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

PI0038_F0

Unità Funzionale	OPERA DI ATTRAVERSAMENTO
Tipo di sistema	IMPIANTI TECNOLOGICI
Raggruppamento di opere/attività	SISTEMI DI MONITORAGGIO
Opera - tratto d'opera - parte d'opera	Design report
Titolo del documento	Structural Health Monitoring System (SHMS)

CODICE: C G 1 0 0 0 | P | 2 S | D | P | I T | M 3 | S M | 0 0 | 0 0 | 0 0 | 0 1 | F0

REV	DATA	DESCRIZIONE	REDATTO	VERIFICATO	APPROVATO
F0	20/06/2011	EMISSIONE FINALE	SDN	JCA	ABR/JCA

NOME DEL FILE: PI0038_F0.docx

INDICE

Abbreviations

BMS	Bridge Management Systems
Bridge	Messina Strait Bridge
Network CMS	Control and Monitoring System of the Network of approach structures
Bridge CMS	Control and Monitoring System of the Bridge
Constructor	Eurolink
CS	Communication Systems
CSP	Computing, Simulation & Prediction system
DAU	Data Acquisition and data processing Unit
E&M	Electrical and Mechanical systems
EDMS	Electronic Document Management System
ICMS	Information and Coordination Management System
IDRU	Intermediate Data Relay Unit
LAN	Local Area Network
MACS	Management and Control System
MMS	Management, Maintenance and Simulations system
PMS	Power Monitoring System
SCADA	Supervisory Control And Data Acquisition system
SHMS	Structural Health Monitoring System
SHMS MFS	SHMS Main Frame Server located in SCADA
SHMS DSS	SHMS Data Storage Server located in SCADA
TCMS	Temporary Construction Monitoring Sensors
Network TMS	Traffic Management System of the Network of approach structures
Railway TMS	Traffic Management System of the Railway
Bridge TMS	Traffic Management System of the Bridge
UPS	Uninterruptable Power Supply
WAN	Wide Area Network including Bridge Area Network
WSMS	Work Site Management System

1 Executive Summary

The Messina Bridge is a highly innovative bridge design for the world's longest span (3300m) to link Sicily with mainland Italy. The bridge is to be a suspension bridge formed from 4 main cables, a steel triple box girder, and steel towers that are 399m tall. Not only are the bounds of current bridge experience being pushed to the limit with a structure that is significantly larger than the current world's longest span of 1991m (the Akashi Kaikyo bridge), the aerodynamic stability of the deck structure is reliant on the beneficial characteristics provided by the innovative triple deck box structure. Thus permanent structural monitoring of the structure is desired to ensure that the structure is behaving as intended and remains safe to use. Furthermore a permanent monitoring system lends itself to condition monitoring for maintenance programming, thus maintaining the structure in good condition for a long service life.

Permanent monitoring of the bridge will be established through the installation of a Structural Health Monitoring System (SHMS). This SHMS will be a component of the Supervisory Control and Data Acquisition system (SCADA), which is turn forms part of the Management and Control Systems (MACS). Figure 1.1 shows the arrangement of MACS and its sub-components.

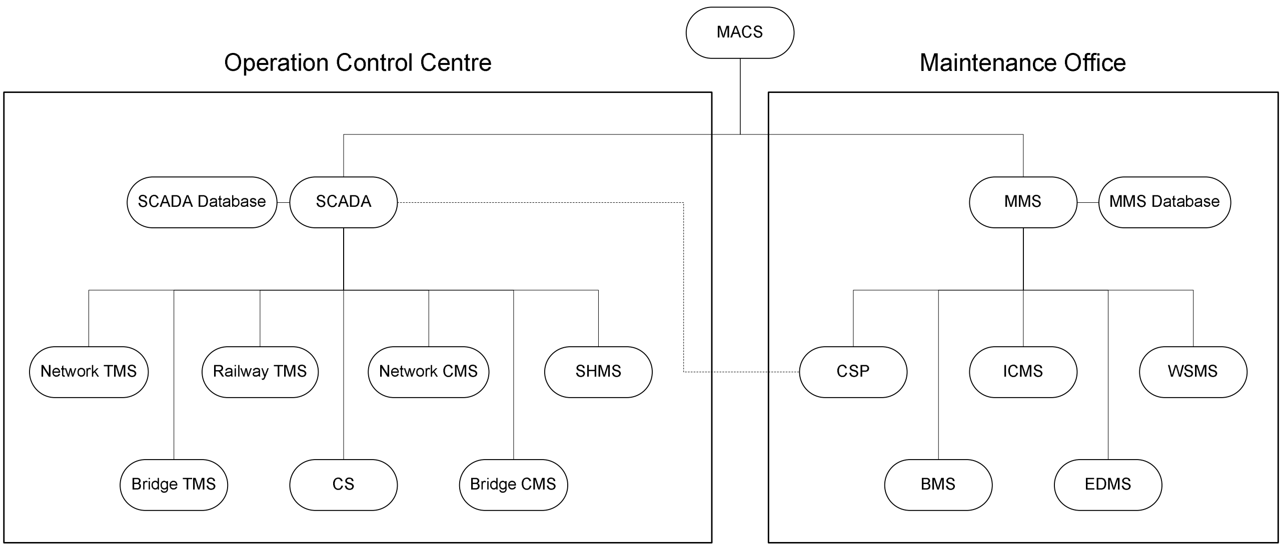


Figure 1.1 Arrangement of the Management and Control Systems (MACS)

A detailed design for the SHMS has been developed based on the technical specifications prepared by Stretto di Messina (2004), and based on the tender submission prepared by ATI Impregilo (2005). The monitoring plan has been updated and refined, improving the sensor arrangement to include monitoring of identified critical parameters, and taking into consideration changes in the design of the bridge, and developments in SHMS technology.

The SHMS has been developed in accordance with the following principles:

- Sufficient flexibility and robustness to allow integration into the SCADA system
- Sufficient flexibility and robustness to allow future extension and integration of new functions
- Sufficient flexibility and robustness to allow modification during development to allow incorporation of suitable advances in technology
- Sufficient robustness and redundancy to allow uninterrupted operation of the bridge management and control systems

The SHMS has been developed around the following objectives:

- to provide data for design, construction and performance verification
- to provide data for review of design loading and development of assessment loading
- to provide current information on load conditions for effective bridge operation
- to provide current information on the condition of structural components
- to provide data for maintenance planning
- to provide data for trouble-shooting unforeseen structural problems

The SHMS will provide the following system functions:

- Monitoring of the physical environment and its actions
- Monitoring of the bridge during construction
- Monitoring of the bridge during operation
- Monitoring of total traffic load on the bridge
- Monitoring of load events
- Monitoring of structural response events

- Providing data for risk analysis of bridge safety
- Information on the current state of the bridge

The SHMS will provide data that will assist with the following SCADA system functions:

- Management of road and railway traffic
- Management of event scenarios
- Management of emergencies scenarios
- Management for safety of the infrastructure
- Management for safety of users
- Information on the expected state of the bridge
- Review of components of the bridge that are not directly monitored

The SHMS will be a sophisticated redundant set-up that will provide the owner and operator with important information concerning structural behaviour and safety as well as information that will assist with operation and maintenance planning. The SHMS will also provide a valuable tool for investigating and trouble-shooting unforeseen problematic behaviour such as wind induced vibrations. The SHMS will be in place prior to construction and will be progressively brought online as the bridge is built, which will provide the constructor with important information during the erection stage concerning structural behaviour and safety.

The SHMS will be a stand-alone system that, in function, operates independently of other operation systems of the SCADA system, although all SCADA systems will use a common database for storing data. The SHMS consists of a central mainframe server that is located in the operation control centre, 15 on-structure data acquisition and processing units, and a network of sensors. The sensors will be connected directly to the data acquisition units. The data acquisition units will transmit data to the mainframe server via a general purpose communications network installed on the bridge, as illustrated in Figure 1.2. The measurement of rail and vehicle load using Weigh-in-Motion systems installed next to the terminal structures will be included as part of the Network TMS component of the SCADA system. Traffic (vehicle) flow will also be recorded at various positions across the network and bridge by the Network TMS and Bridge TMS components of the SCADA system. Traffic data will be delivered to the SHMS for processing. A common database will be provided for all components of SCADA; SHMS data that is identified for long term storage will be stored in this common database.

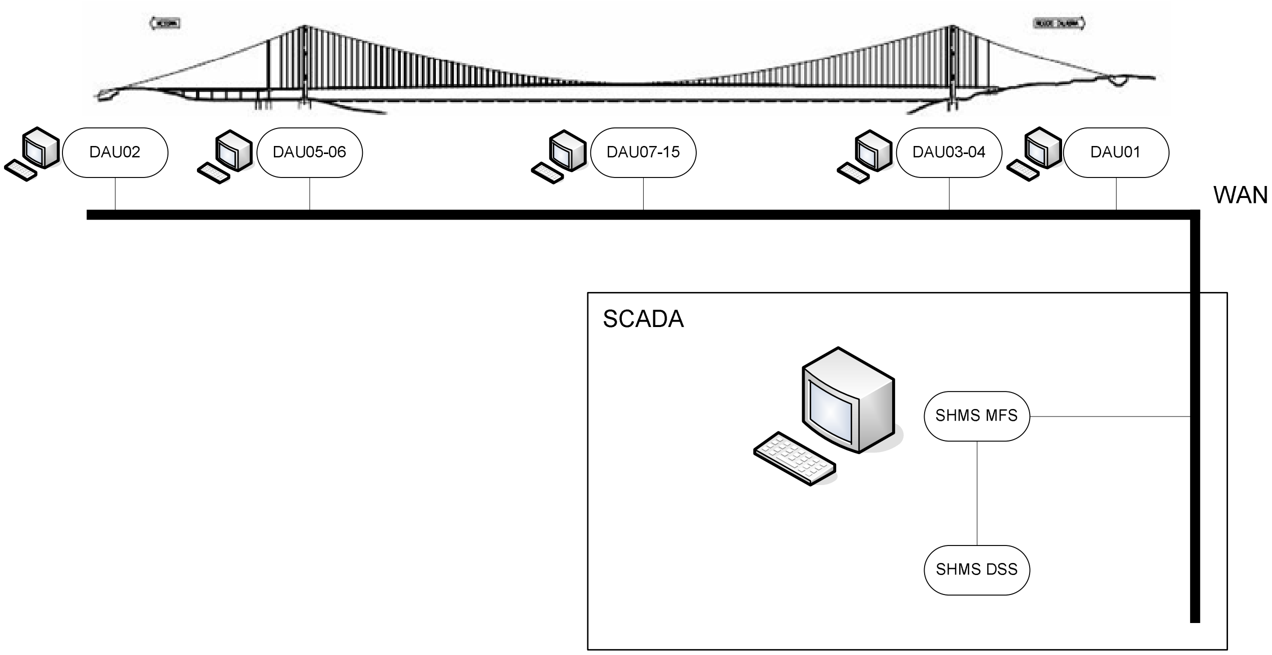


Figure 1.2 SHMS General System Architecture

There will be 3301 measurement locations and portable sensors, of which 2999 will be integrated into the permanent SHMS data-stream. A further 128 additional sensors will be provided specifically to supplement the primary arrangement. The installation of these additional sensors shall be determined following bridge construction and initial structural behaviour studies. The sensors include:

- Anemometers
- GPS receivers
- Air temperature sensors
- Pyrometers
- Hygrometers
- Fibre-optic relative humidity sensors

- Barometers
- Rain gauges
- Surface hygrometers
- Road temperature sensors
- Accelerometers
- Portable accelerometers
- Inclinometers
- Fibre-optic temperature sensors
- Fibre-optic strain sensors
- Linear displacement sensors
- Hydraulic pressure gauges
- Oil temperature sensors
- Concrete corrosion sensors
- Ground pressure sensors
- Interstitial ground-water pressure sensor
- Portable video displacement sensors
- Half-cell potentiometers
- Railway track temperature sensors
- Corrosion rate sensors
- Microwave interferometric radar

336 additional strain sensors shall be provided to the legs of the towers and to the longitudinal girders of the deck for the purposes of calibration. These sensors will not be connected to the SHMS data management system. The calibration strain sensors shall allow the 'active' strain

sensors to be calibrated at regular intervals, and shall allow the accurate calibration of replacement 'active' strain sensors.

Data quantity is vast, and as such effective data management processes have been planned so that data are presented in an effective manner for effective bridge operation and maintenance. Data management routines will be developed to implement the data management processes. The basic operation of the system will be as far as practicable automatic, requiring minimal input. The system will:

- Display live data
- Process data
- Maintain a temporary rolling data-buffer of live data for access by other components of the SCADA system
- Create history records that consist of low definition point value data and basic statistical data
- Detect (using data-triggers) and report events
- Create event records that consist of high definition point value data
- Create an automatic initial assessment of the cause and relevance of events
- Detect and report sensor malfunction
- Deactivate data-channels associated to malfunctioning sensors
- Create automatic reports on the system and structure performance

Day-to-day operation of the system will be kept as simple as possible. The mainframe control for the SHMS will be located in the SCADA operation room. A dedicated interface display will continuously present data in simple format. A facility will exist for displaying interface displays onto the main wall-screen provided as part of the SCADA system.

This document is a monitoring plan for the SHMS. It cannot be used as a tender document. It is expected that, during Progetto Esecutivo, this document will be further developed into a Specification. This monitoring plan presents:

- the bridge monitoring aims, including development principles and the monitoring requirements
- the system arrangement
- the sensor minimum requirements
- the hardware minimum requirements
- the mounting minimum requirements
- the installation minimum requirements
- the software minimum requirements
- the system operation minimum requirements
- the system security minimum requirements
- the documentation minimum requirements
- the quality control minimum requirements
- the copyright minimum requirements
- the design life and warranty minimum requirements
- requirements concerning the provision of access for maintenance
- requirements concerning the development of the maintenance strategy
- requirements concerning the design of the system for future expansion
- requirements concerning the process for adopting new technologies at a later stage in the project
- SHMS requirements for the SCADA building
- recommendations addressed to Stretto di Messina for the adoption of new monitoring techniques that are beyond the scope of this project
- requirements concerning the creation of a log of the construction works

- discussion concerning structural load testing
- a list of design tasks for the Progetto Esecutivo
- discussion concerning general responsibilities of various project participants during the construction phase

This document does not address temporary sensors for construction monitoring that will not be used after construction. These sensors will be detailed during Progetto Esecutivo following construction sequence planning.

The monitoring plan presents the fundamental architecture of the SHMS that will form the basis for further detailing and refinement during Progetto Esecutivo. Due to the evolution of the structural design in parallel with the development of the monitoring plan, the monitoring plan will be reviewed at the beginning of Progetto Esecutivo within the context of the completed structural design. Thereafter, the next step in the design involves the detailing of the architecture of the system, upon which the most efficient choice of software and hardware will depend. Numerous methods are available for delivering the detailed architecture; each SHMS sub-contractor will have a preferred system. It is therefore recommended that the constructor chooses an SHMS sub-contractor to work with the SHMS designer to prepare the specifications and shop drawings in Progetto Esecutivo.

The fibre-optic cables that will be embedded inside the main-cables will need to be developed for durability and function, to avoid damage during main-cable erection. Furthermore the embedded fibre-optic relative humidity sensor itself will need to be developed for this project. A phase of development and proof-testing will therefore be required to ensure that appropriate sensor designs are adopted. Development and proof-testing is to be completed prior to the commencement of Progetto Esecutivo.

The fibre-optic sensors that will be embedded in the main-cable require development in order to ensure successful installation. The fibre-optic relative humidity sensors also require development. In particular are to be developed and proof-tested

The detailing of the SHMS requires contributions to be made by numerous different participants of the bridge project, since the SHMS bridges many disciplines. The list of detailing tasks identified for Progetto Esecutivo provides a guide to the contributions that have been identified, including the appropriate sequencing of SHMS installation works into the construction programme by the constructor. With good collaboration of the various participants through Progetto Esecutivo, as well as the construction stage, a structural health monitoring system that is of high quality, and that is also well integrated with the bridge and the management and control systems, will be efficiently and successfully delivered.

2 Introduction

The Messina bridge is a highly innovative bridge design for the world's longest span (3300m) to link Sicily with mainland Italy. The bridge is to be a suspension bridge formed from 4 main cables, a steel triple box girder, and steel towers that are 399m tall. Not only are the bounds of current bridge experience being pushed to the limit with a structure that is significantly larger than the current world's longest span of 1991m (the Akashi Kaikyo bridge), the aerodynamic stability of the deck structure is reliant on the beneficial characteristics provided by the innovative triple deck box structure. Thus permanent monitoring of the structure is desired to ensure that the structure is behaving as intended and remains safe to use. Furthermore a permanent monitoring system lends itself to condition monitoring for maintenance programming, thus maintaining the structure in good condition for a long service life.

Permanent monitoring of the bridge will be established through the installation of a Structural Health Monitoring System (SHMS). This SHMS will be a component of the Supervisory Control and Data Acquisition system (SCADA), which is turn forms part of the Management and Control Systems (MACS). Figure 2.1 shows the arrangement of MACS and its sub-components.

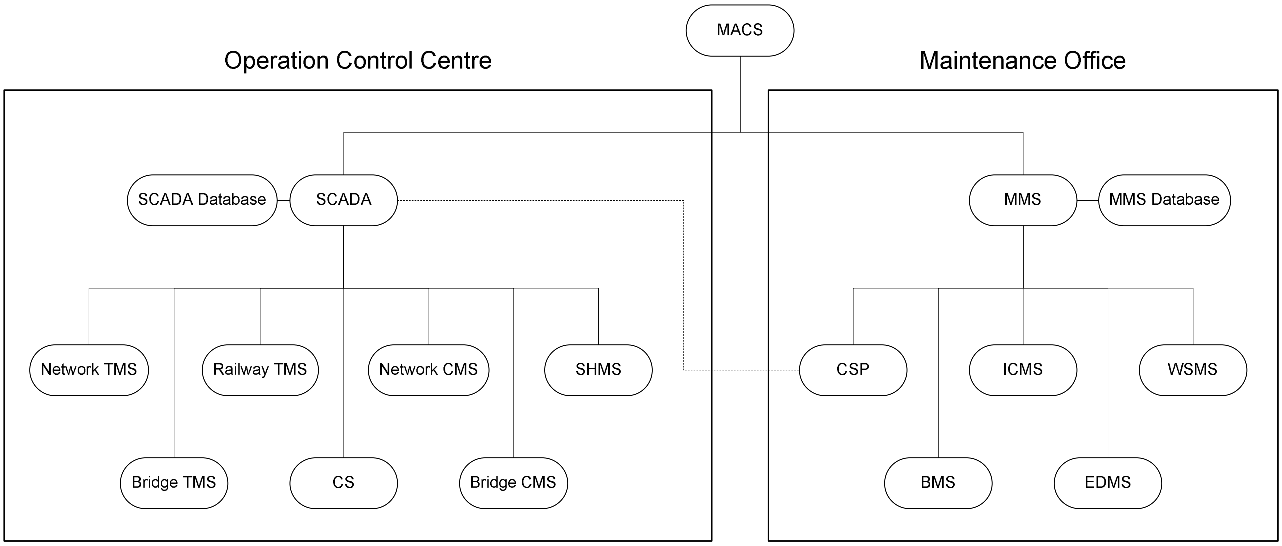


Figure 2.1 Arrangement of the Management and Control Systems (MACS)

This document is a monitoring plan for the Structural Health Monitoring System (SHMS). It presents the basic system philosophy and architecture as well as minimum requirements for the system, system hardware, system software, sensor and cabling hardware, and installation.

This document does not address temporary sensors for construction monitoring that will not be used after construction. These sensors will be grouped under the term Temporary Construction Monitoring Sensors (TCMS). The TCMS will be detailed during Progetto Esecutivo following construction sequence planning.

This document presents a list of detailing tasks to be undertaken during Progetto Esecutivo in order to finalise the detailing of the SHMS.

The successful overall implementation of the SHMS is dependent on cooperation, contributions and commitments from other project participants during the detailing of the design and construction of the bridge and its supportive systems. Roles and responsibilities of other project participants have been discussed in this document.

This document cannot be used as a tender document. It is expected that during Progetto Esecutivo this document will be further developed into a Specification.

This document has been created on the basis of the following documents:

- GCG F.05.03 rev 1; 22 Oct 2004; Design development requirements and guidelines; Technical specifications for the definitive planning and execution of the works; Stretto di Messina
- GCG F.06.01 rev 0; 12 Oct 2004; Management and control system; Technical specifications for maintenance and control management systems engineering; Stretto di Messina
- PG_2D_BO-106_5_N01 to N06; Tender drawings; 20 Apr 2005; ATI Impregilo
- Technical Design Change No. 11-02; Mar 2005; Technical Design Change Report; Messina Strait Bridge Tender Design; ATI Impregilo
- Technical Design Change No. 11-03; Mar 2005; Technical Design Change Report; Messina Strait Bridge Tender Design; ATI Impregilo

3 Bridge Monitoring Aims

3.1 Leading Principles

The SHMS has been developed in accordance with the following principles:

- Sufficient flexibility and robustness to allow integration into the SCADA system
- Sufficient flexibility and robustness to allow future extension and integration of new functions
- Sufficient flexibility and robustness to allow modification during development to allow incorporation of suitable advances in technology
- Sufficient robustness and redundancy to allow uninterrupted operation of the bridge management and control systems

3.2 System Functionality

The SHMS will provide the following system functions:

- Monitoring of the physical environment and its actions
- Monitoring of the bridge during construction
- Monitoring of the bridge during operation
- Monitoring of total traffic load on the bridge
- Monitoring of load events
- Monitoring of structural response events
- Providing data for risk analysis of bridge safety
- Information on the current state of the bridge

The SHMS will provide data that will assist with the following SCADA system functions:

- Management of road and railway traffic
- Management of event scenarios

- Management of emergencies scenarios
- Management for safety of the infrastructure
- Management for safety of users
- Information on the expected state of the bridge
- Review of components of the bridge that are not directly monitored

3.3 System Aims and Objectives

The following SHMS plan has been designed around the following system aims:

- to monitor the bridge during the construction phase
- to monitor the bridge during the operational phase
- to monitor the bridge structure (including stress-state and geometry), physical environment, weather, traffic, and any other event that might influence the operation, safety and durability of the bridge
- to monitor the development of the permanent load condition
- to provide real-time data to the operator
- to provide direct access to all data recorded with an easy to use and understand display system
- to provide a historical record of data with resolution appropriate to long term data storage
- to monitor for events that influence the operation, safety and durability of the bridge and to bring this to the attention of the bridge operator
- to provide a record of data due to load events and structural events, including data leading up to the event, with a resolution appropriate to review of the event
- to provide direct access to data concerning load events and structural events with an easy to use and understand display system
- to produce initial assessments of the implications of load events and structural events

- to provide summary system reports that identify load events and structural events
- to provide data that will allow both the present-day and expected level of service to be determined
- to provide data that will allow the traffic conditions, structural performance and physical environment to be determined in the short term, medium term and long term
- to provide a store of data that will form a historical database of the bridge
- to ensure continual operation (in function and communication) during loading events including weather events, seismological events, and traffic-loading events

The following SHMS plan has been designed around the following system objectives:

- to provide data for design, construction and performance verification
- to provide data for review of design loading and development of assessment loading
- to provide current information on load conditions for effective bridge operation
- to provide current information on the condition of structural components
- to provide data for maintenance planning
- to provide data for trouble-shooting unforeseen structural problems

3.4 Priorities of the System

The following SHMS Plan is designed to cater for a range of monitoring issues, but is aimed at the following as a priority:

- Monitoring of wind conditions during construction to confirm safe operational environment
- Monitoring during construction to confirm assumptions for construction stages and structural behaviour in temporary erection conditions
- Monitoring the development of the dead load ‘stress-state’ to accurately record the dead load conditions and accurately set the SHMS initial parameters
- Monitoring following construction to confirm final geometry and design assumptions

- Monitoring of wind conditions and road conditions to confirm a safe environment exists for traffic using the structure
- Monitoring of loads to confirm safety for traffic use of the structure
- Monitoring to confirm bridge geometry and performance during regular loading events and extreme loading events
- Monitoring position of tower foundations, anchor blocks and tie-down pier foundations to verify foundation movement and stability
- Monitoring to provide data for future statistical analysis and review of design loading
- Study of response of the bridge structure to wind, to confirm agreement with predictions during design and wind tunnel testing
- Study of response of the bridge structure to rail and vehicle traffic, to confirm agreement with predictions during design
- Study of response of the hangers to wind, to confirm agreement with predictions during design and wind tunnel testing and to verify needs for additional damping to prevent the development of excessive aerodynamic effects
- Study of response of the hangers to rail and vehicle traffic, to confirm acceptable vibration levels
- Monitoring of structural response during seismic event
- Rapid reporting of the bridge condition following seismic event or wind storm loading
- Monitoring of main-cable stress at lateral extremities of each main-cable cable to monitor for the development of bending stresses due to lateral displacement of the main-cables, and developing due to the rigid clamping of cable pairs
- Monitoring of hanger-cable stress at mid-span to monitor the effectiveness of hanger-cable spherical bearings by monitoring bending stress development due to longitudinal and lateral differential displacement of the deck to main-cables
- Monitoring of hanger-cable stress variations for up-to-date fatigue life evaluation

- Monitoring of orthotropic deck stress variations for up-to-date fatigue life evaluation
- Condition monitoring to assist effective maintenance programming, including expansion joint performance, buffer performance, and tower Tuned Mass Damper performance
- Monitoring of internal environmental conditions to assist with effective control of the dehumidification system and to monitor for the development of abnormal conditions

3.5 Principles of Operation

The SHMS will be a sophisticated redundant set-up that will provide the owner and operator with important information concerning structural behaviour and safety as well as information that will assist with operation and maintenance planning. The SHMS will also provide a valuable tool for investigating and trouble-shooting unforeseen problematic behaviour such as wind induced vibrations. The SHMS will be in place prior to construction and will be progressively brought online as the bridge is built, which will provide the constructor with important information during the erection stage concerning structural behaviour and safety.

The SHMS will be a stand-alone system that, in function, operates independently of other operation systems of the SCADA system. The SHMS will display live data and triggered event data (including seismic triggered event data) to assist with bridge operation and maintenance. A log will be provided with the event interface for event categorisation. The SHMS will provide data in a database which can be accessed by other operation systems of the SCADA system and the MMS system. Data will be received from on-site sensors as part of the SHMS network as well as from other components of the SCADA system.

For the purposes of installation and system operation, the SHMS component of the SCADA system will include the measuring of all physical parameters that are identified for measurement as part of the project, except for measurement of rail and vehicle load. The measurement of rail and vehicle load using Weigh-in-Motion systems installed next to the terminal structures will be included as part of the Network TMS component of the SCADA system, described further under Component No. 45. Traffic (vehicle) flow will also be recorded at various positions across the network and bridge by the Network TMS and Bridge TMS components of the SCADA system. Data will be delivered to the SHMS for processing.

The SHMS will facilitate data from nearly 3000 sensors located strategically around the structure. Data quantity is vast, and as such effective data management processes have been planned so that data are presented in an effective manner for effective bridge operation and maintenance. Data management routines will be developed to implement the data management processes. The basic operation of the system will be as far as practicable automatic, requiring minimal input. The system will:

- Display live data
- Process data
- Maintain a temporary rolling data-buffer of live data for access by other components of the SCADA system
- Create history records that consist of low definition point value data and basic statistical data
- Detect (using data-triggers) and report events
- Create event records that consist of high definition point value data
- Create an automatic initial assessment of the cause and relevance of events
- Detect and report sensor malfunction
- Deactivate data-channels associated to malfunctioning sensors
- Create automatic reports on the system and structure performance

Day-to-day operation of the system will be kept as simple as possible. The mainframe control for the SHMS will be located in the SCADA operation room. A dedicated interface display will continuously present data in simple format. A facility will exist for displaying interface displays onto the main wall-screen provided as part of the SCADA system.

3.6 Monitoring Requirements

The SHMS will provide the bridge operator with live feedback of loading, environmental conditions and structural response. The SHMS will also be progressively brought on-line during the construction of the bridge. The SHMS will provide the constructor with live information to manage the construction process and ensure the safety of the structure and workforce, as well as to verify construction of the structure within the construction tolerances.

3.6.1 Bridge Geometry - during Construction and Operation

The design process is inherently based on assumptions of bridge final geometry. Construction actions, such as temporary erection load cases or welding effects, inevitably impact on the geometry; the construction team will be applying techniques to compensate for the effects of residual construction actions on geometry. Construction tolerances are established to enable the bridge to be constructed to an acceptable geometry that is consistent with the design assumptions. Long term monitoring of position not only provides structural response characteristics to loading but also provides an early warning to the development of unexpected bridge movement that may be related to collapse mechanisms.

MONITORING DEFLECTION

Nodes:

On structures of the scale of this bridge, node positions are most effectively monitored with GPS receivers. GPS receivers provide plan as well as vertical coordinates for each monitored node. *Bridge Geometry* will be monitored during construction and in the long term with a network of GPS receivers installed at important structural-nodes:

- Anchorages
- Pier bases
- Tower bases
- Intermediate level of the towers
- Tower tops
- Intermediate positions along each side of the deck
- Intermediate positions along each pair of main cables

A static ground reference is also required to improve the accuracy of the GPS data. This will be located on top of the SCADA building. The SCADA building will need to be detailed by the SCADA building structural designers against settlement to maintain reference at an accurate level for increased accuracy of vertical measurements from the GPS network. The position of the GPS reference station will need to be surveyed at regular intervals as well as following significant events.

Accuracy may be reduced for up to 24hours, in the event of signal loss from a GPS receiver.

3.6.2 Bridge Quasi-Static Response

Structures respond to load by transfer of force and by deflection. The design process involves the development of load path models that are used to develop strength requirements, and the development of deflection predictions to verify that these are not excessive. Monitoring of *Bridge Quasi-Static Response* allows the design assumptions to be verified. It also allows the deflection to be monitored against the operation limits e.g. to ensure that the bridge remains clear of the navigation channel or to ensure that acceptable slope for railway operation is maintained. To monitor bridge static response, both deflections and applied loads need to be monitored. Stresses in the hangers, main cable, deck and towers can also be monitored to verify load path assumptions. Superimposed quasi-static load cases that are relevant to superstructure design are wind, traffic (vehicle), traffic (rail), temperature (effective), temperature (differential), and differential settlement of the foundations.

MONITORING DEFLECTION

Nodes:

The GPS network established for monitoring of *Bridge Geometry* will provide deflection response to loading e.g. vertical deflection of the deck due to applied traffic load or lateral deflection of the deck due to applied wind load.

Expansion joints:

Additional data that is useful to the monitoring of *Bridge Quasi-Static Response* is deflection data at the expansion joints. The expansion joints will deflect as a result of general applied loading conditions. These data will be collected by sensors established for monitoring of *Expansion Joint Behaviour*.

MONITORING APPLIED LOAD

Wind:

Wind load cannot be measured directly. Wind speed and direction will be recorded by a network of anemometers installed in the following locations:

- Intermediate positions along the deck
- Intermediate positions up the towers

Anemometers will be installed on stiff booms to either side of the towers, and on the top of the wind-shield on either side of the deck. Anemometers will be positioned in the free-flow field, remote from flow affected by the structure. Wind load will be represented by wind pressure, which will be calculated from wind speed. Most of the anemometers will be ultrasonic anemometers. However, ultrasonic anemometers can develop errors during wet conditions, thus, in order to maintain reliable wind data during all conditions, the anemometers at the third points shall be mechanical anemometers and an additional mechanical anemometer shall be added to each tower top.

Traffic (Vehicle):

Traffic (vehicle) load can be measured directly for each passing vehicle. However presenting accurate load distribution across the structure on the SHMS is complex and of limited value. Traffic distribution can be established, if required, from traffic camera records. Traffic (vehicle) load will be measured by high-speed Weigh-in-Motion (WiM) systems installed to each lane, at each end of the bridge. WiM will be provided as part of the Network TMS component of the SCADA system. Traffic (vehicle) flow will also be measured at various positions across the network and bridge by the Network TMS and Bridge TMS components of the SCADA system. The data shall be available to SHMS for calculation of total (vehicle and rail) traffic load on bridge data.

Traffic (Rail):

Traffic (rail) load can be measured directly for each passing train axle. However presenting accurate load distribution across the structure on the SHMS is complex and of limited value. Traffic distribution can be established, if required, from traffic camera records. Traffic (rail) load will be measured by high-speed Rail Weigh-in-Motion (RWiM) systems on the track for trains approaching the bridge, at each end of the bridge. Train detection facilities will be provided on the track for trains leaving the bridge, at each end of the bridge. RWiM and train detection facilities will be provided as part of the Network TMS component of the SCADA system. The data shall be available to SHMS for calculation of total (vehicle and rail) traffic load on bridge data.

Temperature (Effective and Differential):

Historically, temperature characteristics of steel structures have not been monitored in detail. The consequences of temperature effects are relatively well understood. Structures heat up partly from air temperature but more significantly from solar radiation. The black top surfacing applied to bridge boxes also serves to intensify the heat input due to solar radiation. Since solar radiation is only applied from one direction heat develops and migrates through the structure. Consequently structures experience a temperature variation across their section.

The temperature profile can be considered as an effective uniform temperature superimposed by a differential temperature distribution. The effective uniform temperature generates a change in length of the structure. Temperature change thus generates deck joint movement. The longer the continuous structure, the greater the change in length associated with a particular change in temperature. Thus with a span of 3300m the joint movements will be significant. The differential temperature distribution serves to bend the structure. Suspension bridges have low levels of intermediate restraint to the deck and towers, and therefore differential temperature is not expected to be a critical load case.

The main cable is a dense steel object with minimal surface area to steel volume. The main-cable is therefore slow to heat and slow to cool. The effective temperature of the main-cable tends to lag behind the effective temperature of the deck. The difference in effective temperature that can develop between the main-cable and the deck can be of significance for structures that have longitudinal restraint between the deck and main-cable. However, the design for the bridge does not have this form of restraint, therefore the difference in temperature is not expected to present a significant load case.

The temperature distribution through the steel box structures of the deck and tower can be monitored with contact temperature sensors distributed around the section. This long and tall structure may experience temperature conditions that differ between different positions on the structure. Temperature profiles will therefore be monitored at a number of sections along the deck and up to tower. One temperature sensor will be installed to each quadrant of the road and rail deck girders, deck cross-beams, tower cross-beams, and to each face of the multi-facetted tower legs. Additional temperature sensors will be installed at one position in each tower leg and at two positions along each deck girder to monitor temperature profile with increased definition. The temperature of the railway tracks will also be monitored at 4 locations along the bridge.

The temperature distribution through the main-cable can also be monitored with temperature sensors distributed through the section. Instrumentation installation within the main-cables is inherently challenging and, once installed, access for maintenance is effectively nil. The life of such instrumentation is short in comparison to the life of the bridge. Thus a strategy for increased redundancy of internal sensors as well as surface mounted accessible sensors has been adopted. As the main-cables are compacted the steel wires will slide over each other forming a dense matrix. Soft data-cables that pass across the path of the parallel wires can be damaged by the compacting process. Experience with installation of local nodes of internal temperature sensors, with data-cables fed out through the splay of strands at saddles, has demonstrated that a proportion of sensors can be damaged. A number of installation techniques will be adopted to reduce the risk of losing all internal measurements.

The main sensor array will be formed from fibre-optic cables running parallel to the main-cable wires, thus reducing the risk of the cable being cut during compaction. The fibre-optic cables will be provided with a durable coating, and will be formed to have the same diameter as the standard main-cable wires. They will be placed into, and become part of, the appropriate main-cable strand during strand fabrication. They will be placed in the external lay of the strand on the side that will be on the top of the strand as it passes over the saddles, which will reduce the radial stresses to which they will be subjected. They will emerge from the main-cable at the splay of the strands as they enter the anchorage saddles. The installation of fibre-optic cables within the main-cable represents an advancement in current technology. The fibre-optic cable will need to developed for durability and will need to be proof-tested against the cable compaction process. The temperature at a particular radius in the main-cable will not vary significantly over several metres of length, therefore measurements will be taken using distributed techniques. Main-cable temperature variation shall be monitored using slow sampling rates. Data will be recorded for the whole length of the main-cables, and primarily for the nominated sections for monitoring. Only data translated for a selection of the nominated sections will be added the SHMS database. The remaining data will be retained in the data-store. Once installed, the fibre-optic cables will not be accessible for maintenance. The development of a break in the fibre-optic cable may end the function of the entire length of fibre-optic cable.

Due to the severe conditions expected to be experienced during installation and service, and due to the lack of access for maintenance, additional discrete sensors will be installed in the main-span main-cables adjacent to the Sicily tower. As the main-cable strands are erected, the sensors will be laid into the main-cable, beyond the first clamp. Durable data-cables will be fed out of the main-cable at the splay of the strands at the tower saddles. A number of surface-mounted, fully accessible, sensors will also be installed at the Sicily towers as well as at mid-span. At the tower tops, as well as at mid-span, access ports through the main-cable wrapping wire will be detailed by the bridge structural designers. The adoption of the above techniques, both innovative and tested, will reduce the risk of losing all of the main-cable temperature data-stream during the life of the structure.

Differential Settlement (Foundation Movement):

The GPS network established for monitoring of *Bridge Geometry* will provide data for monitoring of differential settlement. In particular GPS receivers installed on the anchor blocks will indicate longitudinal and vertical movements of the anchor blocks, and GPS receivers installed on the towers will indicate vertical movements as well as global rotational movement about the tower base.

GPS receivers will be installed at the tower base, as well as at the base of the tie-down piers. Due to the towers and the piers, satellite signal reception may be poor.

A GPS receiver will be installed to each side of each anchor block, tower base and tie-down pier, which will provide information on differential settlement of one side of the foundation relative to the other. This is of particular importance for the tower base tie, which is significantly influenced by this effect.

MONITORING FORCE/STRESS

Bridge deck:

Stress can be measured at discrete points with temperature-compensated strain sensors. The bridge deck girders and cross-beams are steel box sections with diaphragms installed regularly. The combined deck girder system is supported by a flexible cable suspension system. The box sections are not expected to experience significant shear lag effects. Stress distribution is expected to be well correlated between the applied forces and moments and the effective cross sectional properties. Temperature-compensated strain sensors will be positioned on the longitudinal stiffened plates close to the axes of the neutral axes of each box section that is monitored so that the stress variation from the different load effects (vertical and transverse) can be separated through post processing analysis. Locally, the temperature-compensated strain sensors will be placed on the neutral axis of the calculated effective stiffened section to minimise secondary effects from local out of plane bending. Stress will be monitored at a number of locations, including the rail girder that extends beyond the expansion joints of the roadway girder at the towers and terminal structures.

Towers:

Stress can be measured at discrete points with temperature-compensated strain sensors. The tower legs and cross-beams are steel box sections with diaphragms installed regularly to maintain the shape of the box. The sections are not expected to experience significant shear lag effects. Stress distribution is expected to be well correlated between the applied forces and moments and the effective cross sectional properties. Temperature-compensated strain sensors will be positioned on the longitudinal stiffened plates close to the axes of the neutral axes of each box section that is monitored so that the stress variation from the different load effects (axial, longitudinal and transverse) can be separated through post processing analysis. Locally, the temperature-compensated strain sensors will be placed on the neutral axis of the calculated effective stiffened section to minimise secondary effects from local out of plane bending. Stress will be monitored in the towers legs above and below each portal, at deck level and at the tower base. Stress will also be monitored at the ends of the portals.

A selection of tower base anchor bars will also be monitored. Monitoring of the anchor bars is particularly important during the erection phases when applied tension conditions are expected from temporary tower pull-back required to facilitate main-cable erection.

Main-cables:

The main-cables are formed from parallel wires, compacted and clamped into a tight bundle. In general, main-cable force can be measured from temperature-compensated wire-strain. However, on this bridge the main-cables will be formed from two cables linked intermittently by rigid clamps, forming a ladder arrangement. Lateral displacement of the main-cable is expected to induce additional lateral bending stresses due to the ladder-arrangement. These bending stresses, as well as the general axial stress state associated with the main-cable force, will be monitored. Historically, where Structural Health Monitoring has been designed following construction, main-cable strain has not been monitored in detail due to difficulties with access for installation.

Temperature-compensated strain will be measured at a number of positions within the main-cable as well as on the surface of the main-cable. Temperature-compensated strain will also be measured on the cable-clamps adjacent to the towers.

Instrumentation installation within the main-cables is inherently challenging and, once installed, access for maintenance is effectively nil. The life of instrumentation is short in comparison to the life of the bridge. Thus a strategy for increased redundancy of internal sensors as well as surface mounted accessible sensors has been adopted. As the main-cables are compacted the steel wires will slide over each other forming a dense matrix. Soft data-cables that pass across the path of the parallel wires can be damaged by the compacting process. Experience with installation of local nodes of internal temperature sensors, with data-cables fed out through the splay of strands at saddles, has demonstrated that a proportion of sensors can be damaged. A number of installation techniques will be adopted to reduce the risk of losing all internal measurements.

The installation of internal fibre-optic cables running parallel to the main-cable wires over the full main-cable length, which will strain with the main-cable wires, will not be adopted in the monitoring plan. The strain that will be experienced by the 'bonded' fibre-optic cable is expected to create significant problems with obtaining reliable data. Based on current experience and technology, the development costs and residual uncertainties rule out the benefit of pursuing this method of monitoring. At the beginning of Progetto Esecutivo, the feasibility of this method could be reconsidered taking into account improvements in technology at the time.

Temperature-compensated strain sensors will be installed to the side-span and main-span main-cables at each tower, where the force in the main-cables is maximised, and to the main-cables at each anchor-block. The sensors will be installed to the middle of each quadrant of the section in order to pick-up bending stress variations. As the main-cable strands are erected, the sensors will be laid into and physically attached to the main-cable, beyond the first clamp from the nearby saddle. Durable data-cables will be fed out of the main-cable at the splay of the strands at the tower saddles. The installation of fibre-optic cables within the main-cable represents an advancement in current technology. The fibre-optic cable will need to developed for durability and will need to be proof-tested against the cable compaction process. Once installed, the fibre-optic cables will not be accessible for maintenance. The development of a break in the fibre-optic cable will end the function of the sensor. Due to the severe conditions expected to be experienced during installation and service, and due to the lack of access for maintenance, a number of surface-mounted, fully accessible, sensors will be installed for system redundancy. They shall be positioned to each side of the main-cable walkway defined by the hand-strands, as well as to the underside of the main-cable. This distribution will allow bending stress variations to be picked-up. Access ports through the main-cable wrapping wire will be developed by the bridge structural designers. The monitoring of main-cable stress is discussed in greater detail in Appendix 2.

Main-cable stress at the tie-down hangers will also be monitored with surface-mounted sensors, for which access ports will be required. The main interest at this location is the vertical bending of the main-cable induced by the restraint of the tie-down hangers. The axial force of the main-cable is not maximised at this location. Surface-mounted sensors will provide an efficient monitoring strategy. Internal sensors would require long lengths of cable to be installed during strand erection. Without very careful installation of the sensors, cables and subsequent strands, the sensors are not expected to survive the strand erection process. Therefore, in view of limited benefits derived from measuring stress internally at the tie-down hangers and in view of the disruptive impact on the construction process in conjunction with the risk of sensor loss from damage, internal sensors will not be installed at the position of tie-down hangers.

Main-cable stress measurements shall be complemented by monitoring of a selection of main-cable strand anchor bars with temperature-compensated strain sensors.

Stresses within the main-cable clamps adjacent to the towers, associated with the lateral sway of the main-cable, will be monitored with temperature-compensated strain sensors. The precise locations of monitoring is to be identified by the bridge structural designers at Progetto Esecutivo.

