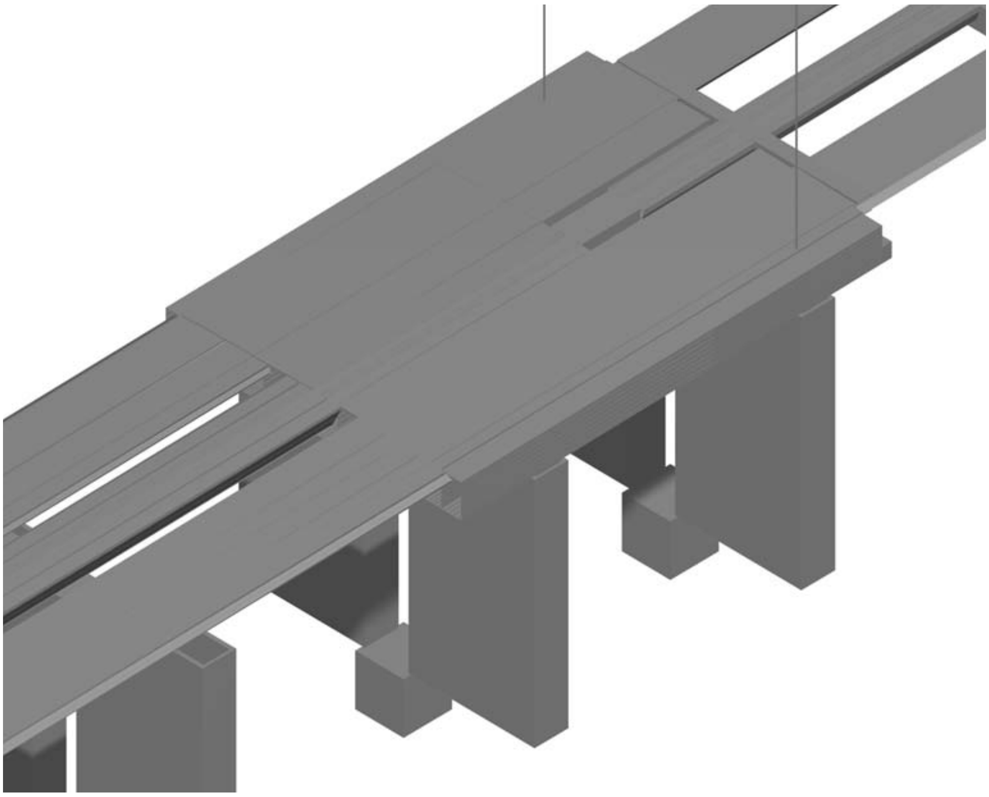


Figure 2.8: Messina Strait Bridge, geometry model of the Sicily

2.2.6 Transverse Deck/Tower Connection

The transverse connection between the suspended deck and the towers is modelled with beam elements having a constant rectangular hollow cross-section.

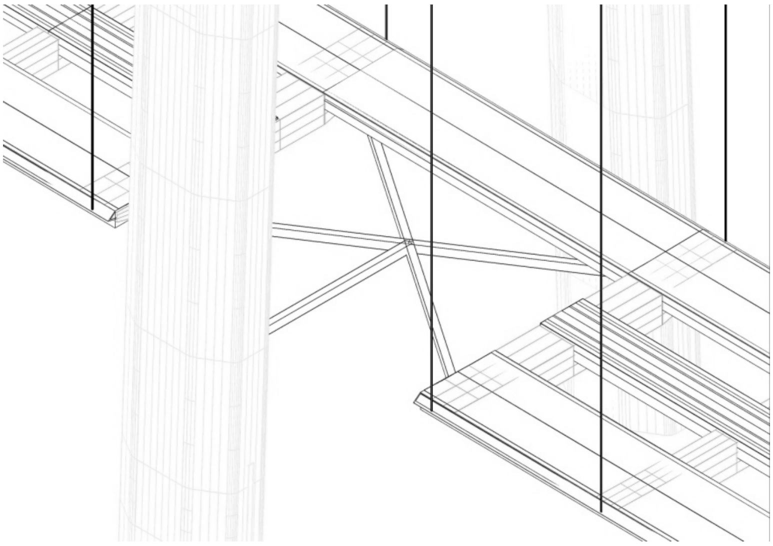


Figure 2.9: Messina Strait Bridge, geometry model of the transverse connection between the suspended deck and the towers (X-stiffener). For better view, the railway girder and one of the road girders are not shown in the region above the connection.

The directions of free movement of the connections can be seen in section 2.9 of this report.

The transverse connection to the tower is equipped with a seismic buffer. The non-linear effect of the buffers is to be investigated in seismic time history analyses. Longitudinal buffers are included into the global model and the non-linear effect of the buffers is investigated in seismic time history analyses.

2.2.7 Tower Foundations

The tower foundations have been modelled with three elements as shown below.

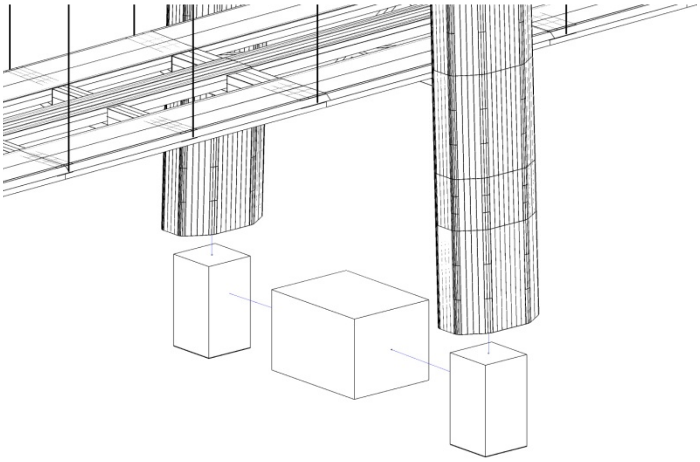


Figure 2.10: Messina Strait Bridge, geometry of the tower foundations

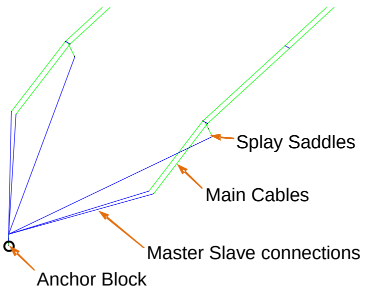
The connections to the tower legs, stiffness properties, weight as well as damping properties of the elements are adjusted to estimate the behaviour of the real geometry of the foundations.

2.2.8 Anchor Blocks

The anchor blocks have been modelled with a rigid beam from a point just below the centre of gravity of the anchor block as the unique numbering system in IBDAS does not allow for nodes without corresponding elements. The weight is added separately as structural weight (PP) as described in section 3.2.

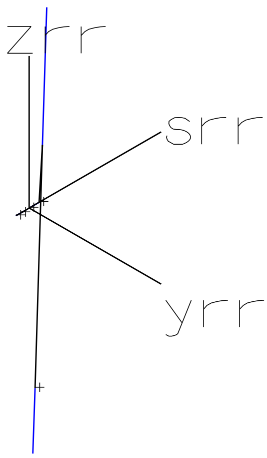
The Splay Saddles are modelled separately and connected to anchor block. The weights of these are also added separately.

An illustration of the model at the anchor blocks are shown below from the Finite Element model for easy overview.



2.2.9 Tower TMD's

The TMD's have been grouped with one TMD in each leg placed at level 243. Each TMD has been modelled with two beam elements with springs and dashpots as defined below. The elements are free in one end and connect to the tower legs in the other. Weight is applied to the node connected to the tower legs and masses are applied with ms (mass in s-dir) applied outside the springs and my and mz applied to the node connected to the tower leg.



The overall weight/mass in each tower is 550 t and the spring stiffness respectively damping has been calibrated to give 5 % relative damping at 0.477 Hz (modal mass = 47.5 Mkg).