Hangers:

The hanger-cables are formed from parallel wires. In general, hanger-cable force can be measured from temperature-compensated wire-strain. However, hanger-cables experience additional bending stresses due to the hanger vibration (for long hangers) and due to main-cable to deck differential displacement (for short mid-span hangers). These bending stresses, as well as the general axial stress state associated with the hanger-cable force, will be monitored. Temperature-compensated strain sensors will be installed onto wires in the outer-lay, just above the deck level socket, and will be accessible for maintenance. Temperature-compensated strain sensors will be installed in pairs, on diametrically opposite sides of the cable. The long hanger-cables adjacent to the towers, and the mid-span hanger-cables, will be provided with two pairs of strain-sensors to monitor stresses in each quadrant. Other hanger-cables will only be provided with one pair of strain-sensors. Hanger-cable force will be derived from the average of the strain sensors readings to eliminate fluctuations in measurements associated with hanger-cable vibration and local bending. Hanger-cable forces calculated during the design demonstrate an even distribution of maximum values over the main span, with increased values immediately adjacent to the towers (hangers 5, 6, 114 and 115) and connected to the tie-down pier (hangers 1 and 119). The design caters for these increased values, as well as additional stiffness requirements, by increasing the size of the hanger-cables, for hangers 1 to 8 and 112 to 119. The force in cables forming hangers 1, 5, 6, 114, 115 and 119 will be monitored as well as a selection of groups of hangers elsewhere, including at mid-span. Each group of monitored hangers will consist of 2 or 3 adjacent hangers, to verify load distribution between adjacent hangers. The hangers are formed from a pair of longitudinally separated cables, rather than a single cable, which therefore induces a degree of local moment restraint. These pairs of cables will therefore experience local variations in axial force associated with the passage of individual vehicles or trains. The forces in paired cables may also be affected by tolerances in hanger length, particularly at mid-span. All cables forming a monitored hanger will therefore be instrumented.

Portable accelerometers and video displacement sensors provided for monitoring of *Hanger-cable Dynamic Response* can be used to assess hanger-cable force for all of the hangers.

3.6.3 Deck Dynamic Response

Long span bridges are light flexible structures that are inherently sensitive to fluctuating load, and exhibit noticeable dynamic response. Dynamic response can develop from wind and traffic, as well as seismic action, which is discussed separately. Dynamic response is considered in the design process. In particular, wind induced aerodynamic response is considered in detail with support from wind-tunnel testing, since a number of aerodynamic mechanisms can result in catastrophic collapse. The innovative triple-box design of the bridge is more stable than conventional single box-girder arrangements and has been demonstrated by wind-tunnel testing to be stable for the critical wind speed on site. However, wind-tunnel tests are based on scaled modelling, which has known limitations and accuracy. The bridge dynamic response, and in particular aerodynamic response, will therefore be monitored. In order to understand the cause and development of bridge dynamic response, the local wind structure will be monitored.

MONITORING DYNAMIC RESPONSE

Bridge dynamic response will be monitored with accelerometers positioned strategically along the deck to register all important modal characteristics. At each monitoring location two 3-directional accelerometers will be installed. The accelerometers will be placed at each end of the stiff deck cross-beams so that only global response is recorded and so that the components of response are registered directly without the need for excessive data manipulation e.g.

- Vertical response is recorded by the vertical axis of the accelerometers
- Lateral response is recorded by the transverse axis of the accelerometers
- Longitudinal response is recorded by the longitudinal axis of the accelerometers
- Torsion response is recorded by the difference of accelerations from the vertical axis of the accelerometers

Local dynamic response of the deck girder 30m local spans between cross-beams will not be monitored. Local dynamic response of these 30m local spans is not a concern.

MONITORING WIND STRUCTURE

General wind characteristics will be monitored by the array of anemometers set-up for monitoring of *Bridge Quasi-Static Response*. An additional array of anemometers installed at mid-span will provide measurements of wind cross-correlation.

3.6.4 Tower Dynamic Response and Tuned-Mass-Damper Response

The towers of the bridge are tall structures. An investigation is in progress into requirements for adding Tuned-Mass-Dampers to each tower leg at the middle portal level to control wind-induced vibrations. If added, the Tuned-Mass-Dampers are likely to be pendulum-form. Tuned-Mass-Dampers are effective at controlling structural vibrations at the natural frequency of the damper unit. The performance of Tuned-Mass-Dampers is dependent on the movement of the mass relative to the structure that is being damped. Bumpers will be installed to limit the movements of the mass and prevent damage to the structure. However impact of the mass with the bumpers may induce local vibrations which may damage the unit. As the Tuned-Mass-Dampers are important components for the control of tower vibrations, their continued function will be monitored. Tower vibrations will also be monitored. Both response measurements and wind structure measurements are required if further investigation into the development of tower dynamic response is necessary.

MONITORING DYNAMIC RESPONSE

Tower dynamic response will be monitored with accelerometers positioned strategically up the towers to register all important modal characteristics. At each monitoring location two 3-directional accelerometers will be installed. The accelerometers will be placed in each tower leg adjacent to the stiff tower cross-beams so that only global tower response is recorded and so that the components of response are registered directly without the need for excessive data manipulation e.g.

- Vertical response is recorded by the vertical axis of the accelerometers
- Horizontal response transverse to the bridge alignment is recorded by the axis of the accelerometers aligned transverse to the bridge alignment
- Horizontal response longitudinal to the bridge alignment is recorded by the axis of the accelerometers aligned longitudinal to the bridge alignment
- Torsion response is recorded by the difference of accelerations from the axis of the accelerometers aligned longitudinal to the bridge alignment

MONITORING TUNED-MASS-DAMPER RESPONSE

The response of each of the Tuned-Mass-Dampers will be monitored. The response will be monitored by measuring the relative displacement of the Tuned-Mass-Damper mass to the structure using linear displacement gauges.

MONITORING WIND STRUCTURE

General wind characteristics will be monitored by the array of anemometers set-up for monitoring of *Bridge Quasi-Static Response*. An additional array of anemometers installed at mid-span will provide measurements of wind cross-correlation

3.6.5 Main-cable Dynamic Response

The main cables of long-span suspension bridges are long flexible structures that can experience significant dynamic response, either independently of, or in conjunction with, bridge modal response. Furthermore, since the main-cables are formed from intermittently clamped pairs of cables, with restraint provided to the deck via centrally located hangers, the main-cables may be susceptible to torsion response. Main-cable response could develop either directly from wind effects or from vibrations associated with the bridge deck. *Main-cable Dynamic Response* will therefore be monitored.

MONITORING DYNAMIC RESPONSE

Main-cable dynamic response will be monitored with accelerometers positioned strategically to register all important modal characteristics. At each monitoring location two 3-directional accelerometers will be installed. The accelerometers will be placed on stiff cable clamps, adjacent to each cable, so that only global main-cable response is recorded and so that the components of response are registered directly without the need for excessive data manipulation e.g.

- Out-of-plane vertical response is recorded by the vertical axis of the accelerometers
- Out-of-plane response transverse to the bridge alignment is recorded by the axis of the accelerometers that is aligned transverse to the bridge alignment
- Along-cable response is recorded by the axis of the accelerometers that is aligned with the main-cable longitudinal axis
- Torsion response is recorded by the difference of accelerations from the vertical axis of the accelerometers

MONITORING WIND STRUCTURE

Information on wind structure will be provided by the array of anemometers set-up to monitor *Bridge Quasi-Static Response* and *Deck Dynamic Response*.

3.6.6 Hanger-cable Dynamic Response

Hangers tend to respond to background vibration applied to the bridge as well as to wind-energy input. Aerodynamic response can be significant with the development of vibrations at large amplitudes. Often hanger aerodynamic response is aggravated adjacent to the towers where significant flow variation is induced by flow around the tower legs. Aerodynamic response is not uncommon for long hangers, and is accounted for in the design by the provision of additional damping. As hanger-cables become shorter in length they become stiffer, their natural frequencies increase, and they tend to respond less to aerodynamic effects. Thus it is common for damping design to extend over a limited range of hangers rather than over all of the hangers. It is therefore possible to identify hangers that are at greatest risk of developing significant aerodynamic response: these are the longest hangers with the nominated level of damping.

The hangers attached to the tie-down piers (hangers 1 and 119) serve to stiffen the bridge structure system around the towers by restraining vertical movement of the main-cables. These hangers are also the first hangers, adjacent to the long free length of side span main-cable. The hanger-cables may therefore respond to parasitic effects from the main-cables as well as remain aerodynamically sensitive due to their length.

Both response measurements and wind structure measurements are required to understand the cause and significance of the dynamic mechanisms that are recorded.

Monitoring Dynamic Response

Hanger-cable dynamic response is monitored most effectively with 2-directional accelerometers that record transversal accelerations. Accelerometers need to be installed at sufficient distance from the hanger-cable sockets in order to register dynamic response effectively. Accelerometers will be positioned as far up the hanger-cables as possible (but within the lower third of the hanger length) whilst remaining within reach of common cherry-pickers, to allow access for future maintenance.

The response of the longest hanger-cables that are adjacent to the towers (hangers 5, 6, 114 and 115) as well as those forming the tie-down hangers (hangers 1 and 119) will be monitored. The longest hanger-cables which have no additional damping will also be monitored.

Portable accelerometers and video displacement sensors, supported by portable monitoring computers and portable monitoring servers, will also be provided. Mounting brackets with unique identification tags will be installed to all of the hanger-cables. This equipment will allow all hanger-cables to be monitored, as required, if significant dynamic response is observed.

MONITORING WIND STRUCTURE

Information on wind structure will be provided by the array of anemometers set-up to monitor *Bridge Quasi-Static Response* and *Bridge Dynamic Response*.

The local wind flow around the longest main-span hanger-cables, that are adjacent to the towers, will be monitored with anemometers positioned between the hanger-cables, installed on bespoke frame structures.

3.6.7 Fatigue of the Hanger-cables

The hanger-cables are formed from parallel wires, terminated at each end in rigid sockets that are pinned to stool- and clamp- starter plates. It is common for the pinned sockets to act as semi-rigid or rigid end-connections, particularly for rotation perpendicular to the axis of the pin. The hanger-cable tends to bend locally about the end of the socket from which it emerges, presenting a fatigue sensitive location. Hanger-cables that experience long duration vibration, for example due to aerodynamic response, are thus susceptible to hanger fatigue from local bending stresses. It is not uncommon for hanger-cables to require replacement within the design life of the hanger-cables.

Short hanger-cables are most susceptible to the development of local bending stresses in the cable adjacent to the socket. The short hangers are less susceptible than the long hangers to long duration aerodynamic response, however the short hangers are susceptible to longitudinal and transverse differential movements between the main-cables and the deck structure. The mid-span hanger-cables (hangers 41 to 79) will be provided with spherical bearings which are expected to significantly improve the performance of the cable/socket interface. Hanger-cables 21 to 40 and 80 to 99 will be provided with bend limiters.

Axial stress fluctuations will develop from traffic loading, and in particular local vehicle passage. The longitudinal separation of hanger-cables forming the hanger will induce a local moment restraint that may induce amplified local axial stress fluctuation with local passage of vehicles. This represents an additional contribution to fatigue loading.

Monitoring hanger-cable stresses from wires on the surface of the hanger-cable will provide a good indication of maintenance requirements.

MONITORING STRESS

Temperature-compensated strain fluctuations, and hence stress fluctuations, will be measured with temperature-compensated strain sensors installed for *Bridge Quasi-Static Response*. Typically 2 temperature-compensated strain sensors will be installed on each monitored hanger-cable. 4 temperature-compensated strain sensors will be installed to those monitored hangers that are most susceptible to significant aerodynamic response (hangers 1, 5, 6, 114, 115, and 119) to monitor bending stresses from in-plane and out-of-plane vibrations. 4 temperature-compensated strain sensors will be installed to those monitored hangers that are most susceptible to longitudinal and transverse differential movements between the main-cables and the deck structure (hangers 59 to 61) to monitor bending stresses. Stress fluctuations will be processed with rain-flow count and miners summation routines to facilitate an automatic fatigue review.

3.6.8 Fatigue of the Deck Girders

Steel structures are sensitive to fatigue. Historically, orthotropic decks have been particularly sensitive to fatigue since they see significant local stress fluctuations from each wheel passage. Details that have historically seen the development of fatigue cracking are:

- trough to plate longitudinal weld
- trough to trough weld at splice
- trough to diaphragm weld
- diaphragm cope-hole

The rail-beams are expected to be sensitive to fatigue as a result of the direct connection of the rails to the deck, the heavy nature of train axles, the significant number of train axles, and the defined alignment of the axles as a result of the rail tracks.

Local deck plate fatigue will be monitored at two locations along the bridge:

- Remote location which is representative of the general fatigue performance of the bridge. A regular crossing point for trains travelling on each track would represent the best location to monitor fatigue. However, currently no defined train schedule is established and therefore no defined crossing point is currently known. A sensible remote location for monitoring has been identified, however the final position of monitoring may be changed in the final stages of SHMS design

- Adjacent to the bridge joint which will see increased dynamic vehicle loading due to the bridge joint and which in general is the most susceptible location to fatigue cracking

Trough longitudinal stresses and transverse stresses will be monitored under each wheel track of each lane. Rail-beam longitudinal stresses and transverse stresses will be monitored under each rail of each rail track. Stresses at the edge of cope holes in diaphragms associated with monitored troughs and rail-beams will also be monitored.

Orthotropic decks derive benefit from the additional stiffness provided by the road surfacing which reduces the applied stresses and thus improves the fatigue characteristics. The stiffness of the road surfacing is temperature dependent, with an increase in temperature influencing a reduction in stiffness. The temperature of the road surfacing at the steel interface will be monitored to provide supplementary data to assist with interpretation of the fatigue histories.

The long flexible deck structure will also experience global stress variation due to variation in applied loading (wind and traffic) as well as possibly due to bridge dynamic response. General longitudinal stresses in the girders and cross-beams will be monitored at a number of locations, including the rail girder that extends beyond the expansion joints of the roadway girder at the towers and terminal structures. An option shall be available to monitor stress fluctuations for fatigue analysis if this is required.

A number of local details have been identified as likely to be susceptible to fatigue resulting from global stress variation, and will therefore also be monitored:

- Deck-plate corner transition between girders and cross-beam (to be monitored in the same location as the local deck plate fatigue monitoring)

Although fatigue issues have been carefully considered in the design, it is important to monitor actual stress history and compare it against design stress history. Changes over time of traffic volumes and vehicle types can significantly vary the stress history that is experienced. Monitoring of stress history will therefore provide a good indication of maintenance requirements. Also monitoring of stress history will confirm the design assumptions.

MONITORING STRESS

Local deck plate temperature-compensated strain fluctuations, and hence stress fluctuations, will be monitored with temperature-compensated strain sensors. Longitudinal stresses will be monitored at the tip of the troughs, where stresses are greatest, and adjacent to trough splices, where the troughs are most sensitive to fatigue. Transverse stresses will be monitored in the deck plate, troughs and rail-beams. Measurements will be taken mid-way between box diaphragms. Temperature-compensated strain sensors will be offset from the trough to plate longitudinal welds, nominally by 15mm; this offset is required to provide a standard reference stress for the fatigue classification. Local deck plate strain fluctuations will occur rapidly due to short influence lines in combination with rapid vehicle transit. Monitoring of local deck plate strain fluctuations will therefore require very high frequency sampling (to the order of 500Hz).

Global longitudinal temperature-compensated strain fluctuations, and hence stress fluctuations, will be measured with temperature-compensated strain gauges installed for *Bridge Quasi-Static Response*.

The additional identified fatigue sensitive local details will be monitored with temperature-compensated strain sensors.

Stress fluctuations will be processed with rain-flow count and Miner's summation routines to facilitate an automatic fatigue review.

MONITORING ROAD TEMPERATURE

Road surfacing temperature shall be measured at five locations along each carriageway, with temperature sensors installed at the asphalt/steel interface.

3.6.9 Buffer Response

Buffers are installed between the deck and the towers, and between the terminal structures (intermediate structures that connect the bridge to the approaches) and the supporting piers. The buffers play an important role in controlling the performance of the structure. They modify the restraints of the structure depending on the load conditions experienced. The buffers perform in two states: rigid and sprung. The normal function of the buffers is to act as a rigid link. Under certain load conditions they activate and change state to become sprung, which effectively releases the bridge deck. All of the buffers are required to activate during earthquakes. The longitudinal buffers at the towers are also required to activate for short duration loading events such as traffic and wind. The buffers are characterised by prescribed force to displacement response curves.

The buffers are active mechanical devices that require constant attention to ensure that they are performing as expected and are also adequately maintained so that they function properly when required. Furthermore, the mechanical control mechanisms of the buffers will leave them in a position that requires resetting after they have performed. This represents an additional maintenance requirement, which will also be monitored.

The railway deck structure is continuous as it passes through the towers. A buffered transverse restraint is provided between the deck and the towers. Due to thermal action, the deck will displace significantly relative to the towers along the longitudinal axis of the bridge. The buffered transverse restraint has been designed as a slender pin-ended strut to allow for this movement. One-end of the strut is a true-pin. The other end is formed from a pair of buffers with spherical bearings, which will displace and rotate so that it functions as a pin-end. The detail of this connection is currently under review. Free operation of the spherical bearings and transverse buffers is required, otherwise a moment restraint may result that could cause overstress of the buffered transverse restraint. Stresses in the strut will therefore also be monitored to identify any changes in bearing restraint.

The pins of the buffers, particularly at the towers, will be subjected to significant fluctuations of load. The pins or pin-plates may wear as a result of these fluctuations of load, resulting in pin movement relative to the pin plates. The movement of a selection of pins, relative to the pin-plates, will be monitored.

MONITORING BUFFER RESPONSE

The response of all buffers will be monitored. Buffer force will be measured through monitoring of the hydraulic pressure in each of the buffer's two chambers as well as monitoring of the oil temperature. Displacement of the pistons will be monitored with linear displacement gauges. Furthermore, the hydraulic pressure in each of the accumulator tanks will be monitored. The sensors required for monitoring the *Buffer Response* will be supplied and installed by the buffer manufacturer.

MONITORING STRESS

The stress-state of the strut of the buffered transverse restraint between the deck and the towers will be monitored with temperature-compensated strain sensors installed adjacent to the connection to the buffers.

MONITORING BUFFER PIN MOVEMENT

A selection of representative pins of buffers at the towers will be monitored for movement relative to the pin-plates, using linear displacement gauges.

3.6.10 Expansion Joint Behaviour

The movement of the deck at the expansion joints is to be measured to record regular bridge deck movement for temperature correlation, to measure the travel of the expansion joints and to confirm that they are working freely. Measurement before, during and after major wind and seismic events will be critical in assessment of potential damage to the structure. Accumulated expansion joint movement will be monitored on a long-term basis to indicate expansion joint use. Expansion joint vibration will also be monitored on a long-term basis, at the roadway joint as well as at the bearing. Changes in joint movement patterns and joint vibration patterns will indicate the development of wear of components in the expansion joint, in order to assist with planning and budgeting for replacement.

MONITORING EXPANSION JOINT MOVEMENT

Expansion joint movement will be monitored with linear displacement gauges. The expansion range of the primary expansion joints at the ends of the bridge is significant: up to +/-2m of movement. The expansion range of the expansion joints in the road girder at the towers is +/-0.8m (main span) and +/-0.1m (side span). Electronic distance measurement (EDM) or laser distance measurement will therefore be used, although alternative techniques may be proposed to the SHMS sub-contractor. Distance measurement using EDMs or lasers is based on an emitted directional signal that is reflected by a target, received and translated into a measured distance. A draw-back with using EDM or laser displacement sensors is that false readings can be registered if the emitted directional signal is not received. Due to deck rotations, the emitted directional signal can be reflected away from the receiver inducing intermittent false signals. If EDM or laser displacement sensors are used, the current techniques established for using these sensors will need to be developed further to minimise erroneous data spikes. None-the-less erroneous data spikes can be easily differentiated from actual output data with data-conditioning processes developed to remove the data spikes from the data stream.

Expansion joint wear is related to total expansion joint movement and, in particular, is due to fretting action. An accumulation of expansion joint movement, in conjunction with observations of wear rates, can be used by the bridge operator to develop maintenance plans. A problem exists with simple accumulation of data recorded using sensors. All sensors exhibit background noise in the data-stream, which is not representative of actual joint movement. Also the magnitude of joint movement can have differing influence on wear, therefore simple direct accumulation of joint movement may not be representative of expansion joint wear. These problems will be dealt with by processing recorded joint movement fluctuations with rain-flow count routines to produce data on movement range versus number of cycles experienced. A facility will exist for the bridge operator to apply weighting rules to movement ranges. Miner's summation routines will then be applied to data to produce an indicator of wear. The process of developing the indicator will be performed by the bridge operator during service with input from inspections.

MONITORING EXPANSION JOINT VIBRATION

An increase in background vibrations of the roadway expansion joints as vehicles pass over, and as the joints operate, may indicate the development of wear of the roadway joints. Background vibrations of the main vehicle-deck large-movement expansion joints at the ends of the bridge and at the towers will be monitored by vertically orientated accelerometers installed onto the expansion joint bridging rails.

MONITORING EXPANSION JOINT VIBRATION AT THE BEARING

An increase in vibrations adjacent to the main expansion joint as the joint operates may indicate the development of sticking conditions and hence wear of the expansion joint bearings. Vibrations emanating through the vertical posts above the bearings at the ends of the bridge will be monitored by longitudinally orientated accelerometers installed onto the posts adjacent to the bearings.

3.6.11 Main-cable Slip over Saddles

The tower top saddles and anchor block saddles are designed so that the main-cable does not slip over the saddles. Main-cable slip is not a common problem for completed suspension bridges; however the critical condition is during erection. There is interest in monitoring for main-cable slip following completion as well as during erection, due to the significant scale of this bridge, to verify that slip does not occur.

MONITORING MAIN-CABLE DISPLACEMENT RELATIVE TO THE SADDLES

The main-cable strands splay out to pass between spacers in the troughs of the saddles. At each saddle, the displacement of a representative lower main-cable strand relative to the saddle block will be monitored with linear displacement gauges.

3.6.12 Extreme Load (not including Seismic Load)

Extreme loading events are by definition rare, thus the likelihood of being able to measure such an event during the service life of a structure is low. However, there may be several occurrences of high magnitude events that, albeit are lower magnitude than the design load, will give indications of the likely success of the structure in carrying the intended design loads. Bridge response to high magnitude loading will be registered through the monitoring of *Bridge Quasi-Static Response* and *Deck Dynamic Response* as well as the other monitoring tasks.

Design loads are also developed based on statistical review of loading conditions and occurrences. Loading conditions will be monitored and relevant data stored so that future statistical reviews of the loads can be performed.

MONITORING EXTREME WIND LOAD

Long span suspension bridges can be vulnerable to high winds either through overloading of elements which provide lateral support (primarily the towers) or from aerodynamic excitation.

Information on wind structure will be provided by the array of anemometers set-up to monitor *Bridge Quasi-Static Response* and *Deck Dynamic Response*, including the additional array of anemometers at mid-span for monitoring wind correlation.

MONITORING EXTREME TRAFFIC LOAD (VEHICLE AND RAIL)

Traffic conditions can develop over time beyond the original design assumptions. It is not uncommon for major bridges to see significant increases in traffic volumes and vehicle weights within the life of the structure. This is reflected by the progressive increase in traffic loads in successive issues of codes of practice for the design of bridges as allowable vehicle weights increase.. Most bridge elements can therefore be considered as potentially vulnerable to overloading from increased traffic loading.

Traffic (vehicle) load will be measured by high-speed Weigh-in-Motion (WiM) systems as part of the Network TMS component of the SCADA system. Traffic (rail) load will be measured by high-speed Rail Weigh-in-Motion (RWiM) systems as part of the Network TMS component of the SCADA system. The WiM and RWiM have been further described by Component No. 45.

MONITORING EXTREME TEMPERATURE LOAD

Thermal loads (i.e. expansion of the bridge due to changes in temperature) do not tend to control the critical load conditions for bridges with expansion joints, although they do contribute to critical load conditions. There is usually little benefit derived in studying the effects of thermal loading unless there is a high degree of restraint in the structure. The design of the buffers between the deck and the towers includes a restraint that will resist thermal loads applied to the deck. These buffers are however designed to limit the load to an upper bound so as to avoid overstressing the bridge. Additional restraint also to the bridge dependent on the performance of the buffers as well as the expansion joints.

Although basic studies have been performed on temperature effects, leading to the design load cases presented in common standards, little is known about the correlation between ambient temperature, solar radiation and the average cable temperature for suspension bridges. Furthermore, temperature variation due to varying micro-climates, over the significant distances represented by the length and height of this bridge, has not been investigated thoroughly before. Monitoring of temperature data will provide an opportunity to develop increased understanding of the temperature conditions experienced by very long span bridges.

Information on structural temperature will be provided by the array of contact temperature sensors set-up to monitor *Bridge Quasi-Static Response*. Information on solar radiation and air temperature will be recorded at a number of selected locations along the bridge deck and up the towers.

3.6.13 Seismic Load and Response

The bridge is located in a zone of known seismicity. The bridge is the only high capacity fixed link available between Sicily and mainland Italy. As a consequence the structure may be considered as a life-line structure warranting a higher level of seismic protection than other structures in the local area, particularly since after a major seismic event it may be important for facilitating rescue actions. In a seismic event, it will be important to be able to carry out a rapid assessment of the effect of the event on the structure and to confirm that the structure may continue to operate safely.

A rapid means of measuring the response of the structure to an earthquake has been developed which will provide initial confirmation within minutes of the event that the bridge has remained within its operational envelope. This will be achieved by comparing the data recorded by specific sensors with the expected behaviour of the bridge under a design-level earthquake, as well as with permissible limits. Routines will be applied to recorded ground accelerometers to compare the earthquake response spectrum with an equivalent design spectrum. The performance of the bridge may be deemed acceptable if each of the specific sensors shows that a predetermined expected design value (from seismic actions) has not been exceeded. If the design spectrum has not been exceeded, a certain initial level of confidence will also gained e.g. the structure will have experienced an earthquake for which it has been designed and therefore is capable of surviving. The initial assessment gained from the SHMS can then be used to support targeted visual checks of the bridge which will allow the operator to choose whether or not to reopen the bridge without further engineering review.

Installing accelerometers in a dispersed arrangement in the countryside around the bridge will allow free-field motions to be captured at a number of locations, which when analysed will provide an indication of spatial variation of ground motion as the seismic wave propagates from the hypocentre to the various bridge foundations. This information in conjunction with structural response can be used for calibrating the bridge model.

MONITORING DEFLECTION

The deflection of the structure will be monitored with GPS receivers established for monitoring *Bridge Geometry*. A difference in position before and after a seismic event will provide a good indicator of the condition of the bridge. However, since GPS readings are dependent on the position of the GPS reference station, the GPS reference station will need to be surveyed following significant seismic events. Inclinometers installed in the tower legs will also indicate change in geometry resulting from a seismic event. The maximum movements recorded at the expansion joints, using linear displacement sensors established for monitoring of *Expansion Joint Behaviour*, will provide an indication into the performance of the structure and joints during the seismic event including an assessment of damage if movements recorded exceed the travel provided.

MONITORING THE BUFFERS

The buffers are devices explicitly included in the design to change the bridge characteristics during a seismic event, as a means of reducing the risk of damage to the structure. Monitoring of the force to displacement characteristics, which will have been established by the monitoring of *Buffer Response,* with comparison against the prescribed behaviour will indicate if the buffers have performed as expected.

MONITORING FORCE/STRESS

Sensors installed for monitoring force and stress as part of monitoring of *Bridge Quasi-Static Response* will indicate whether or not limits have been exceeded during the seismic event.

MONITORING LOAD

The *Seismic Load* will be monitored by an array of seismic-capable high definition accelerometers installed in the local terrain and to the foundations of the bridge (anchor blocks, tower bases and tie-down piers). Data will be supplemented by dynamic inclinometers installed on the foundations of the bridge and on the underwater escarpments. An automatic process will be implemented whereby the ground accelerations recorded will be processed using a Duhamel integral producing a seismic spectrum for comparison with an equivalent design spectrum.

MONITORING OF GROUND MOVEMENTS

The survey of ground movements following earthquakes will be facilitated by the addition of solid and robust survey benchmarks installed onto the underwater escarpments.

The change in slope of the escarpments will be monitored with dynamic inclinometers installed onto the benchmark structures. The relative positional movement of the bridge foundations (and hence indicatively of the escarpments) will be registered by the GPS receivers set-up on the bridge foundations for monitoring of *Bridge Quasi-Static Response*. However, since GPS readings are dependent on the position of the GPS reference station, the GPS reference station will need to be surveyed following significant seismic events.

3.6.14 Internal Environment

An advanced dehumidification system will be installed on the bridge, with the purpose of maintaining relative humidity levels that are below the level at which corrosion develops. All internal spaces, including the inside of the main cable, will be dehumidified. The dehumidification system is an important part of the maintenance strategy for the bridge. Monitoring of the *Internal Environment* is necessary for efficient and effective control of the dehumidification system, as well as verification of its performance.

MONITORING INTERNAL ENVIRONMENT

Relative humidity and air temperature measurements will be taken at representative positions within the deck girders and cross-beams, tower legs and portals, and anchor blocks. These measurements will be converted to dew point temperatures against which minimum steel temperature measurements, taken for monitoring of *Bridge Quasi-Static Response*, will be compared. Surface humidity (condensation) measurements will also be taken inside the deck girders and cross-beams.

Relative humidity will be monitored in the main-cables with fibre-optic cables, incorporating fibre-bragg-gratings, running parallel to the main-cable wires, thus reducing the risk of the cable being cut during compaction. The fibre-optic cables will be provided with a durable coating, such as kevlar, and will be formed to the standard main-cable wire size. They will be placed into, and become part of, the appropriate main-cable strand during strand fabrication. They will be placed in the external lay of the strand on the side that will be at the top of the strand as it passes over the saddles, to reduce the radial stresses to which they will be subjected. They will emerge from the main-cable at the splay of the strands as they enter the anchorage saddles. The installation of fibre-optic cables within the main-cables, as well as the sensor itself, represents an advancement in current technology. The sensor will need to be developed and tested. The fibre-optic cable will need to developed for durability and will need to be proof-tested against the cable compaction process. Relative humidity measurements will be taken with slow sampling rates. Once installed, the cables will not be accessible for maintenance. The development of a break in the fibre-optic may end the function of the entire length of fibre-optic cable. However redundancy is provided by the measurement of humidity at the exhaust outlets by the dehumidification system itself. The monitoring of relative humidity in the main-cables and feasibility testing plan is discussed in greater detail in Appendix 2.

Relative humidity measurements in the main-cables will be supplemented by measurements of corrosion rate, using Linear Polarization Resistance sensors, installed through the section of each main-cable at the the tower tops, adjacent to the anchor blocks and at midspan. At the tower tops and adjacent to the anchor blocks, the sensors will be positioned beyond the first clamp; the data-cables will be placed parallel to the main-cable wires and emerge from the main-cable at the splay of the strands as they enter the saddles. At mid-span the data-cables will cross the main-cable wires and emerge from the main-cables at access ports. As the main-cables are compacted the steel wires will slide over each other forming a dense matrix. Soft data-cables that pass across the path of the parallel wires can be damaged by the compacting process. Experience with installation of local nodes of internal temperature sensors, with data-cables fed out through the splay of strands at saddles, has demonstrated that a proportion of sensors can be damaged. Survivability of the sensors and data-cables to the cable compaction process will need to be demonstrated for both arrangements. The sensors and data-cables will be proof-tested against the cable compaction process. If required, the data-cables will be developed for durability and survival of the cable compaction process. The access ports through the main-cable wrapping wire will be detailed by the bridge structural designers.

3.6.15 Road Condition

The road and environmental conditions experienced on the bridge may vary from position to position on the bridge due to micro-climates, and may also vary significantly from the conditions at the control building. The conditions may determine whether or not the road is safe to use e.g.

- has a water veil developed on the road surface that presents a risk of aqua-planning
- is black-ice forming on the road surface that presents a risk of sliding
- are wind conditions too strong such that there is a risk of vehicle-overturn or reduction in driver-vehicle-control

Monitoring of road and environmental conditions will allow the bridge operator to manage the safety of vehicles using the bridge by, for example, varying traffic speed limits or limiting the access of vehicles at risk.

MONITORING ROAD SERVICEABILITY CONDITIONS

Wind conditions will be monitored with anemometers set-up for monitoring of *Bridge Quasi-Static Response*, to complement monitoring by the Bridge TMS component of SCADA. In particular gust wind speeds based on a 3-sec rolling average will be presented, as this duration of gust is expected to correlate to known data on vehicle over-turning.

The condition of the road on the bridge will be monitored by the Bridge TMS component of SCADA.

3.6.16 Concrete Condition

Concrete foundations do not frequently present severe maintenance concerns. Known problems, such as alkali-silica reaction, are dealt with in the design. The main symptom experienced by modern concrete design is rebar corrosion which, although designed for with appropriate levels of concrete cover, will none-the-less develop in the lifetime of the structure as water and oxygen migrate through the concrete. Corrosion of rebar will therefore be monitored. Concrete spalling, another symptom associated with rebar corrosion, is most effectively assessed through visual inspections.

MONITORING REBAR CORROSION

Two techniques will be adopted for monitoring of the corrosion of concrete rebar:

- Corrosion cells will be added to the concrete cover of the outer layers of rebar of the concrete foundations. These sensors will provide an indication into the development of corrosion
- Studs will be added to the concrete, which will allow potentiometer readings to be taken intermittently by the inspection and maintenance teams

3.6.17 Ground Conditions

The ground conditions around the bridge foundations can contribute to the behaviour of the foundations. Ground behaviour is reviewed and applied in the design. Basic ground characteristics will be monitored at the foundations (anchor blocks, tower bases, and tie-down piers) to support design assumptions.

MONITORING GROUND CHARACTERISTICS

Ground pressure and interstitial ground-water pressure will be monitored with sensors placed in boreholes adjacent to the foundations.

4 System Arrangement

4.1 Definition

All instrumentation for structural monitoring to be performed during operation of the bridge will be grouped within the SHMS. Using the same instrumentation, the system will also be established to provide structural monitoring during the construction phase.

Temporary sensors for construction monitoring, which will not be used after construction, will not be grouped under the term SHMS. They will be grouped under the term Temporary Construction Monitoring Sensors (TCMS). The TCMS will be detailed during Progetto Esecutivo following final construction sequence planning. The remainder of this monitoring plan discusses only the SHMS.

4.2 General Overview

The general system arrangement will be as shown in Figure 4.1.

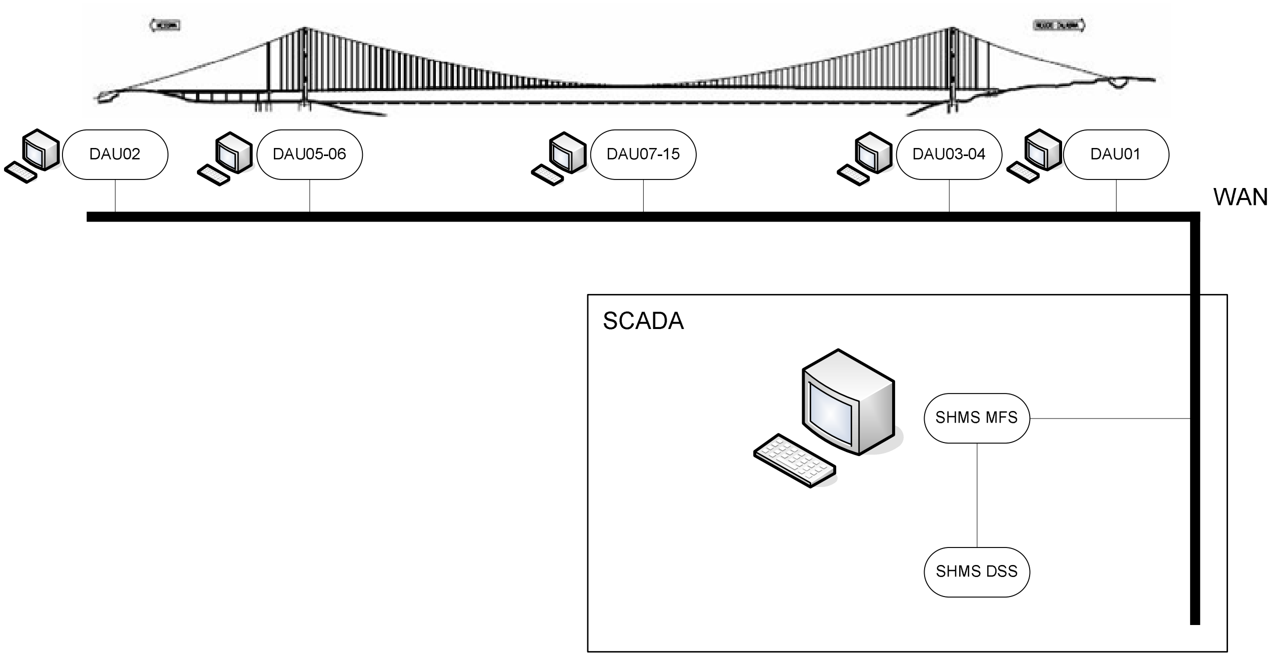


Figure 4.1 SHMS General System Architecture

Arrays of sensors and loggers will be connected up to DAUs. Sensors in the nearby countryside and on the underwater escarpments will transfer data to the anchorage DAUs via a WAN network. The sensors in the nearby countryside will also be supplied with wireless communication systems. The wireless connection is required for the construction phase, and will act as a back-up communication connection in the event of failure of the WAN.

DAUs will process data from the local array of sensors and loggers. DAUs will be provided with access terminals. Data will be transmitted to the SHMS MFS within the SCADA via a WAN network. They will also be supplied with wireless communication systems. The wireless connections are required for the construction phase, and will act as a back-up communication connection in the event of failure of the WAN.

Data provided by other components of SCADA and MMS will be sent to the SHMS via the SCADA database or retrieved by the SHMS MFS from the SCADA database.

The SHMS MFS will process data received from other components of SCADA and MMS. Other processing functions will be performed at the SHMS MFS, however these will be minimised to those functions that cannot be performed at the DAUs

The main SHMS operator interface terminal will be connected to the SHMS MFS.

Data for permanent storage will be transmitted from the SHMS MFS to the SHMS DSS (which shall be an allocated partition of the SCADA database). Data for temporary storage will be retained in a buffer on the SHMS MFS. Other components of the SCADA will be able to access permanent data from the SHMS DSS, and temporary data from the buffer on the SHMS MFS.

4.3 System Components

The SHMS will consist of:

- Permanently installed sensors and measuring devices
- Permanently installed calibration sensors that are not connected to the SHMS data management system
- Data-loggers
- On-structure Data-cabling
- On-structure Power-cabling
- Data-relay units
- Data Acquisition and processing Units (local servers located on the structure) including temporary data storage
- Uninterruptable Power Supply units
- Brackets and local support structures for all on-structure equipment including weather protection, cooling, service lighting and other related equipment
- Physical protection for all on-structure equipment including lightning finials
- Data communication system: all data will be transferred via the WAN network. Sensors installed in the countryside and to the underwater escarpments will also be provided with a wireless communication system, which will act as a back-up communication system to WAN. During construction wireless communication systems will be provided with each DAU, which will act as a back-up communication system to WAN during service

- Mainframe server in SCADA, including buffer for temporary data storage, and operator access terminals and equipment
- Data storage in SCADA
- Portable SHMS equipment: sensors (accelerometers, video displacement sensors and microwave interferometric radar), data-loggers, data cabling, portable monitoring computers, portable monitoring servers
- Complementary SHMS equipment: half-cell potentiometers to complement studs for potentiometer monitoring of corrosion
- Tectonic survey markers
- Spare parts for maintenance of SHMS system
- Tools to assist with maintenance of SHMS system
- Network test equipment to test the SHMS Local Area Network (LAN)
- Documentation: certificates, manuals, guides, etc.

4.4 Monitoring Modules

Sensors will be grouped into modules by function and purpose as given in Table 4.1.

Table 4.1 SHMS Modules

IEM	Internal Environment Monitoring, including monitoring of main cable
EEM	External Environment Monitoring
DWM	Detailed Wind Monitoring
RCM	Road Condition Monitoring
PM	Position Monitoring
DM	Dynamics Monitoring, including monitoring of seismicity and monitoring of inclination
TMDM	Tuned Mass Damper Monitoring
GSTM	General Structural Temperature Monitoring

LSTM	Local Structural Temperature Monitoring
GSSM	General Stress State Monitoring
FSSM	Fatigue Stress State Monitoring
DRM	Deck Restraint Monitoring, including monitoring of buffers
SRM	Saddle Restraint Monitoring
SCM	Soil Condition Monitoring

4.5 Data Loggers

Data loggers are components that condition and convert analogue signals into digital data. Data loggers can be internal components e.g. of the DAUs or IDRUs, or external devices or fibre-optic cable interrogators. Data loggers should be positioned to optimise cabling requirements, for example they could be positioned in IDRUs in close proximity to sensor groups reducing quantities and lengths of individual analogue cables.

The detailed arrangement of data-loggers will depend on final decision for hardware architecture, which shall be dependent upon the SHMS sub-contractor chosen as well as future technological developments. A detailed arrangement of data loggers shall be developed at Progetto Esecutivo.

Data from loggers will be sent via data-cables to nearby DAUs for on-structure processing. IDRUs may be used to economise on installed cabling, by sending data from numerous sensors through a common data-cable. Due to the physical spread of sensors, IDRUs will be used in the towers. Data from the sensors installed in the nearby-countryside and on the underwater escarpments will be sent via the WAN to the DAUs in the anchorages.

4.6 Data Acquisition Units

DAUs will be located at and labelled as given in Table 4.2.

Table 4.2 SHMS DAU distribution

DAU01	anchorage Sicily
DAU02	anchorage Calabria
DAU03	tower leg Sicily East

DAU04	tower leg Sicily West
DAU05	tower leg Calabria East
DAU06	tower leg Calabria West
DAU07	deck Sicily end
DAU08	deck Sicily tower
DAU09	deck Sicily 1/6
DAU10	deck Sicily 1/3
DAU11	deck mid-span
DAU12	deck Calabria 1/3
DAU13	deck Calabria 1/6
DAU14	deck Calabria tower
DAU15	deck Calabria end

2 additional DAUs shall be provided as part of the additional sensor set that is presented in Section 4.9. The installation of the additional sensor set shall be determined following construction and initial structural behaviour studies.

IDRUs to be installed in the towers will be located at and labelled as given in Table 4.3, where nn refers to the DAU number. The location and labelling of other IDRUs will be subject to the approval of the SHMS designer.

Table 4.3 Primary IDRU distribution

IDRUnn-TUP	upper cross beam level
IDRUnn-TMP	middle cross beam level
IDRUnn-TLP	lower cross beam level
IDRUnn-TD	tower base

DAUs will process data and send data to the SHMS MFS via the WAN that will be installed as part of CS.

4.7 Sensor Labelling Nomenclature

For the purposes of labelling, the longitudinal axis of the bridge will be considered to align with a local North-South (Sicily-Calabria) axis.

Sensors will be identified by the labelling nomenclature given in Table 4.4. This labelling nomenclature will be adopted throughout the system including naming of data-channels.