Mass: M = 550/2 t pr tower leg

Spring stiffness: k = 4.72/2 MN/m pr. tower leg

Damping: C = 0.3543/2 MN-s/m pr. tower leg

2.3 Global coordinate system

In the model several coordinate systems have been defined. The global coordinate system used for reporting of e.g. displacements and reactions is a left-hand coordinate system, defined as follows:

- the **S**-axis (1st axis) extends along the centre line of the bridge, positive towards Calabria, s=0 is at the centre of the main span.
- the **Y**-axis (2nd axis) is orthogonal to the **S**-axis and the **Z**-axis forming a left hand coordinate system. The Y-axis thus extends horizontally transverse to the centre line of the bridge.
- the **Z**-axis (3rd axis) is vertical and extends positive upward, zero at elevation 0.00 according to the project drawings.

The global coordinate system can be seen in Figure 2.11.

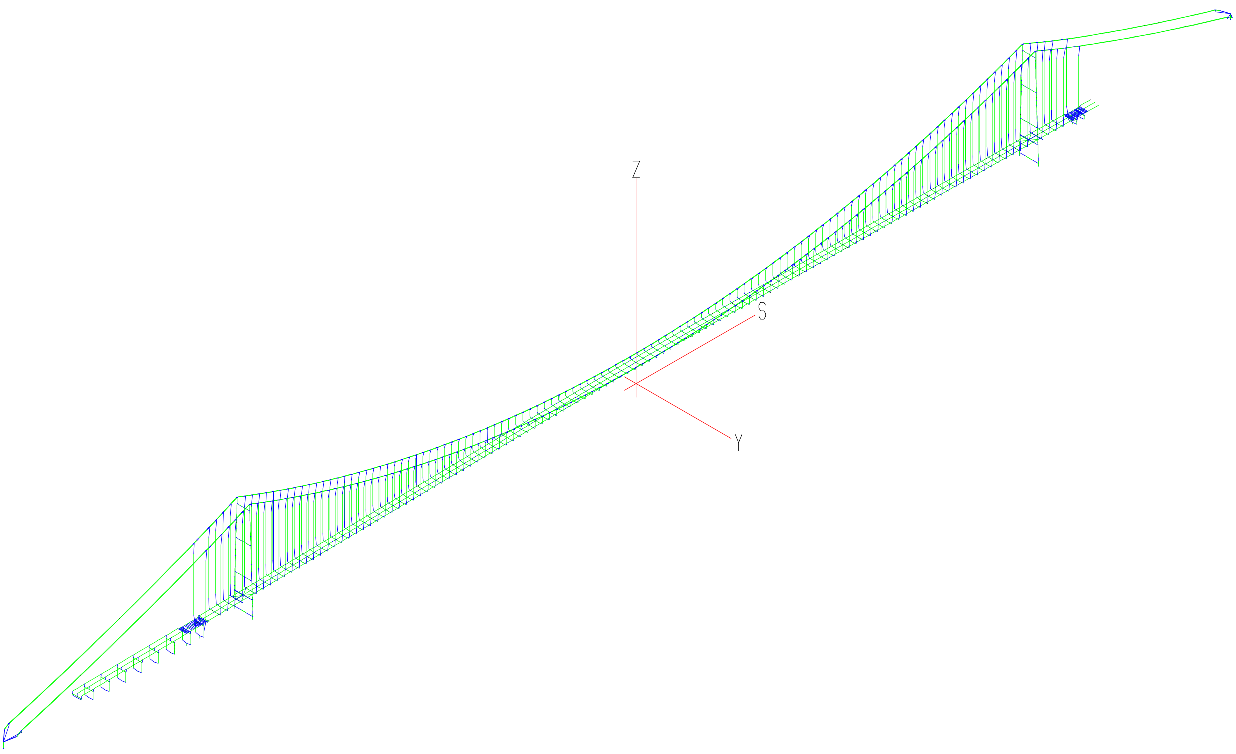


Figure 2.11: Global left hand coordinate system used in the IBDAS model. The plot also shows the entire FE-model.

2.4 Basic assumptions

The following materials are used in the IBDAS model:

Structural Steel:	Density:	77.0 kN/m^3
	E-modulus:	210,000 MPa
Steel Main Cable:	Density:	77.0 kN/m^3
	E-modulus:	200,000 MPa
Steel Hangers:	Density:	77.0 kN/m^3
	E-modulus:	200,000 MPa
Concrete Piers:	Density:	25.0 kN/m^3
	Strength (cylinder)	45 N/mm^2
	E-modulus(cracked concrete):	17,850 MPa

The coefficient of thermal expansion is taken as:

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

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

2.5 Elements

The IBDAS elements used in the global model are all 3D iso-parametric beam or truss elements.

The towers, piers and the bridge deck, including the cross girders, are all modelled with 3-noded parabolic beam elements (IBDAS BEAM18 elements) with 6 degrees of freedom in each node. Shear deformations are taken into account.

The hanger cables and main cables are modelled with 2-noded truss elements (IBDAS TRUSS6 elements) with 3 degrees of freedom in each node.

2.6 Node and Element numbering

In an IBDAS model the elements and nodes are divided into:

- Parts
- Segments
- Slices (group of elements) / tcuts (group of nodes)
- Elements / Nodes

That is every element and node is uniquely identified by the above four numbers. The parts and segments may be connected together with master-slave connections.

There is a unique relation between the part/segment/tcut/node for nodes and part/segment/slice/element for elements.

Information on nodal co-ordinates, master-slave connections and supports are enclosed in Appendix B.

2.7 Part list

The following part and segment numbers are used in the global model of the Messina Straits Bridge.

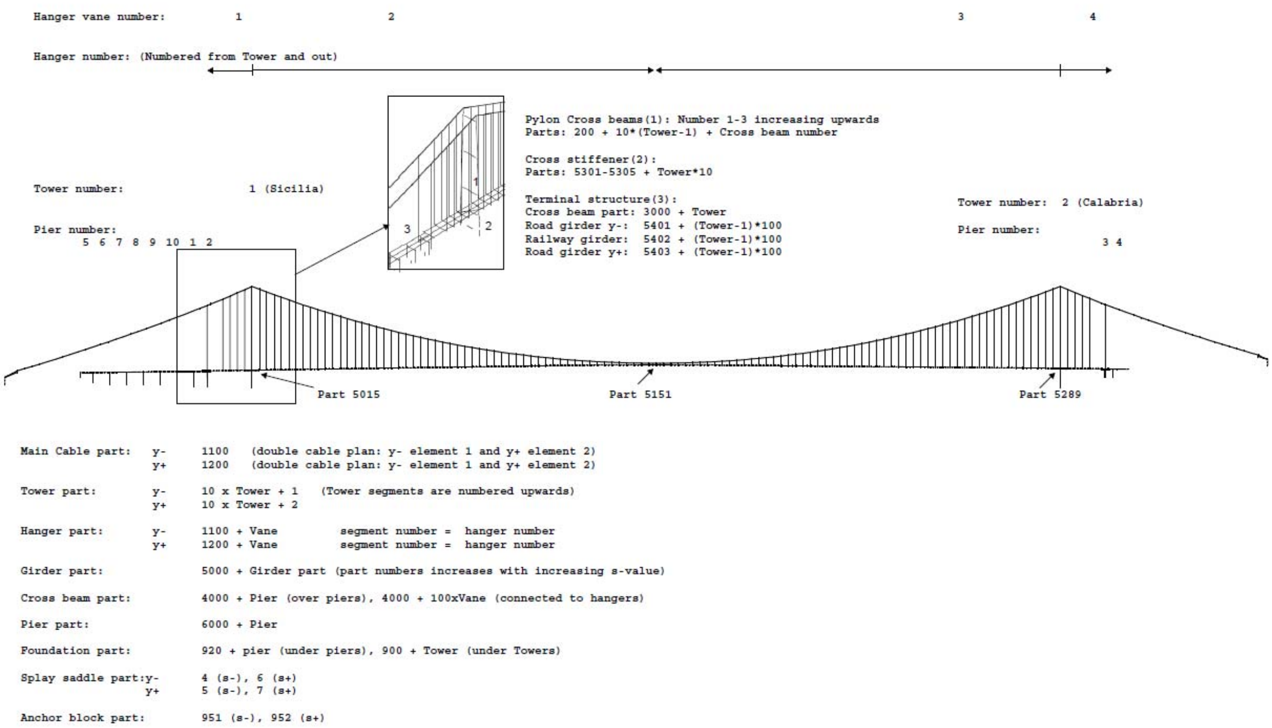


Figure 2.12: Overview of part numbering in the Global IBDAS model, see also table below.