Table 4.4 SHMS Labelling Nomenclature

W	West
C	Centre
E	East
D	Deck
CG	Cross Girder
MC	Main Cable
TB	Tower Leg at Tower Base
TD	Tower Leg at Deck Level
TLP	Tower Leg at Lower Portal (Cross-beam)
TMP	Tower Leg at Middle Portal (Cross-beam)
TUP	Tower Leg at Upper Portal (Cross-beam)
TT	Tower Top
LP	Lower Portal (Cross-beam)
MP	Middle Portal (Cross-beam)
UP	Upper Portal (Cross-beam)
H	Hanger
PB	Pier Base
AB	Anchorage Block
R	Remote
UE	Underwater Escarpment
(int)	A sensor positioned internally

(ext)	A sensor positioned externally
AD	Anemometer
WS(3)	Wind Speed measured in 3-axes using AD
WS(2), WD	Plan Wind Speed, Vertical Wind Speed, and Plan Wind Direction, measured using AD
GPS	GPS sensor
CT	Air Temperature sensor
SR	Solar Radiation sensor
RH	Relative Humidity sensor
CR	Corrosion Rate sensor
B	Air Pressure sensor
RG	Rain Gauge
SH	Surface Humidity (Condensation Formation) sensor
RT	Road Temperature sensor
A(1)	Accelerometer with 1-axis
A(2)	Accelerometer with 2-axes
A(3)	Accelerometer with 3-axes
SA(3)	Accelerometer with 3-axes for seismic response capability
SIN(2)	Static Inclinometer with 2-axes
DIN(2)	Dynamic Inclinometer with 2-axes
ST	Steel Temperature sensor
SG	Strain Gauge
SG(3)	3 Strain Gauges in the form of a Rosette
CSG	Calibration Strain Gauge
LD	Linear Displacement sensor
HP	Hydraulic Pressure sensor
OT	Oil Temperature sensor
CC(4)	Corrosion rebar Cell with 4 data channels

P	Ground Pressure sensor
IP	Ground Interstitial Pressure sensor
(above MP) or (below MP)	Measurements from above the MP or below the MP, respectively
(near CG) or (away from CG)	Measurements from near the CG or away from the CG, respectively
(long)	Measurements longitudinal to trough
(tr)	Measurements transverse to trough
(diap)	Measurements at cope holes of diaphragms
(add)	Additional measurements at other selected positions
(rt)	Measurements from railway track
(bu)	Measurements from buffer
(bt)	Measurements from buffer accumulator tank
(bp)	Measurements of relative movement of buffer pin to pin-plates
(exp jt)	Measurements from expansion joint
(be)	Measurements of expansion joint at the bearing
(clamp)	Measurements from main-cable clamps
(add strands)	Measurements from additional side span main-cable strands
(anchor bolts)	Measurements from tower base anchor bolts

4.8 Principle Hardware Architecture

Modules will be named, and include sensors, as given in Table 4.5 to Table 4.19. Sensors installed from the additional sensor set, that is presented in Section 4.9, may be added to any of the DAUs presented in Table 4.5 to Table 4.19 or to 2 additional DAUs provided as part of the additional sensor set. The installation of the additional sensor set shall be determined following construction and initial structural behaviour studies.

Table 4.5 Modules and Sensors: DAU 01 (anchorage Sicily)

DAU 01 (anchorage Sicily)		
Module Name	Data channels	No. Channels
IEM01-AB-E	RH(int), CT(int)	2

IEM01-AB-W	RH(int), CT(int)	2
IEM01-MC-E	9 CR(int), 9 CR(int)	18
IEM01-MC-W	9 CR(int), 9 CR(int)	18
IEM01-MC-01-E	5 RH(int), 5 RH(int)	10
IEM01-MC-02-E	5 RH(int), 5 RH(int)	10
IEM01-MC-03-E	5 RH(int), 5 RH(int)	10
IEM01-MC-04-E	5 RH(int), 5 RH(int)	10
IEM01-MC-05-E	5 RH(int), 5 RH(int)	10
IEM01-MC-06-E	5 RH(int), 5 RH(int)	10
IEM01-MC-07-E	5 RH(int), 5 RH(int)	10
IEM01-MC-08-E	5 RH(int), 5 RH(int)	10
IEM01-MC-09-E	5 RH(int), 5 RH(int)	10
IEM01-MC-10-E	5 RH(int), 5 RH(int)	10
IEM01-MC-11-E	5 RH(int), 5 RH(int)	10
PM01-AB-E	GPS(3)(ext)	3
PM01-AB-W	GPS(3)(ext)	3
PM01-R	4 GPS(3)(ext)	12
DM01-AB-E	4 SIN(2)(int)	8
DM01-AB-C	2 SA(3)(int), 2 DIN(2)(int)	10
DM01-AB-W	4 SIN(2)(int)	8
DM01-R	4 SA(3)(ext)	12
DM01-UE	5 DIN(2)(ext)	15
GSTM01-AB-E	ST(int)	1
GSTM01-AB-W	ST(int)	1
GSTM01-MC-02-E	9 ST(int), 9 ST(int)	18
GSTM01-MC-05-E	9 ST(int), 9 ST(int)	18
GSTM01-MC-07-E	9 ST(int), 9 ST(int)	18
GSTM01-MC-10-E	9 ST(int), 9 ST(int)	18

GSSM01-MC-AB-E	14 SG(int), 14 SG(int)	28
GSSM01-MC-AB-W	14 SG(int), 14 SG(int)	28
GSSM01-MC-E	3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int)	14
GSSM01-MC-W	3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int)	14
SRM01-AB-W	LD(int)	1
SRM01-AB-E	LD(int)	1
SCM01-AB-E	3 CC(4)(ext), P(ext), 2 IP(ext)	15
	Total No. Channels:	396

Table 4.6 Modules and Sensors: DAU 02 (anchorage Calabria)

DAU 02 (anchorage Calabria)		
Module Name	Data channels	No. Channels
IEM02-AB-E	RH(int), CT(int)	2
IEM02-AB-W	RH(int), CT(int)	2
IEM02-MC-E	9 CR(int), 9 CR(int)	18
IEM02-MC-W	9 CR(int), 9 CR(int)	18
IEM02-MC-01-W	5 RH(int), 5 RH(int)	10
IEM02-MC-02-W	5 RH(int), 5 RH(int)	10
IEM02-MC-03-W	5 RH(int), 5 RH(int)	10
IEM02-MC-04-W	5 RH(int), 5 RH(int)	10
IEM02-MC-05-W	5 RH(int), 5 RH(int)	10
IEM02-MC-06-W	5 RH(int), 5 RH(int)	10
IEM02-MC-07-W	5 RH(int), 5 RH(int)	10
IEM02-MC-08-W	5 RH(int), 5 RH(int)	10
IEM02-MC-09-W	5 RH(int), 5 RH(int)	10
IEM02-MC-10-W	5 RH(int), 5 RH(int)	10
IEM02-MC-11-W	5 RH(int), 5 RH(int)	10
PM02-AB-E	GPS(3)(ext)	3

PM02-AB-W	GPS(3)(ext)	3
PM02-R	4 GPS(3)(ext)	12
DM02-AB-E	4 SIN(2)(int)	8
DM02-AB-C	2 SA(3)(int), 2 DIN(2)(int)	10
DM02-AB-W	4 SIN(2)(int)	8
DM02-R	4 SA(3)(ext)	12
DM02-UE	5 DIN(2)(ext)	15
GSTM02-AB-E	ST(int)	1
GSTM02-AB-W	ST(int)	1
GSTM02-MC-02-W	9 ST(int), 9 ST(int)	18
GSTM02-MC-05-W	9 ST(int), 9 ST(int)	18
GSTM02-MC-07-W	9 ST(int), 9 ST(int)	18
GSTM02-MC-10-W	9 ST(int), 9 ST(int)	18
GSSM02-MC-AB-E	14 SG(int), 14 SG(int)	28
GSSM02-MC-AB-W	14 SG(int), 14 SG(int)	28
GSSM02-MC-E	3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int)	14
GSSM02-MC-W	3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int)	14
SRM02-AB-W	LD(int)	1
SRM02-AB-E	LD(int)	1
SCM02-AB-E	3 CC(4)(ext), P(ext), 2 IP(ext)	15
	Total No. Channels:	396

Table 4.7 Modules and Sensors: DAU 03 (tower leg Sicily East)

DAU 03 (tower leg Sicily East)		
Module Name	Data channels	No. Channels
IEM03-MC-E	9 CR(int), 9 CR(int), 9 CR(int), 9 CR(int)	36
IEM03-TT-E	RH(int), CT(int)	2
IEM03-TUP-E	RH(int), CT(int)	2

IEM03-TMP-E	RH(int), CT(int)	2
IEM03-TLP-E	RH(int), CT(int)	2
IEM03-TB-E	RH(int), CT(int)	2
PM03-TT-E	GPS(3)(ext)	3
PM03-TB-E	GPS(3)(ext)	3
EEM03-TUP-E	WS(3)(ext)	3
EEM03-TMP-E	WS(3)(ext)	3
EEM03-TLP-E	WS(3)(ext)	3
EEM03-TD-E	WS(3)(ext)	3
DM03-TUP-E	A(3)(int), SIN(2)(int)	5
DM03-TMP-E	A(3)(int)	3
DM03-TLP-E	A(3)(int)	3
DM03-TB-E	A(3)(int), 2 DIN(2)(int)	7
TMDM03-TMP-E	8 LD(int)	8
GSTM03-MC-E	3 ST(ext), 4 ST(int), 3 ST(ext), 4 ST(int)	14
GSTM03-TUP-E	10 ST(int)	10
GSTM03-TMP-E	10 ST(int)	10
GSTM03-TLP-E	10 ST(int)	10
GSTM03-TB-E	10 ST(int)	10
LSTM03-TLP-E	8 ST(int)	8
GSSM03-MC-E	3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 2 SG(ext)(add strands), 2 SG(3)(ext)(clamp), 2 SG(3)(ext)(clamp)	42
GSSM03-TUP-E	4 SG(int)(below UP)	4
GSSM03-UP-E	4 SG(int)	4
GSSM03-TMP-E	4 SG(int)(above MP), 4 SG(int)(below MP)	8
GSSM03-MP-E	4 SG(int)	4
GSSM03-TLP-E	4 SG(int)(above MP), 4 SG(int)(below MP)	8

GSSM03-LP-E	4 SG(int)	4
GSSM03-TD-E	4 SG(int)	4
GSSM03-TB-E	4 SG(int), 4 SG(int)(anchor bolts)	8
SRM03-TT-E	LD(ext)	1
SCM03-TB-E	2 CC(4)(ext), P(ext), 2 IP(ext)	11
	Total No. Channels:	250

Table 4.8 Modules and Sensors: DAU 04 (tower leg Sicily West)

DAU 04 (tower leg Sicily West)		
Module Name	Data channels	No. Channels
IEM04-MC-W	9 CR(int), 9 CR(int), 9 CR(int), 9 CR(int)	36
IEM04-TT-W	RH(int), CT(int)	2
IEM04-TUP-W	RH(int), CT(int)	2
IEM04-UP-C	RH(int), CT(int)	2
IEM04-TMP-W	RH(int), CT(int)	2
IEM04-MP-C	RH(int), CT(int)	2
IEM04-TLP-W	RH(int), CT(int)	2
IEM04-LP-C	RH(int), CT(int)	2
IEM04-TB-W	RH(int), CT(int)	2
PM04-TT-W	GPS(3)(ext)	3
PM04-TLP-W	GPS(3)(ext)	3
PM04-TB-W	GPS(3)(ext)	3
EEM04-TT-W	WS(2)(ext), WD(ext), RH(ext), CT(ext), SR(ext), B(ext)	7
EEM04-TUP-W	WS(3)(ext)	3
EEM04-TMP-W	WS(3)(ext)	3
EEM04-TLP-W	WS(3)(ext)	3
EEM04-TD-W	WS(3)(ext), RH(ext), CT(ext), B(ext)	6
DM04-TUP-W	A(3)(int), SIN(2)(int)	5

DM04-TMP-W	A(3)(int)	3
DM04-TLP-W	A(3)(int)	3
DM04-TB-W	2 SA(3)(int), 2 DIN(2)(int)	10
TMDM04-TMP-W	8 LD(int)	8
GSTM04-MC-W	3 ST(ext), 4 ST(int), 3 ST(ext), 4 ST(int)	14
GSTM04-TUP-W	10 ST(int)	10
GSTM04-UP-C	4 ST(int)	4
GSTM04-TMP-W	10 ST(int)	10
GSTM04-MP-C	4 ST(int)	4
GSTM04-TLP-W	10 ST(int)	10
GSTM04-LP-C	4 ST(int)	4
GSTM04-TB-W	10 ST(int)	10
LSTM04-TLP-W	8 ST(int)	8
GSSM04-MC-W	3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 2 SG(ext)(add strands), 2 SG(3)(ext)(clamp), 2 SG(3)(ext)(clamp)	42
GSSM04-TUP-W	4 SG(int)(below UP)	4
GSSM04-UP-W	4 SG(int)	4
GSSM04-TMP-W	4 SG(int)(above MP), 4 SG(int)(below MP)	8
GSSM04-MP-W	4 SG(int)	4
GSSM04-TLP-W	4 SG(int)(above MP), 4 SG(int)(below MP)	8
GSSM04-LP-W	4 SG(int)	4
GSSM04-TD-W	4 SG(int)	4
GSSM04-TB-W	4 SG(int), 4 SG(int)(anchor bolts)	8
SRM04-TT-W	LD(ext)	1
SCM04-TB-W	2 CC(4)(ext)	8
	Total No. Channels:	281

Table 4.9 Modules and Sensors: DAU 05 (tower leg Calabria East)

DAU 05 (tower leg Calabria East)		
Module Name	Data channels	No. Channels
IEM05-MC-E	9 CR(int), 9 CR(int), 9 CR(int), 9 CR(int)	36
IEM05-TT-E	RH(int), CT(int)	2
IEM05-TUP-E	RH(int), CT(int)	2
IEM05-TMP-E	RH(int), CT(int)	2
IEM05-TLP-E	RH(int), CT(int)	2
IEM05-TB-E	RH(int), CT(int)	2
PM05-TT-E	GPS(3)(ext)	3
PM05-TB-E	GPS(3)(ext)	3
EEM05-TUP-E	WS(3)(ext)	3
EEM05-TMP-E	WS(3)(ext)	3
EEM05-TLP-E	WS(3)(ext)	3
EEM05-TD-E	WS(3)(ext)	3
DM05-TUP-E	A(3)(int), SIN(2)(int)	5
DM05-TMP-E	A(3)(int)	3
DM05-TLP-E	A(3)(int)	3
DM05-TB-E	A(3)(int), 2 DIN(2)(int)	7
TMDM05-TMP-E	8 LD(int)	8
GSTM05-TUP-E	10 ST(int)	10
GSTM05-TMP-E	10 ST(int)	10
GSTM05-TLP-E	10 ST(int)	10
GSTM05-TB-E	10 ST(int)	10
LSTM05-TLP-E	8 ST(int)	8
GSSM05-MC-E	3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 2 SG(ext)(add strands), 2 SG(3)(ext)(clamp), 2 SG(3)(ext)(clamp)	42
GSSM05-TUP-E	4 SG(int)(below UP)	4

GSSM05-UP-E	4 SG(int)	4
GSSM05-TMP-E	4 SG(int)(above MP), 4 SG(int)(below MP)	8
GSSM05-MP-E	4 SG(int)	4
GSSM05-TLP-E	4 SG(int)(above MP), 4 SG(int)(below MP)	8
GSSM05-LP-E	4 SG(int)	4
GSSM05-TD-E	4 SG(int)	4
GSSM05-TB-E	4 SG(int), 4 SG(int)(anchor bolts)	8
SRM05-TT-E	LD(ext)	1
SCM05-TB-E	2 CC(4)(ext)	8
	Total No. Channels:	233

Table 4.10 Modules and Sensors: DAU 06 (tower leg Calabria West)

DAU 06 (tower leg Calabria West)		
Module Name	Data channels	No. Channels
IEM06-MC-W	9 CR(int), 9 CR(int), 9 CR(int), 9 CR(int)	36
IEM06-TT-W	RH(int), CT(int)	2
IEM06-TUP-W	RH(int), CT(int)	2
IEM06-UP-C	RH(int), CT(int)	2
IEM06-TMP-W	RH(int), CT(int)	2
IEM06-MP-C	RH(int), CT(int)	2
IEM06-TLP-W	RH(int), CT(int)	2
IEM06-LP-C	RH(int), CT(int)	2
IEM06-TB-W	RH(int), CT(int)	2
PM06-TT-W	GPS(3)(ext)	3
PM06-TLP-W	GPS(3)(ext)	3
PM06-TB-W	GPS(3)(ext)	3
EEM06-TT-W	WS(2)(ext), WD(ext), RH(ext), CT(ext), SR(ext), B(ext)	7
EEM06-TUP-W	WS(3)(ext)	3

EEM06-TMP-W	WS(3)(ext)	3
EEM06-TLP-W	WS(3)(ext)	3
EEM06-TD-W	WS(3)(ext), RH(ext), CT(ext), B(ext)	6
DM06-TUP-W	A(3)(int), SIN(2)(int)	5
DM06-TMP-W	A(3)(int)	3
DM06-TLP-W	A(3)(int)	3
DM06-TB-W	2 SA(3)(int), 2 DIN(2)(int)	10
TMDM06-TMP-W	8 LD(int)	8
GSTM06-TUP-W	10 ST(int)	10
GSTM06-UP-C	4 ST(int)	4
GSTM06-TMP-W	10 ST(int)	10
GSTM06-MP-C	4 ST(int)	4
GSTM06-TLP-W	10 ST(int)	10
GSTM06-LP-C	4 ST(int)	4
GSTM06-TB-W	10 ST(int)	10
LSTM06-TLP-W	8 ST(int)	8
GSSM06-MC-W	3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 3 SG(ext), 4 SG(int), 2 SG(ext)(add strands), 2 SG(3)(ext)(clamp), 2 SG(3)(ext)(clamp)	42
GSSM06-TUP-W	4 SG(int)(below UP)	4
GSSM06-UP-W	4 SG(int)	4
GSSM06-TMP-W	4 SG(int)(above MP), 4 SG(int)(below MP)	8
GSSM06-MP-W	4 SG(int)	4
GSSM06-TLP-W	4 SG(int)(above MP), 4 SG(int)(below MP)	8
GSSM06-LP-W	4 SG(int)	4
GSSM06-TD-W	4 SG(int)	4
GSSM06-TB-W	4 SG(int), 4 SG(int)(anchor bolts)	8
SRM06-TT-W	LD(ext)	1

SCM06-TB-W	2 CC(4)(ext), P(ext), 2 IP(ext)	11
	Total No. Channels:	270

Table 4.11 Modules and Sensors: DAU 07 (deck Sicily end)

DAU 07 (deck Sicily end)		
Module Name	Data channels	No. Channels
IEM07-D-E	RH(int), CT(int), SH(int)	3
IEM07-D-C	RH(int), CT(int), SH(int)	3
IEM07-CG-C	RH(int), CT(int), SH(int)	3
IEM07-D-W	RH(int), CT(int), SH(int)	3
RCM07-D-E	RT(ext)	1
RCM07-D-W	RT(ext)	1
PM07-D-E	GPS(3)(ext)	3
PM07-D-W	GPS(3)(ext)	3
PM07-MC-E	GPS(3)(ext)	3
PM07-MC-W	GPS(3)(ext)	3
PM07-PB-E	GPS(3)(ext)	3
PM07-PB-W	GPS(3)(ext)	3
DM07-MC-E	2 A(3)(ext)	6
DM07-MC-W	2 A(3)(ext)	6
DM07-H-E	A(2)(ext), A(2)(ext)	4
DM07-H-W	A(2)(ext), A(2)(ext)	4
DM07-PB-C	2 DIN(2)(ext)	4
GSTM07-D-E	4 ST(int)	4
GSTM07-D-C	4 ST(int), 1 ST(ext)(rt)	5
GSTM07-D-W	4 ST(int)	4
GSTM07-CG-E	4 ST(int)	4
GSTM07-CG-W	4 ST(int)	4

GSSM07-D-E	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM07-D-C	4 SG(int)(near CG), 4 SG(int)(away from CG), 6 SG(int)(add)	14
GSSM07-D-W	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM07-CG-E	4 SG(int)	4
GSSM07-CG-C	4 SG(int)	4
GSSM07-CG-W	4 SG(int)	4
GSSM07-MC-E	3 SG(ext), 3 SG(ext)	6
GSSM07-MC-W	3 SG(ext), 3 SG(ext)	6
FSSM07-D-E	8x2 SG(int)(long), 8x1 SG(int)(tr), 8x1 SG(int)(diap), SG(int)(deck pl)	33
FSSM07-D-C	4x3 SG(int)(long), 4x3 SG(int)(tr), 4x1 SG(int)(diap), 2 SG(int)(deck pl)	30
FSSM07-D-W	8x2 SG(int)(long), 8x1 SG(int)(tr), 8x1 SG(int)(diap), SG(int)(deck pl)	33
FSSM07-H-E	4 SG(ext), 4 SG(ext)	8
FSSM07-H-W	4 SG(ext), 4 SG(ext)	8
DRM07-D-E	LD(ext)(exp jt), A(1)(ext)(exp jt), 2x2 HP(ext)(bu), 2 LD(ext)(bu), 2 OT(ext)(bu), 1 A(1)(ext)(be)	11
DRM07-D-C	LD(ext)(exp jt), 4x2 HP(ext)(bu), 4 LD(ext)(bu), 4 OT(ext)(bu), 1 HP(ext)(bt), 1 A(1)(ext)(be)	19
DRM07-D-W	LD(ext)(exp jt), A(1)(ext)(exp jt), 2x2 HP(ext)(bu), 2 LD(ext)(bu), 2 OT(ext)(bu), 1 A(1)(ext)(be)	11
SCM07-PB-E	2 CC(4)(ext), P(ext), IP(ext)	10
SCM07-PB-W	CC(4)(ext)	4
	Total No. Channels:	298

Table 4.12 Modules and Sensors: DAU 08 (deck Sicily tower)

DAU 08 (deck Sicily tower)		
Module Name	Data channels	No. Channels

IEM08-D-E	RH(int), CT(int), SH(int)	3
IEM08-D-C	RH(int), CT(int), SH(int)	3
IEM08-CG-C	RH(int), CT(int), SH(int)	3
IEM08-D-W	RH(int), CT(int), SH(int)	3
PM08-D-E	GPS(3)(ext)	3
PM08-D-W	GPS(3)(ext)	3
EEM08-D-E	WS(3)(ext)	3
EEM08-D-W	WS(3)(ext)	3
DM08-H-E	A(2)(ext), A(2)(ext), A(2)(ext), A(2)(ext)	8
DM08-H-W	A(2)(ext), A(2)(ext), A(2)(ext), A(2)(ext)	8
GSSM08-D-E	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM08-D-C	4 SG(int)(near CG), 4 SG(int)(away from CG), 12 SG(int)(add)	20
GSSM08-D-W	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM08-CG-E	4 SG(int)	4
GSSM08-CG-C	4 SG(int)	4
GSSM08-CG-W	4 SG(int)	4
FSSM08-H-E	4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext)	16
FSSM08-H-W	4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext)	16
DRM08-D-E	2 LD(ext)(exp jt), A(1)(ext)(exp jt), 4x2 HP(ext)(bu), 4 LD(ext)(bu), 4 OT(ext)(bu), 1 LD(ext)(bp), 2 HP(ext)(bt)	22
DRM08-D-W	2 LD(ext)(exp jt), A(1)(ext)(exp jt), 4x2 HP(ext)(bu), 4 LD(ext)(bu), 4 OT(ext)(bu), 1 LD(ext)(bp), 2x2 HP(ext)(bu), 2 LD(ext)(bu), 2 OT(ext)(bu), 1 LD(ext)(bp), 2 HP(ext)(bt)	31
	Total No. Channels:	173

Table 4.13 Modules and Sensors: DAU 09 (deck Sicily 1/6)

DAU 09 (deck Sicily 1/6)		
Module Name	Data channels	No. Channels

IEM09-D-E	RH(int), CT(int), SH(int)	3
IEM09-D-C	RH(int), CT(int), SH(int)	3
IEM09-CG-C	RH(int), CT(int), SH(int)	3
IEM09-D-W	RH(int), CT(int), SH(int)	3
EEM09-D-E	WS(3)(ext)	3
EEM09-D-W	WS(3)(ext), CT(ext), SH(ext)	5
RCM09-D-E	RT(ext), RG(ext)	2
RCM09-D-W	RT(ext), RG(ext)	2
PM09-D-E	GPS(3)(ext)	3
PM09-D-W	GPS(3)(ext)	3
PM09-MC-E	GPS(3)(ext)	3
PM09-MC-W	GPS(3)(ext)	3
DM09-CG-E	A(3)(int)	3
DM09-CG-W	A(3)(int)	3
DM09-MC-E	2 A(3)(ext)	6
DM09-MC-W	2 A(3)(ext)	6
DM09-H-E	A(2)(ext), A(2)(ext), A(2)(ext), A(2)(ext)	8
DM09-H-W	A(2)(ext), A(2)(ext), A(2)(ext), A(2)(ext)	8
GSTM09-D-E	4 ST(int)	4
GSTM09-D-C	4 ST(int)	4
GSTM09-D-W	4 ST(int)	4
GSTM09-CG-E	4 ST(int)	4
GSTM09-CG-W	4 ST(int)	4
LSTM09-D-C	6 ST(int)	6
GSSM09-D-E	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM09-D-C	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM09-D-W	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM09-CG-E	4 SG(int)	4

GSSM09-CG-C	4 SG(int)	4
GSSM09-CG-W	4 SG(int)	4
GSSM09-H-E	2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext)	8
GSSM09-H-W	2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext)	8
FSSM09-D-E	8x2 SG(int)(long), 8x1 SG(int)(tr), 8x1 SG(int)(diap), SG(int)(deck pl)	33
FSSM09-D-C	4x3 SG(int)(long), 4x3 SG(int)(tr), 4x1 SG(int)(diap), 2 SG(int)(deck pl)	30
FSSM09-D-W	8x2 SG(int)(long), 8x1 SG(int)(tr), 8x1 SG(int)(diap), SG(int)(deck pl)	33
	Total No. Channels:	244

Table 4.14 Modules and Sensors: DAU 10 (deck Sicily 1/3)

DAU 10 (deck Sicily 1/3)		
Module Name	Data channels	No. Channels
IEM10-D-E	RH(int), CT(int), SH(int)	3
IEM10-D-C	RH(int), CT(int), SH(int)	3
IEM10-CG-C	RH(int), CT(int), SH(int)	3
IEM10-D-W	RH(int), CT(int), SH(int)	3
EEM10-D-E	WS(2)(ext), WD(ext)	3
EEM10-D-W	WS(2)(ext), WD(ext)	3
PM10-D-E	GPS(3)(ext)	3
PM10-D-W	GPS(3)(ext)	3
PM10-MC-E	GPS(3)(ext)	3
PM10-MC-W	GPS(3)(ext)	3
DM10-CG-E	A(3)(int)	3
DM10-CG-W	A(3)(int)	3
DM10-MC-E	2 A(3)(ext)	6

DM10-MC-W	2 A(3)(ext)	6
GSTM10-D-C	1 ST(ext)(rt)	1
GSSM10-D-E	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM10-D-C	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM10-D-W	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM10-CG-E	4 SG(int)	4
GSSM10-CG-C	4 SG(int)	4
GSSM10-CG-W	4 SG(int)	4
GSSM10-H-E	2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext)	12
GSSM10-H-W	2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext)	12
	Total No. Channels:	109

Table 4.15 Modules and Sensors: DAU 11 (deck mid-span)

DAU 11 (deck mid-span)		
Module Name	Data channels	No. Channels
IEM11-MC-E	9 CR(int), 9 CR (int)	18
IEM11-MC-W	9 CR(int), 9 CR (int)	18
IEM11-D-E	RH(int), CT(int), SH(int)	3
IEM11-D-C	RH(int), CT(int), SH(int)	3
IEM11-CG-C	RH(int), CT(int), SH(int)	3
IEM11-D-W	RH(int), CT(int), SH(int)	3
EEM11-D-E	WS(3)(ext)	3
EEM11-D-W	WS(3)(ext), RH(ext), CT(ext), SR(ext)	6
DWM11-D-E	4 WS(3)(ext)	12
DWM11-D-W	4 WS(3)(ext)	12
RCM11-D-E	RT(ext)	1
RCM11-D-W	RT(ext)	1
PM11-D-E	GPS(3)(ext)	3

PM11-D-W	GPS(3)(ext)	3
PM11-MC-E	GPS(3)(ext)	3
PM11-MC-W	GPS(3)(ext)	3
DM11-CG-E	A(3)(int)	3
DM11-CG-W	A(3)(int)	3
DM11-MC-E	2 A(3)(ext)	6
DM11-MC-W	2 A(3)(ext)	6
GSTM11-D-E	4 ST(int)	4
GSTM11-D-C	4 ST(int)	4
GSTM11-D-W	4 ST(int)	4
GSTM11-CG-E	4 ST(int)	4
GSTM11-CG-W	4 ST(int)	4
GSTM11-MC-E	3 ST(ext), 3 ST(ext)	6
GSTM11-MC-W	3 ST(ext), 3 ST(ext)	6
GSSM11-D-E	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM11-D-C	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM11-D-W	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM11-CG-E	4 SG(int)	4
GSSM11-CG-C	4 SG(int)	4
GSSM11-CG-W	4 SG(int)	4
GSSM11-MC-E	2 SG(3)(ext)(clamp), 2 SG(3)(ext)(clamp)	12
GSSM11-MC-W	2 SG(3)(ext)(clamp), 2 SG(3)(ext)(clamp)	12
FSSM11-H-E	4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext)	24
FSSM11-H-W	4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext)	24
	Total No. Channels:	253

Table 4.16 Modules and Sensors: DAU 12 (deck Calabria 1/3)

DAU 12 (deck Calabria 1/3)		

Module Name	Data channels	No. Channels
IEM12-D-E	RH(int), CT(int), SH(int)	3
IEM12-D-C	RH(int), CT(int), SH(int)	3
IEM12-CG-C	RH(int), CT(int), SH(int)	3
IEM12-D-W	RH(int), CT(int), SH(int)	3
EEM12-D-E	WS(2)(ext), WD(ext)	3
EEM12-D-W	WS(2)(ext), WD(ext)	3
PM12-D-E	GPS(3)(ext)	3
PM12-D-W	GPS(3)(ext)	3
PM12-MC-E	GPS(3)(ext)	3
PM12-MC-W	GPS(3)(ext)	3
DM12-CG-E	A(3)(int)	3
DM12-CG-W	A(3)(int)	3
DM12-MC-E	2 A(3)(ext)	6
DM12-MC-W	2 A(3)(ext)	6
GSTM12-D-C	1 ST(ext)(rt)	1
GSSM12-D-E	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM12-D-C	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM12-D-W	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM12-CG-E	4 SG(int)	4
GSSM12-CG-C	4 SG(int)	4
GSSM12-CG-W	4 SG(int)	4
GSSM12-H-E	2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext)	12
GSSM12-H-W	2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext)	12
	Total No. Channels:	109

Table 4.17 Modules and Sensors: DAU 13 (deck Calabria 1/6)

DAU 13 (deck Calabria 1/6)		

Module Name	Data channels	No. Channels
IEM13-D-E	RH(int), CT(int), SH(int)	3
IEM13-D-C	RH(int), CT(int), SH(int)	3
IEM13-CG-C	RH(int), CT(int), SH(int)	3
IEM13-D-W	RH(int), CT(int), SH(int)	3
EEM13-D-E	WS(3)(ext)	3
EEM13-D-W	WS(3)(ext), CT(ext), SH(ext)	5
RCM13-D-E	RT(ext), RG(ext)	2
RCM13-D-W	RT(ext), RG(ext)	2
PM13-D-E	GPS(3)(ext)	3
PM13-D-W	GPS(3)(ext)	3
PM13-MC-E	GPS(3)(ext)	3
PM13-MC-W	GPS(3)(ext)	3
DM13-CG-E	A(3)(int)	3
DM13-CG-W	A(3)(int)	3
DM13-MC-E	2 A(3)(ext)	6
DM13-MC-W	2 A(3)(ext)	6
DM13-H-E	A(2)(ext), A(2)(ext), A(2)(ext), A(2)(ext)	8
DM13-H-W	A(2)(ext), A(2)(ext), A(2)(ext), A(2)(ext)	8
GSTM13-D-E	4 ST(int)	4
GSTM13-D-C	4 ST(int)	4
GSTM13-D-W	4 ST(int)	4
GSTM13-CG-E	4 ST(int)	4
GSTM13-CG-W	4 ST(int)	4
LSTM13-D-C	6 ST(int)	6
GSSM13-D-E	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM13-D-C	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM13-D-W	4 SG(int)(near CG), 4 SG(int)(away from CG)	8

GSSM13-CG-E	4 SG(int)	4
GSSM13-CG-C	4 SG(int)	4
GSSM13-CG-W	4 SG(int)	4
GSSM13-H-E	2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext)	8
GSSM13-H-W	2 SG(ext), 2 SG(ext), 2 SG(ext), 2 SG(ext)	8
	Total No. Channels:	148

Table 4.18 Modules and Sensors: DAU 14 (deck Calabria tower)

DAU 14 (deck Calabria tower)		
Module Name	Data channels	No. Channels
IEM14-D-E	RH(int), CT(int), SH(int)	3
IEM14-D-C	RH(int), CT(int), SH(int)	3
IEM14-CG-C	RH(int), CT(int), SH(int)	3
IEM14-D-W	RH(int), CT(int), SH(int)	3
PM14-D-E	GPS(3)(ext)	3
PM14-D-W	GPS(3)(ext)	3
EEM14-D-E	WS(3)(ext)	3
EEM14-D-W	WS(3)(ext)	3
DM14-H-E	A(2)(ext), A(2)(ext), A(2)(ext), A(2)(ext)	8
DM14-H-W	A(2)(ext), A(2)(ext), A(2)(ext), A(2)(ext)	8
GSSM14-D-E	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM14-D-C	4 SG(int)(near CG), 4 SG(int)(away from CG), 12 SG(int)(add)	20
GSSM14-D-W	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM14-CG-E	4 SG(int)	4
GSSM14-CG-C	4 SG(int)	4
GSSM14-CG-W	4 SG(int)	4
FSSM14-H-E	4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext)	16
FSSM14-H-W	4 SG(ext), 4 SG(ext), 4 SG(ext), 4 SG(ext)	16

DRM14-D-E	2 LD(ext)(exp jt), A(1)(ext)(exp jt), 4x2 HP(ext)(bu), 4 LD(ext)(bu), 4 OT(ext)(bu), 1 LD(ext)(bp), 2 HP(ext)(bt)	22
DRM14-D-W	2 LD(ext)(exp jt), A(1)(ext)(exp jt), 4x2 HP(ext)(bu), 4 LD(ext)(bu), 4 OT(ext)(bu), 1 LD(ext)(bp), 2x2 HP(ext)(bu), 2 LD(ext)(bu), 2 OT(ext)(bu), 1 LD(ext)(bp), 2 HP(ext)(bt)	31
	Total No. Channels:	173

Table 4.19 Modules and Sensors: DAU 15 (deck Calabria end)

DAU 15 (deck Calabria end)		
Module Name	Data channels	No. Channels
IEM15-D-E	RH(int), CT(int), SH(int)	3
IEM15-D-C	RH(int), CT(int), SH(int)	3
IEM15-CG-C	RH(int), CT(int), SH(int)	3
IEM15-D-W	RH(int), CT(int), SH(int)	3
RCM15-D-E	RT(ext)	1
RCM15-D-W	RT(ext)	1
PM15-D-E	GPS(3)(ext)	3
PM15-D-W	GPS(3)(ext)	3
PM15-MC-E	GPS(3)(ext)	3
PM15-MC-W	GPS(3)(ext)	3
PM15-PB-E	GPS(3)(ext)	3
PM15-PB-W	GPS(3)(ext)	3
DM15-MC-E	2 A(3)(ext)	6
DM15-MC-W	2 A(3)(ext)	6
DM15-H-E	A(2)(ext), A(2)(ext)	4
DM15-H-W	A(2)(ext), A(2)(ext)	4
DM15-PB-C	2 DIN(2)(ext)	4
GSTM15-D-E	4 ST(int)	4

GSTM15-D-C	4 ST(int), 1 ST(ext)(rt)	5
GSTM15-D-W	4 ST(int)	4
GSTM15-CG-E	4 ST(int)	4
GSTM15-CG-W	4 ST(int)	4
GSSM15-D-E	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM15-D-C	4 SG(int)(near CG), 4 SG(int)(away from CG) , 6 SG(int)(add)	14
GSSM15-D-W	4 SG(int)(near CG), 4 SG(int)(away from CG)	8
GSSM15-CG-E	4 SG(int)	4
GSSM15-CG-C	4 SG(int)	4
GSSM15-CG-W	4 SG(int)	4
GSSM15-MC-E	3 SG(ext), 3 SG(ext)	6
GSSM15-MC-W	3 SG(ext), 3 SG(ext)	6
FSSM15-H-E	4 SG(ext), 4 SG(ext)	8
FSSM15-H-W	4 SG(ext), 4 SG(ext)	8
DRM15-D-E	LD(ext)(exp jt), A(1)(ext)(exp jt), 2x2 HP(ext)(bu), 2 LD(ext)(bu), 2 OT(ext)(bu), 1 A(1)(ext)(be)	11
DRM15-D-C	LD(ext)(expjt), 4x2 HP(ext)(bu), 4 LD(ext)(bu), 4 OT(ext)(bu), 1 HP(ext)(bt), 1 A(1)(ext)(be)	19
DRM15-D-W	LD(ext)(exp jt), A(1)(ext)(exp jt), 2x2 HP(ext)(bu), 2 LD(ext)(bu), 2 OT(ext)(bu) ,1 A(1)(ext)(be)	11
SCM15-PB-E	2 CC(4)(ext), P(ext), IP(ext)	10
SCM15-PB-W	CC(4)(ext)	4
	Total No. Channels:	202

4.9 Additional Sensor Set

An additional sensor set shall to be provided, which shall be available for installation following construction of the bridge and following initial studies into the structural behaviour of the bridge. The additional sensor set shall not be considered as a set of spare sensors. The additional sensor set shall be supplied with all the hardware necessary,including cabling, to link all of the sensors to the DAUs. The DAUs are to be assumed to be located at up to 200m from the additional sensors. All deck DAUs shall be detailed so that the full complement of the additional deck sensor set can be attached to any of the deck DAUs. All tower DAUs and IDRUs shall be detailed so that the full complement of the additional tower sensor set can be attached to any of the tower DAUs and IDRUs. The SHMS MFS shall be detailed for inclusion of the additional sensor set. The installation of these sensors shall be the responsibility of the bridge operator.

The purpose of this additional sensor set is to provide flexibility to the monitoring scheme so that sensors can be installed in critical locations identified from structural behaviour studies that may not otherwise be known until the construction of the bridge has been completed. If the structural behaviour studies do not identify additional locations for monitoring, these sensors could then be installed so as to introduce additional redundancy at nominated sensors. When installed for additional redundancy, the sensors shall not be connected to the DAUs, but shall only be available for reconnection upon failure of the nominated sensor.

The additional deck sensor set shall consist of:

- 12no. A(2) for monitoring of hanger vibrations
- 4no. A(3) for monitoring of deck vibrations
- 96no. SG for monitoring of deck fatigue stress

The additional tower sensor set shall consist of:

- 16no. SG for monitoring of tower stress

2no. additional DAU units shall be provided to support, if found to be required, the installation of the additional deck sensor set. Each additional DAU shall be detailed to support the full complement of additional deck sensors.

4.10 Calibration Strain Sensor Set

A calibration strain sensor set shall be provided, which shall be installed at the same time as the 'active' strain sensors next to which they are to be installed. The calibration strain sensors shall allow the 'active' strain sensors to be calibrated at regular intervals, and shall allow the accurate calibration of replacement 'active' strain sensors. The calibration strain sensors shall not be connected to the SHMS data management system.

The calibration strain sensor set shall consist of:

- 96no. CSG to be installed on the legs of the towers
- 240no. CSG to be installed on the longitudinal deck girders

Readings from the calibration sensors shall be provided through the portable monitoring computers and the portable montoring servers. The calibration strain sensor set shall be reviewed, within the context of the completed structural design, at the start of Progetto Esecutivo by the SHMS designer in collaboration with the bridge structural designers.

4.11 Hardware Summary

The data management system will consist of:

- 15no. DAUs
- Up to 2no. additional DAUs assigned to the additional sensor set
- 16no. tower IDRUs
- Other IDRUs as required
- 2no. SHMS MFSs (primary and back-up)

The SHMS DSS shall be an allocated partition of the SCADA data storage provided as part of SCADA.

The DAUs and IDRUs will be capable of storing a pre-defined duration of processed data in case of connection failure to the SHMS MFS. The DAUs will also have a dedicated pre-defined data buffer to facilitate processing of triggered alarms. The SHMS MFS will have a dedicated pre-defined data buffer to allow access to recent data from other components of the SCADA, as well as to facilitate processing of triggered alarms.

A summary of the main sensor array is given in Table 4.20. A summary of the additional sensor array is given in Table 4.21. A summary of the calibration strain sensor array is given in Table 4.22.

Table 4.20 Summary of Main Sensor Array

Sensor	Number of Sensors
AD e.g. WS(3), WS(2)&WD	40
GPS(3)	58
CT(ext)	7
CT(int)	66
SR	3
RH(ext)	5
RH(int)	286
CR(int)	252
B	4
RG	4
SH(ext)	2
SH(int)	36
RT	10
A(1)	14
A(2)	40
A(3)	52
SA(3)	16
SIN(2)	20
DIN(2)	26
ST	772
SG	1264
SG(3)	24
LD	96
HP	82
OT	36

CC	20
P	6
IP	10
PORTABLE A(2)	16
PORTABLE VIDEO SENSOR	33
MICROWAVE INTERFEROMETRIC RADAR	1
Total	3301

Table 4.21 Summary of Additional Sensor Set Array

Sensor	Number of Sensors
A(2)	12
A(3)	4
SG	112
Total	128

Table 4.22 Summary of Calibration Strain Sensor Set Array

Sensor	Number of Sensors
CSG	336
Total	336

Traffic (vehicle) load and traffic (rail) load measurements will form part of the Network TMS. Traffic flow monitoring at discrete locations will also be provided as part of the Network TMS and Bridge TMS. Data will be available to the SHMS for processing.

3no. portable monitoring computers and 3no. portable monitoring servers will be provided for on-site monitoring activities.

4.12 Layout Drawings

The primary layout of the system is shown in the drawings listed in Table 4.23.

Table 4.23 SHMS Overview drawings

CG1000-P1LDPIT-M3SM000000-01	SHMS Overview: Towers and Foundations
CG1000-P1LDPIT-M3SM000000-02	SHMS Overview: Deck
CG1000-P1LDPIT-M3SM000000-03	SHMS Overview: Hangers and Main Cables

5 Sensor Minimum Requirements

5.1 General

5.1.1 Minimum Protection Rating

Minimum protection rating of IP65 as defined by IEC 60529 shall be provided for all components (e.g. sensors, loggers, other hardware, cabling, interfaces, seals, glands, etc). Minimum protection rating of IP66W shall be provided for all external components. All external components shall be suitable for a marine environment. If the component itself does not have sufficient protection rating, then protection shall be detailed and installed so that the component has equivalent minimum protection rating. Cabinets may be detailed and installed to provide equivalent minimum rating. Cabinets shall need to be secured to the structure. Data cables running external to the structure shall be protected against damage from wind. Liaison with the bridge structural designers shall be required.

5.1.2 Durability

All equipment shall be of high quality and robust construction, and capable of resisting accidental damage. Accidental damage is a particular risk during bridge construction since equipment shall be installed during fabrication and before site assembly. All equipment shall be capable of resisting a mechanical shock resulting from a drop of 1.5m (5ft). Equipment commonly used in offshore installation is preferable. A damage risk assessment shall be carried out for any item that does not satisfy this criterion. The risk assessment shall identify all actions that represent risk of damage to the item, through the life of the item from delivery. Special precautions shall be identified and applied for each action representing a risk of damage. Special precautions may include the provision of additional packing, the construction of a protective container, the installation of notices, etc. Appropriately detailed and installed cabinets shall be provided for all data-loggers and hardware. Cabinets shall be secured to the structure, shall have no leverage points, shall be fitted where possible with anti-tamper fixings and shall be provided with locks to prevent opportunist theft. Liaison with the bridge structural designers shall be required. Data and power cables shall be not be connected directly to the structural steelwork. Good house-keeping practices shall be applied to the installation of data and power cables. Appropriately detailed and installed cable ducts and cable-trays shall be provided for all data and power cables. Liaison with the bridge structural designers shall also be required.

5.1.3 Vibration

Bridges are dynamic structures that experience continuous vibrations due to wind, traffic, etc..All components (e.g. sensors, loggers, other hardware, cabling, interfaces, seals, glands, cabinets, ducts, fixings, connections, etc) shall be detailed and installed with due consideration of continuous structural vibrations including:

- low frequency large amplitude vibration of the whole bridge
- high frequency small amplitude vibration of the local structural element

In particular all components shall function correctly under vibrations of the bridge structures induced by:

- Railways: about 200 trains a day
- Road traffic: about 140,000 cars a day
- High wind velocities

The components shall withstand earthquake vibrations and shock of the bridge structures.

5.1.4 Protection from Birds

Where practical, all external sensors shall be provided with protection against interference from birds including direct contact and bird droppings. Protection that is provided shall not interfere with the operation and readings of the sensors, nor shall it interfere with structural behaviour or services provided on the structure e.g. gantries.

5.1.5 Electrical Protection

All components shall be provided with sufficient protection against electrical surge from power fluctuations, Electro-Magnetic Interference (EMI) related to the railway, lightning strike, and Electro-Magnetic Pulses (LEMP) generated by lightning strike. Protection can be in the form of lightning arrests, grounding system power-surge fuse circuits (switch-based), optical bridges, etc.

Lightning finials shall be provided to all booms and masts provided for SHMS components. Lightning finials shall be connected to the bridge structural steel. The path for the electrical surge shall be capable of transferring the surge without deterioration to the instrumentation or structural components. Refer to document CG1001-P-2S-D-P-IT-M4-C3-00-00-00-06 “Design Specifications - Mechanical and Electrical Works” for further discussion.

Data-cables from sensors installed on all booms and masts, as well as installed externally at the tower tops, shall be optically isolated from the remainder of the SHMS system and provided with lightning protection fuses.

All data-loggers and hardware shall be provided with power-surge fuse circuits.

5.1.6 Power Supply

Power shall be supplied to the SHMS from a dedicated 230V power supply, installed by others as part of the general services to the bridge. Refer to document CG1001-P-2S-D-P-IT-M4-C3-00-00-00-06 “Design Specifications - Mechanical and Electrical Works”. Sensors shall be powered from the loggers through power-cables. Loggers shall be plugged into cabinet-sockets within the appropriately detailed and installed secure and appropriately rated cabinets. Cabinet-sockets shall be fed from a power cable connected to the dedicated power supply. The power cable shall be connected to the power supply with unique plugs to connect to unique sockets that shall only be capable of receiving plugs from the SHMS system. The unique sockets shall be located in appropriately detailed and installed power-supply-cabinets. The unique sockets and power-supply-cabinets, and unique plugs, are to be provided by others responsible for providing the power supply. If transformers are required these are to be provided with the loggers.

UPS shall be supplied to all loggers. The UPS shall ensure a minimum of 6hrs operation of the sensors and loggers in the event of power interruption. The UPS shall charge from the power supply when power supply is not interrupted.

5.1.7 Data Sampling Resolution

All data shall be sampled with minimum 24-bit resolution.

5.1.8 Data Sampling Rates

For minimum required data sampling rates refer to Table 10.1.

5.1.9 Temporary Data Storage

Loggers shall be provided with data storage capability for temporary data storage in the event of connection failure to the IDRUs and DAUs for data transfer. Sufficient data storage shall be provided for 24hrs of data collection. Data collected in the temporary data store shall not be overwritten once the data store is full. The data store shall be cleared once data has been transferred to the IDRUs and DAUs. The data store shall only be cleared by instruction from the IDRUs and DAUs once successful data transfer is confirmed. Data that is stored shall not be lost in the event of complete power failure and logger shutdown.

5.1.10 Fixings to Main Structure

The attachment of any component to the structure shall not damage the structure or protective system (e.g. paint system or similar). If the removal of the protective system is necessary for installation, for example for the installation of strain sensors, then the protective system shall be re-instated after installation.

Components that are in contact with the structure shall not induce corrosion of the structure or sacrifice existing bimetallic protective coatings.

5.1.11 Colour

All components of the SHMS that are installed externally shall be provided in a colour that matches the final colour scheme of the structural element to which it is attached unless otherwise specified or agreed with the SHMS designer.

5.2 Specific

A list of example equipment is provided in Appendix 3. Sampling speed requirements, for each sensor type, are discussed in section 10 and given in table 10.1.

5.2.1 Tri-axial Sonic Anemometer

Tri-axial sonic anemometer for the measurement of wind characteristics in 3 axes, WS(3).

Sensor Type	Ultra-sonic
Measuring Parameters	Measurement in 3 orthogonal directions U, V and W. U is to be aligned parallel to the deck alignment towards Sicily, W is true vertical upwards, leaving V as perpendicular to the bridge alignment.
Speed of Sound C	340 m/s
Wind Speed Range	0 to 65m/s
Wind Speed Resolution	0.01 m/s
Wind Speed Accuracy	<+/-1% RMS
Wind Direction Range	Full 3D: 0 to 360degs in plan, -90 to 90degs vertically
Wind Direction Resolution	1 degs
Wind Direction Accuracy	<+/-1 degs
Speed of Sound Range	300-370 m/s
Speed of Sound Resolution	0.01m/s
Speed of Sound Accuracy	<+/-5% at 20 degC
Gust Survival Wind Speed	100 m/s
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature Range	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

Installation of anemometer to the tower legs: the anemometer shall be installed on a stiff boom extending out Eastwards or Westwards from the East and West tower legs respectively. The anemometer is to be positioned between 5m and 10m away from the outer face of the tower leg. The final offset shall be established during Progetto Esecutivo, following the completion of the bridge wind studies. The boom, local supporting structures and ancillaries must not interfere with the free-flow wind field being measured, nor with the operation of the tower maintenance gantries. The boom shall be detailed so that the anemometer can be accessed from an access hole through the tower leg or from an external platform (if provided). The detailing of the boom structure shall be undertaken during Progetto Esecutivo when tower external access and platform details, detailed tower structural details, tower gantry details and internal and external fit-out details are known. The preliminary design concept for the boom is a lattice structure, hinged at the base, and stabilised with stays that feed around sheaves and up to the access position at the boom length above the base. The anemometer and boom are to be detailed for an ultimate limit state condition of 100m/s factored wind speed. A material partial safety factor of 1.05 (members) 1.25 (connections) is to be included. The boom is to be detailed to minimise inference to readings from vibration, and shall be detailed for the manufacturer's minimum requirements. If the dynamics of the supporting structure exceeds the manufacturer's minimum requirements or the performance requirements, then a tri-axial accelerometer shall be added, or the tip of the boom shall be stayed. All power and data cables shall be fed where practicable through the centre of the posts. Where power and data cables are to be fed externally down posts, these are to be arranged in a spiral and secured regularly. Power and data cable arrangement shall be subject to the approval of the SHMS designer.

Installation of anemometer to the deck not adjacent to the towers: the anemometer shall be installed to the top of a 1m tall still vertical mast installed onto the top of the wind-shield, in-line with the stiff vertical structural posts. The mast, local supporting structures and ancillaries must not interfere with the free-flow wind field being measured nor the operation of the deck maintenance gantries. The anemometer and mast are to be detailed for an ultimate limit state condition of 100m/s factored wind speed. A material partial safety factor of 1.05 (members) 1.25 (connections) is to be included. The mast and support structures are to be detailed to minimise inference to readings from vibration, and shall be detailed for the manufacturer's minimum requirements. If the dynamics of the supporting structure exceeds the manufacturer's minimum requirements or the performance requirements, then a tri-axial accelerometer shall be added. All power and data cables shall be fed where practicable through the centre of the posts. Where power and data cables are to be fed externally down posts, these are to be arranged in a spiral and secured regularly. Power and data cable arrangement shall be subject to the approval of the SHMS designer.

Installation of anemometer to the deck adjacent to the towers: the anemometer shall be installed adjacent to the first stool of the main span. The anemometer shall be installed to the top of a 1m tall still vertical mast installed onto bespoke frame structure. The bespoke frame structure shall be attached to the top of the wind-shield, in-line with the stiff vertical structural posts, and to the sloping web in-between the pair of hanger cables. It shall be detailed so that the anemometer is positioned 6m above the deck and shall be provided with a hinge and locking mechanism so that the horizontal bar across the access path can be swung round to provide clearance for tall vehicles. The mast, bespoke frame structure, local supporting structures and ancillaries must not interfere with the free-flow wind field being measured nor the operation of the deck maintenance gantries. The anemometer, mast and bespoke frame structure are to be detailed for an ultimate limit state condition of 100m/s factored wind speed. A material partial safety factor of 1.05 (members) 1.25 (connections) is to be included. The bespoke frame structure, mast and support structures are to be detailed to minimise inference to readings from vibration, and shall be detailed for the manufacturer's minimum requirements. If the dynamics of the supporting structures exceeds the manufacturer's minimum requirements or the performance requirements, then a tri-axial accelerometer shall be added. All power and data cables shall be fed where practicable through the centre of the posts. Where power and data cables are to be fed externally down posts, these are to be arranged in a spiral and secured regularly. Power and data cable arrangement shall be subject to the approval of the SHMS designer.

Wind speed data is to be provided in m/s.

5.2.2 Tri-axial Mechanical Anemometer

Tri-axial mechanical anemometer for the measurement of wind characteristics in 3 axes, WS(2)&WD.

Sensor Type	Mechanical
Measuring Parameters	Measurement as plan wind speed and wind direction with local North aligned parallel to the deck alignment towards Sicily, and vertical wind speed.
Plan Wind Speed Range	0 to 65m/s

Vertical Wind Speed Range	-25 to 25 m/s
Wind Speed Resolution	0.1 m/s
Wind Speed Accuracy	<+/-0.3 m/s or 1% of reading
Plan Wind Direction Range	0 to 360 degs
Plan Wind Direction Resolution	1 degs
Plan Wind Direction Accuracy	<+/-3 degs
Gust Survival Wind Speed	100 m/s
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature Range	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300 mm/hr
Power Supply	24 VDC

Installation of anemometer to the tower tops: the anemometer shall be installed on a stiff vertical mast secured at the centre of the saddle and stayed to the hand-strand posts. The anemometer is to be positioned 6m above the top of the saddle. The mast, local supporting structures and ancillaries must not interfere with the free-flow wind field being measured, nor with the operation of the main cable maintenance gantries or access to the main cable. The mast is to incorporate a hinge, locking mechanism and counter-balance, so that the anemometer can be lowered so that it can be accessed without climbing of the mast. The anemometer and mast are to be detailed for an ultimate limit state condition of 100m/s factored wind speed. A material partial safety factor of 1.05 (members) 1.25 (connections) is to be included. The mast and support structures are to be detailed to minimise inference to readings from vibration, and shall be detailed for the manufacturer's minimum requirements. If the dynamics of the supporting structures exceeds the manufacturer's minimum requirements or the performance requirements, then a tri-axial accelerometer shall be added. All power and data cables shall be fed where practicable through the centre of the posts. Where power and data cables are to be fed externally down posts, these are to be arranged in a spiral and secured regularly. Power and data cable arrangement shall be subject to the approval of the SHMS designer.

Installation of anemometer to the deck at the third points: the anemometer shall be installed on the top of a 1m tall stiff vertical mast installed onto the top of the wind-shield, in-line with the stiff vertical structural posts. The mast, local supporting structures and ancillaries must not interfere with the free-flow wind field being measured, nor with the operation of the deck maintenance gantries. The anemometer is to be detailed for an ultimate limit state condition of 100m/s factored wind speed. A material partial safety factor of 1.05 (members) 1.25 (connections) is to be included. The mast and support structures are to be detailed to minimise inference to readings from vibration, and shall be detailed for the manufacturer's minimum requirements. If the dynamics of the supporting structures exceeds the manufacturer's minimum requirements or the performance requirements, then a tri-axial accelerometer shall be added. All power and data cables shall be fed where practicable through the centre of the posts. Where power and data cables are to be fed externally down posts, these are to be arranged in a spiral and secured regularly. Power and data cable arrangement shall be subject to the approval of the SHMS designer.

Wind speed data is to be provided in m/s.

Wind direction data is to be provided relative to true North. Wind direction data is to be provided in degrees East of true North.

5.2.3 GPS receiver

GPS receiver for the measurement of node co-ordinates, GPS.

Sensor Type	Antenna
Position Measurement Range	Actual
Resolution	+/-1 mm
Accuracy	<+/-1 mm
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The deck-installed GPS receiver shall be positioned so that interference to readings from the deck, maintenance gantries, passing vehicles, etc, is minimised. The GPS receiver shall be provided with a physical guard to prevent interference from reflected GPS signals from the sea and structure. The GPS receiver shall be installed onto the top of the wind-shield, in-line with the stiff vertical structural posts.

The tower-installed GPS receiver shall be positioned so that interference to readings from the tower legs, cross-beams, maintenance gantries, etc, is minimised. The GPS receiver shall be provided with a physical guard to prevent interference from reflected GPS signals from the sea and structure. The GPS receiver shall be installed onto the stiff boom provided for the tri-axial sonic anemometer, unless other facilities that are accessible are provided e.g. external platforms or aircraft warning light mounting frames that are accessible. The position shall depend on the access arrangements for maintenance. The current design concept would require the GPS to be installed at end of the boom at 5 to 10m from the tower face.

The GPS receiver installed in the countryside shall be positioned so that interference to readings is minimised. The GPS receiver shall be connected to the WAN network, and shall also be provided with wireless connection to the anchorage DAUs. The wireless connection is required for the construction phase, and shall act as a back-up communication connection in the event of failure of the WAN.

The GPS reference station shall be installed onto the top of the SCADA building. The GPS reference station shall be attached to a stiff part of the SCADA building structure in a position that minimises interference to the readings. The support structure shall itself be stiff, so that the GPS receiver cannot move.

For the GPS receiver installed on the main-cable, if an IDRU is not provided on the cable clamp, the data cable shall feed down to deck-level by spiral down the hangers, with more than 1-turn every 900mm and secured at maximum 1m intervals, before entering into the deck through a drilled hole with gland in the sloping web. The attachments shall not damage the sheath of the hangers. The hole shall be detailed by the bridge structural designers.

Coordinates are typically provided by GPS systems in latitude, longitude and ellipsoid height. This data shall be converted to a cartesian coordinate system (for example UTM-form of coordinates) based on a local geoid.

Plan coordinates shall be provided in m relative to a local reference geoid with plan axes positioned at the location of the GPS reference station installed on the SCADA building.

Height coordinates shall be provided in m relative to a local reference geoid with height axis positioned a mean-sea level of the site.

5.2.4 Air Temperature Sensor (1)

Air Temperature Sensor for the measurement of air temperature of external conditions, CT(ext).

Sensor Type	PT-100 including radiation shield
Measurement Range	-20 to +60degC
Resolution	0.1degC
Accuracy	<+/-0.5degC
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The air temperature sensor shall be positioned at sufficient distance from surfaces so that readings are not affected by surface heat emission and heat reflection, particularly from the main cable and deck surfacing. The air temperature sensor shall be positioned at sufficient height above the road level such that readings are not affected by heat emission from vehicles.

Data is to be provided in deg C.

5.2.5 Air Temperature Sensor (2)

Air temperature sensor for the measurement of air temperature of internal conditions, CT(int).

Sensor Type	PT-100
Measurement Range	-20 to +60degC
Resolution	0.1degC
Accuracy	<+/-0.5degC
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Power Supply	24 VDC

The air temperature sensor shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission.

Data is to be provided in deg C.

5.2.6 Pyrometer

Pyrometer for the measurement of solar radiation, SR.

Sensor Type	High Stability Silicon Photovoltaic Detector
Wavelength Measurement Range	400 to 1100 nanometers
Solar Radiation Intensity Measurement Range	0 to 2000 W/m2
Resolution	+/-50 W/m2
Accuracy	<+/-50 W/m2
Field of View	180 degrees
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC

Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The pyrometer shall be installed in a position that does not create interference to readings from shade. The pyrometer shall be installed to avoid shade created by, inter alia:

- Vehicles (road and rail) on the deck structure
- Ancillary items (non-structural) such as wind-shields, lamp-posts, minor support steelwork, cables, other instrumentation, etc.
- Gantries
- Main-cables
- Hangers

Data is to be provided in W/m2.

5.2.7 Hygrometer (1)

Hygrometer for the measurement of relative humidity of external conditions, RH(ext).

Sensor Type	Capacitance including radiation shield
Measurement Range	0 to 100%
Resolution	0.5%
Accuracy	<+/-2%
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The hygrometer shall be positioned at sufficient height above horizontal surfaces so that readings are not affected by local ponding, splash and spray. The hygrometer shall be positioned at sufficient distance from water-related services so that readings are not affected by breaks of service equipment or use of the services.

Data is to be provided in %Relative Humidity.

5.2.8 Hygrometer (2)

Hygrometer for the measurement of relative humidity of internal conditions, RH(int).

Sensor Type	Capacitance
Measurement Range	0 to 100%
Resolution	0.5%
Accuracy	<+/-2%
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Power Supply	24 VDC

The hygrometer shall be positioned at sufficient distance from water-related services so that readings are not affected by breaks of service equipment or use of the services.

Data is to be provided in %Relative Humidity.

5.2.9 Fibre-optic Relative Humidity Sensor

Fibre-optic relative humidity sensor for measurement of relative humidity within the main-cables using embedded multiple sensor, RH(int).

Sensor Type	Embedded stress-free and temperature-compensated fibre-optic cable with Fibre-Bragg-Grating inscribed hygrometer cells and with Fibre-Bragg-Grating multiplexor-interrogator for relative humidity readings. Temperature compensation

	can be applied using readings from a nearby fibre-optic temperature sensor.
Temperature Compensation	Yes
No. of measurement points per fibre-optic cable	11
Cable outside diameter (including outer sheath)	5.4mm
Durability Strain Range	0 to 7,000 micro-strain (tension)
Measurement Range	0 to 100%
Resolution	1%
Accuracy	<+/-1%
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required to survive installation procedure; reel diameter = 1500 mm; in-service radial stress = 15 MPa
Power Supply	24 VDC

The fibre-optic relative humidity sensors shall not be located within 1m of a cable clamp.

The measurement of relative humidity with fibre-optic cables is not currently well established. Research has however been conducted into the development and use of hygrometer cells in fibre-optic cables for the measurement of relative humidity, for example:

- spliced segment of polymer optical fibre, based on polymethyl methacrylate (PMMA), with Fibre-Bragg-Grating
- Fibre-Bragg-Grating coated with polyimide
- long-period Fibre-Bragg-Grating coated with a thin film of silica nanospheres

The approach that shall be adopted shall be that approach that is demonstrated to be the most reliable. Proving tests shall be required for this assessment.

The fibre-optic cables shall be installed within the main cable via the main-cable strand fabrication and installation process. The fibre-optic cable shall replace one of the top surface wires of the strand. A maximum of one fibre-optic cable shall be installed within a strand. The fibre-optic cable shall be installed on a standard reel appropriate to the fabrication of the strand. The fibre-optic cable will be pulled from the reel, and will be assembled and compacted with the other steel wires to form the strand. The strand will be fitted with form-retaining straps, and will be fed directly onto a storage and transportation reel. The fibre-optic cable will not be included in the formation of the sockets at each end of the strand so that they can be accessed for signal interrogation. The fibre-optic cable shall be fitted with a splice at each end, and any remaining unsupported length of the fibre-optic cable shall be strapped securely to the strand, to protect the fibre-optic cable from damage due to handling of the strand. On-site the strand will be pulled from the transportation reel, and will be dragged across the bridge over the saddles at the anchor blocks and tower tops to be placed in position within the main-cable. The assembled strands will be compacted and fitted with cable clamps and wrapping-wire. The installation of fibre-optic cables in this manner is unproven. The fibre-optic cables will need to be formed to the shape and diameter of the steel wires. The sheave will need to be appropriately detailed for survivability of the installation process as well as function. The fibre-optic cable shall be appropriately detailed so as not to influence cathodic deterioration of the main-cable. Proving trials shall be required to ensure development of a fibre-optic cable that will survive the installation process and function as required.

Multi-channel multiplexor-interrogator units and switch-type units may be used to optimise data-logger strategy. Multi-channel multiplexor-interrogator units and switch-type units may be shared with other fibre-optic sensors.

The fibre-optic cable that emerges from the main-cable in the anchor blocks shall be placed in appropriately detailed and installed cable ducts for durability. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission.

Data is to be provided in %Relative Humidity.

5.2.10 Barometer

Barometer for the measurement of air pressure, B.

Sensor Type	No specific requirement
Measurement Range	600 to 1100 hPa
Resolution	1hPa
Accuracy	<+/-1hPa
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

Data is to be provided in hPa.

5.2.11 Rain Gauge

Rain gauge for the measurement of rainfall, RG.

Sensor Type	Tipping bucket with reed-switch to WMO specification
Measurement Range	2cm3 volume of tipping buckets
Measuring Surface	200cm2
Resolution	0.1mm per tip
Accuracy	<+/-5%
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The rain gauge shall be positioned at sufficient height above horizontal surfaces so that readings are not affected by splash and spray. It shall be positioned so that readings are not affected by water-run and drip from nearby structures. It shall also be positioned at sufficient distance from water-related services so that readings are not affected by breaks of service equipment or use of the services.

Data is to be provided in mm/hr.

5.2.12 Surface Hygrometer (1)

Surface hygrometer for the measurement of condensation formation on external surfaces, SH(ext).

Sensor Type	As required
Measurement Range	dry – wet (condensation)
Resolution	N/A
Accuracy	N/A
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Power Supply	24 VDC

The surface hygrometer shall be positioned so that readings are not affected by local ponding, splash and spray. The surface hygrometer shall be positioned at sufficient distance from water-related services so that readings are not affected by breaks of service equipment or use of the services. Readings shall include detection of moisture due to rain.

Data is to be provided as 0 (dry) or 1 (wet).

5.2.13 Surface Hygrometer (2)

Surface hygrometer for the measurement of condensation formation on internal surfaces, SH(int).

Sensor Type	As required
Measurement Range	dry – wet (condensation)

Resolution	N/A
Accuracy	N/A
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Power Supply	24 VDC

The surface hygrometer shall be positioned at sufficient distance from water-related services so that readings are not affected by breaks of service equipment or use of the services.

Data is to be provided as 0 (dry) or 1 (wet).

5.2.14 Road temperature sensor

Road temperature sensor for the measurement of temperature of the road surfacing at the interface with the steel deck plate, RT.

Sensor Type	No specific requirement
Measurement Range	-20 to +60degC
Resolution	0.1degC
Accuracy	<+/-0.5degC
Operating Temperature	-20 to +80 degC
Storage Temperature Range	-20 to +60 degC
Survival Temperature	+250 degC
Operating Humidity Range	0 to 100%
Power Supply	24 VDC

The road temperature sensor shall be secured to the top of the steel deck plate prior to application of the waterproofing layer/road surfacing. The sensor arrangement shall be subject to approval by the bridge structural designers at Progetto Esecutivo. Notionally, the sensor shall be located in the middle of the emergency lane. A 20mm diameter drilled hole with nylon plug shall be provided in the steel deck plate for feeding the data cable. The data cable shall pass through a hole of matching diameter in the nylon plug. The cable shall be secured to the deck by micro-welding a foil restraint. The sensor shall be positioned within 100mm of the hole aligned on a line parallel to the longitudinal axis of the bridge. The hole shall be detailed by the bridge structural designers. The nylon plug and sensor shall be capable of surviving raised temperatures due to the laying of the surfacing.

Data is to be provided in deg C.

5.2.15 1D Accelerometer (1)

1D accelerometer for the measurement of expansion joint vibration, A(1).

Sensor Type	Capacitive
Acceleration Measurement Range	-/+2 g
Frequency Measurement Range	0.05 to 50Hz
Resolution	1000 micro-g
Accuracy	<+/-1000 micro-g
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The accelerometer shall be secured directly to the expansion joint rail, 1.0m from the restrained end of the rail, and below the middle of the slow lane. The data cable shall feed along the rail to the restrained end of the expansion joint rail. The data cable shall be secured directly to the rail.

Data is to be provided in m/s^2.

The axis shall be aligned vertical upwards.

5.2.16 1D Accelerometer (2)

1D accelerometer for the measurement of expansion joint bearing vibration, A(1).

Sensor Type	Capacitive
Acceleration Measurement Range	-/+2 g
Frequency Measurement Range	0.05 to 50Hz
Resolution	1000 micro-g
Accuracy	<+/-1000 micro-g
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The accelerometer shall be attached to the vertical support of the bridge deck structure, 100mm above the bearing. Cables shall be secured so that they are not at risk of damage from the movements of the bridge deck relative to the terminal structure.

Data is to be provided in m/s^2.

The axis shall be aligned horizontally along the longitudinal axis of the bridge towards Sicily (notional North).

5.2.17 2D Accelerometer (1)

2D accelerometer for the measurement of hanger-cable dynamics, A(2).

Sensor Type	Capacitive
Acceleration Measurement Range	-/+2 g
Frequency Measurement Range	0.05 to 25Hz
Resolution	1000 micro-g

Accuracy	<+/-1000 micro-g
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The accelerometer shall be secured to the hanger at 10,000mm+/-10mm above the centre of the lower hanger-pin or at the lower third point, whichever is the lesser, or at the position of dog-bone damper units if provided. The accelerometer shall be secured directly to the hanger, so that hanger accelerations are measured directly. The accelerometer shall be secured with fixings that have anti-tamper fittings.

The accelerometer data cable shall feed down to deck-level by spiral down the hanger, with more than 1-turn every 900mm and secured at maximum 1m intervals, before entering into the deck through a drilled hole with gland in the sloping web. The attachments shall not damage the sheath of the hangers. The hole shall be detailed by the bridge structural designers.

Data is to be provided in m/s^2.

The X-axis shall be aligned horizontal along the longitudinal axis of the bridge towards Sicily (notional North); the Y-axis shall be aligned transverse to the longitudinal axis of the bridge.

5.2.18 2D Accelerometer (2)

2D accelerometer for the measurement of hanger dynamics (and other bridge element dynamics) with portable equipment, A(2).

Sensor Type	Capacitive
Acceleration Measurement Range	-/+2 g
Frequency Measurement Range	0.05 to 25Hz
Resolution	100 micro-g

Accuracy	<+/-100 micro-g
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

Mountings shall be detailed and supplied to every hanger-cable. Mountings shall be detailed so that the accelerometer is restricted to be installed with one orientation only. Mountings shall be detailed such that the accelerometer is secured directly to the hanger-cable, so that hanger-cable accelerations are measured directly. The mountings shall include bar-codes for unique identification, which shall be compatible with the barcode readers provided with the portable monitoring computers. The mountings shall be secured to the hanger-cables at 1,500mm+/-10mm above the centre of the lower hanger-pin or at the lower third point, whichever is the lesser. The mountings shall be secured with anti-tamper fittings. The assembly (mounting and installed accelerometer) shall be detailed against theft.

Data is to be provided in m/s^2.

The hanger-cable mountings shall be detailed so that the X-axis of the accelerometer shall be aligned horizontal along the longitudinal axis of the bridge towards Sicily (notional North); the Y-axis shall be aligned transverse to the longitudinal axis of the bridge.

5.2.19 3D Accelerometer (1)

3D accelerometer for the measurement of deck, main-cable and tower dynamics, A(3).

Sensor Type	Capacitive
Acceleration Measurement Range	-/+2 g
Frequency Measurement Range	0.01 to 25Hz
Resolution	100 micro-g

Accuracy	<+/-100 micro-g
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The accelerometer shall be secured directly to the structural steelwork, so that deck, main-cable and tower accelerations are measured directly. In the deck and towers the accelerometer shall be installed so that they do not pick-up vibrations other than global structural vibrations, including vibrations from passing plant, passing people, or nearby plant that transmits vibration. On the main-cables the accelerometer shall be installed so as to minimise non-structural response e.g. vibrations from passing gantries or operational loading.

For the accelerometer installed on the main-cable, if an IDRU is not provided on the cable clamp, the data cable shall feed down to deck-level by spiral down the hangers, with more than 1-turn every 900mm and secured at maximum 1m intervals, before entering into the deck through a drilled hole with gland in the sloping web. The attachments shall not damage the sheath of the hangers. The hole shall be detailed by the bridge structural designers.

Data is to be provided in m/s^2.

For the deck: the X-axis shall be aligned horizontal along the longitudinal axis of the bridge towards Sicily (notional North); the Y-axis shall be aligned vertical upwards; the Z-axis shall be aligned transverse to the longitudinal axis of the bridge.

For the towers: the X-axis shall be aligned horizontal along the longitudinal axis of the bridge towards Sicily (notional North); the Y-axis shall be aligned vertical upwards along the longitudinal axis of the towers; the Z-axis shall be aligned transverse to the longitudinal axis of the bridge.

For the main-cables: the X-axis shall be aligned along the local longitudinal axis of the main-cable towards Sicily; the Y-axis shall lie in the plane defined by the local longitudinal axis of the main-cable and vertical aligned upwards; the Z-axis shall be aligned transverse to the longitudinal axis of the bridge.

5.2.20 3D Accelerometer (2)

3D accelerometer for the measurement of seismic event characteristics, SA(3).

Sensor Type	Servo, with AC-coupled zero output for elimination of tilt-induced error
Acceleration Measurement Range	-/+2 g
Frequency Measurement Range	0 to 50Hz
Resolution	1 micro-g
Accuracy	<+/-2 micro-g
Output Noise	<1micro-g
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The accelerometer shall be secured to a rigid structure embedded in the ground e.g. directly to foundations, so that ground accelerations are measured directly. The accelerometer shall be installed so as to minimise response not associated with seismic ground accelerations e.g. passing vehicles, over-ground or under-ground transit systems, operational loading.

The accelerometer installed in the countryside shall be connected to the WAN network, and shall also be provided with wireless connection to the anchorage DAUs. The wireless connection is required for the construction phase, and shall act as a back-up communication connection in the event of failure of the WAN.

Data shall be provided in m/s^2.

The X-axis shall be aligned horizontal along the longitudinal axis of the bridge towards Sicily (notional North); the Y-axis shall be aligned vertical upwards; the Z-axis shall be aligned transverse to the longitudinal axis of the bridge.

5.2.21 2D Static Inclinometer

2D static inclinometer for the measurement of static response, SIN(2).

Sensor Type	Force balance or gravity referenced servo
Inclination Measurement Range	-/+10 degrees
Frequency Measurement Range	0 to 1Hz
Resolution	0.001 degrees
Accuracy	<+/-0.001 degrees
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Power Supply	24 VDC

The static inclinometer shall be secured directly to the structural steelwork or structural concrete, so that tower top, anchor block saddle, main-cable and anchor block inclinations are measured directly. The static inclinometer shall be installed so that it does not pick-up vibrations other than global structural vibrations, including vibrations from passing plant, passing people, or nearby plant that transmits vibration.

Data is to be provided in degs.

The X-axis shall be aligned horizontal along the longitudinal axis of the bridge towards Sicily (notional North); the Y-axis shall be aligned horizontal transverse to the longitudinal axis of the bridge.

5.2.22 2D Dynamic Inclinometer

2D dynamic inclinometer for the measurement of seismic event characteristics, DIN(2).

Sensor Type	Gravity referenced servo
Inclination Measurement Range	-/+10 degrees
Frequency Measurement Range	0 to 25 Hz
Resolution	0.001 degrees
Accuracy	<+/-0.001 degrees
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Power Supply	24 VDC

The dynamic inclinometer shall be secured to a rigid structure embedded in the ground e.g. directly to foundations, so that ground inclinations are measured directly. The dynamic inclinometer shall be installed so as to minimise response not associated with seismic ground vibrations e.g. passing vehicles, over-ground or under-ground transit systems, operational loading.

The dynamic inclinometer that is to be installed to the underwater escarpment shall be attached to the benchmark for ground movement survey. Power and data-cables shall feed along the sea-bed, in appropriately detailed and buried ducts, to land-based base stations located near to the tower foundations. Land-based base stations shall be connected to the WAN network, and shall also be provided with wireless connection to the anchorage DAUs. The wireless connection is required for the construction phase, and shall act as a back-up communication connection in the event of failure of the WAN.

The dynamic inclinometer installed in the countryside shall be connected to the WAN network, and shall also be provided with wireless connection to the anchorage DAUs. The wireless connection is required for the construction phase, and shall act as a back-up communication connection in the event of failure of the WAN.

Data shall be provided in degs.

The X-axis shall be aligned horizontal along the longitudinal axis of the bridge towards Sicily (notional North); the Y-axis shall be aligned horizontal transverse to the longitudinal axis of the bridge.

5.2.23 Fibre-Optic Temperature Sensor (1)

Fibre-optic temperature sensor for measurement of steel temperature on the surface of structural steelwork (excluding main-cables) using surface-mounted multiple sensor, ST.

Sensor Type	Surface-mounted stress-free fibre-optic cable with multiple Fibre-Bragg-Gratings and with Fibre-Bragg-Grating multiplexor-interrogator for temperature readings
No. of defined measurement points per fibre-optic cable	As required
Embedded cable length	Not Applicable
Total cable length	As required
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	-2,000 (compression) to 2,000 (tension) micro-strain
Measurement Range	-20 to +60 degC
Fibre-Bragg-Grating length	<100mm
Resolution	0.1 degC
Accuracy	<+/-0.5 degC
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The fibre-optic strain sensor shall be secured at the measurement location. Intermediate lengths of fibre-optic cable shall be placed in appropriately detailed and installed cable ducts for durability. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission.

Multi-channel multiplexor-interrogator units and switch-type units may be used to optimise data-logger strategy. Multi-channel multiplexor-interrogator units and switch-type units may be shared with other fibre-optic sensors.

Data is to be provided in deg C.

5.2.24 Fibre-Optic Temperature Sensor (2)

Fibre-optic temperature sensor for measurement of steel temperature within the main-cables using embedded continuous sensor, ST.

Sensor Type	Embedded stress-free fibre-optic cable (without Fibre-Bragg-Gratings) with interrogator for distributed temperature readings based on Raman scattering process
No. of defined measurement points per fibre-optic cable	11
Embedded cable length	5400m
Total cable length	5400m from rear of anchor chamber to rear of anchor chamber
Cable outside diameter (including outer sheath)	5.4mm
Durability strain range of cable	0 to 7,000 micro-strain (tension)
Measurement Range	-20 to +60 degC
Spatial Resolution	1m
Resolution	0.1 degC
Accuracy	<+/-0.5 degC
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required to survive installation procedure; reel diameter = 1500 mm; in-service radial stress from cable clamp = 15 MPa
Power Supply	24 VDC

Data-streams recorded from the fibre-optic temperature sensor shall be analysed to produce data for the 11no. defined measurement points along the sensor, of which 4no. are for inclusion in the SHMS data-stream and 7no. are to be sent to the SHMS DSS for storage as additional data. The defined measurement points shall not be located within 1m of a cable clamp.

The fibre-optic cables shall be installed within the main cable via the main-cable strand fabrication and installation process. The fibre-optic cable shall replace one of the top surface wires of the strand. A maximum of one fibre-optic cable shall be installed within a strand. The fibre-optic cable shall be installed on a standard reel appropriate to the fabrication of the strand. The fibre-optic cable will be pulled from the reel, and will be assembled and compacted with the other steel wires to form the strand. The strand will be fitted with form-retaining straps, and will be fed directly onto a storage and transportation reel. The fibre-optic cable will not be included in the formation of the sockets at each end of the strand so that they can be accessed for signal interrogation. The fibre-optic cable shall be fitted with a splice at each end, and any remaining unsupported length of the fibre-optic cable shall be strapped securely to the strand, to protect the fibre-optic cable from damage due to handling of the strand. On-site the strand will be pulled from the transportation reel, and will be dragged across the bridge over the saddles at the anchor blocks and tower tops to be placed in position within the main-cable. The assembled strands will be compacted and fitted with cable clamps and wrapping-wire. The installation of fibre-optic cables in this manner is unproven. The fibre-optic cables will need to be formed to the shape and diameter of the steel wires. The sheave will need to be appropriately detailed for survivability of the installation process as well as function. The fibre-optic cable shall be appropriately detailed so as not to influence cathodic deterioration of the main-cable. Proving trials shall be required to ensure development of a fibre-optic cable that will survive the installation process and function as required.

Multi-channel interrogator units and switch-type units may be used to optimise data-logger strategy.

The fibre-optic cable that emerges from the main-cable in the anchor blocks shall be placed in appropriately detailed and installed cable ducts for durability. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission.

Data is to be provided in deg C.

5.2.25 Fibre-Optic Temperature Sensor (3)

Fibre-optic temperature sensor for measurement of steel temperature within the main-cables using embedded single sensor, ST.

Sensor Type	Embedded stress-free fibre-optic cable with single Fibre-Bragg-Grating and with Fibre-Bragg-Grating interrogator for temperature readings
No. of defined measurement points per fibre-optic cable	1
Embedded cable length	12m
Total cable length	60m from clamp to bottom of tower portal
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	0 to 5,000 micro-strain (tension)
Measurement Range	-20 to +60 degC
Fibre-Bragg-Grating length	<100mm
Resolution	0.1 degC
Accuracy	<+/-0.5 degC
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required to survive installation procedure; in-service radial stress from cable clamp = 15 MPa
Power Supply	24 VDC

The fibre-optic cable shall be installed within the main-cable during on-site strand installation. The fibre-optic cable shall be laid and secured to the top of the appropriate installed strand before subsequent strands are positioned. The Fibre-Bragg-Grating shall be located 1m beyond the first clamp, with the fibre-optic cable fed out of the main-cable at the strand splay. A maximum of one fibre-optic cable shall be installed to a strand. The assembled strands will be compacted and fitted with cable clamps and wrapping-wire. The installation of fibre-optic cables in this manner is unproven. The sheave of the fibre-optic cable will need to be appropriately detailed for survivability of the installation process as well as function. The fibre-optic cable shall be appropriately detailed so as not to influence cathodic deterioration of the main-cable. Proving trials shall be required to ensure development of a fibre-optic cable that will survive the installation process and function as required.

Multi-channel interrogator units and switch-type units may be used to optimise data-logger strategy. Multi-channel interrogator units and switch-type units may be shared with other fibre-optic sensors.

The fibre-optic cable that emerges from the main-cable shall be placed in appropriately detailed and installed cable ducts for durability, and where externally mounted, for protection against solar radiation. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission. The fibre-optic cable shall feed along the inside of the shroud, and up to the saddle where it shall exit the shroud through a hole with gland. It shall then feed to the access ladder of the saddle and down to the upper portal before entering into the tower leg through a drilled hole with gland. The holes shall be detailed by the bridge structural designers.

Data is to be provided in deg C.

5.2.26 Fibre-Optic Temperature Sensor (4)

Fibre-optic temperature sensor for measurement of steel temperature on the surface of the main-cables using surface-mounted multiple sensor, ST.

Sensor Type	Surface-mounted stress-free fibre-optic cable with multiple Fibre-Bragg-Gratings and with Fibre-Bragg-Grating multiplexor-interrogator for temperature readings
No. of defined measurement points per fibre-optic cable	As required
Embedded cable length	Not Applicable
Total cable length	60m from clamp to bottom of tower portal
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	0 to 5,000 micro-strain (tension)

Measurement Range	-20 to +60 degC
Fibre-Bragg-Grating length	<100mm
Resolution	0.1 degC
Accuracy	<+/-0.5 degC
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The fibre-optic temperature sensor shall be installed following construction of the main-cable. At the tower tops and at mid-span the fibre-optic temperature sensor shall be attached directly to main-cable wires, which are 5.4mm diameter. A steel band with access holes shall be provided immediately adjacent to the first cable clamp. The access holes shall be sealed following sensor installation. The steel band with access holes shall be detailed by the bridge structural designers.

Multi-channel multiplexor-interrogator units and switch-type units may be used to optimise data-logger strategy. Multi-channel multiplexor-interrogator units and switch-type units may be shared with other fibre-optic sensors.

The fibre-optic cable shall be placed in appropriately detailed and installed cable ducts for durability, and where externally mounted, for protection against solar radiation. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission. Where the fibre-optic cable feeds along the main cable it shall be positioned to the outside of the walking zone defined by the main-cable hand-strands. The fibre-optic cable shall be secured at maximum 2m intervals. The attachments shall not damage the main-cable. At the tower tops the fibre-optic cable shall feed along the outside of the shroud, and up to the saddle. It shall then feed to the access ladder of the saddle and down to the upper portal before entering into the tower leg through a drilled hole with gland. The hole shall be detailed by the bridge structural designers. At mid-span, if an IDRU is not provided on the cable clamp, the data cable shall feed down to deck-level by spiral down the hangers, with more than 1-turn every 900mm and secured at maximum 1m intervals, before entering into the deck through a drilled hole with gland in the sloping web. The attachments shall not damage the sheath of the hangers. The hole shall be detailed by the bridge structural designers.

Data is to be provided in deg C.

5.2.27 Fibre-Optic Strain Sensor (1)

Fibre-optic strain sensor for measurement of uni-axial steel stress on the surface of structural steelwork (excluding main-cables, main-cable strand anchor bars, hangers, orthotropic deck plate, and tower anchor bolts) using surface-mounted multiple sensor, SG.

Sensor Type	Surface-mounted temperature-compensated fibre-optic cable with multiple Fibre-Bragg-Gratings and with Fibre-Bragg-Grating multiplexor-interrogator for stress readings
No. of defined measurement points per fibre-optic cable	As required
Embedded cable length	Not Applicable
Total cable length	As required
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	- 2,000 (compression) to 2,000 (tension) micro-strain
Measurement Range	- 355 (compression) to 355 (tension) MPa
Fibre-Bragg-Grating length	<100mm
Resolution	0,5 MPa (2 micro-strain)
Accuracy	<+/-1 MPa (<+/-5 micro-strain)
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The fibre-optic strain sensor shall be pre-stressed to allow for measurement over the full measurement range.

The fibre-optic strain sensor shall be secured at the measurement location. Intermediate lengths of fibre-optic cable, between fibre-optic strain sensors, shall be placed in appropriately detailed and installed cable ducts for durability. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission.

Multi-channel multiplexor-interrogator units may be used to optimise data-logger strategy. Multi-channel multiplexor-interrogator units may be shared with other fibre-optic sensors. Switch-type units shall not be used. Stress data is to be synchronised across the whole structure.

Data is to be provided in MPa.

An increase in tension stress shall be represented by a positive change in value.

5.2.28 Fibre-Optic Strain Sensor (2)

Fibre-optic strain sensor for the measurement of uni-axial stress in the orthotropic deck plate using surface-mounted multiple sensor, SG.

Sensor Type	Surface-mounted temperature-compensated fibre-optic cable with multiple Fibre-Bragg-Gratings and with Fibre-Bragg-Grating multiplexor-interrogator for stress readings
No. of defined measurement points per fibre-optic cable	As required
Embedded cable length	Not Applicable
Total cable length	As required
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	- 2,000 (compression) to 2,000 (tension) micro-strain
Measurement Range	- 355 (compression) to 355 (tension) MPa
Fibre-Bragg-Grating length	<10mm
Resolution	0,5 MPa (2 micro-strain)

Accuracy	<+/-1 MPa (<+/-5 micro-strain)
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The fibre-optic strain sensor shall be pre-stressed to allow for measurement over the full measurement range.

The fibre-optic strain sensor shall be secured at the measurement location. Intermediate lengths of fibre-optic cable, between fibre-optic strain sensors, shall be placed in appropriately detailed and installed cable ducts for durability. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission.

Multi-channel multiplexor-interrogator units may be used to optimise data-logger strategy. Multi-channel multiplexor-interrogator units may be shared with other fibre-optic sensors. Switch-type units shall not be used. Stress data is to be synchronised across the whole structure.

Data is to be provided in MPa.

An increase in tension stress shall be represented by a positive change in value.

5.2.29 Fibre-Optic Strain Sensor (3)

Fibre-optic strain sensor for the measurement of uni-axial stress on the surface of the hanger cables using surface-mounted multiple sensor, SG.