Model part	Part number	Segment number	Element number	Description	type
Longitudinal girders	5006-5298	All	1 2 3	Roadway Girder, West (y-) Railway Girder Roadway Girder, East (y+)	beam
Terminal Structure, Sicilia	5002-5005	All	1 2 3	Roadway Girder, West (y-) Railway Girder Roadway Girder, East (y+)	beam
Extra console beams at terminal structure, Sicilia	5401 5402 5403	All	All	Roadway Girder, West (y-) Railway Girder Roadway Girder, East (y+)	beam
Terminal Structure, Calabria	5299-5302	All	1 2 3	Roadway Girder, West (y-) Railway Girder Roadway Girder, East (y+)	beam
Extra console beams at terminal structure, Calabria	5501 5502 5503	All	All	Roadway Girder, West (y-) Railway Girder Roadway Girder, East (y+)	beam
Approach Spans	5001 5303	All	All	Pantano Viaduct Calabria Approach Spans	beam
Cross girders, at hanger positions	4100 4200 4300 4400	All, Counted from Towers	All	Back Span, Sicilia side Half Main Span, Sicilia side Half Main Span, Calabria side Back Span, Calabria side	beam
Cross girders at terminal structure	3001 3002	All	All	At girder expansion joint, Sicilia At girder expansion joint, Calabria	beam
Sicilia Tower	11 21	All, Counted from foundation	1	West leg (y-) East Leg (y+)	beam
Sicilia Tower Cross beams	201 202 203	All	All	Lower Cross beam Middle Cross beam Upper Cross beam	beam
Sicilia Tower X below girders	5311-5315	All	All	X below girders at Sicilia Tower	beam
Sicilia Tower Longitudional Buffer	5335-5337	All	All	Fictive elements used for modelling longitudinal buffer	beam
Sicilia Tower Foundation	901	All	All	Foundation elements at Sicilia Tower	beam
Calabria Tower	12 22	All Counted from foundation	1	West leg (y-) East Leg (y+)	beam
Calabria Tower Cross beams	211 212 213	All	All	Lower Cross beam Middle Cross beam Upper Cross beam	
Calabria Tower X below	5321-5325	All	All	X below girders at Calabria Tower	beam

Model part	Part number	Segment number	Element number	Description	type
girders					
Calabria Tower Longitudinal Buffer	5345-5347	All	All	Fictive elements used for modelling longitudinal buffer	beam
Calabria Tower Foundation	902	All	All	Foundation elements at Calabria Tower	beam
Piers	6001-6002 6003-6004 6005-6010	All	1	Piers at Terminal Structure, Sicilia Piers at Terminal Structure, Calabria Piers, Approach Span Sicilia	beam
Main Cables (twin)	1100 1200	All	1,2 1,2	West Cables (y-) East Cables (y+)	truss
Hangers, y- side (west)	1101 1102 1103 1104	All Counted from towers	1	Hangers in vane 1 Hangers in vane 2 Hangers in vane 3 Hangers in vane 4	truss
Hangers, y+ side (east)	1201 1202 1203 1204	All Counted from Towers	1	Hangers in vane 1 Hangers in vane 2 Hangers in vane 3 Hangers in vane 4	truss
Splay Saddles	4 5 6 7	All	All	Sicilia, y- Sicilia, y+ Calabria, y- Calabria, y+	beam
Anchor blocks	951 952	All	All	Sicilia Calabria	beam
TMD's in Tower Legs	711 811 911 1011	All	All	Sicilia, Leg y- Sicilia, Leg y+ Calabria, leg y- Calabria, leg y+	beam
Pull Back Ropes (stay cables)	2110 2210 2120 2220	All	All	Sicilia, Leg y- Sicilia, Leg y+ Calabria, leg y- Calabria, leg y+	truss

Table 2.1: Overview of part numbering in the Global IBDAS model.

2.8 Element coordinate systems

The following plots show the element coordinate systems. The coordinate systems are all left-hand systems. These coordinate systems are used for reporting of element actions such as generalised stresses (section forces).

All elements always have the s-axis along the element.

The element coordinate systems for the deck girders (roadway, railway and terminal structure) follow the global left hand coordinate system, see section 2.3.

All transverse cross beams in the deck have the s-axis along the global y-axis direction and the z-axis in the global z-axis direction.

The towers are modelled with the s-axis along the global z-axis direction and the z-axis in direction of the global s-axis direction.

The tower cross beams are modelled with the s-axis in the global y-direction and the z-axis in the global s-direction.

The piers are modelled as the towers, i.e. with an s-axis in the global z-axis direction and a z-axis in direction of the global s-axis.

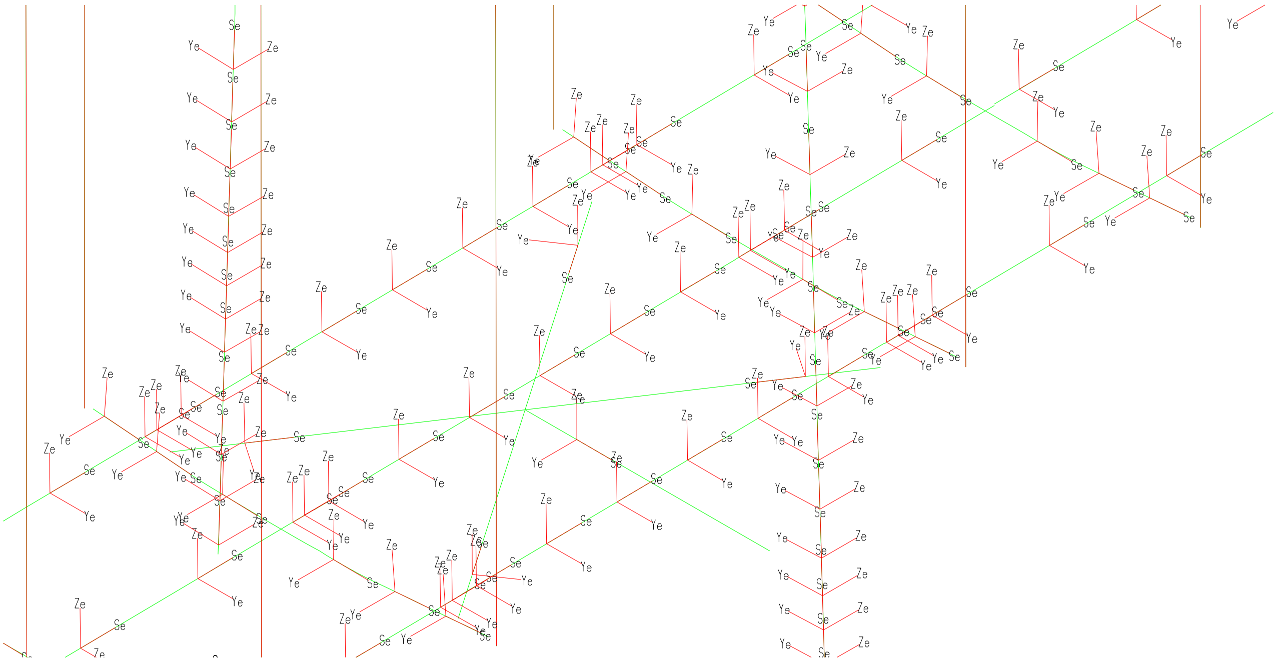


Figure 2.13: Element coordinate systems (left hand) at the three longitudinal girders and at the transverse cross girders at hanger positions. The tower legs and X-stiffener beams are also shown.