Sensor Type	Surface-mounted temperature-compensated fibre-optic cable with multiple Fibre-Bragg-Gratings and with Fibre-Bragg-Grating multiplexor-interrogator for stress readings
No. of defined measurement points per fibre-optic cable	As required
Embedded cable length	Not Applicable

Total cable length	As required
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	0 to 7,000 micro-strain (tension)
Measurement Range	0 to 1400 MPa (tension)
Fibre-Bragg-Grating length	<10mm
Resolution	0,5 MPa (2 micro-strain)
Accuracy	<+/-1 MPa (<+/-5 micro-strain)
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The fibre-optic cable shall be installed before the hanger is lifted into position. The fibre-optic strain sensor shall be attached directly to hanger wires, which are 7.0mm diameter. An annulus of sheath, extending 100mm up from the hanger socket, shall be removed for installation of the fibre-optic cable. Following installation of the fibre-optic cable, an annulus of sheath shall be reinstated and sealed to ensure the protection of the hanger-cable is not diminished in anyway. The fibre-optic cable shall be fitted with a splice where it emerges from the sheath, and any remaining unsupported length of the fibre-optic cable shall be strapped securely to the hanger, to protect the fibre-optic cable from damage due to handling of the hanger.

Multi-channel multiplexor-interrogator units may be used to optimise data-logger strategy. Multi-channel multiplexor-interrogator units may be shared with other fibre-optic sensors. Switch-type units shall not be used. Stress data is to be synchronised across the whole structure.

The fibre-optic cable shall be placed in appropriately detailed and installed cable ducts for durability, and where externally mounted, for protection against solar radiation. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission. The fibre-optic cable shall emerge from the sheave and feed down the hanger socket before entering into the deck through a drilled hole with gland in the sloping web. The hole shall be detailed by the bridge structural designers.

Data is to be provided in MPa.

An increase in tension stress shall be represented by a positive change in value.

5.2.30 Fibre-Optic Strain Sensor (4)

Fibre-optic strain sensor for the measurement of uni-axial stress within the main-cables using embedded single sensor, SG.

Sensor Type	Embedded temperature-compensated fibre-optic cable with single Fibre-Bragg-Grating and with Fibre-Bragg-Grating interrogator for stress readings
No. of defined measurement points per fibre-optic cable	1
Embedded cable length	12m (at tower tops) 2m (at anchor block)
Total cable length	60m from clamp to bottom of tower portal (at tower top) 30m from clamp to rear of anchor chamber (at anchor block)
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	0 to 5,000 micro-strain (tension)
Measurement Range	400 to 1400 MPa (tension)
Fibre-Bragg-Grating length	<100mm
Resolution	0,5 MPa (2 micro-strain)
Accuracy	<+/-1 MPa (<+/-5 micro-strain)
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required to survive installation procedure; in-service radial stress from cable clamp = 15 MPa

Power Supply	24 VDC

The fibre-optic cable shall be installed within the main-cable during on-site strand installation. The fibre-optic cable shall be laid and secured to the top of the appropriate installed strand before subsequent strands are positioned. The Fibre-Bragg-Grating shall be located 1m beyond the first clamp, with the fibre-optic cable fed out of the main-cable at the strand splay. A maximum of one fibre-optic cable shall be installed to a strand. The assembled strands will be compacted and fitted with cable clamps and wrapping-wire. The installation of fibre-optic cables in this manner is unproven. The sheave of the fibre-optic cable will need to be appropriately detailed for survivability of the installation process as well as function. The fibre-optic cable shall be appropriately detailed so as not to influence cathodic deterioration of the main-cable. Proving trials shall be required to ensure development of a fibre-optic cable that will survive the installation process and function as required. Proving tests for function and durability, including proving of the bonding requirements, has been detailed in Appendix 2.

Multi-channel interrogator units may be used to optimise data-logger strategy. Multi-channel interrogator units may be shared with other fibre-optic sensors. Switch-type units shall not be used. Stress data is to be synchronised across the whole structure.

The fibre-optic cable that emerges from the main-cable shall be placed in appropriately detailed and installed cable ducts for durability, and where externally mounted, for protection against solar radiation. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission. At the tower tops the fibre-optic cable shall feed along the inside of the shroud, and up to the saddle where it shall exit the shroud through a hole with gland. It shall then feed to the access ladder of the saddle and down to the upper portal before entering into the tower leg through a drilled hole with gland. The holes shall be detailed by the bridge structural designers. At the anchor blocks the fibre-optic cable shall feed out of the strand splay directly into the anchor block.

Data is to be provided in MPa.

An increase in tension stress shall be represented by a positive change in value.

5.2.31 Fibre-Optic Strain Sensor (5)

Fibre-optic strain sensor for the measurement of uni-axial stress on the surface of the main-cables using surface mounted multiple sensor, SG.

Sensor Type	Surface-mounted temperature-compensated fibre-optic cable with multiple Fibre-Bragg-Gratings and with Fibre-Bragg-Grating multiplexor-interrogator for stress readings
No. of defined measurement points per fibre-optic cable	As required
Embedded cable length	Not Applicable
Total cable length	60m from clamp to bottom of tower portal 30m from clamp to rear of anchor chamber (at anchor block)
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	0 to 5,000 micro-strain (tension)
Measurement Range	400 to 1400 MPa (tension)
Fibre-Bragg-Grating length	<100mm
Resolution	0,5 MPa (2 micro-strain)
Accuracy	<+/-1 MPa (<+/-5 micro-strain)
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The fibre-optic strain sensor shall be installed following construction of the main-cable. The fibre-optic strain sensor shall be attached directly to main-cable wires, which are 5.4mm diameter. A steel band with access holes shall be provided immediately adjacent to the first cable clamp. The access holes shall be sealed following sensor installation. The steel band with access holes shall be detailed by the bridge structural designers.

Multi-channel multiplexor-interrogator units may be used to optimise data-logger strategy. Multi-channel multiplexor-interrogator units may be shared with other fibre-optic sensors. Switch-type units shall not be used. Stress data is to be synchronised across the whole structure.

The fibre-optic cable shall be placed in appropriately detailed and installed cable ducts for durability, and where externally mounted, for protection against solar radiation. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission. Where the fibre-optic cable feeds along the main cable it shall be positioned to the outside of the walking zone defined by the main-cable hand-strands. The fibre-optic cable shall be secured at maximum 2m intervals. The attachments shall not damage the main-cable. At the tower tops the fibre-optic cable shall feed along the outside of the shroud, and up to the saddle. It shall then feed to the access ladder of the saddle and down to the upper portal before entering into the tower leg through a drilled hole with gland. The hole shall be detailed by the bridge structural designers. At the anchor blocks the fibre-optic cable shall feed into the anchor block. At the tie-down hangers, if an IDRU is not provided on the cable clamp, the data cable shall feed down to deck-level by spiral down the hangers, with more than 1-turn every 900mm and secured at maximum 1m intervals, before entering into the deck through a drilled hole with gland in the sloping web. The attachments shall not damage the sheath of the hangers. The hole shall be detailed by the bridge structural designers.

Data is to be provided in MPa.

An increase in tension stress shall be represented by a positive change in value.

5.2.32 Fibre-Optic Strain Sensor (6)

Fibre-optic strain sensor for measurement of uni-axial steel stress on the surface of main-cable strand anchor bars using surface-mounted multiple sensor, SG.

Sensor Type	Surface-mounted temperature-compensated fibre-optic cable with multiple Fibre-Bragg-Gratings and with Fibre-Bragg-Grating multiplexor-interrogator for stress readings
No. of defined measurement points per fibre-optic cable	As required
Embedded cable length	Not Applicable

Total cable length	As required
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	0 to 5,000 micro-strain (tension)
Measurement Range	0 to 1000 MPa (tension)
Fibre-Bragg-Grating length	<100mm
Resolution	0,5 MPa (2 micro-strain)
Accuracy	<+/-1 MPa (<+/-5 micro-strain)
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The fibre-optic strain sensor shall be secured at the measurement location. Intermediate lengths of fibre-optic cable, between fibre-optic strain sensors, shall be placed in appropriately detailed and installed cable ducts for durability. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission.

Multi-channel multiplexor-interrogator units may be used to optimise data-logger strategy. Multi-channel multiplexor-interrogator units may be shared with other fibre-optic sensors. Switch-type units shall not be used. Stress data is to be synchronised across the whole structure.

Data is to be provided in MPa.

An increase in tension stress shall be represented by a positive change in value.

5.2.33 Fibre-Optic Strain Sensor (7)

Fibre-optic strain sensor for measurement of uni-axial steel stress on the surface of tower anchor bolts using surface-mounted single sensor, SG.

Sensor Type	Surface-mounted temperature-compensated fibre-optic cable with single Fibre-

	Bragg-Gratings and with Fibre-Bragg-Grating interrogator for stress readings
No. of defined measurement points per fibre-optic cable	1
Embedded cable length	Not Applicable
Total cable length	As required
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	0 to 5,000 micro-strain (tension)
Measurement Range	0 to 1000 MPa (tension)
Fibre-Bragg-Grating length	<100mm
Resolution	0,5 MPa (2 micro-strain)
Accuracy	<+/-1 MPa (<+/-5 micro-strain)
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The fibre-optic cable that emerges from the anchor bolt housing shall be placed in appropriately detailed and installed cable ducts for durability. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission.

Multi-channel interrogator units may be used to optimise data-logger strategy. Multi-channel interrogator units may be shared with other fibre-optic sensors. Switch-type units shall not be used. Stress data is to be synchronised across the whole structure.

Data is to be provided in MPa.

An increase in tension stress shall be represented by a positive change in value.

5.2.34 Fibre-Optic Strain Rosette in Delta Formation

Fibre-optic strain rosettes in delta formation for the measurement of stress-state on the main-cable clamps, SG(3).

Sensor Type	Surface-mounted temperature-compensated fibre-optic cable with multiple Fibre-Bragg-Gratings and with Fibre-Bragg-Grating multiplexor-interrogator for stress readings
No. of defined measurement points per fibre-optic cable	As required
Embedded cable length	Not Applicable
Total cable length	As required
Cable outside diameter (including outer sheath)	No specific requirement
Durability strain range of cable	- 2,000 (compression) to 2,000 (tension) micro-strain
Measurement Range	- 355 (compression) to 355 (tension) MPa
Fibre-Bragg-Grating length	<10mm
Resolution	0,5 MPa (2 micro-strain)
Accuracy	<+/-1 MPa (<+/-5 micro-strain)
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The sensor shall be formed from 3no. fibre-optic strain sensors installed in delta formation. The fibre-optic strain sensor shall be pre-stressed to allow for measurement over the full measurement range.

The fibre-optic strain sensor shall be secured at the measurement location. A cover shall be provided to protect intermediate lengths of fibre-optic cable between fibre-optic strain sensors.

Multi-channel multiplexor-interrogator units may be used to optimise data-logger strategy. Multi-channel multiplexor-interrogator units may be shared with other fibre-optic sensors. Switch-type units shall not be used. Stress data is to be synchronised across the whole structure.

The fibre-optic cable shall be placed in appropriately detailed and installed cable ducts for durability, and where externally mounted, for protection against solar radiation. The fibre-optic cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission. Where the fibre-optic cable feeds along the main cable it shall be positioned to the outside of the walking zone defined by the main-cable hand-strands. The fibre-optic cable shall be secured at maximum 2m intervals. The attachments shall not damage the main-cable. At the tower tops the fibre-optic cable shall feed along the main-cable to the tower top. It shall feed along the outside of the shroud, and up to the saddle. It shall then feed to the access ladder of the saddle and down to the upper portal before entering into the tower leg through a drilled hole with gland. The hole shall be detailed by the bridge structural designers. At mid-span, if an IDRU is not provided on the cable clamp, the data cable shall feed down to deck-level by spiral down the hangers, with more than 1-turn every 900mm and secured at maximum 1m intervals, before entering into the deck through a drilled hole with gland in the sloping web. The attachments shall not damage the sheath of the hangers. The hole shall be detailed by the bridge structural designers.

Data is to be provided in MPa.

An increase in tension stress shall be represented by a positive change in value.

5.2.35 Linear Displacement Sensor (1)

Linear value displacement sensor for the measurement of expansion joint movement, LD.

Sensor Type	Electronic Distance Measurement (EDM) or Laser, with prism-reflector
Measurement Range	-2000 to 2000mm (at ends) -800 to 800mm (at towers for main span) -100 to 100mm (at towers for side span)
Resolution	3 mm
Accuracy	<+/-3 mm

Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The EDM/Laser, and associated prism-reflector on the other side of the expansion joint, shall be installed through cut-outs in the end diaphragms. The cut-outs shall be 100mm x 100mm. The cut-outs shall be detailed by the bridge structural designers. Housing boxes for the EDM/Laser and prism-reflector shall be detailed and supplied. The housing boxes shall be attached to the end diaphragm with a vertical hinge. A rubber seal shall be provided with each housing box. The housing boxes shall be bolted closed to the end diaphragm. Cables shall pass through a drilled hole with gland at the rear of the housing. The arrangement shall be detailed so that the seal of the internal space of the bridge is not compromised. The housing boxes shall be detailed to minimise the aggregation of dirt on the lens of the EDM/Laser and on the reflector of the prism-reflector.

Data is to be provided in mm.

The X-axis shall be aligned horizontal along the longitudinal axis of the bridge. An increase in expansion joint spacing shall be represented by a positive change in value.

5.2.36 Linear Displacement Sensor (2)

Linear value displacement sensor for the measurement of buffer displacement, LD.

The sensors for measuring linear displacement of the buffer piston shall be supplied and installed by the buffer manufacturers. The interface of the sensor with data-loggers shall be coordinated. Output analogue signals (4-20mA) shall be available through potential free contacts in the local junction box. Output signals are to be converted into displacement data.

Data is to be provided in mm.

5.2.37 Linear Displacement Sensor (3)

Linear value displacement sensor for the measurement of buffer pin movement within the pin-plates, LD.

Sensor Type	Linear value displacement transducer with protective stainless steel housing and rotation-capable end-connections
Measurement Range	-5 to 5mm
Resolution	0.1 mm
Accuracy	<+/-0.5 mm
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The linear value displacement sensor shall be attached to the centre of the cover plate of the pin at one end, and the structure to which the inner joint plate is attached at the other. A connection shall also be provided on the female joint plates for monitoring relative movement of the pin to these plates. The mountings for the attachments shall be bolted. The linear value displacement sensor shall be installed along the nominal orientation of the buffer. The installed linear value displacement sensor shall allow rotations to take place at each end e.g. to allow complete 360degree free rotation of the pin as well as to allow change in relative vertical position and horizontal position of the ends of the sensor.

Data is to be provided in mm.

The X-axis shall be aligned along the longitudinal axis of the buffer. Movement of the pin away from the inner joint plate shall be represented by a positive change in value.

5.2.38 Linear Displacement Sensor (4)

Linear value displacement sensor for the measurement of main-cable to saddle displacement, LD.

Sensor Type	Linear value displacement transducer with protective stainless steel housing and rotation-capable end-connections
Measurement Range	-5 to 5mm
Resolution	0.1 mm
Accuracy	<+/-0.5 mm
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

The linear value displacement sensor shall be attached to the bottom of a main-cable strand at one end, and the saddle at the other. The mounting for the attachment to the strand shall be held in place with straps. The straps shall not damage the wires of the main-cable or the environmental protection. The mounting for the attachment to the saddle shall be bolted. The linear value displacement sensor shall be installed along the orientation of the strand. The installed linear value displacement sensor shall allow rotations to take place at each end e.g. to allow change in relative vertical position and horizontal position of the ends of the sensor.

Data is to be provided in mm.

The X-axis shall be aligned along the longitudinal axis of the main-cable strand to which it is attached. A displacement of the strand away from the saddle shall be represented by a positive change in value.

5.2.39 Linear Displacement Sensor (5)

Linear value displacement sensor for the measurement of Tuned-Mass-Damper displacement, LD.

The sensors for measuring linear displacement of the Tuned-Mass-Damper relative to the tower shall be supplied and installed by the Tuned-Mass-Damper manufacturers. The interface of the sensor with data-loggers shall be coordinated. Output analogue signals (4-20mA) shall be available through potential free contacts in the local junction box. Output signals are to be converted into displacement data.

Data is to be provided in mm.

5.2.40 Hydraulic Pressure Gauge (1)

Hydraulic pressure gauge for the measurement of pressure in the cylinders of the buffers, HP.

The sensors for measuring hydraulic pressure shall be supplied and installed by the buffer manufacturers. The interface of the sensor with data-loggers shall be coordinated. Output analogue signals (4-20mA) shall be available through potential free contacts in the local junction box. Output signals are to be converted into pressure data.

Data is to be provided in kPa.

An increase in pressure shall be represented by a positive change in value.

5.2.41 Hydraulic Pressure Gauge (2)

Hydraulic pressure gauge for the measurement of pressure in the accumulator tanks of the buffers, HP.

The sensors for measuring hydraulic pressure shall be supplied and installed by the buffer manufacturers. The interface of the sensor with data-loggers shall be coordinated. Output analogue signals (4-20mA) shall be available through potential free contacts in the local junction box. Output signals are to be converted into pressure data.

Data is to be provided in kPa.

An increase in pressure shall be represented by a positive change in value.

5.2.42 Oil Temperature Sensor

Oil temperature sensor for the measurement of temperature of the oil in the buffers, OT.

The sensors for measuring oil temperature shall be supplied and installed by the buffer manufacturers. The interface of the sensor with data-loggers shall be coordinated. Output analogue signals (4-20mA) shall be available through potential free contacts in the local junction box. Output signals are to be converted into temperature data.

Data is to be provided in degC.

5.2.43 Concrete corrosion sensor

Concrete corrosion sensor for the monitoring of the development of conditions for corrosion of concrete rebar, CC.

Sensor Type	Corrosion current with mild steel elements
Number of mild steel elements	4
Measurement Range	-1 to +1 mA
Resolution	0.2 mA
Accuracy	<+/-0.2 mA
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Power Supply	24 VDC

The concrete corrosion sensor shall be attached securely to the outer layer of the reinforcement cage, extending towards the surface. The first mild steel element probe shall be positioned in-line with the surface of the outer layer of the reinforcement cage. The other three mild steel probes shall be positioned at equal spacing and at different depths from the surface. The concrete corrosion sensor shall be buried in the concrete structure. The cable to the sensor shall be buried below the outer layer of the reinforcement cage, except where it emerges from the concrete where the cable shall emerge perpendicular to the surface. The concrete corrosion sensor shall be installed so that it does not compromise the integrity and durability of the concrete and reinforcement.

Data is to be provided in mA.

5.2.44 Ground Pressure Sensor

Ground pressure sensor for the measurement of horizontal total ground pressure next to the foundations, P.

Sensor Type	Vibrating Wire
Measurement Range	0 to 3000kPa
Resolution	1kPa
Accuracy	<+/-1kPa
Environmental Requirements	Suitable for exposure in salt water
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Power Supply	24 VDC

The ground pressure sensors shall be installed in bore-holes within 1m of the face of the retaining walls. The bore-holes will be back-filled with excavated ground provided that this material is uncontaminated, otherwise like-for-like uncontaminated replacement fill shall be used. The sensors shall be positioned horizontally to register horizontal ground pressure. The installation process shall minimise impact on local existing ground pressure.

Data is to be provided in kPa.

An increase in pressure shall be represented by a positive change in value.

5.2.45 Interstitial Ground-Water Pressure Sensor

Ground interstitial ground-water pressure sensor for the measurement of interstitial ground-water pressure sensor next to the foundations, IP.

Sensor Type	Vibrating Wire
Measurement Range	0 to 1000kPa
Resolution	1kPa
Accuracy	<+/-1kPa

Environmental Requirements	Suitable for exposure in salt water
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Power Supply	24 VDC

The ground interstitial ground-water pressure sensors shall be installed in bore-holes within 1m of the face of the retaining walls. The bore-holes will be back-filled with excavated ground provided that this material is uncontaminated, otherwise like-for-like uncontaminated replacement fill shall be used. The sensors shall be positioned horizontally to register horizontal ground interstitial ground-water pressure. The installation process shall minimise impact on local existing ground interstitial ground-water pressure.

Data is to be provided in kPa.

An increase in pressure shall be represented by a positive change in value.

5.2.46 Video Displacement Sensor

Video displacement sensor for the measurement of hanger dynamics with portable equipment.

Sensor Type	video camera with on-site lighting for night-time operation, or Microwave Interferometric Radar
Maximum Sampling Rate	100 frames per second
Image Definition at 10m	<0.1mm
Detectable range of movement at 10m	+/-100mm
Target Definition at 10m	<+/-0.1mm
Resolution	0.1mm
Accuracy	<+/-0.1mm
Environmental Requirements	Suitable for exposure in marine environments, and suitable for day-time, night-time, and wet weather measurements
Operating Temperature	-20 to +60 degC

Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Precipitation	Operation maintained to 300mm/hr
Power Supply	24 VDC

A cost, reliability and benefit assessment shall be performed to compare a system based on video camera and a system based on microwave interferometric radar. If numerous hanger-cables can be monitored simultaneously and reliably with the microwave interferometric radar, the required quantity of radars shall be reduced to a minimum of 6, subject to the approval of the SHMS designer. The assessment shall be submitted to the SHMS designer. The final system shall be subject to the approval of the SHMS designer.

Targets shall be detailed and supplied to every hanger-cable. Targets shall be detailed so as to provide a point-defined measurement reference point for high accuracy and resolution measurements in the day-time, night-time (with lighting), and wet weather. Targets shall be detailed and installed so that object recognition routines that process the images can differentiate between the measurement axes directions e.g. axis aligned along the longitudinal axis of the bridge and axis aligned transverse to the longitudinal axis of the bridge. Targets shall be detailed and installed so that hanger-cable vibrations are measured directly. The bar-codes for unique identification, provided with the mountings for the portable accelerometers, shall be used to identify the monitored target. The targets shall be secured to the hanger-cables at 10,000mm+/-10mm above the centre of the lower hanger-pin or at the lower third point, whichever is the lesser. The targets shall be secured with anti-tamper fittings.

A portable mounting frame shall be detailed and supplied with each video camera (or radar). The portable mounting frame shall be detailed for installation on and securing to the hanger stools. The attachment of the mounting frame shall not damage the hanger stool or environmental protection. The mounting frame shall be detailed so that the video camera (or radar) is installed looking up the hanger-cable, in a position to optimise view of the target for detection of the measurement reference point during vibrations. If a radar system is adopted mountings shall be detailed so that the radar can be installed in other general locations, including on the tower portals, for simultaneous monitoring of multiple hanger-cables. The assembly (mounting and installed video camera (or radar)) shall be detailed against theft.

The video camera (or radar) is to be compatible with the portable monitoring server and portable monitoring computer. Software is to be provided for recording images, processing images, and translating the movements of the measurement reference point into a data stream of displacements in the measurement axes.

Data is to be provided in mm.

The hanger-cable targets shall be detailed so that the X-axis of the recorded movement shall be aligned horizontal along the longitudinal axis of the bridge towards Sicily (notional North); the Y-axis shall be aligned transverse to the longitudinal axis of the bridge.

5.2.47 Half-cell potentiometer and Studs

Half-cell potentiometer and studs for monitoring of corrosion of concrete rebar.

Sensor Type	Half-cell potentiometer with high-impedence voltmeter and electrical contact solution, for performing tests in accordance with ASTM C876
Voltmeter input impedence	>10MOhms when operated at a full scale of 100mV
Measurement Range	-1000 to 0mV
Resolution	20mV
Accuracy	<+/-10mV with temperature compensation
Electrical Contact Solution	As required
Accessories for Applying the Electrical Contact Solution	As required
Quantity of Electrical Contact Solution	Sufficient for investigating all exposed concrete surface area once
Type of Cable	Low resistance
Length of Cable	Minimum 100m
Cable Protection	Direct burial type insulation
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature	-40 to +60 degC
Storage Temperature Range	-40 to +60 degC

Operating Humidity Range	0 to 100%
Power Supply	Battery

3no. half-cell potentiometers shall be provided.

The studs for potentiometer monitoring of corrosion shall be formed from minimum 16mm diameter steel reinforcement bar bent into an L-form. One leg shall be lapped and tied to the reinforcement cage of the foundations over a minimum length of 100mm. The other leg shall protrude out of the surface of the foundations by a minimum of 50mm, aligned perpendicular to the surface. A cover shall be detailed for each stud, which shall:

- Protect the exposed and buried stud against corrosion
- Protect the surface of the concrete within a radius of 100mm of the stud
- Eliminate the hazard presented by the exposed stud

The stud shall be installed so that it does not compromise the integrity and durability of the concrete and reinforcement.

5.2.48 Benchmark

Benchmark for providing the reference to tectonic surveys of the underwater escarpments.

The benchmarks for tectonic surveys shall be durable concrete structures anchored to the sea-bed rock of the underwater escarpments. The detail and location of the benchmark shall be agreed with local seismological institutions.

5.2.49 Railway Track Temperature Sensor

Railway track temperature sensor for the measurement of temperature of the rail track, ST.

Sensor Type	No specific requirement
Measurement Range	-20 to +60degC
Resolution	0.1degC
Accuracy	<+/-0.5degC

Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Survival Temperature	+60 degC
Operating Humidity Range	0 to 100%
Power Supply	24 VDC

The railway track temperature sensor shall be secured to the side of the rail and shall not affect or interfere with the use of the rail. Cabling shall be installed in cable ducts for durability, which shall be secured at regular intervals so that it does not affect or interfere with the use of the rail. The cable shall be passed through the deck plate in a location nominated by the bridge structural designers. A 20mm diameter drilled hole with sealed gland shall be provided in the steel deck plate for feeding the data cable. The hole shall be detailed by the bridge structural designers. The sensor arrangement shall be developed in conjunction with the supplier of the railway track, and shall be subject to approval by the bridge structural designers at Progetto Esecutivo.

Data is to be provided in deg C.

5.2.50 Corrosion Rate Sensor

Corrosion rate sensor for the monitoring of rate of corrosion in the main-cables, CR.

The Analatom Linear Polarisation Resistance (LPR) Corrosion sensor with 150µm interdigitation gap between the electrodes, or similar, is to be provided. Refer to Appendix 5 for information on the sensor as presented by Analatom.

The LRP sensor and data-cable shall be installed within the main-cable during on-site strand installation.

Where the LRP sensor is installed next to the splay of the main-cable strands (i.e. at the tower tops and next to the anchor blocks), the sensor and data-cable shall be laid and secured to the top of the appropriate installed strand before subsequent strands are positioned. The sensor shall be located 1m beyond the first clamp, with the data-cable fed out of the main-cable at the strand splay. A maximum of one data-cable shall be installed to a strand. The assembled strands will be compacted and fitted with cable clamps and wrapping-wire. The installation of the sensor and data-cable in this manner is unproven. The data-cable in particular will need to be appropriately detailed for survivability of the installation process as well as function. Proving trials shall be required to ensure development of a data-cable that will survive the installation process and function as required.

Where the LRP sensor is installed remote from the splay of the main-cable strands (i.e. at midspan), the data-cable shall be laid across the alignment of the main-cable wires to emerge at the surface of the main-cable. A steel band with access holes shall be provided immediately adjacent to the nearest clamp. The access holes shall be sealed following sensor installation. The steel band with access holes shall be detailed by the bridge structural designers. The sensor and data-cable shall be laid and secured to the top of the appropriate installed strand before subsequent strands are positioned. The node of sensors shall be located so that the data-cables can be gradually fed across the main-cable wires and out of the main-cable. A maximum of one data-cable shall be installed to a strand. The assembled strands will be compacted and fitted with cable clamps and wrapping-wire. The installation of the sensor and data-cable in this manner is unproven. The data-cable in particular will need to be appropriately detailed for survivability of the installation process as well as function. Proving trials shall be required to ensure development of a data-cable that will survive the installation process and function as required.

The data-cable that emerges from the main-cable shall be placed in appropriately detailed and installed cable ducts for durability, and where externally mounted, for protection against solar radiation. The data-cable shall be positioned at sufficient distance from concentrated heat-sources so that readings are not affected by heat emission. At the tower tops the data-cable shall feed along the inside of the shroud, and up to the saddle where it shall exit the shroud through a hole with gland. It shall then feed to the access ladder of the saddle and down to the upper portal before entering into the tower leg through a drilled hole with gland. The holes shall be detailed by the bridge structural designers. At the anchor blocks the data-cable shall feed out of the strand splay directly into the anchor block. At mid-span, if an IDRU is not provided on the cable clamp, the data cable shall feed down to deck-level by spiral down the hangers, with more than 1-turn every 900mm and secured at maximum 1m intervals, before entering into the deck through a drilled hole with gland in the sloping web. The attachments shall not damage the sheath of the hangers. The hole shall be detailed by the bridge structural designers. Where the data-cable feeds along the main cable it shall be positioned to the outside of the walking zone defined by the main-cable hand-strands. The data-cable shall be secured at maximum 2m intervals. The attachments shall not damage the main-cable.

Data is to be provided in mV.

5.2.51 Microwave Interferometric Radar

The IDS Ingegneria Dei Sistemi IBIS-S Microwave Interferometric Radar, or similar, is to be provided. Refer to Appendix 4 for the brochure.

5.2.52 Calibration Strain Sensor

Calibration strain sensor for the calibration of fibre-optic strain sensors installed onto the surface of structural steelwork (excluding main-cables, main-cable strand anchor bars, hangers, orthotropic deck plate, and tower anchor bolts), CSG

Sensor Type	Vibrating Wire
Durability strain range of cable	- 2,000 (compression) to 2,000 (tension) micro-strain
Measurement Range	- 355 (compression) to 355 (tension) MPa
Resolution	0,5 MPa (2 micro-strain)
Accuracy	<+/-1 MPa (<+/-5 micro-strain)
Operating Temperature	-20 to +60 degC
Storage Temperature Range	-20 to +60 degC
Operating Humidity Range	0 to 100%
Durability	As required
Power Supply	24 VDC

The sensor is to be installed next to the relevant fibre-optic strain sensor.

The sensor shall not be connected to the SHMS data management system.

The sensors shall be provided with all relevant hardware and software such that readings can be taken using the portable monitoring computers and the portable montoring servers.

6 Hardware Minimum Requirements

6.1 General

6.1.1 Minimum Protection Rating

All on-structure hardware (e.g. DAU, IDRU, etc) shall be installed in hardware-cabinets that are positioned in air-conditioned internal spaces (e.g. inside the deck boxes, tower boxes, anchor blocks, etc). Minimum protection rating of IP65 as defined by IEC 60529 shall be provided for all hardware-cabinets. Under no circumstances shall hardware-cabinets be installed externally. Hardware-cabinets shall be secured to the structure. Liaison with the bridge structural designers will be required when positioning the cabinets.

All off-structure hardware, e.g. located around the foundations, in the remote countryside, or serving the sensors on the underwater escarpments, shall be installed in hardware-cabinets suitable for marine environment. Minimum protection rating of IP66W as defined by IEC 60529 shall be provided for all hardware-cabinets. Hardware-cabinets shall be secured to embedded concrete structures e.g. foundations. Liaison with the bridge structural designers will be required when positioning the cabinets.

SHMS MFS shall be installed in the SCADA building in an air-conditioned internal environment. The responsibility for the provision of the air-conditioned space lies with others.

All portable monitoring computers shall be provided with minimum protection rating of IP65.

All portable monitoring servers shall be provided with minimum protection rating of IP66W and shall be suitable for a marine environment. If the server itself does not have sufficient protection rating, then protection shall be detailed so that the server has equivalent minimum protection rating.

6.1.2 Durability

All on-structure hardware, and hardware-cabinets shall be of high quality and robust construction, and capable of resisting accidental damage. Accidental damage is a particular risk during bridge construction since equipment shall be installed during fabrication and before site assembly. All on-structure and off-structure hardware, and hardware-cabinets shall be capable of resisting a mechanical shock resulting from a drop of 1.5m (5ft). Equipment commonly used in offshore installations is preferable. A damage risk assessment shall be carried out for any item that does not satisfy this criterion. The risk assessment shall identify all actions that represent risk of damage to the item, through the life of the item from delivery. Special precautions shall be identified and applied for each action representing a risk of damage. Special precautions may include the provision of additional packing, the construction of a protective container, the installation of notices, etc. Hardware-cabinets shall be secured to the structure, shall have no leverage points, shall be fitted where possible with anti-tamper fixings, and shall be provided with locks to prevent opportunist theft. Liaison with the bridge structural designers shall be required. Data and power cables shall be not be connected directly to the structural steelwork. Good house-keeping practices shall be applied to the installation of data and power cables. Appropriately detailed and installed cable ducts and cable-trays shall be provided for all data and power cables. Liaison with the bridge structural designers shall also be required. All portable monitoring computers and portable monitoring servers shall be of high quality and robust construction, and capable of resisting accidental damage. All portable monitoring computers and portable monitoring servers shall be capable of resisting a mechanical shock resulting from a drop of 1.5m (5ft).

SHMS MFS shall be installed in the SCADA building. Minimum commercial standards of durability are required.

6.1.3 Vibration

Bridges are dynamic structures that experience continuous vibrations due to wind, traffic, etc. all on-structure hardware, hardware-cabinets, fixings, connections, etc. shall be detailed and installed with due consideration of continuous structural vibrations including:

- low frequency large amplitude vibration of the whole bridge
- high frequency small amplitude vibration of the local structural element

In particular all on-structure hardware, hardware-cabinets, fixings, connections, etc, shall function correctly under vibrations of the bridge structures induced by:

- Railways: about 200 trains a day
- Road traffic: about 140,000 cars a day

- High wind velocities

The equipment shall withstand earthquake vibrations and shock of the bridge structures.

6.1.4 Electrical Protection

All hardware components shall be provided with sufficient protection against electrical surge from power fluctuations, Electro-Magnetic Interference (EMI) related to the railway, lightning strike, and Electro-Magnetic Pulses (LEMP) generated by lightning strike. Protection can be in the form of lightning arrests, grounding system power-surge fuse circuits (switch-based), optical bridges, etc. Refer to document CG1001-P-2S-D-P-IT-M4-C3-00-00-00-06 “Design Specifications - Mechanical and Electrical Works” for further discussion.

6.1.5 Power Supply

Power shall be supplied to the SHMS from a dedicated 230V power supply, installed by others as part of the general services to the bridge.

All on-structure hardware shall be plugged into cabinet-sockets within the appropriately detailed and installed secure and appropriately rated cabinets. Cabinet-sockets shall be fed from a power cable connected to the dedicated power supply. The power cable shall be connected to the power supply with unique plugs to connect to unique sockets that shall be capable of only receiving plugs from the SHMS system. The unique sockets shall be located in appropriately detailed and installed power-supply-cabinets. The unique sockets and power-supply-cabinets, and unique plugs, are to be provided by others responsible for providing the power supply. If transformers are required, these are to be provided with the loggers.

UPS shall be supplied to all on-structure hardware so that SHMS data continues to be measured and recorded in the event of interruption to the power supply. The UPS shall ensure a minimum of 6hrs operation of the on-structure hardware in the event of power supply interruption. The software shall signal power supply loss immediately to the SHMS MFS and shall provide an indicator of residual power in the UPS. The software shall shut-down the systems automatically and safely prior to complete power loss from the UPS. The UPS shall charge from the power supply when power supply is not interrupted.

All portable monitoring computers shall be provided with 3 batteries each and AC adapter for 230V power supply. Each battery shall have a minimum battery life of 6 hours.

All portable monitoring servers shall be plugged into the 230V power supply.

SHMS MFS shall be installed in the SCADA building where standard sockets shall be provided to the power supply.

UPS shall be supplied to the SHMS MFS with sufficient duration to allow the systems to be shut-down safely without interruption.

6.1.6 Colour

All components of the SHMS that are installed externally shall be provided in a colour that matches the final colour scheme of the structural element to which it is attached unless otherwise specified or agreed with the SHMS designer.

6.2 Specific

The hardware minimum requirements provided herewith are indicative of expectation. Final hardware specification shall be subject to SHMS detailed development and shall be subject to the approval of the SHMS designer.

6.2.1 SHMS MFS

Processor Speed	minimum 3.1GHz
No. of Cores	Minimum 4
Operating System Architecture	64-bit
Random Access Memory	minimum 12Gb and capability for being increased
No. of Hard Disks	minimum 2
Hard Drive Disk Space	minimum 320Gb per HD
Connection	10/100 RJ45/8 Ethernet LAN
Additional Components	DVD writer, USB 2.0 port, Graphics Card, ports for keyboard, mouse and colour monitor

No. of Monitors	minimum 6
Monitor Type	24" LCD Colour Monitor
Operating Temperature Range	-0 to +50 degC
Storage Temperature Range	-0 to +50 degC
Operating Humidity Range	10 to 90% at 25 degC non-condensing

The system architecture shall allow the organised memory to be utilised for maximum efficiency. Data processing shall be performed on real-time operating systems assigned to dedicated cores.

The SHMS MFS shall be provided with a temporary data buffer to:

- act as a rolling buffer of recent temporary high-definition data received from the Network TMS and Bridge TMS components of SCADA
- act as a rolling buffer of recent temporary high-definition data created by the SHMS MFS
- act as a rolling buffer of recent data for use by other components of SCADA and MMS

The temporary data buffer shall be sufficient to retain the following data:

- latest 30mins of temporary high-definition data received from the Network TMS and Bridge TMS
- latest 30mins of temporary high-definition data created by the SHMS MFS
- latest 10mins of all SHMS temporary high-definition data, down sampled to 100Hz
- latest 24hrs of all SHMS temporary high-definition data, down sampled to 1/3Hz

Data collected in the temporary data buffer shall be continuously overwritten. Data that is stored shall not be lost in the event of complete power failure and SHMS MFS shutdown.

The SHMS MFS shall be provided with data storage capability for temporary data storage in the event of connection failure to the SHMS DSS. Sufficient data storage shall be provided for 672hrs of processed data (e.g. history data, rainflow count data, event data, etc). If the temporary data store is full before 672hrs of processed data is recorded then event files shall be overwritten, with the exception of the first 24hrs of data which shall not be overwritten. The data store shall be cleared once data has been transferred to the SHMS DSS. The data store shall only be cleared by instruction from the operator once successful data transfer is confirmed. Data that is stored shall not be lost in the event of complete power failure and SHMS MFS shutdown.

The SHMS MFS will be provided with additional data storage capability for temporary data storage of high-definition data created by the SHMS MFS only, in the event of connection failure of a DAU to the SHMS MFS. Sufficient data storage shall be provided for 24hrs temporary high-definition data. Data shall initially be recorded continuously, but shall be overwritten once the temporary data storage is full, with the exception of the first 24hrs of data which shall not be overwritten. If the data store is full before 24hrs of temporary high-definition data is recorded then only the first 12hrs of temporary high-definition data shall be retained. The data store shall only be cleared once all DAUs are reconnected to the SHMS MFS and once all event signals have been processed. The data store shall only be cleared by instruction from the operator. Data that is stored shall not be lost in the event of complete power failure and SHMS MFS shutdown.

6.2.2 DAU

Processor Speed	minimum 3.1GHz
No. of Cores	minimum 4
Operating System Architecture	64-bit
Random Access Memory	minimum 12Gb and capability for being increased
No. of Hard Disks	minimum 2
Hard Drive Disk Space	minimum 320Gb per HD
Connection	10/100 RJ45/8 Ethernet LAN
Additional Components	DVD writer, USB port, Graphics Card, ports for keyboard, mouse and colour monitor
No. of Monitors	minimum 1
Monitor Type	19” LCD Colour Monitor
Operating Temperature Range	-0 to +50 degC
Storage Temperature Range	-0 to +50 degC

Operating Humidity Range	10 to 90% at 25 degC non-condensing

The system architecture shall allow the organised memory to be utilised for maximum efficiency. Data processing shall be performed on real-time operating systems assigned to dedicated cores.

DAUs shall be provided with temporary data buffers to act as a rolling buffer of recent high-definition data. The buffer shall be sufficient for retaining 30mins of high-definition data. Data collected in the temporary data buffer shall be continuously overwritten. Data that is stored shall not be lost in the event of complete power failure and DAU shutdown.

DAUs shall be provided with data storage capability for temporary data storage in the event of connection failure to the SHMS MFS and SHMS DSS, or for temporary data storage of high-definition data only in the event of connection failure of another DAU to the SHMS MFS and SHMS DSS. Sufficient data storage shall be provided for 672hrs of processed data (e.g. history data, rainflow count data, event data, etc). Temporary high-definition data shall initially be recorded, but shall be overwritten once the temporary data storage is full, with the exception of the first 24hrs of data which shall not be overwritten. If the data store is full before 24hrs of temporary high-definition data is recorded then only the first 12hrs of temporary high-definition data shall be retained. If the temporary data store is full before 672hrs of processed data is recorded then event files shall be overwritten, with the exception of the first 24hrs of data which shall not be overwritten. The data store of processed data shall be cleared once data has been transferred to the SHMS MFS and SHMS DSS. The data store of processed data shall only be cleared by instruction from the SHMS MFS once successful data transfer is confirmed. The data store of temporary high-definition data shall only be cleared once all DAUs are reconnected to the SHMS MFS and once all event signals have been processed. The data store of temporary high-definition data shall only be cleared by instruction from the operator via the SHMS MFS. Data that is stored shall not be lost in the event of complete power failure and DAU shutdown.

6.2.3 IDRU

Processor Speed	minimum 3.1GHz
No. of Cores	minimum 4
Random Access Memory	minimum 4Gb and capability for being increased

No. of Hard Disks	minimum 2
Hard Drive Disk Space	minimum 320Gb per HD
Connection	10/100 RJ45/8 Ethernet LAN
Additional Components	DVD writer, USB port, Graphics Card, ports for keyboard, mouse and colour monitor
No. of Monitors	minimum 1
Monitor Type	19" LCD Colour Monitor
Operating Temperature Range	-0 to +50 degC
Storage Temperature Range	-0 to +50 degC
Operating Humidity Range	10 to 90% at 25 degC non-condensing

The system architecture shall allow the organised memory to be utilised for maximum efficiency. Data processing shall be performed on real-time operating systems assigned to dedicated cores.

IDRUs shall be provided with data storage capability for temporary data storage in the event of connection failure to the DAUs for data transfer. Sufficient data storage shall be provided for a minimum of 24hrs of data collection. The first 24hrs of data shall not be overwritten. The data store shall be cleared once data has been transferred to the DAUs. The data store shall only be cleared by instruction from the DAU once successful data transfer is confirmed. Data that is stored shall not be lost in the event of complete power failure and IDRU shutdown.

If an IDRU is provided to the main-cable, the power and data cables shall feed down to deck-level by spiral down the hangers, with more than 1-turn every 900mm and secured at maximum 1m intervals, before entering into the deck through a drilled hole with gland in the sloping web. The attachments shall not damage the sheath of the hangers. The holes shall be detailed by the bridge structural designers. The IDRU shall not interfere with the operation of the cable gantries, and shall be installed outside the walking zones defined by the main-cable hand-strands.

6.2.4 Portable Monitoring Computers

Processor Speed	minimum 1.2GHz
No. of Cores	minimum 1

Random Access Memory	minimum 2Gb
No. of Hard Disks	minimum 1
Hard Drive Disk Space	minimum 160Gb per HD
Connection	10/100 RJ45/8 Ethernet LAN
Additional Components	Serial port, USB 2.0 port, SD slot, SDHC slot, Graphics Card
No. of Monitors	minimum 1
Monitor Type	10” LCD Colour Monitor
Operating Temperature Range	-0 to +50 degC
Storage Temperature Range	-0 to +50 degC
Operating Humidity Range	10 to 90% at 25 degC non-condensing

The portable monitoring computers shall be provided with the following additional security feature:

- GPS-tracking

A bar-code reader, for reading the unique barcodes attached to mountings for the portable accelerometers, shall be supplied with each portable monitoring computer.

6.2.5 Portable Monitoring Servers

Processor Speed	minimum 1.2GHz
No. of Cores	minimum 1
Random Access Memory	minimum 2Gb
No. of Hard Disks	minimum 1
Hard Drive Disk Space	minimum 160Gb per HD
Connection	10/100 RJ45/8 Ethernet LAN
Additional Components	Serial port, USB 2.0 port, SD slot, SDHC slot, Graphics Card, port to connect portable monitoring computer
Environmental Requirements	Suitable for exposure in marine environments
Operating Temperature Range	-0 to +50 degC

Storage Temperature Range	-0 to +50 degC
Operating Humidity Range	10 to 90% at 25 degC non-condensing
Precipitation	Operation maintained to 300mm/hr

The portable monitoring servers will be positioned unsupervised on the deck for medium length periods of time. The portable monitoring servers shall therefore be provided with the following additional security features:

- Anti-vandal features
- Anti-theft features
- Heavy-duty steel anti-corrosion security chains and fixings, to secure the portable monitoring servers to the structure (e.g. around hangers, lamp posts, fence posts, etc.)
- GPS tracking

6.2.6 Wireless Communication System

A secure wireless communication system shall be provided between the DAUs and the SHMS MFS, and between the sensors installed in the countryside and on the underwater escarpments and the anchorage DAUs. The wireless communication systems shall be provided primarily for the construction phase. Following construction the wireless communication systems shall act as a secondary back-up communication system to the primary WAN system. The wireless communication systems are to be proposed to the SHMS designer for approval.

6.3 SHMS DSS Minimum Requirements

A common data store shall be provided for all components of SCADA. The data store shall be in the form of a database. The SHMS DSS shall be a partition of the SCADA database. 10Tb of the data store shall be allocated to the SHMS DSS.

The SCADA data store shall maintain at all times a mirror of all SHMS data to guard against complete data loss in the event of SCADA data store hardware failure.

7 Mounting Minimum Requirements

7.1 General

7.1.1 Strength

All components of the SHMS shall be connected to the structure with appropriate mountings that are detailed for the factored design loading, so that the SHMS remains operational during design loading events. The mountings shall be detailed by the SHMS designer. Coordination with the bridge structural designers shall be required to detail local strengthening for transfer of local loads into the primary structure.

7.1.2 Damage due to installation of mounting

The attachment of any component to the structure shall not damage the structure or protective system (e.g. paint system or similar). If the removal of the protective system is necessary for installation then the protective system shall be re-instated after installation.

7.1.3 Changes to the Structure

All changes to the structure required for installation (e.g. the addition of holes) shall be detailed by the bridge structural designers, or shall be subject to the approval of the bridge structural designers.

7.1.4 Accelerated Corrosion

Components that are in contact with the structure shall not induce corrosion of the structure or sacrifice existing bimetallic protective coatings.

7.1.5 Internal Environment Seal

The attachment or passage of any component shall not compromise the seal of the internal conditioned environment.

7.1.6 Vibration

Bridges are dynamic structures that experience continuous vibrations due to wind, traffic, etc. all mountings, fixings, connections, cables, ducts, cable trays etc. shall be detailed and installed with due consideration of continuous structural vibrations including:

- low frequency large amplitude vibration of the whole bridge
- high frequency small amplitude vibration of the local structural element

In particular all mountings, fixings, connections, cables, ducts, cable trays etc. shall be detailed and installed for vibrations of the bridge structures induced by:

- Railways: about 200 trains a day
- Road traffic: about 140,000 cars a day
- High wind velocities.

The mountings, fixings, connections, cables, ducts, cable trays etc. shall withstand earthquake vibrations and shock of the bridge structures.

7.1.7 Colour

All components of the SHMS that are installed externally shall be provided in a colour that matches the final colour scheme of the structural element to which it is attached unless otherwise specified or agreed with the SHMS designer.

8 Installation Minimum Requirements

8.1 General

8.1.1 Installation Planning

On-structure SHMS equipment shall be installed, where possible, following section fabrication hot-works and prior to shipping to site. Installation of equipment whilst in the fabrication yard or holding depot has many purposes including:

- to create a safe working environment for the workforce.

- to create a controlled working environment for good quality installation.
- to minimise the presence of SHMS installation workforce on the site for improved site management.
- to record true stress states rather than derived stress states for improved accuracy of the SHMS.
- to expedite activation of sensors on the SHMS for improved construction phase monitoring.

The constructor shall need to sequence SHMS installation works into the construction programme.

8.1.2 Construction Sequence

Final positioning of sensors and equipment shall take into account the construction sequence, so as to optimise interaction of SHMS installation works with the main construction works, and therefore minimise disruption to the construction programme. Sensors shall be installed on the pre-fabricated sections and connected into IDRUs, which once connected to the network shall relay data to the DAUs.

8.1.3 Protective Measures

All SHMS equipment (sensors, loggers, IDRUs, DAUs, cabling, etc) shall be provided with protective housings to protect against damage from construction activities as well as to protect against damage during the service of the bridge. Cabling that passes between pre-fabricated sections shall be stored on reels within the pre-fabricated sections. In the towers, reels shall be positioned so that the cables can be lowered down to the relevant connection point. Reels shall also be provided with a temporary protective housing to protect against damage from construction works.

8.1.4 System Connection

SHMS data channels shall be activated on the SHMS MFS at the earliest opportunity.

Sensors shall be connected to the DAUs at the earliest opportunity in the bridge erection phase. DAUs shall be provided with wireless communication systems for immediate connection to the SHMS MFS. Sensors installed in the remote countryside and on the underwater escarpments shall be provided with wireless communication systems for immediate connection to the anchorage DAUs. The DAUs and sensors installed in the remote countryside and on the underwater escarpments shall be connected to the WAN at the earliest opportunity.

8.1.5 Cable Slack

All SHMS cables shall be installed with sufficient slack so that they do not pick-up load. This is of particular importance where SHMS cables cross expansion joints or run along the full length of the buffers.

8.1.6 Calibration of Fibre-Optic Strain Sensors

The fibre-optic strain sensors, with the exception of the main-cable fibre-optic strain sensors, shall be installed on the structural components at zero stress-state and interrogated at zero stress-state to determine calibration parameters prior to delivery of the fabricated structural components to site.

8.2 Main-cable Sensor Installation

8.2.1 Embedded Fibre-Optic Continuous and Multiple Sensors

Embedded fibre-optic continuous and multiple sensors shall be durable and formed with an outside diameter equivalent to the main-cable wire diameter. The fibre-optic cable shall be appropriately detailed so as not to influence cathodic deterioration of the main-cable. The fibre-optic cables shall be installed within the main cable via the main-cable strand fabrication and installation process. The fibre-optic cable shall replace one of the top surface wires of the strand. A maximum of one fibre-optic cable shall be installed within a strand. The fibre-optic cable shall be installed on a standard reel appropriate to the fabrication of the strand. The fibre-optic cable shall be pulled from the reel, and shall be assembled and compacted with the other steel wires to form the strand. The fibre-optic cable shall not be included in the formation of the sockets at each end of the strand so that they can be accessed for signal interrogation. The fibre-optic cable shall be fitted with a splice at each end, and any remaining unsupported length of the fibre-optic cable shall be strapped securely to the strand, to protect the fibre-optic cable from damage due to handling of the strand. On-site the strand shall be placed untwisted in position within the main-cable so that the fibre-optic cable remains in the correct position within the main-cable and so that the fibre-optic cable remains on the top of the strand as it passes over the tower saddles. The fibre-optic cable shall be fed out of the main-cable at the anchorage strand splay.

8.2.2 Embedded Fibre-Optic Single Sensor

Embedded fibre-optic single sensors shall be durable. The fibre-optic cable shall be appropriately detailed so as not to influence cathodic deterioration of the main-cable. Fibre-optic single sensors shall be installed within the main-cable during on-site strand installation. The fibre-optic cable shall be laid on and the sensor secured to the top of the appropriate installed strand before subsequent strands are positioned. The fibre-optic cable shall be fed out of the main-cable at the strand splay. A maximum of one fibre-optic sensor shall be installed to a strand. The assembled strands will be compacted and fitted with cable clamps and wrapping-wire.

The strain sensors shall be interrogated for calibration parameters following completion of the construction of the main-cables (including wrapping and clamping) and prior to the suspending of deck segments. The initial main-cable stress-state shall be predicted from the Finite Element model of the bridge, to be provided by the bridge structural designers. The main-cable stress-state shall be monitored during construction of the deck and compared against predictions from the Finite Element model as a verification exercise of the initial calibration.

8.2.3 Surface Mounted Fibre-Optic Multiple Sensor

Fibre-optic multiple sensors shall be installed following construction of the main-cable but prior to the suspending of the deck segments. The fibre-optic sensors shall be attached directly to main-cable wires. A steel band with access holes shall be provided immediately adjacent to the first cable clamp. The access holes shall be sealed following sensor installation.

The multiple strain sensors shall be interrogated for calibration parameters following completion of the construction of the main-cables (including wrapping and clamping) and prior to the suspending of deck segments. The initial main-cable stress-state shall be predicted from the Finite Element model of the bridge, to be provided by the bridge structural designers. The main-cable stress-state shall be monitored during construction of the deck and compared against predictions from the Finite Element model as a verification exercise of the initial calibration.

8.3 Main-cable Clamp Sensor Installation

8.3.1 GPS Receiver

GPS receivers shall initially be connected to the main-cable catwalk, following installation of the catwalk. The GPS receiver shall be relocated and attached to the main-cable clamp following completion of installation of the main-cable clamp including bolt tightening.

8.3.2 Accelerometer

Accelerometers shall be installed to the main-cable clamps prior to lifting into position.

8.3.3 Fibre-Optic Strain Sensors in Delta Formation

Fibre-optic strain sensors shall be installed on the main-cable clamps, and interrogated at zero stress-state to determine calibration parameters prior to lifting of the clamp into position.

8.4 Hanger-cable Sensor Installation

8.4.1 Fibre-Optic Multiple Strain Sensor

Fibre-optic multiple strain sensors shall be installed before the hanger-cables are delivered to site. A 100mm wide annulus of the sheath adjacent to the lower hanger-cable socket shall be carefully removed. The hanger-cable shall not be stressed for installation of the sensor. The fibre-optic multiple strain sensor shall be bonded to or between the 7.0 diameter wires of the hanger-cable. Sufficient but not excessive slack shall be provided between the sensor attachment points. Following installation of the fibre-optic multiple strain sensor, an annulus of sheath shall be reinstated and sealed. The fibre-optic cable shall be fitted with a splice where it emerges from the sheath, and any remaining unsupported length of the fibre-optic cable shall be strapped securely to the hanger, to protect the fibre-optic cable from damage due to handling of the hanger. The fibre-optic multiple strain sensor shall be interrogated at zero stress-state as well as at a known stressed stress-state to determine calibration parameters prior to delivery of the hanger-cable to site.

8.4.2 Accelerometer

Accelerometers shall be attached to the hanger-cables following application of the hanger-cable protective sheath but prior to installation on-site. The position of the accelerometer shall be marked on the hanger-cable prior to reeling of the hanger-cable for transport to site. The accelerometers shall be installed onto the hanger-cables prior to lifting into position.

8.4.3 Video Displacement Sensor Target

Video displacement sensor targets shall be attached to the hanger-cables following application of the hanger-cable protective sheath but prior to installation on-site. The position of the target shall be marked on the hanger-cable prior to reeling of the hanger-cable for transport to site. The accelerometers shall be installed onto the hanger-cables prior to lifting into position.

8.4.4 Portable Accelerometer Mounting

The portable accelerometer mountings can be installed onto the hanger-cables prior to lifting into position.

8.5 Proprietary System Sensor Installation

Proprietary systems include the buffers, tuned-mass-dampers and the roadway expansion joints.

Sensors shall be installed on the proprietary systems by the suppliers, with the exception of the roadway expansion joint accelerometer which shall be installed prior to lifting of the joint into position.

8.6 SCADA building

The SCADA building shall either be built and fitted-out prior to construction of the bridge, or a temporary building shall be provided. The SHMS MFS and SHMS DSS shall be installed and operational prior to construction of the bridge superstructure.

9 Software Minimum Requirements

9.1 General

9.1.1 Operating Systems

The operator-interface operating systems of the SHMS MFS, DAUs, and IDRUs shall be the latest edition of Microsoft Windows, subject to approval of the SHMS designer up to 1 year before the date of purchase. Other operating systems may be proposed, and are subject to the approval of the SHMS designer.

Data processing shall be performed on real-time operating systems assigned to dedicated cores.

The system architecture shall allow the organised memory to be utilised for maximum efficiency.

9.1.2 Programming Environment

The programming environment of the SHMS MFS, DAUs, and IDRUs shall be common to all and shall be capable of delivering all of the functions detailed in this monitoring plan. The programming environment is to be proposed to the SHMS designer for approval.

9.1.3 Graphical Interface Software

The software for delivering the graphical interface of the SHMS MFS, DAUs, and IDRUs shall be common to all and shall be capable of delivering all of the functions detailed in this monitoring plan. The software for delivering the graphical interface is to be proposed to the SHMS designer for approval.

9.1.4 Automatic Updates

All automatic update protocols of all software shall be switched off when the SHMS is in operation.

9.1.5 Watchdog Monitors

The DAUs, IDRUs, and SHMS MFS shall have watchdog monitors to automatically re-initialise the systems on lock-up.

The DAUs, IDRUs, and SHMS MFS shall have watchdog monitors to automatically shut-down the systems in the event of power supply loss and UPS power loss, prior to complete power loss from the UPS.

The DAUs, IDRUs, and SHMS MFS shall have watchdog monitors to automatically report hardware failures.

The DAUs and SHMS MFS shall have watchdog monitors to automatically report sensor failures.

10 System Operation Minimum Requirements

10.1 General System Operation

The basic system operation is shown on drawing CG1000-PDXDPIT-M3SM000000-01.

10.1.1 Sensors and Loggers

Data is registered by the sensors, processed with an anti-alias filter set to the event sampling frequency (or with other filter types as required) if nominated by the operator, and sampled at the data loggers. Where feasible, the data is converted at the logger into the required engineering units. All data on the SHMS shall be synchronised. Different sampling frequencies may be adopted in accordance with the minimum requirements for data sampling presented in Table 10.1. All data with common minimum requirement for sampling frequency shall be synchronised, with the exception of data from fibre-optic temperature sensors and fibre-optic humidity sensors which may be staggered, particularly if switch-type interrogators are used. Data from higher frequency sampling strategies shall be synchronised with data from all lower frequency sampling strategies, so that all data is synchronised to the data sampled at the lowest frequency. This principle is illustrated in Figure 10.1.

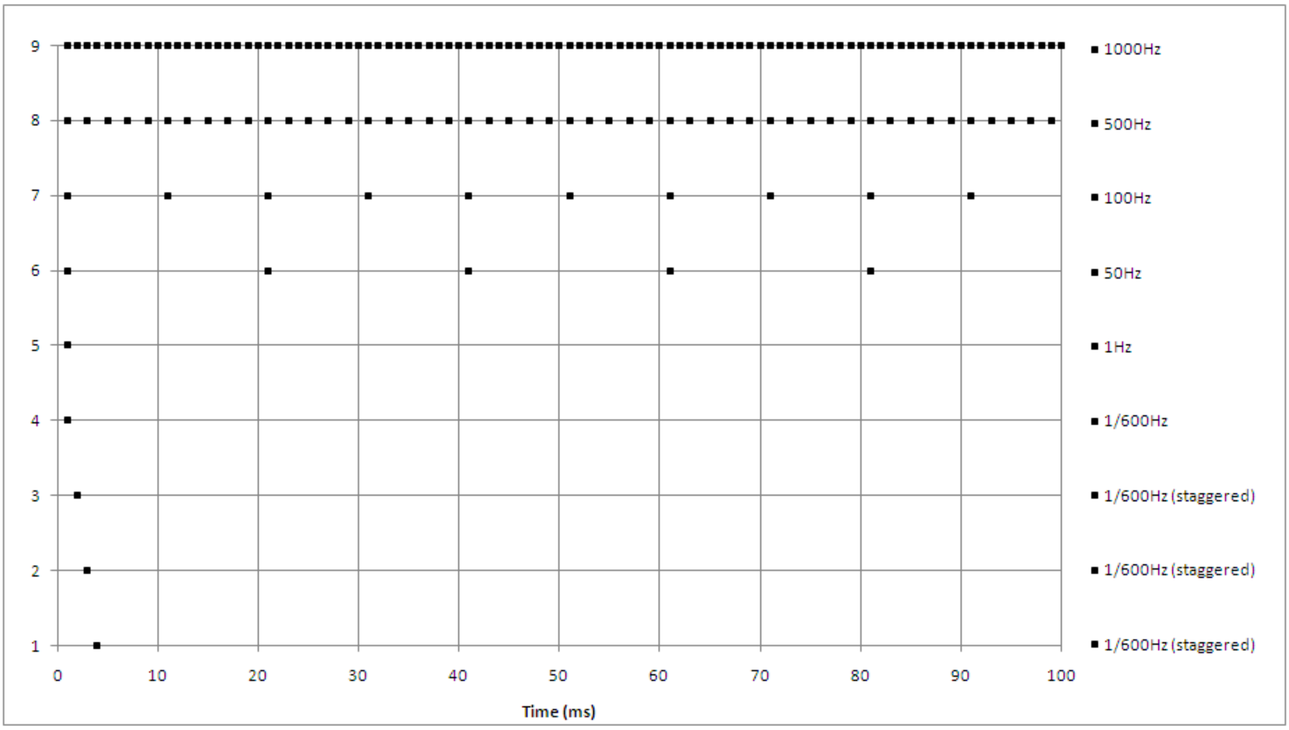


Figure 10.1 Illustration of Data Synchronisation

Sampled data is sent to the DAUs, via the IDRUs if present. The IDRUs allow data from numerous loggers to be sent to the DAUs using a single fibre-optic data cable.

10.1.2 DAU

All data processing is performed in the DAUs, unless noted otherwise. Sampled data is converted into the required engineering units. Data that needs to be derived is calculated from the sampled data. Data is then conditioned to remove all known anomalous data spikes. The conditioned data is the primary source of data collection.

The data is collected as follows:

- A temporary file of high definition data is created. This high definition data is transmitted with high priority to the SHMS MFS for live display of data and temporary storage in the data buffer on the SHMS MFS. The temporary high-definition data is also temporarily stored in a data buffer on the DAU for processing of event data

- The temporary file of high definition data is processed for sensor malfunction detection. If a sensor malfunction is identified its status shall be adjusted to suit. Data from malfunctioning sensors shall continue to be recorded, but shall be exempt from event detection
- The temporary file of high definition data is processed as a high priority in the DAU for event data. If a trigger of an event is found, an event detection signal with the appropriate time-stamp and triggered channel is sent to the SHMS MFS and the other DAUs. The event detection signal changes the status of the data channel on the SHMS displays and is added to the log of events. The event detection signal also initiates a processing routine in each DAU that assembles event data. Two types of event data are identified: a) standard event data, and b) seismic event data. Event data is sampled from the live data at channel-specific operator-nominated sampling frequencies. Data shall only be assembled for channels nominated to be recorded in conjunction with the triggered data channel. Event data is sent to the SHMS MFS for storage on the SHMS DSS
- The temporary file of high definition data is processed in the DAU for history data. History data files are sent to the SHMS MFS for storage on the SHMS DSS
- Data nominated for rainflow counting is processed with rainflow count routines. Rainflow count files are sent to the SHMS MFS for storage on the SHMS DSS
- Data nominated as additional data for collection shall be collected and sent to the SHMS MFS for storage on the SHMS DSS
- Data nominated as statistical data for collection shall be collected and sent to the SHMS MFS for storage on the SHMS DSS

In the above descriptions 'high priority' indicates a need for data to be immediately available. The system should operate so that high priority data is processed and delivered with minimal delay. A delay in the processing and delivery of other data is acceptable to facilitate the high priority data.

The DAUs temporarily store temporary high definition data in a data buffer for processing of event data.

10.1.3 SHMS MFS

The SHMS MFS receives data from:

- DAUs – as given above.
- Network TMS component of SCADA via the SCADA database – traffic (vehicle and train) data including train detection data (received as a live data-stream)
- Network TMS component of SCADA via the SCADA database - traffic (vehicle) flow data at various positions across the network (received as a live data-stream)
- Bridge TMS component of SCADA via the SCADA database - traffic (vehicle) flow data at various positions across the bridge (received as a live data-stream)
- CSP component of MMS via the SCADA database – wind and traffic prediction data for display only (received notionally at 30mins intervals)

The SHMS MFS also:

- Processes traffic (vehicle and rail) data received from the Network TMS to produce a live data stream of total traffic (vehicle and rail) load on the bridge
- Processes traffic (vehicle) data received from the Network TMS to produce a live data stream of traffic flow on each carriageway at each end of the bridge
- Processes total traffic (vehicle and rail) load on bridge data for event data and history data. The processing of event data and history data is as described above for the DAUs
- Processes data to generate derived virtual data
- Processes derived virtual data for event data and history data. The processing of event data and history data is as described above for the DAUs
- Processes total traffic (vehicle and rail) load on bridge data in combination with wind data from the DAUs for event data and history data. The processing of event data and history data is as described above for the DAUs
- Assembles rainflow count data received from the DAUs to form a single record of total rainflow count data recorded since the system became operational
- Calculates fatigue and maintenance utilisation data based on total rainflow count data

- Processes warning and event detection signals, as well as nominated data for bridge event warning conditions and serviceability warning conditions, and updates the event log
- Displays temporary high definition data
- Displays wind and traffic prediction data received from the CSP
- Processes adjustments to the displays in accordance with warning and event detection signals, as well as bridge event warning signals and serviceability warning signals, and updates the event log
- Temporarily stores temporary high definition data, received from the Network TMS and Bridge TMS as well as created by the SHMS MFS, in a data buffer for processing of event data
- Temporarily stores high definition data from the whole SHMS, as well as down-sampled high definition data from the whole SHMS, for the CSP
- Facilitates the storage of data on the SHMS DSS
- Provides the main interface for displaying event data
- Provides the main interface for acknowledging events, grouping events and updating the event log
- Produces automatic reports
- Provides the main interface for sensor calibration
- Controls the DAU temporary storage protocols in the event of communication failure of any DAU with the SHMS MFS
- Controls the temporary storage protocols in the event of communication failure of the SHMS MFS with the SHMS DSS

The SHMS MFS shall not send any information to other components of SCADA or MMS. Other components of SCADA and MMS shall be able to copy data from the SHMS DSS. The CSP shall be able to copy data from the temporary data buffer on the SHMS MFS. Data on the SHMS DSS shall not be accessed directly by other components of the SCADA and MMS unless this is for the purpose of display only.

10.1.4 System Flexibility

The SHMS is a modularised system that shall be able to be modified and expanded. Sensor arrangement at each DAU can be modified, and extra sensors can be added. Extra DAUs can also be added to the system. The data file system and basic system operation has been developed for maximum flexibility to allow straightforward adjustment. The System Operation Software shall need to be developed so that modifications to the arrangement can be easily implemented, including changes to displays, by competent software engineers. A version label and log shall be included for tracking changes. The System Operation Software shall be password protected.

10.1.5 Data Communication

All data shall be transferred between the DAUs and the SHMS MFS, and between the remote countryside sensors and underwater escarpment sensors and the anchorage DAUs, using the WAN. In the event of connection failure of the WAN the dormant wireless communication systems provided for the construction phase shall activate as a back-up communication system between the affected DAU and SHMS MFS or between the affected remote sensors and the anchorage DAUs.

Temporary high-definition data, additional data and statistical data shall not be transferred over the wireless communication system. The wireless communication system shall transfer data in the following order of priority:

- Control signals
- Event detection signal
- Time-synchronisation
- Configuration file
- Event file
- History file
- Rainflow Count file

In the event of failure of both the WAN and the wireless communication system, e.g. a DAU becomes isolated from the SHMS MFS, the DAU shall initiate special temporary data storage protocols. The SHMS MFS shall also initiate special temporary data storage protocols of temporary high definition data and shall send out a signal to initiate special temporary data storage protocols of temporary high definition data in all DAUs. The purpose of these special temporary data storage protocols is to avoid loss of event data initiated by the isolated DAU. Once the complete SHMS network has been re-established and all event signals have been processed the operator shall be prompted to instruct the system to clear all of the special storage of temporary high definition data.

In the event of connection failure between the SHMS MFS and the SHMS DSS, the SHMS MFS shall initiate temporary storage protocols of all data identified for storage on the SHMS DSS.

10.2 Processing of Data provided by Network TMS and Bridge TMS

WiM and RWiM shall be provided as part of the Network TMS component of SCADA. WiM and RWiM data shall be sent as a live data-stream to the SHMS via the SCADA database. The Network TMS has been described in Component No. 2, and the WiM and RWiM sensors have been presented under Component No. 45.

WiM shall be installed to each lane at each end of the bridge. WiM data shall include:

- Time of passage of first axle
- Vehicle classification
- Weight of vehicle
- Length of vehicle
- Speed of Vehicle

A data record shall be provided for each vehicle.

RWiM shall be installed on the track for trains approaching the bridge, at each end of the bridge. RWiM data shall include:

- Time of passage of first axle
- Speed of train
- Weight of axle 1

- Weight of axle 2
- Weight of axle 3
- Etc.

A data record shall be required for each train.

Train detection facilities will also be provided on the track for trains leaving the bridge, at each end of the bridge. Train detection facilities will be provided as part of Network TMS. These facilities will differentiate between the front of the train and the rear of the train. Train detection data shall be sent as a live data-stream to the SHMS via the SCADA database. Traffic (vehicle) flow will be measured at various positions across the network and bridge by the Network TMS and Bridge TMS. Measurements will be based upon vehicle classification from traffic camera images. Parameters such as weight and length shall be assigned according to vehicle classification. The measurement of traffic (vehicle) flow will therefore be an estimate rather than an absolute value. Data shall be sent as a live data-stream to the SHMS via the SCADA database.

The SHMS shall process the traffic data. Traffic data that shall be processed shall include:

- the total traffic (vehicle and rail) load on the bridge. As vehicles are recorded as entering the bridge, their associated loads shall be added to the total. As vehicles are recorded as leaving the bridge, their associated loads shall be subtracted from the total. As trains are recorded as entering the bridge the axle loads shall be added to the total traffic load on the bridge. As the rears of trains are recorded as leaving the bridge, the total train load shall be subtracted from the total
- the density of vehicle traffic on the bridge. As vehicles are recorded as entering the bridge, their associated lengths plus a user-defined additional length e.g. 1m, shall be added to the total length of vehicles on the bridge. As vehicles are recorded as leaving the bridge, their associated lengths plus user-defined additional length shall be subtracted from the total. The total shall be divided by the total length of all four lanes on the bridge
- the traffic (vehicle) load flow entering the bridge on each carriageway, and the traffic (vehicle) load flow leaving the bridge on each carriageway. Vehicle load shall be added to a rolling 10-sec (say) total. This shall represent the traffic (load) flow at each of these locations

- the traffic (vehicle) density flow entering the bridge on each carriageway, and the traffic (vehicle) density leaving the bridge on each carriageway. Vehicle length plus user-defined additional length shall be added to a rolling 10-sec (say) total. The total shall be divided by the total length of all two lanes on a carriageway. This shall represent the traffic (density) flow at each of these locations.

WiM data shall be affected by accuracy of the WiM systems. Since separate WiM systems with differing accuracies shall be used for adding and subtracting loads/lengths from the total load/total length, a process shall be established for reducing the accumulation of error. For the generation of these totals only, WiM data shall be rounded to pre-determined levels that reflect the accuracy of the least accurate WiM that is installed. Procedures shall also be established for cleaning-up an accumulation of residual errors to the total count.

The CSP shall copy traffic data required for simulations and predictions from the SHMS MFS temporary data buffer. Predictions of total traffic (vehicle and rail) load on the bridge, covering the short term e.g. 10mins and the medium term e.g. 1-2hrs, shall be sent to the SHMS MFS via the SCADA database for display on the live SHMS screens.

Data transferred directly between components of SCADA and MMS shall be presented in a common format, to be agreed at Progetto Esecutivo. Notionally, files are to be in comma-separated text file format, with data presented in columns of which the first columns will be dedicated to the time-stamp with 1ms precision.

The life-cycle of live traffic data through the SCADA system is illustrated in *Figure 10.2*.

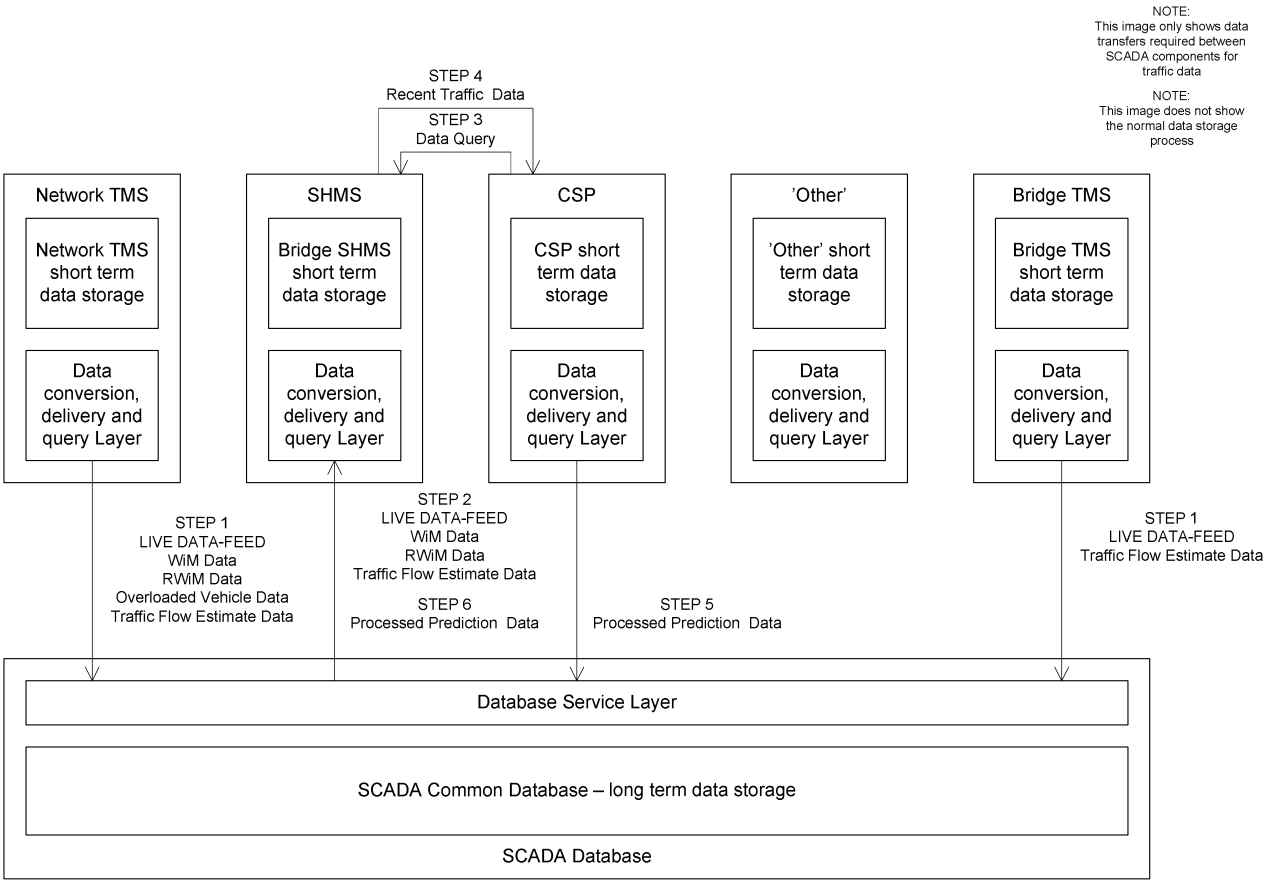


Figure 10.2 Illustration of live vehicle (and train) data life-cycle through the SCADA system

10.3 Output Data

Data recorded by sensors is not necessarily in the format that is most useful for engineering analysis purposes. Data shall therefore be converted into a suitable format. Furthermore additional data channels shall be derived to present a collection of data in a format that is useful to the monitoring of the structure. Engineering conversions and derived data channels required include, inter alia:

- Wind speed and direction measurements (ultrasonic): derived as point value wind speed in 3-axes shall be converted to plan (mean and gust) wind speed, plan (gust) wind direction, vertical (mean and gust) wind speed component, and (gust) vertical angle of wind speed. Mean and gust values shall be based on rolling-average of user-defined time scales e.g. 600 seconds for mean and 3 second for gust. Units: wind speed in m/s, plan wind direction in degs relative to true North (0degs), and vertical wind direction in degs relative to horizontal (0degs)

- Wind speed and direction measurements (mechanical): derived as point value wind speed in plan and direction as well as vertical point value wind speed shall be converted to plan (mean and gust) wind speed, plan (gust) wind direction, vertical (mean and gust) wind speed component, and (gust) vertical angle of wind speed. Mean and gust values shall be based on rolling-average of user-defined time scales e.g. 600 seconds for mean and 3 second for gust. Units: wind speed in m/s, wind direction in degs relative to true North (0degs), and vertical wind direction in degs relative to horizontal (0degs)
- Transverse wind pressure measurements: mean and gust transverse wind pressures to be calculated from the component of plan (mean and gust) wind speed that is transverse to the deck alignment. Units: N/m2
- Deck notional Torsion Accelerations: to be calculated at each cross-beam from the difference in accelerations recorded from the Y-axes (vertical). Units: m/s^2
- Main-cable notional Torsion Accelerations: to be calculated at each clamp from the difference in accelerations recorded from the Y-axes (aligned with vertical). Units: m/s^2
- Tower notional Torsion Accelerations: to be calculated at each portal from the difference in accelerations recorded from the X-axes (aligned with the longitudinal axis of the bridge). Units: m/s^2
- Dew point temperature measurements (internal and external): to be calculated from local relative humidity and air temperature measurements. Units: deg C
- Effective tower leg temperature measurements: to be calculated from local steel temperature measurements. Units: deg C
- Effective roadway girder temperature measurements: to be calculated from local steel temperature measurements. Units: deg C
- Effective railway girder temperature measurements: to be calculated from local steel temperature measurements. Units: deg C

- Effective main cable temperature measurements: to be calculated from local steel temperature measurements. Units: deg C
- Hanger-cable average stress measurements: to be calculated from local hanger-cable stress measurements. Units: MPa
- Main-cable cable average stress measurements: to be calculated from local main-cable cable stress measurements. Units: MPa
- Main-cable clamp principal stress and shear stress measurements: to be calculated from local main-cable clamp stress measurements. Units: MPa
- Buffer force measurements: to be calculated from pressure measurements from each of two cylinders and with due consideration of oil temperature measurements. Units: kN
- Orthotropic deck plate stress rainflow count measurements: to be calculated from nominated stress measurements. Stress measurements shall be processed into number of fluctuations for each nominated stress range using a rainflow count routine. Output: table of stress ranges and counts at each stress range. Units: MPa and Number of counts
- Deck diaphragm cope-hole plate stress rainflow count measurements: to be calculated from nominated stress measurements. Stress measurements shall be processed into number of fluctuations for each nominated stress range using a rainflow count routine. Output: table of stress ranges and counts at each stress range. Units: MPa and Number of counts
- Deck plate corner at cross-beam stress rainflow count measurements: to be calculated from nominated stress measurements. Stress measurements shall be processed into number of fluctuations for each nominated stress range using a rainflow count routine. Output: table of stress ranges and counts at each stress range. Units: MPa and Number of counts
- Hanger-cable stress rainflow count measurements: to be calculated from nominated stress measurements. Stress measurements shall be processed into number of fluctuations for each nominated stress range using a rainflow count routine. Output: table of stress ranges and counts at each stress range. Units: MPa and Number of counts
- Hanger-cable average stress rainflow count measurements: to be calculated from nominated stress measurements. Stress measurements shall be processed into number of fluctuations

for each nominated stress range using a rainflow count routine. Output: table of stress ranges and counts at each stress range. Units: MPa and Number of counts

- Expansion joint movement rainflow count measurements: to be calculated from expansion joint linear displacement measurements. Linear displacement measurements shall be processed into number of fluctuations for each nominated displacement range using a rainflow count routine. Output: table of displacement ranges and counts at each displacement range. Units: mm and Number of counts
- Orthotropic deck plate stress fatigue utilisations: to be calculated from orthotropic deck plate stress rainflow count measurements. Units: Utilisation
- Deck diaphragm cope-hole plate stress fatigue utilisations: to be calculated from deck diaphragm cope-hole plate rainflow count measurements. Units: Utilisation
- Deck plate corner at cross-beam stress fatigue utilisations: to be calculated from deck plate corner at cross-beam stress rainflow count measurements. Units: Utilisation
- Hanger-cable stress fatigue utilisation: to be calculated from hanger-cable stress rainflow count measurements. Units: Utilisation
- Hanger-cable average stress fatigue utilisation: to be calculated from hanger-cable average stress rainflow count measurements. Units: Utilisation
- Expansion joint movement maintenance utilisation: to be calculated from expansion joint movement rainflow count measurements. Units: Utilisation
- Total traffic (vehicle and rail) load on bridge: to be assembled from vehicle weight data recorded by the Network TMS. Units: MN
- Total traffic (vehicle) density on bridge: to be calculated from vehicle length data recorded by the Network TMS. Units: %
- Traffic (vehicle) load flow entering and leaving bridge on each carriageway: to be calculated from vehicle weight data recorded by the Network TMS. Units: MN/10secs
- Traffic (vehicle) density flow entering and leaving bridge on each carriageway: to be calculated from vehicle length data recorded by the Network TMS. Units: %/10secs

- Virtual Data. Units: as required

All other data shall be in presented in units described in the Sensor Minimum Requirements.

All data shall be linked to the appropriate element references as will be described in the Inspection and Maintenance Manual for the bridge, in order to support data search by other components of SCADA and MMS.

10.4 Virtual Data

The SHMS MFS shall be capable of deriving additional data, to be labelled as virtual data, based on data recorded by the sensors. This virtual data shall be considered part of the SHMS dataset. Virtual data shall be operator-defined.

The virtual data shall be calculated from mathematical treatment of temporary high-definition data. Numerous data can be included in the mathematical treatment of a virtual data parameter. Coefficients can be defined for inclusion in the mathematical treatment.

Standard mathematical functions that shall be available shall include:

- Addition (+)
- subtraction (-)
- multiplication (x)
- division (/)
- raise to the power (^)

An example of a mathematical function that shall be definable is:

((c1 x d1 + c2) ^ c3 + (c4 x d2 x d3)) ^ c5

Where c*n* represents an operator defined coefficient and d*n* represents a data channel.

The following additional specialist functions will be made available, subject to further discussion in Progetto Esecutivo:

- real-time identification of natural frequencies from accelerometer data stream using, for example, the recursive stochastic subspace identification (RSSI) technique, followed by identification of the fundamental natural frequency
- conversion of identified fundamental natural frequency for hanger-cables to prediction of tension in hanger-cable, taking into account flexural stiffness

The SHMS shall be capable of processing 200 virtual data channels.

All data shall be linked to the appropriate element references as will be described in the Inspection and Maintenance Manual for the bridge, in order to support data search by other components of SCADA and MMS.

10.5 System Clock

The system clock shall be set to GMT+1hr. The clock shall not be adjusted at any time for Daylight Saving Time.

The System Clock shall be established around the IEEE1588 grandmaster clock which shall be provided as part of the CS. The clocks of the SHMS MFS and all DAUs and IDRUs shall synchronise with the grandmaster clock using IEEE1588 protocols established by the CS, achieving a synchronisation of <1ms. All data-loggers shall be synchronised to the clock of the local DAU to <1ms difference. Details of the system clock are presented in document CG1001-P-2S-D-P-IT-M4-C3-00-00-00-06 “Design Specifications - Mechanical and Electrical Works”.

Maximum drift on all clocks (SHMS MFS, DAU, IDRU, and dataloggers) shall be <1ms/24hr.

10.6 Data Synchronisation

All data shall be synchronised to and time-stamped in accordance with the system clock.

All data recorded by the Network TMS, Bridge TMS, and CSP shall be synchronised to and time-stamped in accordance with the system clock.

In the event of connection failure using the WAN, and activation of the wireless communication systems, DAUs and remote countryside sensors that are affected shall synchronise with the SHMS MFS using the GPS clock as a reference. At 02:00, every 24hrs, the SHMS MFS shall establish a time-correction with the clock of the GPS reference station. This time-correction shall be sent to all

DAUs and remote countryside sensors, which will adjust the local system clock against the GPS clock and the time-correction.

10.7 DAU Temporary Data Storage

DAUs shall be provided with data storage capability for:

- temporary data storage in the event of connection failure to the SHMS MFS
- temporary data storage of high-definition data only in the event of connection failure of another DAU to the SHMS MFS

Sufficient data storage shall be provided for 672hrs of processed data (e.g. history data, rainflow count data, event data, etc). Temporary high-definition data shall initially be recorded, but shall be overwritten once the temporary data storage is full, with the exception of the first 24hrs of data which shall not be overwritten. If the data store is full before 24hrs of temporary high-definition data is recorded then only the first 12hrs of temporary high-definition data shall be retained. If the temporary data store is full before 672hrs of processed data is recorded then event files shall be overwritten, with the exception of the first 24hrs of data which shall not be overwritten.

The data store of processed data shall be cleared once data has been transferred to the SHMS MFS and SHMS DSS. The data store of processed data shall only be cleared by instruction from the SHMS MFS once successful data transfer is confirmed.

The data store of temporary high-definition data shall only be cleared once all DAUs are reconnected to the SHMS MFS and once all event signals have been processed. The data store of temporary high-definition data shall only be cleared by instruction from the operator via the SHMS MFS. Data that is stored shall not be lost in the event of complete power failure and DAU shutdown.

10.8 DAU Data Buffer

DAUs shall be provided with temporary data buffers to act as a rolling buffer of recent high-definition data. The purpose of the buffer is to allow pre-trigger data to be included in the event data record, as well as to cater for lag in receipt of the event detection signal. The buffer shall be sufficient for retaining 30mins of high-definition data. Data collected in the temporary data buffer shall be continuously overwritten. Data that is stored shall not be lost in the event of complete power failure and DAU shutdown.

10.9 SHMS MFS Temporary Data Storage

The SHMS MFS shall be provided with data storage capability for:

- temporary data storage in the event of connection failure to the SHMS DSS
- temporary data storage of high-definition data created by the SHMS MFS only, in the event of connection failure of a DAU to the SHMS MFS

Sufficient data storage shall be provided for 672hrs of processed data (e.g. history data, rainflow count data, event data, etc) and 24hrs of temporary high-definition data created by the SHMS MFS only, assuming the worst case of both connections failing simultaneously. Temporary high-definition data shall initially be recorded, but shall be overwritten once the temporary data storage is full, with the exception of the first 24hrs of data which shall not be overwritten. If the data store is full before 24hrs of temporary high-definition data is recorded then only the first 12hrs of temporary high-definition data shall be retained. If the temporary data store is full before 672hrs of processed data is recorded then event files shall be overwritten, with the exception of the first 24hrs of data which shall not be overwritten. The data store shall be cleared once:

- data that is to be sent to the SHMS DSS has been transferred to the SHMS DSS. The data store shall only be cleared by instruction from the operator once successful data transfer is confirmed
- all DAUs are reconnected to the SHMS MFS and once all event signals have been processed. The data store shall only be cleared by instruction from the operator

Data that is stored shall not be lost in the event of complete power failure and SHMS MFS shutdown.

10.10 SHMS MFS Data Buffer

The SHMS MFS shall be provided with a temporary data buffer to:

- act as a rolling buffer of recent temporary high-definition data received from the Network TMS and Bridge TMS components of SCADA

- act as a rolling buffer of recent temporary high-definition data created by the SHMS MFS
- act as a rolling buffer of recent data for use by other components of SCADA and MMS

The purpose of the buffer is to:

- provide recently recorded data to the CSP
- allow pre-trigger data to be included in the event data record, as well as to cater for lag in receipt of the event detection signal

The temporary data buffer shall be sufficient to retain the following data:

- latest 30mins of temporary high-definition data received from the Network TMS and Bridge TMS
- latest 30mins of temporary high-definition data created by the SHMS MFS
- latest 10mins of all SHMS temporary high-definition data, down sampled to 100Hz
- latest 24hrs of all SHMS temporary high-definition data, down sampled to 1/3Hz

Data collected in the temporary data buffer shall be continuously overwritten. Data that is stored shall not be lost in the event of complete power failure and SHMS MFS shutdown.