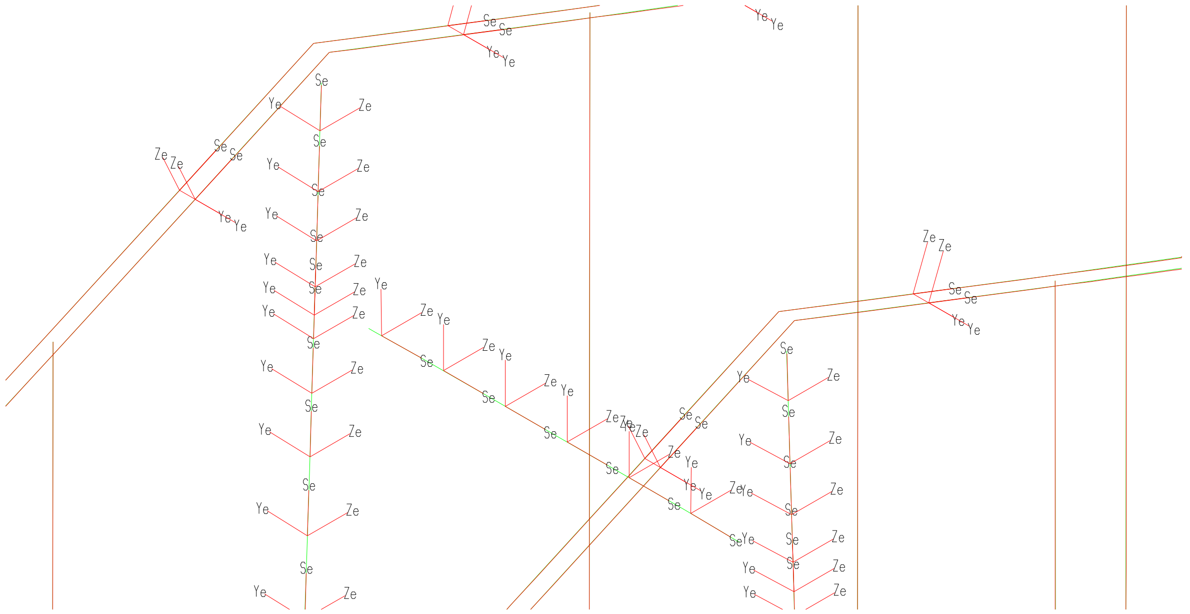


Figure 2.14: Element coordinate systems (left hand) at tower legs and tower cross beams.

The sign conventions in IBDAS for sectional forces are given in Appendix B.

2.9 Support Conditions

The support conditions for the bridge are as follows:

- Fixed supports at viaduct pier foundations
- The terminal Structure piers supported by soil springs as described in section 2.9.3
- The tower foundations are supported by soil springs as described in section 2.9.3
- The anchor blocks are supported by soil springs as described in section 2.9.3
- The defined bearings are described in section 2.9.1
- Buffers are defined as described in section 2.9.2

2.9.1 Bearings and Expansion joints

The bridge bearings and expansion joints are defined according to the layout given in the articulation drawings, and also illustrated in the figures below.

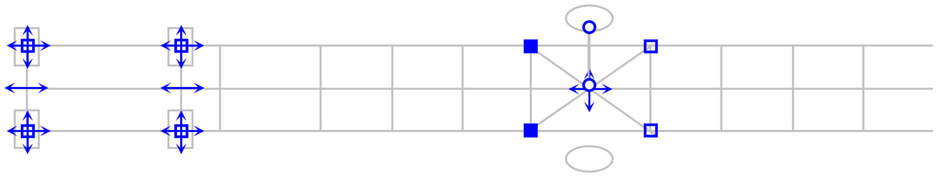


Figure 2.15: Support Conditions: Girder Supports.

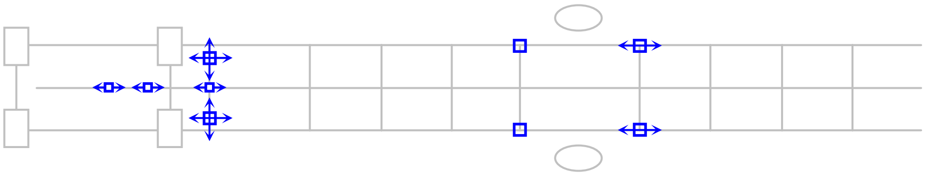


Figure 2.16: Support Conditions: Internal Girder Supports.

The arrows indicate the direction of free movement. Empty squares indicate vertical support. Full squares indicate fixed connections for displacements and rotations. Empty circles indicate rotationally released supports.

2.9.2 Longitudinal and Transverse Buffers

The buffers at the towers and terminal structure are activated for dynamic loads and uniform temperature, all other loads does not exceed the static limit of the buffers.

The figure below show the general positions of the buffers included into the global IBDAS model.

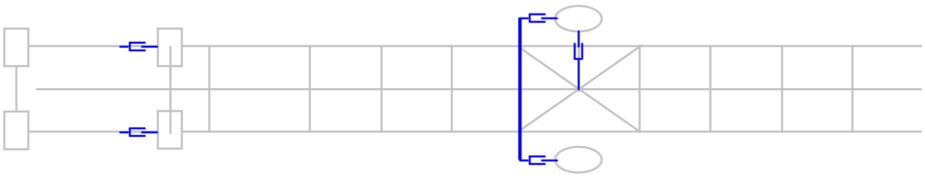


Figure 2.17: Overview of the buffer positions in the IBDAS model

The full function of the buffers can only be analysed in a Time History analysis. The following figures show the buffer characteristics as used in the analysis.

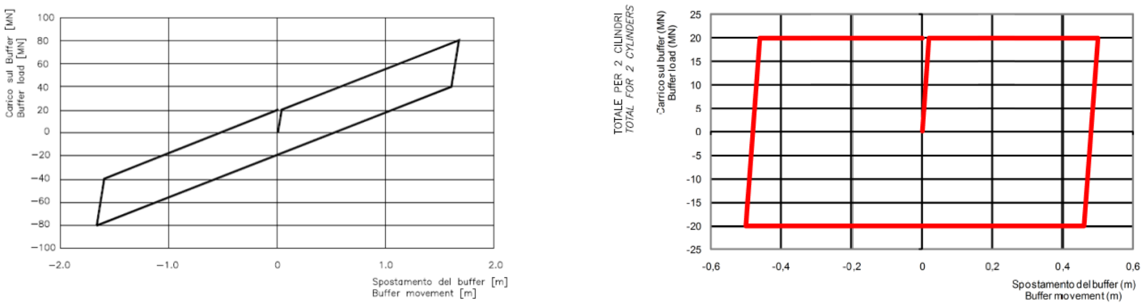


Figure 2.18: Buffer specification for the towers. Longitudinal (left), Transverse (right)

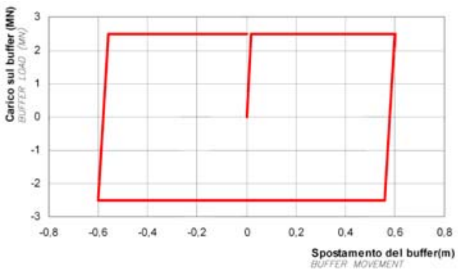


Figure 2.19: Buffer specification for the terminal structure piers

For static analysis two different stiffness's are used, one with a full tangential stiffness at the buffers (fixed-fixed system) and one with a small spring of 33 MN/m (free-free system), corresponding to the weak spring stiffness of the buffers.

The two longitudinal buffers at the towers have been coupled thus only transferring normal force to the tower legs.

At the end of design it has been decided to remove the longitudinal buffers at the terminal structures. This has only impact on the time history analyses in connection with results taken out for the Terminal structures. For all other analyses static loads, wind gust analyses and seismic response spectrum analyses IBDAS is using a full tangential stiffness of the buffers thus corresponding to a fixation of these buffers.