10.11 Data Conditioning and Sensor Malfunction Detection

Data recorded by the sensors and loggers shall be conditioned at the DAUs to remove known significant anomalous data. Significant anomalous data takes the form of short duration spikes of significant magnitude. A spike of significant magnitude is a data signal that significantly exceeds the capable limits of the parameter monitored. For example an expansion joint has limited movement availability and therefore a data signal that reports short duration movement well beyond the limits shall be anomalous. Thus, upper and lower error threshold limits for each data channel shall be defined in the configuration file in conjunction with a maximum duration for which the data-spike can exist in order for it to be considered as an anomalous data-spike, which shall be defined in the system configuration file. When an anomalous data-spike is registered it shall be automatically removed from the data stream and replaced with a copy of the preceding data value. A maximum duration is defined because two other legitimate conditions could cause the duration to be longer: 1) if a significant event has occurred and damage has occurred, then the signal could remain in excess of the threshold for long duration and is thus an important indicator, and 2) sensor malfunction. An event that has legitimately caused a large spike in the data needs to be recorded and notified and therefore should not be removed from the data stream.

A minimum duration shall be defined in the system configuration file which, in conjunction with the error threshold limits, shall enable sensor malfunction to be identified. The minimum duration for sensor malfunction identification shall exceed that maximum duration for anomalous data identification. Intermittent data shall be recorded as standard. When a sensor is identified as malfunctioning the event detection mechanism on the sensor shall be deactivated, the data from the sensor shall not be included in any data derivation, the sensor malfunction shall be identified on the SHMS MFS displays, and the sensor malfunction shall be identified on the event log. Data shall continue to be recorded from malfunctioning sensors, so that retrospective data analysis can be performed.

The values to be assigned to the configuration parameters (error threshold limits, maximum duration to identify anomalous signal for conditioning, minimum duration to identify malfunctioning sensor) shall be determined during Progetto Esecutivo, following bridge structural designer input but prior to completion of the set-up of the SHMS MFS.

10.12 Anti-alias Filtering and Band-pass Filtering

A facility shall be provided to apply an anti-alias filter to data channels before sampling. The anti-alias filter shall filter frequencies above 50% of the event sampling frequency of the data channel. An appropriate anti-alias filter strategy shall be developed e.g. this may involve applying an analogue low-pass filter, followed by a digital band-pass filter, followed by over-sampling and then decimation to achieve an anti-aliased dataset at the required sampling frequency. The strategy shall be proposed to the SHMS designer for approval. Initially the anti-alias filter shall only be applied to hanger, deck and tower accelerometers, as well as seismic accelerometers, although a facility shall exist within the configuration interface for the operator to apply the anti-alias filter to any data channel.

This facility shall also allow other band-pass filters to be applied, including:

- Low-pass
- High-pass

- Band-pass
- Band-stop

10.13 Data Sampling

The SHMS shall be capable of accepting operator applied changes to the data sampling strategy.

10.13.1 Temporary High Definition Data

Temporary high definition data shall be sampled for all sensors with a notional base sampling rate of 1000Hz. Temporary high definition data shall be sampled from data that has been filtered (e.g. with anti-alias filters or band-pass filters) as required. The temporary high definition data is the source data for all subsequent data collection, in particular the event data, therefore adopting a 1000Hz base sampling rate presents flexibility for changing the lower frequency event data sampling rates. If required for system efficiency, the actual sampling rates may be lower than the notional base sampling rate provided that these reduced sampling rates exceed the minimum requirements given for sampling of event data. For example, it is proposed to take main-cable internal temperature measurements from the embedded continuous fibre-optic sensors using a technique that has a limited effective sampling rate. The equipment thus limits the sampling rate to less than the base sampling rate, but shall be sufficient to satisfy the minimum sampling rate requirements. Where the actual sampling rate is lower than the notional base sampling rate, intermediate data in the temporary high definition data may be completed as repetition of the most recent sampled data point. Other strategies for sampling of the temporary high definition data can be proposed, particularly if these improve the efficiency of data handling, and shall be subject to the approval of the SHMS designer.

Temporary high definition data shall be recorded as point values.

10.13.2 History Data

History data records shall be sampled with the following time periods:

- History data 1: 60secs (1min)
- History data 2: 3600secs (1hour)

- History data 3: 86400secs (1day)
- History data 3: 2629800secs (1month)

History data shall be a variety of value types:

- Point
- Mean of high definition data in sampled time period
- Maximum of high definition data in sampled time period
- Minimum of high definition data in sampled time period
- Standard deviation of high definition data in sampled time period

10.13.3 Event Data

Event data records shall be sampled as given in Table 10.1.

Table 10.1 Sampling Rates for Event Data Records

	Module	Sensor	Sampling rate (Hz)	Sampling period (s)
Wind Data – Ultrasonic	EEM	WS(3)(ext)	50	
Wind Speed – Mechanical	EEM	WS(2)(ext)	50	
Wind Directional – Mechanical	EEM	WD(ext)	50	
GPS - for Deck	PM	GPS(3)(ext)	1	
GPS - for Main-Cable	PM	GPS(3)(ext)	1	
GPS - for Tower	PM	GPS(3)(ext)	1	
GPS - for Pier	PM	GPS(3)(ext)	1	
GPS - for Anchor Block	PM	GPS(3)(ext)	1	
GPS - for Countryside	PM	GPS(3)(ext)	1	
Air Temperature - External Shade	EEM	CT(ext)		600
Air Temperature – Internal	IEM	CT(int)		600
Solar Radiation	EEM	SR(ext)		600

Relative Humidity – External	EEM	RH(ext)		600
Relative Humidity - Internal - except for Main-Cable	IEM	RH(int)		600
Relative Humidity - Internal - for Main-Cable	IEM	RH(int)		600
Corrosion Rate - Internal - for Main-Cable	IEM	CR(int)		600
Air Pressure – External	EEM	B(ext)		600
Rainfall	RCM	RG(ext)	1	
Surface Humidity – External	EEM	SH(ext)		600
Surface Humidity – Internal	IEM	SH(int)		600
Road Temperature	RCM	RT(ext)		600
1D Acceleration - for Expansion Joint	DRM	A(1)(ext)	100	
1D Acceleration - for Expansion Joint Bearing	DRM	A(1)(ext)	100	
2D Acceleration - for Hanger-Cable	DM	A(2)(ext)	50	
3D Acceleration - for Deck	DM	A(3)(int)	50	
3D Acceleration - for Main-Cable	DM	A(3)(ext)	50	
3D Acceleration - for Tower	DM	A(3)(int)	50	
3D Seismic Acceleration - for Tower	DM	SA(3)(int)	100	
3D Seismic Acceleration - for Anchor Block	DM	SA(3)(int)	100	
3D Seismic Acceleration - for Countryside	DM	SA(3)(ext)	100	
2D Static Inclination - for Tower	DM	SIN(2)(int)	1	
2D Static Inclination - for Anchor Block	DM	SIN(2)(int)	1	
2D Dynamic Inclination - for Tower	DM	DIN(2)(int)	100	
2D Dynamic Inclination - for Pier	DM	DIN(2)(ext)	100	
2D Dynamic Inclination - for Anchor Block	DM	DIN(2)(int)	100	
2D Dynamic Inclination - for Techtonic Plate	DM	DIN(3)(ext)	100	
Steel Temperature - General - except for Main-Cable	GSTM	ST(int)		600
Steel Temperature - Local - except for Main-Cable	LSTM	ST(int)		600
Steel Temperature - for Main-Cable	GSTM	ST(int)		600
Steel Temperature - for Rail Track	GSTM	ST(ext)		600

Stress - General - for Deck	GSSM	SG(int)	50	
Stress - Fatigue - for Deck	FSSM	SG(int)	500	
Stress - for Main-Cable	GSSM	SG(int)	1	
Stress - for Main-Cable Anchor-Bar	GSSM	SG(int)	1	
Stress - General - for Hanger-Cable	GSSM	SG(int)	50	
Stress - Fatigue - for Hanger-Cable	FSSM	SG(int)	50	
Stress - for Tower	GSSM	SG(int)	1	
Stress - for Tower Anchor-Bolt	GSSM	SG(int)	1	
Stress rosette - for Main-Cable Clamp	GSSM	SG(3)(int)	1	
Displacement - for Expansion Joint	DRM	LD(ext)	50	
Displacement - for Buffer	DRM	LD(ext)	50	
Displacement - for Buffer Pin	DRM	LD(ext)	1	
Displacement - for Main-cable to Saddle	SRM	LD(int)	1	
Displacement - for Tuned-Mass-Damper	TMDM	LD(int)	50	
Hydraulic Pressure - for Buffer (Chambers)	DRM	HP(ext)	50	
Hydraulic Pressure - for Buffer (Accumulator Tank)	DRM	HP(ext)	50	
Oil Temperature - for Buffer	DRM	OT(ext)		600
Corrosion	SCM	CC(ext)		600
Ground Pressure	SCM	P(ext)	1	
Ground Interstitial Presssure	SCM	IP(ext)	1	

Traffic data shall be recorded at a sampling rate of 1Hz.

Event data shall be recorded as point values.

10.13.4 Seismic Event Data

Seismic event data records shall be sampled as for the event data records.

Seismic event data shall be recorded as point values.

10.13.5 Rainflow Count Data

Rainflow data records shall be created every 3600secs (1hour).

Rainflow count data shall be equivalent to point values.

10.13.6 Statistical Data

Statistical data shall be sampled with the following frequencies:

- Wind data : 5Hz

Statistical data shall be recorded as point values.

10.13.7 Additional Data

Additional data shall be sampled at the same time period as History data 1:

- Additional temperature data : 60secs (1min)

Additional data shall be recorded as point values.

10.14 Events and Warnings

Temporary high-definition data recorded by the SHMS shall be assessed for conditions that:

- Indicate that an event of interest has taken place or is taking place
- Indicate proximity to an event

When an event has been identified the following actions are taken:

- An event indicator shall be raised on the SHMS MFS displays
- The event shall be added to the event log
- Data associated with the event shall be recorded

Two types of event are identified:

- Event

- Seismic event

Events shall be identified when the data exceeds assigned upper and lower event threshold limits e.g. not only is an event identified when the data passes the threshold limit, it continues to be identified whilst the data remains beyond the threshold limit. Upper and lower event threshold limits shall be defined for each data channel in the configuration file. To avoid repeated triggering of the event status due to data fluctuating across the trigger threshold limit, in particular due to the background noise level on the data, the data channel shall remain in an event status until the data has dropped below a de-trigger threshold level. An illustration of the trigger / de-trigger principle is given in Figure 10.3. Upper and lower event de-trigger threshold limits shall be defined for each data channel in the configuration file.

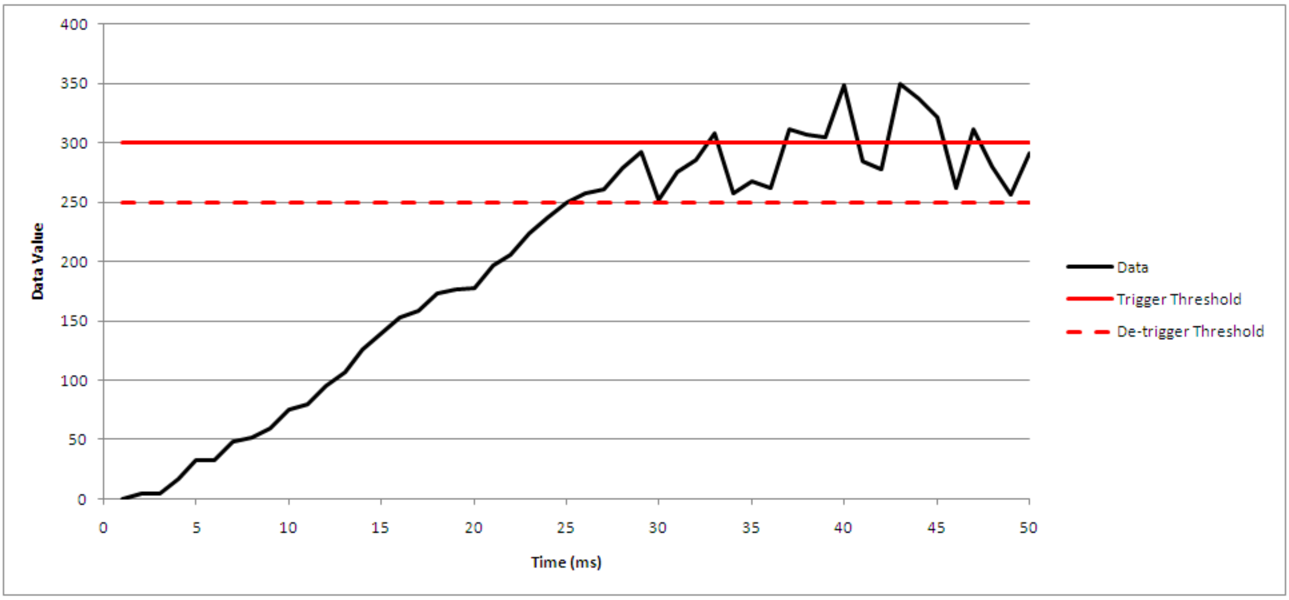


Figure 10.3 Illustration of Trigger / De-trigger Principle

Since vibrations involve fluctuations across a steady-state condition, data recorded from the accelerometers shall require additional treatment to avoid continuous triggering of the event status. The problem is illustrated in Figure 10.4. The triggering on seismic acceleration data shall be treated differently, as discussed below. Following the initial trigger of the event status, the protocol for looking for triggers shall be temporarily de-activated on that accelerometer channel until a user-defined period before the end of the post-trigger period for the event file e.g. 10secs, which shall be defined in the system configuration file. In this way the event status shall only be continued if the acceleration continues to exceed the threshold limit.

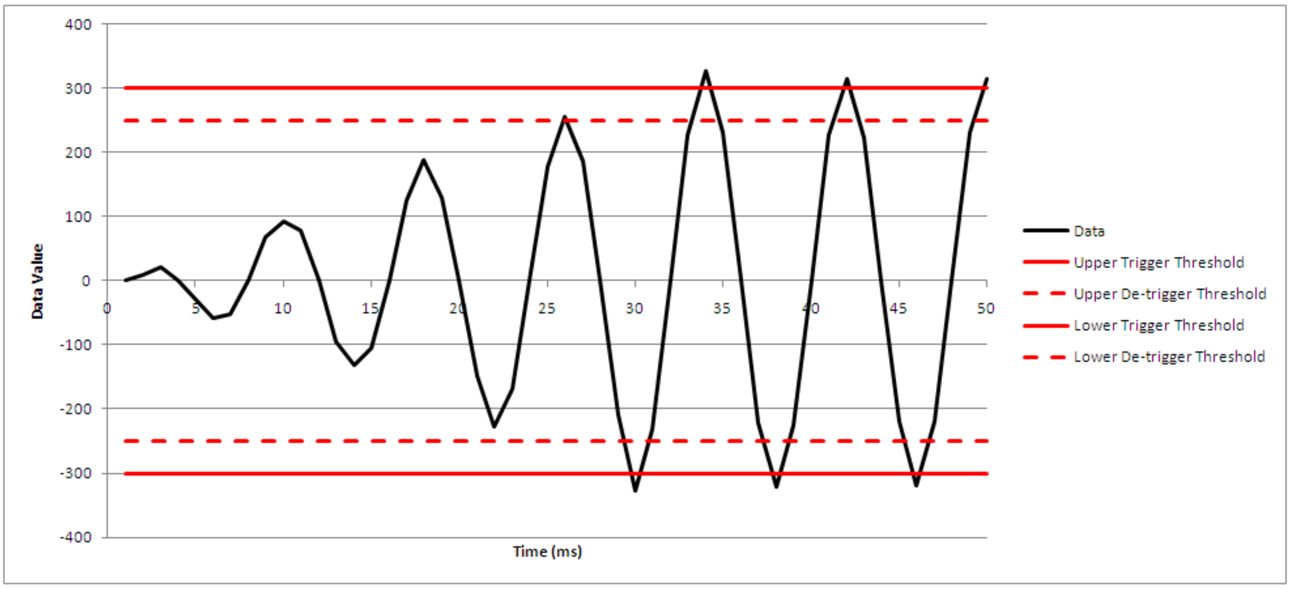


Figure 10.4 Illustration of Trigger / De-trigger Principle against Accelerometer Data

A seismic event is explicitly identified due to the importance of producing an initial assessment into the condition of the structure following a seismic event. A seismic event shall be identified by event detection on ground-based seismic accelerometers only. Two trigger algorithms shall be applied to the system, although only one trigger algorithm shall be selected as active.

Seismic trigger algorithm 1: The level trigger. A seismic event is a global event that will affect a large area, thus a seismic event shall be registered on numerous seismic accelerometers simultaneously. To limit false reporting, a seismic event shall be triggered when event threshold limits are exceeded on numerous seismic accelerometer channels within a defined period: a minimum number of data channels shall be required to trigger within a set time period e.g. 4 seismic accelerometer data channels within a time period of 10secs. Threshold limits shall be defined in the configuration file. Other parameters shall be defined in the system configuration file.

Seismic trigger algorithm 2: The short-term average long-term average trigger (STA/LTA). This algorithm shall be applied to each seismic accelerometer channel. The accelerometer data shall be band-pass filtered. A rolling value of STA to LTA ratio is calculated as a new data channel. The threshold limits are established for this ratio. Threshold limits shall be defined in the configuration file. Other parameters, including the duration of the periods for STA and LTA e.g. 0.5s and 200s, as well as the band-pass characteristics e.g. low-pass and high-pass, shall be defined in the system configuration file.

Advice on parameters for triggering is to be sought from the local seismological centre during Progetto Esecutivo.

Following a seismic event, the ground-based seismic accelerometer data shall be post-processed with a Duhamel integral to produce a response spectrum for comparison against a design response spectrum, and a report shall be automatically produced.

Event data shall include data recorded for a period of time before as well as after the trigger of the event. The recording pre-trigger and post-trigger periods shall be defined in the system configuration file. The pre-trigger period needs to be sufficient to record the build-up to the event e.g. 30secs. The post-trigger period needs to be sufficient to record the entire event including transient build-up and drop-off of vibrations as well as to provide sufficient frequency resolution of accelerometer data converted into the frequency domain e.g. 120secs for non-seismic events and 240secs for seismic events.

Each data channel that is assigned threshold levels for triggering event data (including seismic event data) shall be assigned associated data channels that shall be included in the event data record. These associations shall be given in the Event Association file. When an event trigger is registered an event detection signal shall be transmitted to the SHMS MFS and the DAUs containing the channel triggered and the time stamp of the trigger. This signal shall enable the SHMS MFS to display the trigger on the operator screens, and shall enable the SHMS MFS and DAUs to create the required event data. If subsequent events are triggered during an event record, all associated data with these events shall be added to the active event data record, and the event record shall be extended by the post-trigger timeframe from the time of the latest event. An event data timeframe cut-off shall be required to prevent continuous recording and the generation of excessive file size. The event data timeframe cut-off shall be defined in the system configuration file.

When proximity to an event has been identified the following actions shall be taken:

- A warning indictor shall be raised on the SHMS MFS displays
- The warning shall be added to the event log

Note that data shall not be recorded when a warning has been identified. Warnings shall be identified when assigned upper and lower warning thresholds are exceeded. Upper and lower warning threshold limits shall be defined for each data channel in the configuration file.

The data channels to be assigned with event and warning threshold limits, and the values to be assigned to the configuration parameters (event and warning threshold limits, as well as additional seismic event parameters) shall be determined during the detailed development stage, with bridge structural designer input, but prior to completion of the set-up of the SHMS MFS.

Warnings and events shall be established, for example, for the following parameters:

- Deck level transverse wind speed: limiting design wind speed
- Deck vertical position: movement limit associated with navigation channel clearance envelope
- Deck lateral position: movement limit expected by design
- Tower top longitudinal position: movement limit expected by design
- Tower top transverse position: movement limit expected by design
- Anchor block position: allowable static movement
- Tie-down pier position: allowable static movement
- Tower base position: allowable static movement
- East-side to West-side tower base vertical position: allowable static movement
- Hanger acceleration: acceptable peak acceleration
- Deck acceleration: acceptable peak acceleration
- Deck notional torsion acceleration: acceptable peak acceleration
- Main-cable acceleration: acceptable peak acceleration
- Main-cable notional torsion acceleration: acceptable peak acceleration
- Tower acceleration: acceptable peak acceleration
- Tower notional torsion acceleration: acceptable peak acceleration
- Tower tilt: allowable static movement
- Hanger average stress: limiting stress

- Main-cable average stress: limiting stress
- Deck longitudinal girder stress: limiting stress
- Deck cross-beam stress: limiting stress
- Tower leg stress: limiting stress
- Tower portal (cross-beam) stress: limiting stress.
- Tower base anchor-bolt stress: limiting stress
- Main-cable anchor-bar stress: limiting stress
- Expansion joint displacement: limiting movement
- Buffer force: limiting force
- Buffer displacement: limiting movement
- Tower tuned-mass-damper displacement: limiting movement
- Main-cable to tower saddle displacement: allowable static movement
- Main-cable to anchor block saddle displacement: allowable static movement
- Ground pressure: allowable pressure
- Interstitial ground pressure: allowable pressure
- Ground accelerations for seismic event detection: as defined above

The data channels to be assigned with event and warning threshold limits, and the values to be assigned to the configuration parameters (event and warning threshold limits, as well as additional seismic event parameters) shall be determined during the detailed development stage, with bridge structural designer input, but prior to completion of the set-up of the SHMS MFS.

10.15 Bridge Event Warning

The operator shall need to be made aware of the overall safety status of the bridge. The bridge status shall be reflected by a 3 tier system of "not in danger", "approaching danger", and "danger". The bridge status shall be automatically assessed from an assessment of applied loads and an assessment of combination of warnings and events, in conjunction with a review of the assessed condition of the elements. The criteria for bridge event warnings including matrix of association of individual warnings and events on data channels that lead to bridge event warnings shall be given in the bridge event warning configuration file. When a bridge event warning is identified:

- A warning indicator shall be raised on the SHMS MFS displays
- the warning shall be added to the event log

Bridge status shall be assessed based on the following assessment of applied loads:

- Wind pressure: limit of load effect
- Total traffic load: limit of load effect
- Wind pressure and total traffic load: limit of combined load effects

Bridge status shall be assessed, for example, for the following warning and event associations:

- Downward vertical position of deck and inward longitudinal position of tower top: limiting movements
- Average hanger-cable stress of each hanger-cable in a pair: limiting stresses
- Average main-cable stress of each main-cable cable in a pair at a measurement location: limiting stresses
- Tower leg stress of two opposite face measurement points at a measurement location: limiting stresses
- Tower cross-beam stress of two opposite face measurement points at a measurement location: limiting stresses
- Deck longitudinal girder stress of two opposite face measurement points at a measurement location: limiting stresses
- Deck cross-beam stress of two opposite face measurement points at a measurement location: limiting stresses

The association of warnings and events to be considered for bridge event warnings, the impact of condition, and the bridge status categorisation shall be determined during the detailed development stage, with bridge structural designer input, but prior to completion of the set-up of the SHMS MFS.

Following a bridge event warning, an automatic assessment of the cause and impact of the bridge event shall be presented. Recommendations on actions shall also be presented. Actions may include:

- limit traffic on the bridge
- closing the bridge to traffic
- evacuating the bridge
- investigating visually
- reviewing data

The automatic assessment shall be established around a matrix of anticipated outcomes. Automatic assessments shall be given unique code identifiers, which shall be saved in the event log following a bridge event warning. The matrix and associated codes shall be given in the bridge event warning configuration file. The matrix shall be determined during the detailed development stage, with bridge structural designer input, but prior to completion of the set-up of the SHMS MFS.

10.16 Serviceability (and Maintenance) Warning

The operator will need to be made aware of serviceability (and maintenance) conditions for effective bridge operation and maintenance planning, and therefore a system for raising warnings shall be established. However, event data records do not need to be created with these warnings. Serviceability (and maintenance) warnings shall be determined by comparison of data against lower and upper serviceability warning threshold limits. Upper and lower serviceability warning threshold limits shall be defined for each data channel in the serviceability warning configuration file. When a serviceability warning is identified:

- A warning indictor shall be raised on the SHMS MFS displays
- The warning shall be added to the event log

Serviceability (and maintenance) warnings shall be established, for example, for the following parameters:

- Transverse wind speed at deck level: operation limit for safe road and rail use
- Minimum steel temperature minus dew point temperature at measurement location: limit
- Relative humidity (internal): operation limit
- Main-cable corrosion rate (internal): operation limit
- Deck vertical position: movement limit associated with navigation channel clearance envelope
- Deck acceleration: peak acceleration operation limit for comfort
- Deck notional torsion acceleration: peak acceleration operation limit for comfort
- Rainfall: operation limit for safe road use
- Deck fatigue utilisation: maintenance limit
- Expansion joint movement maintenance utilisation (expansion joint wear indicator): maintenance limit
- Buffer force and buffer displacement: operation limit of combined load effects
- Tower tuned-mass-damper displacement: operation limit
- Concrete rebar corrosion: maintenance limit

The data channels to be assigned with serviceability warning threshold limits, and the values to be assigned to the configuration parameters (serviceability warning threshold limits) shall be determined during the detailed development stage, with bridge structural designer input, but prior to completion of the set-up of the SHMS MFS.

10.17 Strategy for Handling Multiple Simultaneous Events and Warnings

A robust strategy shall be developed for handling multiple simultaneous events and warnings, including bridge event warnings and serviceability warnings, to ensure that the system or part of the system:

- continues to operate in real-time

- does not block-up
- does not crash

In particular a special strategy may be required when a seismic event is registered as significant proportions of the system are expected to register events and warnings.

The strategy may involve prioritisation protocols. None-the-less, all events and warnings are to be registered and handled in accordance with the system operation requirements.

The strategy shall be submitted to the SHMS designer for approval.

10.18 Rainflow Counting

Rainflow counting shall be performed in accordance with the rainflow count method presented in ASTM E–1049 *Standard Practices for Cycle Counting in Fatigue Analysis*. Rainflow counting shall be performed on the temporary high-definition data, with rainflow count data assembled over the duration of the rainflow count file duration e.g. 1hr.

Rainflow counting on stress data shall be based upon 1000 bins with bin size ranging from 0MPa to 1000MPa in 1MPa increments. Fatigue utilisations shall be calculated from total rainflow count data following the procedures presented in the design basis. The fatigue class will be user-definable. The smallest bins will contain fluctuations that are not real but due to noise. The user shall be able to define which bins are not used in the calculation of fatigue utilisations. Initial values shall be determined during the detailed development stage, with bridge structural designer input, but prior to completion of the set-up of the SHMS MFS.

Rainflow counting on linear displacement data shall be based upon 1000 bins with bin size ranging from 0mm to 2000mm in 2mm increments. For processing purposes, the system shall be capable of temporarily recording 2000 bins with bin size ranging from 0mm to 4000mm in 2mm increments. Ranges recorded in excess of 2000mm shall be added to the 1998-2000mm bin. Maintenance utilisations shall be calculated from total rainflow count data. Importance weightings from 0.000 to 1.000 shall be assigned to each bin. An importance weighting of 0.000 will allow the smallest bins, which will contain fluctuations that are not real but due to noise, to be neglected from the calculation of maintenance utilisations. The procedure for calculating maintenance utilisation as well as initial importance weightings shall be determined at the detailed development stage, with bridge structural designer input, but prior to completion of the set-up of the SHMS MFS.

10.19 Data Files and File Contents

The following section describes a management system that needs to be established for managing data and managing operation of the SHMS. The management system has been described in terms files and file structures. However a system established around a database structure shall be acceptable provided that the concepts and functions of the management system are retained. Furthermore, during Progetto Esecutivo the detailed Information Technology (IT) architecture of the SCADA database shall be developed. It may therefore be convenient to directly stream data destined for the SHMS DSS without conversion to physical files. This refinement shall be considered at Progetto Esecutivo.

10.19.1 Files Created by the DAUs

The DAUs shall create the following data file types:

- High-definition file (temporary)
- History file 1 (period 1)
- History file 2 (period 2)
- History file 3 (period 3)
- History file 4 (period 4)
- Event file
- Seismic event file
- Statistical data file
- Additional data file
- Rainflow count file

Filenames shall identify the DAU to which the data relates. Filenames shall identify the time of file creation.

High-definition files shall contain point value data recorded at high definition e.g. 1000Hz. High-definition files shall contain data covering 1 second intervals. High-definition files shall only be stored temporarily in short term. High-definition files shall be saved to the SHMS MFS hard-drive if instructed by the operator at the system interface. High-definition files shall be labelled “Highdef-DAUnn-yyyymmdd-hhmmss”.

History files shall contain maximum value, minimum value, mean value, point value, and standard deviation data for all data channels. History files shall contain data covering user-defined timescales e.g. 1day, 7days, 1 month, 1 year. Data recorded in history files shall be based on user-defined sampling periods e.g. 1min, 1hour, 1day, 1month. History files shall be labelled “Hist1-DAUnn-yyyymmdd”, “Hist2-DAUnn-yyymmdd”, “Hist3-DAUnn-yyyymmdd”, and “Hist4-DAUnn-yyyymmdd”.

Event and Seismic event files shall contain point values recorded at the nominated event sampling frequencies for data channels associated to the event. Data contained in event files shall represent user-defined time periods pre- and post-event trigger. Event and seismic event files shall be labelled “Event-DAUnn-yyyymmdd-hhmmss” and “SeisEvent-DAUnn-yyyymmdd-hhmmss”.

Statistical data files shall contain all point value data recorded for statistical purposes (e.g. wind) with the required parameters. File labelling is to be proposed and agreed with the SHMS designer.

Additional data files shall contain all point value data recorded for additional purposes (e.g. detailed temperature) with the required parameters. File labelling is to be proposed and agreed with the SHMS designer.

Rainflow count files shall contain all rainflow count data for a user-defined period e.g. 1day. Rainflow count data shall also be added to a Total Rainflow Count file on the SHMS MFS. File labelling is to be proposed and agreed with the SHMS designer.

10.19.2 Files Created by the SHMS MFS

The SHMS MFS shall create the following data files:

- Temporary high definition file for traffic data
- History file 1 (period 1) for traffic data
- History file 2 (period 2) for traffic data
- History file 3 (period 3) for traffic data

- History file 4 (period 4) for traffic data
- Event file for traffic data
- Seismic event file for traffic data
- Temporary high definition file for virtual data
- History file 1 (period 1) for virtual data
- History file 2 (period 2) for virtual data
- History file 3 (period 3) for virtual data
- History file 4 (period 4) for virtual data
- Event file for virtual data
- Seismic event file for virtual data.
- Total Rainflow count file
- Utilisation file

The temporary high-definition files for traffic data shall match the format of the main temporary high-definition files created by the DAUs. High-definition files for traffic data shall be labelled “Highdef-TMS-yyyymmdd-hhmmss”.

The history files for traffic data shall match the format of the main history files created by the DAUs. The history files for traffic data shall be labelled “Hist1-TMS-yyyymmdd”, “Hist2-TMS-yyyymmdd”, “Hist3-TMS-yyyymmdd”, and “Hist4-TMS-yyyymmdd”.

The event and seismic event files for traffic data shall match the format of the main event and seismic event files created by the DAUs. Event and seismic event files for traffic data shall be labelled “Event-TMS-yyyymmdd-hhmmss” and “SeisEvent-TMS-yyyymmdd-hhmmss”.

The temporary high-definition files for virtual data shall match the format of the main temporary high-definition files created by the DAUs. High-definition files for vrtual data shall be labelled “Highdef-VIRT-yyyymmdd-hhmmss”.

The history files for virtual data shall match the format of the main history files created by the DAUs. The history files for virtual data shall be labelled “Hist1-VIRT-yyyymmdd”, “Hist2-VIRT-yyyymmdd”, “Hist3-VIRT-yyyymmdd”, and “Hist4-VIRT-yyyymmdd”.

The event and seismic event files for virtual data shall match the format of the main event and seismic event files created by the DAUs. Event and seismic event files for virtual data shall be labelled “Event-VIRT-yyyymmdd-hhmmss” and “SeisEvent-VIRT-yyyymmdd-hhmmss”.

The Total Rainflow count file shall be assembled from discrete rainflow count files received from the DAUs. A Total Rainflow count file shall be saved at 1-day intervals with a unique identifier based on the date. File labelling is to be proposed and agreed with the SHMS designer.

The Utilisation file shall contain point value utilisation data calculated from total rainflow count data, and recorded at intervals equivalent to transfer of each Rainflow count file from the DAUs. A Utilisation file shall be saved at 28-day intervals with a unique identifier based on the date. File labelling is to be proposed and agreed with the SHMS designer.

The SHMS MFS shall update the following log records:

- Event log record

Event log records shall be created directly on the SCADA database. Event log records shall contain a list of all events (events, seismic events, warnings, serviceability warnings, bridge event warnings, sensor malfunction), including time of event, sensor triggered, trigger value exceeded, minimum value in event file, maximum value in event record, average value in event record, standard deviation in event record, event record reference, automatic assessment code (if bridge event warning) and the current operator-nominated condition of the component that has triggered (taken from the condition log). Data shall be added to the event log records by the operator, in response to the event, including grouping of events into a single event, initial assessment of events (importance, relevance and severity), subsequent assessment of events (importance, relevance and severity), assessment of importance of event data for long-term data storage and date and time of change to log entry. If stored in file format, event log records shall contain data covering user-defined timescales e.g. 1day, and shall be labelled “EventLog-yyyymmdd”.

10.19.3 Other Files for Operation of the SHMS

Other files required for operation of the SHMS, and created and managed at the SHMS MFS, shall include:

- Configuration file
- System configuration file
- Channel status file
- Event association file
- Bridge event warning configuration file
- Serviceability warning configuration file
- Condition file
- Configuration Log file
- Software Update Log file
- System Evolution Log file

Configuration files shall contain data channel configuration (including a user-definable offset), event sampling rates, event trigger and de-trigger levels, event warning levels, component limit levels and malfunctioning-indicator limit levels. A single configuration file shall exist for all data channels. Every configuration file created shall be retained and stored on the SHMS DSS. Configurations files shall be labelled “Config-yyyymmdd-hhmmss”.

System configuration files shall provide all general systems configuration data. Every system configuration file created shall be retained and stored on the SHMS DSS. System configuration files shall be labelled “SysConfig-yyyymmdd-hhmmss”.

Channel status files shall report the status of the channel e.g. active, deactivated, malfunctioning. Every channel status file created shall be retained and stored on the SHMS DSS. Channel status files shall be labelled “ChStatus-yyyymmdd-hhmmss”.

Event association files shall contain the association of data channels to be recorded in the event of a triggered event to each data channel that is triggered. Every event association file created shall be retained and stored on the SHMS DSS. Event association files shall be labelled “EventAssoc-yyyymmdd-hhmmss”.

The Bridge Event Warning configuration file shall contain the various combinations of event data channels that indicate a warning condition for the safety of the bridge as well as outcome messages and associated code identifiers. The bridge event warning configuration file shall be labelled "BrWarningConf".

The Serviceability Warning Configuration file shall provide all serviceability warning levels. The serviceability warning configuration file shall be labelled "ServWarningConf".

The Condition file reports the assessed condition of the element monitored. Data shall be added to the condition file by the operator. The condition file shall be labelled “Condition”.

The Configuration Log file reports the status of system reconfiguration including time of reconfiguration, configuration file names, and status of reconfiguration on DAUs. The configuration log file shall be labelled "ConfigLog".

The Software Update Log file is updated manually each time the software of the SHMS is updated. It presents version number, date of update, detail of the update, and the assessed impact of the update on data output. The software update log file shall be labelled "SoftUpdateLog".

The System Evolution Log file is updated manually each time the SHMS evolves. Entries shall be logged by date. Details of changes shall be described, including location of change and assessment of impact of the change on data output. The System Evolution Log file shall also be a log into which general observations concerning any aspect of the system can be made. The System Evolution Log file shall be labelled "SysEvoLog".

10.20 System Data File Format

System data files are data files that are created by the SHMS to facilitate the function of the SHMS e.g. history files. System data files are streamed as records into the SHMS DSS for long-term storage as well as accessibility by other components of SCADA and MMS. All data shall be linked to the appropriate element references as will be described in the Inspection and Maintenance Manual for the bridge, in order to support data search by other components of SCADA and MMS.

System data file structure shall be simple. Data shall be presented in columns according to data channel, with the first columns dedicated to time-stamp. Data shall be time-stamped to 1ms precision. The time-stamp shall include the date in the form yyyy-mm-dd, hour in 24hr clock format, minute, second, and millisecond. The first rows of each data file shall provide identification data including the name of the bridge e.g. Messina Bridge, the DAU and DAU location, configuration file in place, the status of each data channel, and the units of each data channel.

System data files shall either be in text format or database format. Data files shall be compressed to minimise size.

Conversion routines shall be developed for accessing and converting data from the primary data file format to other data file formats, including presenting data in uncompressed comma-separated text format. These conversion routines shall be available in a user-interface program, as well as to other components of SCADA and MMS.

10.21 System Configuration

Configuration of the SHMS shall be performed through a dedicated configuration interface at the SHMS MFS. Some configuration data is required by the SHMS MFS only. Other configuration data is required by the DAUs and must therefore be transmitted to all of the DAUs from the SHMS MFS. With a modularised system of orbit nodes that are communicating with discrete data packages sent over a general purpose WAN (e.g. not a dedicated fixed link system), a robust system must be established for ensuring successful system-wide configuration. The configuration protocol shall involve configuration files that are named with the current date and time, and retained in an archive on the SHMS DSS. The name of the configuration file shall be printed into all data files. The process of reconfiguration shall be as follows:

- Operator shall open the configuration interface
- Operator shall make changes as required (password-permitting)
- Operator shall choose to save the changes
- Configuration interface shall create a new configuration file name with current date and time
- Operator shall choose to send the configuration file to the DAUs
- Configuration interface shall send the configuration file to the DAUs

- DAUs shall replace the current configuration file with the new configuration file
- DAUs shall send a copy of the replaced configuration file to the SHMS MFS configuration interface
- Configuration interface shall compare the received files with the sent file as an error check
- Each returned file that is registered as successfully transferred from DAUs shall be indicated on the configuration interface
- If any DAUs are indicated as not successfully reconfigured then the operator shall be prompted to try sending again to these DAUs
- If this is unsuccessful then the operator shall be given the option to access the DAUs and copy the configuration file over by hand
- The final outcome of re-configuration shall be added to the configuration log file
- The status of reconfiguration shall be indicated on the general overview screen

Note that it is possible that communication with a DAU is interrupted preventing system-wide reconfiguration.

10.22 Data Channel Grouping

Data channels shall be grouped into families (or groups) e.g. sensors installed on the buffers at the towers, to enable efficient and effective system management. This is encouraged for system configuration. However data shall not be recorded based on families (or groups) for event data records as this will impact significantly on the flexibility of the system and on the data storage and event post-processing. The details of data channel grouping, including naming of families (or groups), shall be subject to the approval of the SHMS designer.

10.23 Information Transfer Summary

Information that shall be transferred between the SHMS MFS and the DAUs shall include:

- Data from DAU to SHMS MFS
- Configuration data from SHMS MFS to DAUs

- Configuration data receipt from DAU to SHMS MFS
- Event detection signal from DAU to SHMS MFS and other DAUs
- Event detection signal from SHMS MFS to DAUs
- Sensor malfunction signal from DAU to SHMS MFS
- Temporary storage protocol control-signal from SHMS MFS to DAUs
- Clear temporary storage control-signal from SHMS MFS to DAUs
- Synchronisation time-correction signal from SHMS MFS to affected DAU in the event of connection failure via the WAN

The information that shall be transferred between the SHMS MFS and the DAUs is summarised in Figure 10.5.

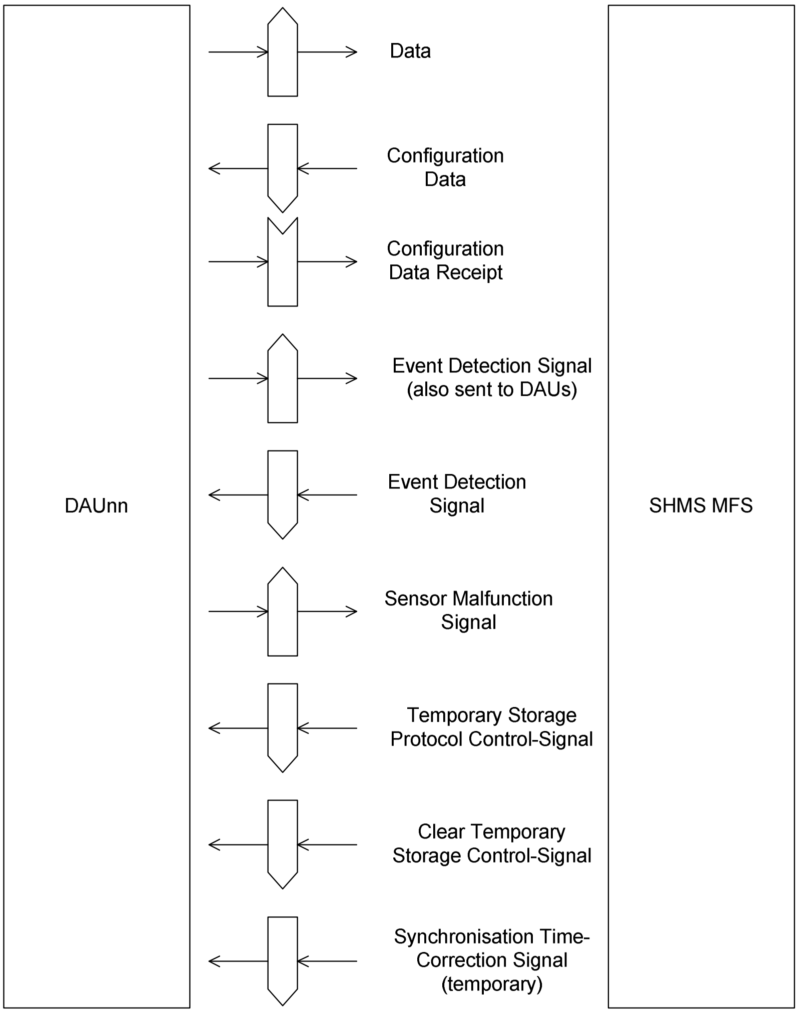


Figure 10.5 Communication between SHMS MFS and DAUs

Other signals sent from and received by the SHMS MFS and DAUs include:

- Synchronisation signals between SHMS MFS and DAUs, and IEEE1588 grandmaster clock

Additionally, general maintenance access to the DAUs from the SHMS MFS shall be provided.

10.24 System Interface

The SHMS shall be accessed primarily from the SHMS MFS, however the SCADA shall at any time be able to take over the control of the SHMS, and as such will have the top priority for control of the SHMS. A dedicated system interface on the SHMS MFS shall:

- Continuously present a summary of the system status (e.g. sensor status, event status, bridge status, etc.)
- Continuously present key data in simple easy-to-follow format
- Provide easy access to the event log from the system and data displays for addition of comments and grouping of events by the operator
- Allow data channel status to be reset by the operator
- Allow event data and seismic event data to be reviewed visually
- Allow automatic reports to be reviewed visually
- Allow the operator to modify the system configuration
- Allow the operator to initiate a record of data in event format from a chosen data channel, from a set of channels (based on data channels assigned to be recorded with the selected data channel) and from all channels, all of which are to be stored on the SHMS DSS (but differentiated from event data)
- Allow the operator to pipe user-defined periods of temporary high-definition data to the hard-drive of the SHMS for manual extraction and data analysis

A facility for displaying and reviewing history data shall be provided with the CSP component of MMS, which is provided by others.