2.9.3 Soil-Structure Interaction

The effect of the foundations and the soil-structure interaction has been incorporated by including stiffness and damping matrices at the supports beneath the foundations. Values have been provided for the tower foundations, the terminal structure piers and the anchor blocks.

The following table's shows the spring- and damping matrices incorporated into the global IBDAS model.

	u_s	u_y	u_z	r_s	r_y	r_z	u_s- r_y	u_y- r_s
	Force along bridge axis [MN/m]	Force lateral to bridge axis [MN/m]	Force vertical [MN/m]	Rotation around bridge axis [MNm/rad]	Rotation around horizontal axis lateral to bridge axis [MNm/rad]	Rotation around vertical axis [MNm/rad]	Mixed mode Coupling of u_s and r_y [MN]	Mixed mode Coupling of u_y and r_s [MN]
Sicilia Tower	55000	55000	53000	$3.3 \cdot 10^7$	$3.3 \cdot 10^7$	$5.5 \cdot 10^7$	$-5.7 \cdot 10^5$	$5.7 \cdot 10^5$
alabria Tower	70000	70000	30000	$.1 \cdot 10^8$	$.1 \cdot 10^8$	$.2 \cdot 10^8$	$-1.0 \cdot 10^6$	$1.0 \cdot 10^6$
Pier 1	24000	3000	8000	$1.9 \cdot 10^8$	$1.5 \cdot 10^8$	$2.7 \cdot 10^8$	$-8.1 \cdot 10^4$	$7.7 \cdot 10^4$
Pier 1a	24000	23000	18000	$1.9 \cdot 10^8$	$1.5 \cdot 10^8$	$2.7 \cdot 10^8$	$-8.1 \cdot 10^4$	$7.7 \cdot 10^4$
Pier 119a	91000	85000	100000	$.1 \cdot 10^8$	$.8 \cdot 10^8$	$.0 \cdot 10^9$	$.9 \cdot 10^5$	$-3.6 \cdot 10^5$
Pier 119	91000	85000	100000	$6.1 \cdot 10^8$	$4.8 \cdot 10^8$	$1.0 \cdot 10^9$	$3.9 \cdot 10^5$	$-3.6 \cdot 10^5$
Sicilia Anchor	80000	78000	100000	$1.4 \cdot 10^8$	$9.8 \cdot 10^7$	$3.6 \cdot 10^8$	$8.9 \cdot 10^5$	$-8.7 \cdot 10^5$
Calabria Anchor	490000	490000	570000	$9.9 \cdot 10^8$	$6.9 \cdot 10^8$	$2.8 \cdot 10^9$	$3.3 \cdot 10^6$	$-3.3 \cdot 10^6$

Table 2.2: Spring stiffness's for Soil- Structure interaction

The following damping matrix is used during seismic time history analysis.

	us	uy	uz	rs	ry	rz
	Along bridge axis [MNs/m]	Lateral to bridge axis [MNs/m]	Force vertical [MNs/m]	Rotation around bridge axis [MNs/rad]	Rotation around horizontal axis lateral to bridge axis [MNs/rad]	Rotation around vertical axis [MNs/rad]
Sicilia Tower	4100	4100	4000	$2.5\cdot10^{6}$	$2.5\cdot10^{6}$	$4.1\cdot10^{6}$
Calabria Tower	5500	5500	2800	$2.3\cdot10^{6}$	$2.3\cdot10^{6}$	$4.6\cdot10^{6}$
Pier 1 & 1a	2200	2200	300	$3.0\cdot10^{6}$	$2.3\cdot10^{6}$	$4.4\cdot10^{6}$
Pier 19 & 19a	835	835	97	$5.6\cdot10^{5}$	$4.3\cdot10^{5}$	$9.5\cdot10^{5}$
Sicilia Anchor	660	650	830	$4.3\cdot10^{7}$	$2.7\cdot10^{7}$	$2.9\cdot10^{6}$
Calabria Anchor	490	490	530	$6.4\cdot10^{7}$	$5.6\cdot10^{7}$	$2.5\cdot10^{6}$

Table 2.3: Damping Parameters

Lower and upper bound values are defined as the values divided by 2 and multiplied by 1.5 respectively.

3 Stiffness, Masses and Weights

3.1 Cross-sectional Properties

Tables with sectional properties for the various elements section properties sorted in the various FE-element types are included in Appendix D.

Element stiffness matrices are calculated via reduced Gaussian numerical integration using 2 sampling points (Gauss points) in each integration direction. For beam elements there are 2 Gauss points located relatively 0.21 times the element length from each end of the element. For truss elements there is only one gauss point, placed at the centre of the element.

The Gauss points are always placed in the centre of gravity of the element.

An example of the printout for beam elements is shown below

Beam Element Data

Pa	Se	Sl	El	Ga	s [m]	y [m]	z [m]	A [m2]	Ay [m2]	Az [m2]	Iy [m4]	Iz [m4]	Iyz [m4]	Iv [m4]	g [kN/m]	ye- [m]	ye+ [m]	ze- [m]	ze+ [m]	E [MPa]	G [MPa]
5012	1	1	1	1	-1496.830	-18.881	58.889	0.543	0	0	0	9	0.175	1.009	53.798	-7.35	6.87	-2	1	210000	80769

where:

- Pa, Se, Sl, El, Ga are Part, Segment, Slice, Element and Gauss point numbers respectively (IBDAS numbering)
- s, y and z (units: [m]) are global coordinates of the output point in question (here the coordinates of the Gauss Point) .
- A, Ay and Az (units: [m²]) are the area and shear areas in Ye and Ze respectively.
- Iy, Iz, Iyz and Iv (units: [m^4]) are moments of inertia
- g (units [kN/m]) is the unit weight of the element per meter (geometrically modelled weight)
- Ye-, ye+, ze- and ze+ (units: [m]) are min/max distances to the outer fibres in the cross-section measured in the element coordinate system
- E: Young's modulus (units: [MPa])
- G: Shear modulus (units: [MPa])

An example of printout for truss elements (cables) is shown below

Truss Element Data

Part	Seg	sl	el	gau	s [m]	y [m]	z [m]	A [m2]
1100	1	1	1	1	-2620.090	-26.875	46.948	0.941

where:

- Pa, Se, Sl, El, Ga are Part, Segment, Slice, Element and Gauss point numbers respectively (IBDAS numbering)
- s, y and z (units: [m]) are global coordinates of the output point in question (here the coordinates of the Gauss Point) .
- A: Area of cable (units: [m^2])

3.2 Masses and Weights

The tables below show the weights defined by the IBDAS geometry model. The tables list structural weights (PP) and non-structural weights (PN) being introduced into the model through the geometry model. The weights in the table are automatically calculated by IBDAS based on the geometry model and the material properties. For dynamic calculations mass moments of inertia are also automatically calculated.

3.2.1 Longitudinal Girders

The modelled longitudinal weights of the steel girder sections are shown in the table below. This weight is excluding the weight of transverse steel (diaphragms etc).

CS	kN/m
1	43.2
2	44.4
3	44.4
4	48.6
5	51.7
6	46.4
7	49.7
8	48.7

CF	kN/m
1	28.1
2	28.1
3	38.9
4	88.6
5	31.2
6	34.1
7	47.4
8	38.6
9	30.9

Table 3.1: Overview of the longitudinal structural steel girder sections modelled in IBDAS

3.2.2 Cross girders

The modelled weight of the individual cross beams is shown in the table below. The weights are excluding the weight of transverse steel (diaphragms etc). The difference between structurally modelled weight and the design weight is corrected, with the values shown to the right in the table below.

T	kN
1	1181
3	1647
4a	3624
4b	2.874
6	2301

Calibration kN
433
388
4051
1279
649

Table 3.2: Overview of the modelled and correction for structural steel in the cross girders

3.2.3 Surfacing

The surfacing has been applied as 40mm over the width of 11.95m. The density of the surfacing material is 25 kN/m^3 with the resulting surface weight 1kN/m^2.

3.2.4 Added weights

In the IBDAS model some masses are not included directly in the geometry and FE-model. Instead they are applied as loads. These masses are listed in the tables below.

These weights are included in the reference condition and thus also in all dynamic calculations.

A load of 0.5 kN/m has been added to each girder to account for not modelled steel plates.

0.4 kN/m has been added to each roadway girder to take into account the additional weight of the strengthening's at the erection joints and the thicker bottom flange and the strengthened orthotropic deck at the cross girders.

0.08 kN/m has been added to the railway girder to take into account the strengthening's at the erection joints.

3.2.4.1 Diaphragms

CS	kN/m
1	4.5
2	4.5
3	4.5
4	10.7
5	5.7
6	4.7
7	4.3
8	4.5

CF	kN/m
1	3.5
2	3.5
3	4.4
4	5.1
5	4.2
6	4.2
7	4.7
8	6.2
9	3.0

Table 3.3: Girder diaphragms. Overview of the weights added as PP (structural) loads in IBDAS as a uniform distributed weights along the longitudinal girders (CS is per roadway girder).

3.2.4.2 Hanger Anchorages

CS	kN
1	89
2	83
3	86
4	233
5	187
6	187
7	233
8	114

Table 3.4: Hanger cross beams - extra steel at anchorages. Overview of the weights added as PP (structural) loads in IBDAS. The weights are included as uniform distributed weights along the longitudinal girders over the length of the cross beams.

3.2.4.3 Service crossovers

Weight of service crossovers are added at a distance of 315 meters from the towers and at 1215 meters from the towers (to centre of cross over). The weight of each cross over is 13.2 kN/m over a full span (30 meters from cross beam to cross beam) and as 7.4kN/m for each of the adjacent spans (30 meters). Half of the load is applied between the railway girder and the first roadway girder and half between the railway girder and the second roadway girder.

3.2.4.4 Additional Self weight

An additional load of 1.5 kN/m uniformly distributed along the axis of each longitudinal girder is applied as a PN load.

3.2.4.5 Other loads

PP – Tower legs		
Cross frames and diaphragms	kN/m	59
Horizontal Splices	kN/m	49
Paint	kN/m	0.49
Extra weight at cross girder intersections	kN	687
PP – Tower cross beam diaphragms		

Weight of tower cross beam diaphragms (percentage of longitudinal)	%	15
PP – Tower saddles		
Tower saddle trough (per saddle, each cable pair)	kN	5300
Tower saddle steelwork (per saddle, each cable pair)	kN	11500
PP – Tower Crosses		
Articulation	kN/m	1.5
PP – Main Cables (per single main cable)		
Cable clamps	kN/m	2.5
Paint and surfacing	kN/m	0.2
S-wire wrapping	kN/m	1.0
Hand strand access system	kN/m	0.2
PP – Hangers (per cable type)		
Corrosion protection (side span cables)	kN/m	0.1
Corrosion protection (main span cables)	kN/m	0.05
PP – Longitudinal Girders		
Welds Road	kN/m	0.35
Paint Road	kN/m	0.62
Welds Railway	kN/m	0.28
Paint Railway	kN/m	0.59
PP – Foundations etc		
Anchor Block Sicilia Side	MN	8343
Anchor Block Calabria Side	MN	7076
Splay saddles (per saddle, each cable pair)	MN	4.9
Tower Sicilia Side	MN	2689
Tower Calabria Side	MN	2237

Table 3.5: Overview of weights added as PP (structural) loads in IBDAS model.

PN - Roadway girder (weight for 1 roadway girder)		
2 nos. parapets	kN/m	2.2
Outer service lane (grating, supporting structure, wind screen)	kN/m	11.3
Light masts	kN/m	0.2
Various cables etc. in deck interior (utilities)	kN/m	0.69

Traffic gantries	kN/m	0.1
Access walkways, interior	kN/m	0.5
Drainage system	kN/m	0.22
2 nos. wind screens along parapets (height 2.4m)	kN/m	2.5
Rails for wagon in road girder	kN/m	*0.4*
PN - Railway girder		
Rails and track equipment incl. catenary masts and cables	kN/m	9.0
2 nos. emergency walkways	kN/m	6.7
Various cables etc. in deck interior (utilities)	kN/m	0.22
Fire main system (with water)	kN/m	1.31
Washing system (with water)	kN/m	0.1
Access walkways, interior	kN/m	0.3
Drainage system	kN/m	0.25
2 nos. solid walls along emergency walkways	kN/m	0.2
PN – Tower Legs		
Access Facilities (stairs, lifts etc)	kN/m	10.0

Table 3.6: Overview of weights added as PN (non-structural) loads in IBDAS model.

4 Construction Phases

A construction process in IBDAS is modelled as a sequence of construction phases, each phase consisting of activities such as: Casting, building-in and removing structural parts, pre-stressing, injection and slacking of pre-stressing tendons, stressing and slacking of cables, changing support/coupling conditions and placing and removing (temporary) construction loads.

A time indication is linked to each phase allowing calculation of time dependent effects such as i.e. creep, shrinkage and relaxation

In IBDAS all activities related to a given construction phase are analytically treated as being simultaneously applied.

The present investigations carried out for the Progetto Definitivo utilise several construction stages, as described below:

- **Completed Bridge**. The buffer arrangement at the towers can only be fully investigated in a time history analysis, which is why the calculations have been completed for two separate construction stages
  - One where the buffers have the tangential stiffness at the towers (named Fixed-Fixed)
  - One with a small spring at the buffers (named Free-Free)
- **Tower Construction**
  - 4 Stage construction with max leg cantilever
  - Free Standing Tower
- **Tie-Back Cables**
  - Stage after constructing the towers and fully stressed tie-back cables
- **Main Cables**
  - The stage after completion of the main cables.
- Construction of the girder system
  - A series of construction sequences have been established with the purpose of investigating various construction schemes as well as the impact from dynamic wind loading.

5 Reference condition

This chapter describes the reference condition of the bridge.

The reference condition is defined as the situation when the bridge is completed and opened to traffic.

The geometry of the girder at the reference condition is as defined by the alignment drawing. The reference condition consists of an initial stress distribution under which the structure has small deformations when loaded with gravity loads only (dead loads and superimposed dead load and time-dependent effects during construction (creep/shrinkage).

The reference geometry is defined as the geometry at the reference temperature of 20°C.

5.1 Geometry

The geometry of the reference condition is documented in Appendix E. The documentation consists of tables giving nodal coordinates as well as displacements due to gravity loads. As stated above the structure should have no or almost no resulting deformations when loaded with gravity loads only.

An example is shown in the following table:

Nodal Displacements, at reference state

Part	Se	Tc	Node	s [m]	y [m]	z [m]	us [m]	uy [m]	uz [m]	rs [rad]	ry [rad]	rz [rad]
5001	1	1	1	-2238.000	-18.445	47.262	0.012	0.000	-0.001	0.000	0.004	0.000

where:

- Part, Segment, Tcut, Node are Part, Segment, Tcut, Node numbers respectively
- s, y and z (units: [m]) are coordinates of the output point
- Us, Uy and Uz (units: [m]) displacements of the Node
- Rs, Ry and Rz (units: [rad]) rotations of the node

A plot of the bridge reference condition is shown below.

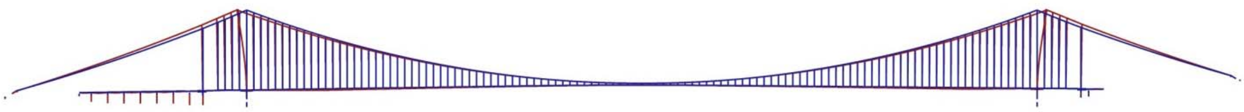


Figure 5.1: Reference condition (red line is deformed state at scale25) - it is important to notice that there is almost no displacements of neither deck nor towers visible, even when multiplying all displacement by a factor of 25.

The pull-back implemented for the towers are seen clearly in the reference condition plot, due to the scale of 25. The deflection of the roadway girder varies from -150 mm approximately 330 m from the towers to +35 mm at the centre of the bridge for the current reference state, which is sufficiently accurate for the current design stage. This will be further improved during Progetto Esecutivo.

The reference condition is established for the roadways with 40mm surfacing.

5.2 Stress condition

5.2.1 Sign convention

The force signs used in IBDAS are as shown in Appendix B.

It generally applies that a positive moment about one cross section axis yields compression in the top side in relation to the other cross section axis directions.

5.2.2 Results from the calculation

The initial stress condition is documented in the form of sectional forces in Appendix E.

An example of a printout for a beam element is shown below

Beam Sectional forces, at reference state

Part	Se	Sl	El	Ga	s [m]	y [m]	z [m]	Ns [MN]	My [MNm]	Mz [MNm]	Vy [MN]	Vz [MN]	Mt [MNm]
5001	1	1	1	1	-2238	-18.445	47.262	-21.043	-96.819	-0.001	0.000	-19.450	0.113

where:

- Part, Se, Sl, El, Ga are Part, Segment, Slice, Element and Gauss point numbers respectively
- s, y and z (units: [m]) are coordinates of the output point in question
- Ns (units: [MN]) is the normal force.
- My and Mz (units: [MNm]) are moments around the y-axis and z-axis respectively
- Vy and Vz (units: [MN]) are shear forces in direction of the y-axis and z-axis respectively
- Mt (units: [MNm]) is the torsional moment

An example of a printout for a truss elements is shown below

Truss forces, at reference state

Part	Seg	sl	el	gau	s [m]	y [m]	z [m]	Ns [MN]
1100	1	1	1	1	-2620.090	-26.875	46.948	616.378

where:

- Part, Se, Sl, El, Ga are Part, Segment, Slice, Element and Gauss point numbers respectively (Ibdas numbering)
- s, y and z (units: [m]) are coordinates of the output point in question (here the coordinates of the Gauss Point).

- Ns (units: [MN]) is the normal force.

5.3 Eigenfrequencies

The 50 first mode shapes of the bridge at the reference condition are shown in appendix F. The eigenfrequencies are determined for the Fixed-Fixed construction stage (see section 4), where the longitudinal buffers at the towers is active. In model 3.3f with active TMD's the movements of the Tower TMD's may be clouding the actual modes in cases were modes of the TMD's are governing as the mode shapes are normalized with the movement in the TMD's.

The table of frequencies in appendix F lists all 2060 frequencies, generalised masses as well as participating masses in percent for the three axes.

6 Loads and Load Combinations

This Section presents the load cases currently implemented in IBDAS and reported to the Design Groups. It also offers information on understanding the results reported, i.e. when to use certain loads and load combinations etc.

For a detailed load description please refer to the Design Basis, reference [1]. In the following the actual implementation of the Design Basis loads in IBDAS is described.

The IBDAS model operates with the following types of loads:

- Basic loads defined as 1.0 times the characteristic load.
- Influence surfaces loaded with traffic load
- Simple load combinations
- Complex load combinations (envelopes of loads and load combinations)
- "Worst" case of selected loads and load combinations
- Fixed loads and load combinations

A fixed load is a load that does not change size or point of attack depending on the effect being investigated. A load can be born fixed, but it is also possible to fix loads or load combinations thereby making it possible to investigate how a 'worst case' load or load combination for a given effect influences the remaining structure.

IBDAS includes facilities for automatic determination of extreme live load effects based on influence line calculations.

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

The basic loads defined are:

- Permanent Loads (Structural weight PP, non-structural components PN)
- Variable man-generated actions (QA, QR, QL)
- Wind Loads (static and dynamic) (VV)
- Seismic Loads (VS)
- Temperature Loads (VT)
- Accidental Actions (A)
- Fatigue loads (F)

6.1 Permanent Loads (PP and PN)

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

Permanent load is calculated automatically by IBDAS 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 2.4 of this report.

The load cases for Permanent Load are presented below:

Case 1	Total load giving all loads included in the reference condition including all material defined in the geometry model, i.e. also deck surfacing (all with factor 1.0), the added masses and time dependent effects (creep, shrinkage and relaxation where these effects occur).
Case 11	Total weight of Concrete - DL status Used for special load factors on concrete (if above 1.00)
Case 12	Total weight of Steel - DL status Used for special load factors on steel (if above 1.00)
Case 13	Extra steel in tower top – DL status Weight of tower saddles and other steel which is not modelled
Case 14	Weight of Hanger Cables – DL status
Case 15	Weight of Main Cables – DL status
Case 16-18	Added weight in Towers – DL status
Case 23	Weight of modelled surfacing – SDL status Used for special load factors on surfacing (if above 1.00)
Case 25	Additional SDL Girder (PN) SDL status
Case 26	Added weight to the Main Cables – SDL status

Results from case 11 to case 26 shall, because of the p-delta effects, be seen in connection with the reference condition.

6.2 Traffic Loading (QA, QR, QL)

Variable man-generated actions for global sizing (QA, QR) and local sizing (QL) are implemented according to the Design Criteria [1], section 5.2.

IBDAS includes facilities for automatic determination of extreme live load effects based on influence line calculations.

The basic cases for traffic loading are defined in the load case list in appendix H.

6.3 Wind Loading (VV)

Wind loading is implemented according to the Design Criteria [1], section 5.3.

The static gust and mean wind is implemented with a vertical profile as described in the Design Criteria [1].

In general a wind load due to natural turbulent wind can be considered as the sum of a static mean wind and a stochastic fluctuating wind load, the latter referred to as buffeting. The response of the structure can thus similarly be divided into response to mean wind (static response) and response to buffeting wind (dynamic response).

The IBDAS model has been analysed for wind in 8 different directions, please refer to section 2.3 for coordinate system:

1	Transverse Wind (Y+ direction)
2	Longitudinal Wind (S+ direction)
3	Transverse Wind (Y- direction)
4	Longitudinal Wind (S- direction)
5	45 deg wind (S+ Y+ Direction)
6	45 deg wind (S+ Y- Direction)
7	45 deg wind (S- Y+ Direction)
8	45 deg wind (S- Y- Direction)

The basic load cases for wind are defined in the load case list in appendix H.

A static gust wind is defined, with a factor 1.35 on the mean wind pressure. This gust wind is used to create different wind scenarios, with e.g. gust wind in the main span at the same time as mean wind in the side spans. These loads are included in the wind envelope combinations.

The model has also been used for analysing dynamic wind loading in the time domain. This analysis is reported elsewhere.

6.3.1 Wind load coefficients

The wind load coefficients have been applied as given in Appendix G.

For wind loads where wind load coefficients have only been given for the railway girder and no approximative distribution have been indicated in Appenix G we have used the following distributions of the wind load coefficients on the individual girders.

As no coefficients are given for the construction wind with 45 degrees to span the construction wind coefficients perpidencular to span are used for 45 degrees wind as well.

Wind load coefficients for Wind 45 degrees to span. ***Service, No traffic***.

Girder	C_D	C_L	C_M
Upwind (B = 14.22)	0.235	-0.128	0
Railway (B = 7.5)	0.173	-0.042	0.0023
Downwind (B = 14.22)	0.091	-0.033	0

Wind load coefficients for Wind perpendicular to span. ***Service, Traffic***.

Girder	$C_{D\ 0.118}$	C_L	C_M
Upwind (B = 14.22)	0.283	-0.179	0
Railway (B = 7.5)	0.208	-0.010	-0.0005
Downwind (B = 14.22)	0.109	-0.091	0

Wind load coefficients for Wind 45 degrees to span. ***Service, Traffic***.

Girder	$C_{D\ 0.098}$	C_L	C_M
Upwind (B = 14.22)	0.235	-0.098	0
Railway (B = 7.5)	0.173	-0.039	0.001
Downwind (B = 14.22)	n. 0.090	-0.030	0

Wind load coefficients for Wind perpendicular to span as well as wind 45 degrees. ***Construction***.

Girder	$C_{D\ 0.049}$	C_L	C_M
Upwind (B = 14.22)	0.118	-0.324	0
Railway (B = 7.5)	0.087	-0.055	0.017
Downwind (B = 14.22)	0.053	-0.131	0

6.4 Seismic Load

Seismic loading is implemented according to the Design Criteria [1], section 5.3.2

Both response spectral analysis and time-history analysis are performed.

6.4.1 Response Spectral Analysis

The ground motion is defined for the four defined limit states, as given in the Design Criteria [1], section 5.3.2, the difference between the limit states being the peak ground acceleration. The peak ground acceleration for the limit states is shown in the table below.

SLS1	SLS2	ULS	SILS
1.2 m/s^2	2.6 m/s^2	5.7 m/s^2	6.3 m/s^2

Each limit state requires a spectral analysis to be performed and since only 1 spectral analysis may be active in IBSDAS at any given time and thus reported in a result file, there will be 4 result files with seismic responses.

The response of the structure subjected to the ground motion is calculated using the mode superposition response spectrum approach. A uniform ground motion is assumed, i.e. all supports are excited in the same manner. The damping ratio of the entire structure is taken as 5% relative to critical reflecting that large amplitude motions may occur during an earthquake.

The response spectrum analyses are carried out for the 2060 lowest modes of vibration thus achieving a participating mass of more than 97% in all three seismic directions.

Complete Quadratic Combination (CQC) is used for combining the effects from different modes. A 100 %, 30 %, 30 % (Newmark) combination rule is adopted for estimating the interaction effects from action in the three directions (S, Y and Z).

6.4.2 Seismic Time-History Analysis

Time series compatible with the ULS design response spectra is used as seismic inputs for time-history analysis.

The following input time histories have been included into the model:

- 4 sets of acceleration time histories for each tower developed by Stretto di Messina S.p.A and attached to the document DT.ISP.S.I.R2.001 " Storie temporali dell'azione sismica" generally referred to as the 1992 Seismic time series. As all the time series in all directions are spectrum compatible these 2 x 4 series have been chosen to be used for the design.

This gives a total of 8 sets of time series, which have been analysed during the design.

Each set of input time histories consists of three orthogonal components: a longitudinal component, a horizontal component and a vertical component. The above time series are all ULS design earthquake events which have been weighted with the adjustment factors: 1.0 in longitudinal direction, 0.8 in transversal directions and 0.75 in vertical direction.

The application for each set of input time histories has been consider by the following two cases:

- Longitudinal direction governing with the adjustments factors 1.0 x longitudinal + 0.8 x transversal + 0.75 x vertical

- Transversal direction governing with the adjustments factors 0.8 x longitudinal + 1.0 x transversal + 0.75 x vertical

All input time histories are compatible with the same design response spectra. Therefore, there is no significant difference in seismic inputs between the Calabria and Sicily shores. The suspended deck is very flexible, and seismic responses of the two towers are essentially decoupled. Therefore, the effects of multi-support excitations (due to different soil conditions, time shift or incoherence) would not be significant for seismic responses of the towers. Therefore, the same set of input acceleration time histories will be applied to all supports along the bridge structure in each dynamic analysis.

The ULS time series are scaled up and down with the peak ground accelerations in order to obtain series for the other 3 limit states SLS1, SLS2 and SILS as well as with the relevant adjustments factors when creating time series for transversal direction governing.Damping in time series has been defined as Rayleigh damping in the elements combined point damping at the soil springs (see chapter 2.9.3) and point damping in the TMD's in the towers (see chapter 2.2.9).

The general Rayleigh damping coefficients has been calibrated with respect to the the tower modes. As the range of modes contribution to the girder response for a series of sections along shows that the frequencies lies in the same range as the tower frequencies the tower damping coefficients are used for the girders and cables as well. The concrete pier of the terminal structures have been calibrated so that the relative damping is 5% at their respective periods.

The following parameters are used in the analyses

	Damping [% relative]	Period 1 [sec]	Period 2 [sec]	Alpha (mass)	Beta (stiffness)
Towers	0.0205	0.77	2.49	7.90×10^{-2}	3.84×10^{-3}
Superstructure	0.0205	0.77	2.49	7.90×10^{-2}	3.84×10^{-3}
Cables	0.0205	0.77	2.49	7.90×10^{-2}	3.84×10^{-3}
Terminal structures Sicily	0.050	0.77	2.49	1.93×10^{-1}	9.36×10^{-3}
Terminal structures Calabria (long pier) Calabria (short pier)	0.050 0.0205	0.77	2.49	1.93×10^{-1} 7.90×10^{-2}	9.36×10^{-3} 3.84×10^{-3}
Sicily Anchor block (freq. approx 1.8 Hz)	0.020	0.77	2.49	7.71×10^{-2}	3.74×10^{-3}
Calabria anchor block (freq approx 4.2 Hz)	0.010	0.77	2.49	3.85×10^{-2}	1.87×10^{-3}
Remaining structures	0.0205	0.77	2.49	7.90×10^{-2}	3.84×10^{-3}

6.5 Temperature Loads

Temperature Loads are implemented according to the Design Criteria [1], section 5.3.2.

The coefficients of thermal expansion are defined in section 2.4 of this report.

The reference temperature of the bridge is 20 deg.

The temperature loads have been defined as

1. Effective bridge temperature (Uniform temperature changes)
2. Temperature difference within deck and tower
3. Temperature differences between structural elements
4. Combinations of the effects (1) - (3)

The basic load cases for temperature are defined in the load case list in appendix H

The uniform temperature has been made with SILS values alone. SLS and ULS uniform temperature can then be found by multiplying the following factors:

	SLS	ULS	SILS
Factor on IBDAS results (case 4510)	0.92	0.96	1.00

6.6 Accidental Actions (A)

The Accidental situations analysed in the model are all determined using time history analysis. The situations currently defined are:

1) Hanger Rupture for cables 1N, 2N, 3N, 4N, 5N, 6N, 7N, 30N, 45N, 60N
2) Hanger Replacement 1N, 2N, 3N, 4N, 5N, 6N, 7N, 30N, 45N, 60N
3) Loss of a complete girder section at hanger position 2N, 3N, 4N, 7N, 30N, 45N, 60N

6.7 Fatigue Loads

Fatigue loads for the rail girder is included into the model, as describes in the Design Criteria [1], section 4.2.2.2.3 (1):

1) Fatigue trains 1-12 is shown in Annex D in 1991-2:2003 [E09]
2) RFI 1 -6

6.8 Load Combinations and Analysis Methods

6.8.1 Analysis methods

The different types of loads defined in the IBDAS model can be divided into the following groups:

1. Static Analysis (DL, Live load, Static Wind, Temperature etc.)
2. Dynamic Buffeting Analysis (Dynamic Wind)
3. Seismic Spectral Analysis (Earthquake)
4. Time-History Analysis (Earthquake, Accidental actions, Fatigue)

In IBDAS it is only possible to refer to one spectral analysis at a time, which means results from dynamic wind analysis and seismic response spectral analysis is given in a number of files, the worst of which must be found afterwards by the design groups.

For dynamic wind this means 8 different files for each of the four limit states and for seismic response spectral analysis 1 file for each of the limit states.

The longitudinal buffers at the towers are not active for all loads, but will be activated by e.g. dynamic loads and uniform temperature. It is not possible to specify such a support condition in the IBDAS model, so instead analyses are carried out for 2 different static systems, one with the buffers fully active (tangential stiffness) and one with a small spring, as described in section 2.9.2. These situations are referred to as “Fixed-Fixed” and “Free-Free”, which name the state of the buffers at the two towers. The situations represent the two boundaries

This means that all the above mentioned results are doubled, as they are all calculated for both systems.

6.8.2 Load combinations

The load combinations implemented in the global IBDAS model are based on section 6.8 in the Design Criteria [1].

The combinations are defined as envelopes of the basic loads or possibly with worst case combinations of the basic loads.

The load case numbers corresponding to the load combinations are listed in the table in appendix H.