The SHMS MFS shall be controlled through a mouse operated graphical user interface, using standard control items such as menus, sliders and radio controls. Where the user is required to select from a list of pre-defined items, this selection shall be made using a menu. Input designed to be exclusively entered by keyboard shall be limited as far as practicable to undefined items such as text and numbers entered by the user. Where standard operations such as printer selection, filename selection, editing text, window resizing, etc have a direct equivalent in the operator-interface operating systems being run on the same platform e.g. Windows, they should either use the same module or retain the same "look and feel" as the module.

Extensive help menus shall be provided to assist the user. All test and graphic display screen shall have a help link, via a mouse or keyboard selection, which shall bring a help screen to view.

A minimum of 6 monitors shall be provided for the purpose of system display:

- 1 monitor shall be dedicated to display of general system overview
- 3 monitors shall be dedicated to display of data screens, with operator choice of screens to display
- 1 monitor shall be dedicated to display of event and seismic event data
- 1 monitor shall be dedicated to automatic report display, configuration, SHMS DSS management and access to DAUs

The monitors are to be arranged in a grid to maximising simultaneous viewing by a single operator e.g. 3 wide x 2 high.

The SHMS MFS and SHMS DSS shall be remotely accessible to allow the bridge owner and operator to review system operation from other locations (e.g. head offices), to allow companies under maintenance contract to maintain the system in an efficient and effective manner and to allow companies under engineering services contract to access data and to review bridge status for efficient and effective performance. Remote access shall be provided via a secure broadband connection with VNC interface, or similar subject to approval by the SHMS designer. Access shall be password protected and in accordance with the System Security Requirements. In addition remote access shall only be possible from registered IP addresses. Initial remote access to the SHMS MFS and SHMS DSS shall be restricted to visual-only. The external body may request access-control, which shall be granted or rejected by the operator, with permissions established in accordance with user-rights. During remote access-control, the operator may at any time remove access-control and restrict access to visual-only. All remote access shall be automatically logged.

Each DAU will be provided with a monitor and facilities for displaying data associated with the DAU concerned. Tools for software maintenance shall also be provided. The data displays shall be similar in character to the main displays on the SHMS MFS. The DAUs shall be accessible:

- At the DAU
- At the DAU via a connected maintenance laptop
- From the SHMS MFS
- Remotely via the SHMS MFS

The DAUs shall be controlled through a mouse operated graphical user interface, using standard control items such as menus, sliders and radio controls. Where the user is required to select from a list of pre-defined items, this selection shall be made using a menu. Input designed to be exclusively entered by keyboard shall be limited as far as practicable to undefined items such as text and numbers entered by the user. Where standard operations such as filename selection, editing text, window resizing, etc have a direct equivalent in the operator-interface operating systems being run on the same platform e.g. Windows, they should either use the same module or retain the same “look and feel” as the module.

10.25 Data Display

A vast amount of data will be acquired by the SHMS for various purposes. Effective data visualisation is important to ensure maximum effectiveness of the SHMS within the operation and maintenance of the structure. Data visualisation will vary by purpose. No single data visualisation strategy is appropriate for all of the data.

A variety of screens for displaying data will be developed:

- General overview screen and sub-screens
- General data display screens
- Event data and seismic event data review screens

Historic data is to be displayed as part of the CSP component of MMS, provided by others.

Data recorded by the portable monitoring computers and servers shall not be displayed.

All text on displays shall be presented in dual language, with an option to select the language shown: Italian and English (UK).

All characters shall be a minimum of 2mm high when displayed on the monitors with the full screen shown. Example screens are presented in Annex A. The data display strategy presented below or/and the minimum requirements of the monitors, may require modification to facilitate the minimum requirement for character height. Screen presentation shall be subject to the approval of the SHMS designer.

Screen manipulation tools are to be developed to assist with viewing information on the screens e.g. zoom.

A number of displays may include graphs. Graphs shall initially be scaled so that all data-values are shown. Dates and times shall be presented as dd/mm/yyyy and hh:mm respectively. The following graph manipulation functions shall be available:

- Manual definition of axis limits
- Manual definition of axis interval values
- Modification of either axis to logarithmic or linear scaling. Suitable warnings shall be provided when data cannot be plotted correctly (e.g. negative values for logarithmic scaling)
- Display the values associated with a data-point identified by the user
- For histograms and bar-charts, display the number corresponding to each value, suitably formatted, next to the respective columns

10.25.1 Generic Details

All general over screens and sub-screens and general data display screens and sub-screens shall show a common colour of background which reflects the live assessed status (overall condition) of the bridge:

- White : the bridge is not in danger
- Yellow : the bridge is approaching danger
- Red : the bridge is in danger

Data shall be presented in data cells. A status button shall be assigned to individual or grouped data cells. The data cells and status button shall be coloured to reflect the local condition associated with the data reading or the status of the sensor. The conditions associated with colours shall be as follows, in order of importance:

- White: when values are within a defined acceptable range of values
- Yellow: when values are beyond a serviceability warning threshold
- Orange: when values are beyond the event warning threshold
- Red: when values are beyond the event threshold
- Blue: when a sensor has registered itself as malfunctioning
- Black: when a sensor is designated by the operator as offline
- Grey: when a value is not recorded with the SHMS

Where a status button represents a group of sensors the order of importance shall be changed as follows:

- White: when all sensor values are within a defined acceptable range of values
- Blue: when any sensor has registered itself as malfunctioning
- Yellow: when any sensor values are beyond a serviceability warning threshold
- Orange: when any sensor values are beyond the event warning threshold
- Red: when any sensor values are beyond the event threshold
- Black: when all sensors are designated by the operator as offline
- Grey: when all sensor values are not recorded with the SHMS

The colour of the data cells shall reflect the condition associated with the live reading. The status button shall display the colour relating to the highest importance of status (or severity of data reading) of the data channel or group of data channels. The status button can only be reset by password release, accessible via the status button menu. If a data channel is in event status during resetting of the status button, the status button shall update to reflect this condition.

The status button menu presents the following options:

- Acknowledge: to open the event log for editing, acknowledge the change in status, and to reset the status button
- Display: to display live data on a timescale equivalent to the temporary high definition data
- Record Data: to manually activate a record of data (in event format)
- Record Event-style Data: to manually activate a record of data (in event format) from all data-channels associated with the active data-channel for the purposes of creating event records
- Record All Data: to manually activate a record of data (in event format) from the whole SHMS

10.25.2 General Overview Screens and Sub-screens

The general overview screen and sub-screens will present the general status of sensors in any particular part of the bridge, as well as the general status of DAU configuration. The general overview screen shall always be displayed on one of the SHMS MFS monitors.

The sensors shall be grouped by module at each location. A coloured status button will indicate the worst status of any sensor in the module in that location. When the status button is chosen a sub-screen will appear which gives more information concerning the group of sensors in the particular location.

An example of the general overview screen and sub-screens is given in Appendix 1.

10.25.3 Generic Data Display Screens

Numerous data-display screens and sub-screens shall be created to present live data values. The design of these screens shall be sympathetic to the data being displayed and the purpose of this data for operation and maintenance, for maximum impact and effective overview of performance.

Example generic data display screens are given in Appendix 1.

GENERIC SCREEN: INTERNAL ENVIRONMENTAL CONDITIONS

Data recorded and derived for internal environmental conditions includes:

- All Relative Humidity (Internal) including Relative Humidity measured inside the main-cables

- All Corrosion Rate (Internal) measured inside the main-cables
- All Air Temperature (Internal)
- All Surface Humidity (Internal)
- All Dew Point Temperature

Data shall be displayed in tables of readings. Status buttons shall be based on group of sensors at a location.

Additional data to be displayed in the tables of readings:

- Minimum Steel Temperature in the location of measurement – to be copied from Steel Temperature data

The minimum steel temperature shall be compared against the dew point temperature.

This screen will allow the operator to quickly verify the continuing influence and function of the dehumidification system. This screen shall be one of the main screens of interest to the operator.

An example of the screen is given in Appendix 1.

Generic Screen: Wind Conditions

Data recorded and derived for wind conditions includes:

- All Wind Data

For all positions (except the additional 4 positions at mid-span specifically identified for acquiring statistical data), the following data shall be displayed:

- Plan Gust Wind Speed
- Plan Mean Wind Speed
- Plan Gust Wind Direction

Data shall be displayed numerically, grouped by position. Plan Gust Wind Speed and Plan Gust Wind Direction shall also be displayed on a rosette for each position.

To demonstrate continued operation, the 3-axes of point value wind data shall be displayed for the additional 4 positions at mid-span specifically identified for acquiring statistical data.

This screen will allow the operator to quickly verify the continued operation of the anemometers and the general wind conditions.

An example of the screen is given in Appendix 1.

GENERIC SCREEN: EXTERNAL ENVIRONMENTAL (AND ROAD AND RAIL TRACK) CONDITIONS

Data recorded and derived for external environmental conditions, including data that influences road conditions to complement data presented by the Bridge TMS component of SCADA, includes:

- All Deck Wind Data (except the additional 4 positions at mid-span specifically identified for acquiring statistical data)
- All Air Temperature (external)
- All Relative Humidity (external)
- All Solar Radiation
- All Air Pressure
- All Surface Humidity (external)
- All Road Temperature
- All Rail Track Temperature
- All Rain Fall

Data shall be presented numerically, by data type and arranged by location.

For all deck wind data the following data shall be displayed:

- Plan Gust Wind Speed
- Plan Gust Wind Direction

Selection buttons shall be provided which shall allow the operator to select up to 2 wind data locations to display on 2 rosettes. The following data shall be given with each rosette:

- Plan Gust Wind Speed
- Plan Mean Wind Speed
- Plan Gust Wind Direction

This screen will allow the operator to quickly verify that conditions experienced on the bridge will permit safe vehicle passage. This screen shall be one of the main screens of interest to the operator.

An example of the screen is given in Appendix 1.

GENERIC SCREEN: POSITION

Data recorded and derived for position includes:

- All GPS coordinates
- All Tower Static Inclination (measured at level of upper portal)
- All Anchor Block Static Inclination (including inclination of saddles and main-cables)
- Main-cable to Saddle Displacement

Data shall be presented numerically, and grouped by location.

An additional graphic shall be provided that shall display deck vertical position. The graphic will provide a visual representation of the navigation clearance limit. 15mins of recent data shall always be displayed, using colour-grading to identify the time of the data.

This screen will allow the operator to quickly verify the overall condition of the bridge as well as the requirements for navigation channel clearance. This screen shall be one of the main screens of interest to the operator.

An example of the screen is given in Appendix 1.

GENERIC SCREEN: BRIDGE DYNAMICS

Data recorded and derived for bridge dynamics includes:

- All Deck Acceleration (including notional torsion acceleration)

- All Tower Acceleration (including notional torsion acceleration)
- All Main-cable Acceleration (including notional torsion acceleration)
- All Tower Tuned-Mass-Damper Displacement

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the bridge dynamics and thus bridge stability.

An example of the screen is given in Appendix 1.

GENERIC SCREEN: GROUND DYNAMICS

Data recorded and derived for ground dynamics includes:

- All Tower Base Acceleration
- All Tower Base Dynamic Inclination
- All Pier Base Dynamic Inclination
- All Anchor Block Acceleration
- All Anchor Block Dynamic Inclination
- All Remote Acceleration
- All Under-water Escarpment Dynamic Inclination

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the ground dynamics, primarily to verify the operation of these sensors that shall record key seismic data.

An example of the screen is given in Appendix 1.

GENERIC SCREEN: HANGER DYNAMICS

Data recorded and derived for hanger dynamics includes:

- All Hanger Acceleration

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the hanger-cable dynamics.

GENERIC SCREEN: MAIN-CABLE STEEL TEMPERATURE

Data recorded and derived for main-cable steel temperature includes:

- All Main-Cable Steel Temperature
- All Effective Main-Cable Steel Temperature

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the continued operation of the main-cable temperature sensors.

GENERIC SCREEN: MAIN-CABLE STRESS

Data recorded and derived for main-cable stress includes:

- All Main-Cable Stress (not including anchor-bars in anchor blocks)
- All Effective Main-Cable Stress

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the stress-state of the main-cables.

GENERIC SCREEN: MAIN-CABLE ANCHOR-BAR STRESS AND STEEL TEMPERATURE, AND MAIN-CABLE CLAMP STRESS

Data recorded and derived for main-cable anchor-bar stress and steel temperature, and main-cable clamp stress includes:

- All Main-Cable Anchor-Bar Stress
- All Main-Cable Anchor-Bar Steel Temperature
- All Main-Cable Clamp Stress (including principal stresses and shear stress)

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the stress-state of the main-cable anchor-bars and main-cable clamps and verify the continued operation of the main-cable anchor-bar temperature sensors.

GENERIC SCREEN: DECK STEEL TEMPERATURE

Data recorded and derived for deck steel temperature includes:

- All Deck Steel Temperature
- All Effective Roadway Girder Steel Temperature
- All Effective Railway Girder Steel Temperature

Additional data to be displayed:

- Minimum Steel Temperature in the location of measurement – to be calculated from the data presented, and to be copied to the Internal Environmental Conditions data screen

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the continued operation of the deck temperature sensors.

GENERIC SCREEN: DECK STRESS

Data recorded and derived for deck stress includes:

- All Deck Stress (not including orthotropic deck fatigue-stress, diaphragm cope-hole fatigue-stress, and plate corner at cross-beam fatigue-stress)

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the stress-state of the deck.

GENERIC SCREEN: TOWER STEEL TEMPERATURE

Data recorded and derived for tower steel temperature includes:

- All Tower Steel Temperature
- All Effective Tower Leg Steel Temperature

Additional data to be displayed:

- Minimum Steel Temperature in the location of measurement – to be calculated from the data presented, and to be copied to the Internal Environmental Conditions data screen

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the continued operation of the tower temperature sensors.

GENERIC SCREEN: TOWER STRESS

Data recorded and derived for tower stress includes:

- All Tower Stress
- All Tower Base Anchor-bolt Stress

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the stress-state of the tower.

GENERIC SCREEN: HANGER-CABLE STRESS – NEAR TOWERS

Data recorded and derived for hanger-cable stress includes:

- Hanger-cable Stress for hanger-cables 1, 5, 6, 114, 115 and 119
- Average Hanger-cable Stress for hanger-cables 1, 5, 6, 114, 115 and 119

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the stress-state of the hanger-cables located near to the towers.

GENERIC SCREEN: HANGER-CABLE STRESS – NEAR QUARTER-SPAN

Data recorded and derived for hanger-cable stress includes:

- Hanger-cable Stress for hanger-cables 18, 19, 41, 42, 43, 77, 78, 79, 101 and 102
- Average Hanger-cable Stress for hanger-cables 18, 19, 41, 42, 43, 77, 78, 79, 101 and 102

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the stress-state of the hanger-cables located near to the quarter-span.

GENERIC SCREEN: HANGER-CABLE STRESS – AT MID-SPAN

Data recorded and derived for hanger-cable stress includes:

- Hanger-cable Stress for hanger-cables 59, 60, and 61
- Average Hanger-cable Stress for hanger-cables 59, 60, and 61

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the stress-state of the hanger-cables located at the mid-span.

GENERIC SCREEN: HANGER-CABLE AVERAGE STRESS

Data recorded and derived for hanger-cable average stress includes:

- Average Hanger-cable Stress for all hanger-cables

Data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the average stress-state of all of the hanger-cables.

An example of the screen is given in Appendix 1.

GENERIC SCREEN: HANGER-CABLE FATIGUE – NEAR TOWERS

Data recorded and derived for hanger-cable fatigue includes:

- Hanger-cable Fatigue Utilisations for hanger-cables 1, 5, 6, 114, 115 and 119
- Hanger-cable Total Rainflow Count Data for hanger-cables 1, 5, 6, 114, 115 and 119

Fatigue Utilisations shall be presented numerically, and grouped by location.

Total Rainflow Count Data shall be presented on a graph of Number of Counts versus Bin Size. The Number of Counts axis shall be presented on a logarithmic scale. Only one location shall be presented on the screen at any one time. The operator shall be able to select which location is shown. An additional graph shall be provided which shall show Fatigue Utilisation versus Time. Residual Life shall be calculated and displayed for the location selected, based on the change in utilisation over the previous 24 hours.

This screen will allow the operator to quickly verify the fatigue-state of the hanger-cables located near to the towers.

GENERIC SCREEN: HANGER-CABLE FATIGUE – NEAR QUARTER-SPAN

Data recorded and derived for hanger-cable fatigue includes:

- Hanger-cable Fatigue Utilisations for hanger-cables 18, 19, 41, 42, 43, 77, 78, 79, 101 and 102
- Hanger-cable Total Rainflow Count Data for hanger-cables 18, 19, 41, 42, 43, 77, 78, 79, 101 and 102

Fatigue Utilisations shall be presented numerically, and grouped by location.

Total Rainflow Count Data shall be presented on a graph of Number of Counts versus Bin Size. The Number of Counts axis shall be presented on a logarithmic scale. Only one location shall be presented on the screen at any one time. The operator shall be able to select which location is shown. An additional graph shall be provided which shall show Fatigue Utilisation versus Time. Residual Life shall be calculated and displayed for the location selected, based on the change in utilisation over the previous 24 hours.

This screen will allow the operator to quickly verify the fatigue-state of the hanger-cables near to the quarter-span.

GENERIC SCREEN: HANGER-CABLE FATIGUE – AT MID-SPAN

Data recorded and derived for hanger-cable fatigue includes:

- Hanger-cable Fatigue Utilisations for hanger-cables 59, 60, and 61
- Hanger-cable Total Rainflow Count Data for hanger-cables 59, 60, and 61

Fatigue Utilisations shall be presented numerically, and grouped by location.

Total Rainflow Count Data shall be presented on a graph of Number of Counts versus Bin Size. The Number of Counts axis shall be presented on a logarithmic scale. Only one location shall be presented on the screen at any one time. The operator shall be able to select which location is shown. An additional graph shall be provided which shall show Fatigue Utilisation versus Time. Residual Life shall be calculated and displayed for the location selected, based on the change in utilisation over the previous 24 hours.

This screen will allow the operator to quickly verify the fatigue-state of the hanger-cables at the mid-span.

GENERIC SCREEN: DECK FATIGUE STRESS

Data recorded and derived for deck fatigue stress includes:

- All Fatigue-related Orthotropic Deck Fatigue Stress
- All Deck Diaphragm Cope-hole Fatigue Stress
- All Deck Plate Corner at Cross-Beam Fatigue Stress

Fatigue Stress shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the continuing function of the deck fatigue sensors.

GENERIC SCREEN: DECK FATIGUE UTILISATION

Data recorded and derived for deck fatigue utilisation includes:

- All Fatigue-related Orthotropic Deck Fatigue Utilisations
- All Fatigue-related Orthotropic Deck Total Rainflow Count Data
- All Deck Diaphragm Cope-hole Fatigue Utilisations
- All Deck Diaphragm Cope-hole Total Rainflow Count Data
- All Deck Plate Corner at Cross-Beam Fatigue Utilisations
- All Deck Plate Corner at Cross-Beam Total Rainflow Count Data

Fatigue Utilisations shall be presented numerically, and grouped by location.

Total Rainflow Count Data shall be presented on a graph of Number of Counts versus Bin Size. The Number of Counts axis shall be presented on a logarithmic scale. Only one location shall be presented on the screen at any one time. The operator shall be able to select which location is shown. An additional graph shall be provided which shall show Fatigue Utilisation versus Time.

Residual Life shall be calculated and displayed for the location selected, based on the change in utilisation over the previous 24 hours.

This screen will allow the operator to quickly verify the fatigue-state of the deck.

GENERIC SCREEN: EXPANSION JOINT MOVEMENT

Data recorded and derived for expansion joint movement includes:

- All Expansion Joint Displacements (not including buffer displacements)
- All Roadway Expansion Joint Accelerations
- All Expansion Joint Accelerations at the Bearings

Expansion Joint Displacements, Roadway Expansion Joint Accelerations and Expansion Joint Accelerations at the Bearings shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the state of the expansion joints and the continued operation of the expansion joint accelerometers.

GENERIC SCREEN: EXPANSION JOINT MOVEMENT ACCUMULATION

Data recorded and derived for expansion joint movement accumulation includes:

- All Expansion Joint Movement Maintenance Utilisations
- All Expansion Joint Movement Total Rainflow Count Data

Maintenance Utilisations shall be presented numerically, and grouped by location.

Total Rainflow Count Data shall be presented on a graph of Number of Counts versus Bin Size. The Number of Counts axis shall be presented on a logarithmic scale. The weighting applied to bin size for calculation of maintenance utilisation shall be shown. Only one location shall be presented on the screen at any one time. The operator shall be able to select which location is shown. An additional graph shall be provided which shall show Maintenance Utilisation versus Time.

Residual Life shall be calculated and displayed for the location selected, based on the change in utilisation over the previous 24 hours.

This screen will allow the operator to quickly verify the maintenance-state of the expansion joints.

GENERIC SCREEN: BUFFER PERFORMANCE

Data recorded and derived for buffer performance includes:

- All Buffer Chamber Pressure Data
- All Buffer Accumulator Tank Pressure Data
- All Buffer Force Data
- All Buffer Displacement Data
- All Buffer Oil Temperature Data
- All Deck-to-Tower Restraint Stress
- All Buffer Pin to Pin-plate Displacement

All data shall be presented numerically, and grouped by location. All Buffer Force Data and Buffer Displacement Data shall be presented graphically, and grouped by location. The graphs shall present Buffer Force against Buffer Displacement. The design performance shall also be shown on the plots. 15mins of recent data shall be presented. The operator shall be able to choose one graph at a time that is shown at larger scale.

This screen will allow the operator to quickly verify the continued performance of the buffers, and to quickly verify the stress-state of the deck-to-tower restraint steelwork and maintenance-state of the buffer pins.

GENERIC SCREEN: GROUND CONDITIONS

Data recorded and derived for ground conditions includes:

- All Corrosion Data
- All Ground Pressure Data
- All Ground Interstitial Pressure Data

All data shall be presented numerically, and grouped by location.

This screen will allow the operator to quickly verify the status of ground conditions.

GENERIC SCREEN: VIRTUAL DATA

Data derived for virtual data includes:

- All Virtual Data

Data shall be displayed numerically in tables.

This screen will allow the operator to quickly verify the status of those parameters that have been identified as important to derive from combinations of different data.

GENERIC SCREEN: APPLIED LOADS

Data recorded and derived for applied loads includes:

- Total traffic (vehicle and rail) load on structure

- Total traffic (vehicle) density on structure
- Deck Transverse Gust Wind Pressure
- Deck Transverse Mean Wind Pressure
- Deck Gust Wind Speed and Direction
- Prediction data received from the CSP

Only one location for Deck Gust Wind Speed and Direction and Deck Transverse Gust and Mean Wind Pressures shall be shown on this screen. The operator shall be able to choose which deck anemometer is used to provide the data that is displayed.

Data shall be displayed graphically.

The following graphs shall be displayed:

- Total traffic (vehicle and rail) load on structure against time including future prediction
- Total traffic (vehicle and rail) load on structure against total traffic (vehicle) density on structure
- Deck gust wind speed against time including future prediction
- Deck gust wind speed and direction on rosettes including future prediction
- Deck transverse gust wind pressure and Deck transverse mean wind pressure against Total traffic (vehicle and rail) load on structure including future prediction

All graphs that show data plotted against time shall show 2hrs of recorded data and 2hrs of prediction data. Colour-grading shall be adopted to show the time of data. Design limits shall be shown.

For the graph showing total traffic (vehicle and rail) load on the bridge plotted against density of vehicle traffic on the bridge, as well as for the rosettes, the duration of data shown shall be user-definable, initially set at 10 minutes of recorded data and 10 minutes of prediction data. Colour-grading shall be adopted to show the time of data. Design limits shall be shown. For the graph showing total traffic (vehicle and rail) load on the bridge plotted against density of vehicle traffic on the bridge, theoretical lines shall also be provided indicating the expected correlation of 1) cars only, and 2) heavy goods vehicles only.

This screen will allow the operator to quickly verify the overall loading condition of the bridge. This screen shall be one of the main screens of interest to the operator.

An example of the screen is given in Appendix 1.

GENERIC SCREEN: CONSTRUCTION PHASE POSITIONAL DATA

An additional data display shall be required for the construction phase to provide vital quick reference feedback on the performance of the structure during construction.

Data recorded and derived for construction phase positional data includes:

- All GPS coordinates

Data shall be presented numerically, and grouped by location.

Selection buttons shall be provided which shall allow the operator to select up to 10 datasets (nominal) to be displayed on separate graphs. Each graph shall present data with time. 6hrs (nominal) of recent data shall be displayed. Each graph shall also present the predicted position from designer analysis, as well as the threshold limits and structural limits. Predicted values, and threshold and limiting values shall be provided by the bridge structural designers and entered onto the system at the appropriate time by the operator.

This screen will allow the operator to quickly verify the overall condition of the bridge as it is erected. This screen shall be one of the main screens of interest to the operator. This display shall only be active during the construction phase.

10.25.4 Event Data and Seismic Event Data Screen

Event data and Seismic Event data shall be presented on a single screen. Event data and seismic event data shall be available from the SHMS DSS.

A status button shall indicate if a seismic event has been registered since the button was last reset. The operator resets the status button. Resetting shall be password protected.

A list of event files and a list of seismic event files shall be presented. The list of seismic event data shall show all seismic event files recorded since the system was initiated. The list of event data shall show all days during which events were recorded; selection of a day will open a list of all events recorded on the chosen day. An event of interest for review shall be selected from these lists.

Selection of an event or seismic event file shall open a list of all data channel records available in that file as well as, in the case of a seismic event file, a list of response spectra. The data channel that initiated the event record shall be highlighted in red. Other data channels that registered events during the event record shall be highlighted in orange. Data channels of interest for review shall be selected from this list of data channels. Two methods of display shall be available: either 12 data channels (nominal) can be displayed on individual graphs of data against time, or any number of selected data channels can be displayed on a single graph of data against time (differentiated by colour and line type). The option of also showing assigned limits shall be available. The option of printing a file-copy of the graph(s) displayed shall be available.

The operator shall be able to rescale (by zoom control) any axis of any of the graphs. The operator shall be able to select any data-point presented on any of the graphs and see the data value and time stamp.

10.26 System Reporting

Automatic reports shall be produced by the SHMS MFS. These reports shall be electronic and presented in Adobe pdf format or similar. The reports shall be automatically sent to the EDMS component of MMS for storage on the MMS database. The reports shall be automatically emailed to a list of email addresses defined by the operator and password protected. The reports shall open automatically onto the nominated SHMS MFS screen.

The following automatic reports shall be produced:

- Weekly - to be labelled "weekly-report-yyyy-mm-dd"
- Monthly - to be labelled "monthly-report-yyyy-mm-dd"
- Yearly - to be labelled "yearly-report-yyyy-mm-dd"
- Immediately following seismic event - to be labelled "seismic-report-yyyy-mm-dd-hh-mm"

Other reports shall be produced at request:

- Load status - to be labelled "load-status-report-yyyy-mm-dd-hh-mm"
- Fatigue status - to be labelled "fatigue-status-report-yyyy-mm-dd-hh-mm"
- External environmental conditions status - to be labelled "weather-report-yyyy-mm-dd-hh-mm"
- Expansion joint status - to be labelled "expansion-joint-status-report-yyyy-mm-dd-hh-mm"
- Log status - to be labelled "log-status-report-yyyy-mm-dd-hh-mm"

For each report the statistical data for the listed default data shall be presented. It shall also be possible for the operator, password permitting, to select additional data to be added to the report.

Where graphs are to be included, these shall be scaled so that all data-values are shown. Dates and times shall be presented as dd/mm/yyyy and hh:mm respectively.

In the following sections, reference to status change of a data channel refers to any change that can be reflected in a change of colour of the status button:

- when a serviceability warning is registered
- when an event warning is registered
- when an event is registered
- when a malfunctioning sensor is registered
- when a sensor is designated by the operator as offline

10.26.1 Weekly Report

The weekly report shall present a list of data channels that have registered a status change during the week along with a count of each type of change in status, the minimum value recorded during the week, the allocated limit to the minimum value, the maximum value recorded during the week, and the allocated limit to the maximum value.

The weekly report shall present a list of bridge event warnings and serviceability warnings registered during the week along with the time of the warnings and the data channels that triggered the warnings.

The weekly report shall present a count of events (log entries) recorded during the week, a count of acknowledged events (log entries) registered during the week, and a count of events (log entries) remaining to be acknowledged since the system was launched.

The weekly report shall present a count of seismic events registered during the week.

The weekly report shall present a graph of maximum and minimum data against time for the whole week for the following data channels:

- Wind speed (horizontal, both mean and gust) at deck level at mid-span
- Wind direction (in horizontal plane) at deck level at mid-span
- Total traffic (vehicle and rail) load on the structure
- Effective deck temperature at mid-span
- Effective tower temperature above the lower portal
- Effective main cable temperature at mid-span
- Tower top GPS longitudinal coordinates
- Tower top GPS transverse coordinates
- Deck mid-span GPS vertical coordinates
- Deck mid-span GPS horizontal coordinates
- Deck mid-span GPS transverse coordinates
- Anchorage GPS vertical coordinates
- Anchorage GPS longitudinal coordinates
- Tower base GPS vertical coordinates
- Tie-down pier GPS vertical coordinates

- Deck mid-span vertical accelerations
- Deck mid-span notional torsion accelerations
- Deck third-point vertical accelerations
- Deck third-point notional torsion accelerations
- Hanger accelerations
- Expansion joint movement
- Deck fatigue utilisation
- Hanger fatigue utilisation.

The weekly report shall present a graph for the whole week for the following data channels:

- Buffer force versus buffer displacement
- Expansion joint movement (large displacement joints) versus effective deck temperature at mid-span.

10.26.2 Monthly Report

The monthly report shall present a list of data channels that have registered a status change during the month along with a count of each type of change in status during the month, the minimum value recorded during the month, the allocated limit to the minimum value, the maximum value recorded during the month, and the allocated limit to the maximum value.

The monthly report shall present a count of bridge event warnings and serviceability warnings registered during the month.

The monthly report shall present a count of events (log entries) recorded during the month, a count of acknowledged events (log entries) registered during the month, and a count of events (log entries) remaining to be acknowledged since the system was launched.

The monthly report shall present a count of seismic events registered during the month.

10.26.3 Yearly Report

The yearly report shall present a list of data channels that have registered a status change during the year along with a count of each type of change in status, the minimum value recorded during the year, the allocated limit to the minimum value, the maximum value recorded during the year, and the allocated limit to the maximum value.

The yearly report shall present a count of bridge event warnings and serviceability warnings registered during the year.

The yearly report shall present a count of events (log entries) recorded during the year, a count of acknowledged events (log entries) registered during the year, and a count of events (log entries) remaining to be acknowledged since the system was launched.

The yearly report shall present a graph of the weekly count of events (log entries) recorded during the year, a graph of the weekly count of events (log entries) registered during the year, and a graph of the count of events (log entries) remaining to be acknowledged since the system was launched.

The yearly report shall present a count of seismic events registered during the year.

10.26.4 Seismic Report

The seismic report shall present a graph of data against time during the seismic event, and the corresponding derived response spectra, for the following data channels:

- Ground (seismic) accelerations

The seismic report shall present a table of first data point and last data point from the seismic event file for the following data channels:

- Tower top GPS longitudinal coordinates
- Tower top GPS transverse coordinates
- Deck mid-span GPS vertical coordinates
- Deck mid-span GPS horizontal coordinates
- Deck mid-span GPS transverse coordinates

- Anchorage GPS vertical coordinates
- Anchorage GPS longitudinal coordinates
- Tower base GPS vertical coordinates
- Tie-down pier GPS vertical coordinates
- Expansion joint position
- Main-cable to saddle position
- Buffer position

The seismic report shall present a graph of data against time for the seismic event for the following data channels:

- Wind speed (horizontal, both mean and gust) at deck level at mid-span
- Wind direction (in horizontal plane) at deck level at mid-span
- Total traffic (vehicle and rail) load on the structure
- Effective deck temperature at mid-span
- Effective tower temperature above the lower portal
- Effective main cable temperature at mid-span
- Tower top GPS longitudinal coordinates
- Tower top GPS transverse coordinates
- Deck mid-span GPS vertical coordinates
- Deck mid-span GPS horizontal coordinates
- Deck mid-span GPS transverse coordinates
- Anchorage GPS vertical coordinates
- Anchorage GPS longitudinal coordinates
- Tower base GPS vertical coordinates

- Tie-down pier GPS vertical coordinates
- Expansion joint movement
- Tuned-Mass-Damper movement
- Main-cable to saddle movement

The seismic report shall present a graph for the seismic event for the following data channels:

- Buffer force versus buffer displacement

Time of data shall be shown with colour-grading.

The seismic report shall present a table of maximum and minimum values recorded during the seismic event for all data channels that exceeded the event threshold limit during the seismic event.

The seismic report shall present all details registered for all bridge event warnings or serviceability warnings registered during the seismic event.

10.26.5 Load Status Report

The load status report shall present a graph of data against time for the preceding 2hrs and prediction of data for the subsequent 2hrs (or as provided), for the following data channels:

- Deck gust wind speed at mid-span
- Deck gust wind direction at mid-span
- Total traffic (vehicle and rail) load on the structure

The load status report shall present a graph of data for the preceding 2hrs and prediction of data for the subsequent 2hrs (or as provided), for the following data channels:

- Deck transverse gust wind pressure and Deck transverse mean wind pressure against Total vehicle (road and rail) load on the structure
- Total traffic (vehicle and rail) load on structure against total traffic (vehicle) density on structure

- Deck gust wind speed at mid-span and Deck gust wind direction at mid-span on a rosette

Time of data shall be shown with colour-grading. Assigned limits shall also be displayed on the graphs.

10.26.6 Fatigue Status Report

The fatigue status report shall present a graph of utilisation development since the system was initiated, current utilisation, residual life, and a plot of current number of counts for each fluctuation range, for the following data channels:

- Orthotropic deck plate stress
- Deck diaphragm cope-hole plate stress
- Deck plate corner at cross-beam stress
- Hanger-cable stress
- Hanger average stress

10.26.7 Weather Report

The weather report shall present a graph of data against time for the preceding 2hrs and prediction of data for the subsequent 2hrs (or as provided), for the following data channels:

- All deck gust wind speed
- All deck mean wind speed
- All deck gust wind direction

The weather report shall present a graph of data against time for the preceding 2hrs for the following data channels:

- All external relative humidity
- All external air temperature
- All solar radiation

- All air pressure
- All road temperature
- All rail track temperature
- All rainfall

10.26.8 Expansion Joint Status Report

The expansion joint status report shall present a graph of utilisation development since the system was initiated, current utilisation, residual life, and a plot of current number of counts for each fluctuation range (current rainflow count data), for the following data channels:

- Expansion joint movement

The expansion joint status report shall present a list of the current user-inputted condition of elements as presented in the condition file.

10.26.9 Log Status Report

The log status report shall present a count of events (log entries) remaining to be acknowledged since the system was launched.

The log status report shall present a graph of the weekly count of events (log entries) recorded since the system was launched, a graph of the weekly count of acknowledged events (log entries) registered since the system was launched, and a graph of the count of events (log entries) remaining to be acknowledged since the system was launched.

10.27 SHMS DSS Storage Management

The SHMS DSS shall be a partition of the SCADA database. Long-term management of the SHMS data shall therefore not be a function of SHMS. Typically SHMS data is required for analysis many years after it is created. Appropriate management of SHMS data in the long-term is therefore essential to ensure that maximum benefit is gained from the SHMS in the long-term.

In addition to mirroring data on the database, procedures for backing-up data to reliable media-types (e.g. dvds, hard-drives, etc…) shall be established. When new media types are developed, all data shall also be backed-up to these whilst old media types are phased out,. The adoption of these procedures would not only protect the data against loss, but would also future-proof the accessibility to the data.

The need for economising on data storage on the database may not be evident from the outset but may arise at some future point. Data quantity reduction routines shall therefore be established in preparation. The approach shall be established around logarithmic data-storage. Data shall be deleted from the database in a structured order following a number of rules:

- Only data that has been backed-up shall be deleted.
- Only data older than a defined period shall be deleted.
- Event data files shall be deleted in preference to history data files and statistical (and additional) data files. Statistical (and additional) data files shall be deleted in preference to history data files. History data files shall not be deleted unless additional data quantity reduction is required following deletion of all alert and statistical (and additional) files.
- Low importance event data files shall be deleted in preference to high importance event data files. Following each event, the operator shall assess the importance of the event for long-term storage and shall assign an importance code on the event log.
- Older data files shall be deleted in preference to more recent data files.

The data quantity reduction routines shall be established during Progetto Esecutivo.

10.28 SHMS Interaction with SCADA Database

The SHMS DSS shall be a partition of the SCADA database. The SHMS MFS shall therefore send data to the SCADA database for storage. All data shall be linked to the appropriate element references as will be described in the Inspection and Maintenance Manual for the bridge, in order to support data search by other components of SCADA and MMS. The SHMS MFS shall also extract from the SCADA database data that has been recorded by other components of SCADA. The SCADA database shall be accessible via a Data Service Layer that shall be established by the designers of the SCADA database. An SHMS Data Conversion, Delivery, and Query Layer shall be developed as part of the SHMS MFS to translate and deliver data to, as well as query and extract data from, the SCADA database via the Data Service Layer.

An independent user-interface programme shall be supplied as part of the SHMS MFS, which shall allow data to be extracted to file for other purposes. The user-interface programme shall allow a variety of common file formats to be produced, including comma-separated text file format.

11 System Security Minimum Requirements

The SHMS shall operate on a user account basis. Users shall be assigned rights for performing various actions including:

- changing screens on monitors in the SCADA
- accessing the DAUs and IDRUs to view the data screens only
- acknowledging events
- accessing the event log to view only
- modifying the event log
- allowing external users to take temporary control of the system
- modifying configuration files
- accessing the DAU data and IDRU data to view only
- accessing the SHMS DSS to view only
- copying data from the DAU and IDRU
- copying data from the SHMS DSS
- modifying and deleting data on the DAU and IDRU
- modifying and deleting data on the SHMS DSS
- administrating the DAU software and IDRU software
- administrating the SHMS MFS software

The following user account types shall be established:

- Operator – the operator shall have rights to change screens in the SCADA room, and to access the DAUs and IDRUs to view the data screens only.
- Senior Operator – the senior operator shall have the rights of the Operator as well as rights to acknowledge events, access the event log, to modify the event log, and to allow external users to take temporary control of the system.
- Engineer – the engineer shall have the rights of the Senior Operator as well as rights to modify configuration files, to access the DAU data and IDRU data to view only, and to access the SHMS DSS to view only.
- Senior Engineer – the senior engineer shall have the rights of the Engineer as well as rights to copy data from the DAU and IDRU, to copy data from the SHMS DSS, to modify and delete data on the DAU and IDRU, and to modify and delete data on the SHMS DSS.
- System Engineer – the system engineer shall have the rights of the Engineer as well as rights to administrate the DAU software and IDRU software, and to administrate the SHMS MFS software.
- System Administrator – the system administrator shall have rights to access all areas of the SHMS, including source code for customised and tailor-made software, and perform modifications. Read-write access to source code for customised and tailor-made software shall be provided.
- SCADA Systems – the SCADA systems (including CSP) shall have the right to access the SHMS MFS data buffer to view data and to copy data.

Unique user accounts shall be allocated to each individual, including the SCADA Systems. All user accounts shall be password protected. Passwords shall expire every 4 weeks, with the exception of passwords allocated to the SCADA Systems.

12 Documentation Minimum Requirements

The following documentation shall be provided with the SHMS:

- Operation manual
- Maintenance manual

- System architecture guide
- Software source code guide
- Printed software source code
- Troubleshooting guide
- Sensor identification lookup sheets (name, location, etc)
- Event diagnosis guide
- Quality Control documents
- 25-year over-haul plan

Three copies of each document shall be provided. Documents shall be provided in both Italian and English.

It is recommended that the bridge owner or operator arranges for an additional manual to be created following 3 years of operation of the bridge, reporting the typical behaviour of the SHMS.

12.1.1 Operation Manual

The operation manual shall describe the complete operation interface of the SHMS MFS as well as local interface at the DAU and IDRU.

12.1.2 Maintenance Manual

The maintenance manual shall set-out all of the maintenance activities required to keep the SHMS functional for 25 years. Maintenance activities shall be divided into the following categories:

- regular general maintenance (including sensor re-calibration and survey of the GPS reference station)
- event-specific maintenance

The maintenance manual shall describe the maintenance activities and time intervals that are required, how the maintenance activities shall be performed, what tools are required, and what spare parts required. The maintenance manual shall also present inspection proforma.

The maintenance manual shall also identify maintenance actions required during events that require maintenance activities e.g. inspection of equipment and reinstatement of lightning protection fuses following lightning strike.

12.1.3 System Architecture Guide

The system architecture guide shall present the complete layout of the hardware of the system. It shall also provide photographs and identification of all terminals, hardware and sensors.

12.1.4 Software Source Code Guide

The guide to the software source code shall present sufficient detail of the software source code for a competent software engineer to understand and modify the system.

12.1.5 Printed software source code

Printed software source code, including a guide to the source code, shall be provided for the SHMS Data Conversion, Delivery, and Query Layer.

12.1.6 Troubleshooting Guide

The troubleshooting guide shall present actions to be taken to resolve basic problems with the system including: system block, system shutdown, data channel data loss, etc.

12.1.7 Sensor Identification Look-up Sheets

The sensor identification look-up sheets shall be a simple list of data channel identifiers, with sensor description and location.

12.1.8 Event Diagnosis Guide

The event diagnosis guide shall be prepared by the SHMS designer and shall present anticipated causes of registered events as well as advice on subsequent actions to be taken. The event diagnosis guide shall be developed around the matrix of anticipated outcomes for automatic assessment of Bridge Event Warnings.

12.1.9 Quality Control Documents

The quality control documents shall be presented in an organised file or document with reference index..

12.1.10 25 year Over-haul Plan

The SHMS is expected to require an over-haul at the end of the design life. As the end of the design life approaches the functionality and condition of the system and its components shall be reviewed. If required a partial over-haul or a complete over-haul shall be performed. The over-haul shall be required:

- for system maintenance
- for upgrade in view of advancement in technologies

If a partial or complete over-haul is required, this shall be performed in a progressive manner, so that:

- the SHMS continues to provide at all times the operational functions
- the SHMS continues to provide at all times more than 90% of all of the data channels
- the SHMS continues to provide at all times more than 75% of data required for each monitoring requirement
- gaps in data are minimised

A strategy for complete system over-haul shall be prepared, including expected sequence for replacement of the various components, and shall be presented in the 25-year over-haul plan.

13 Quality Control Minimum Requirements

13.1 SHMS Sub-contractor Selection

Candidates for SHMS sub-contracts shall submit evidence that they operate under an approved quality system (e.g. ISO 9001). Candidates shall submit evidence of experience with Structural Health Monitoring systems and evidence of successful high quality installations, which shall be as a minimum in the form of client references, CVs of experience, and system demonstrations. The assessment of SHMS sub-contract bids shall include an assessment of experience and quality.

13.2 Testing

Testing of sensors, cabling, hardware, software and data-processing routines shall be required at key stages within the project. Testing shall include testing of function as well as testing of accuracy. All testing shall be accompanied by quality documentation. All testing shall be agreed with the SHMS designer.

13.2.1 Certificates

All equipment, including testing equipment, shall be provided with operation certificates and warranty certificates. All sensors, and testing equipment (if appropriate), shall be provided with calibration certificates.

13.2.2 Factory Acceptance Tests

All data processing and manipulation routines shall be independently tested and approved by the SHMS designer prior to delivery to site.

All software shall be independently tested and approved by the SHMS designer prior to delivery to site. The testing process shall include a full simulation of the operation of the entire SHMS network, including signal and fault testing.

All components of the SHMS shall be independently tested for operation and approved by the SHMS designer before delivery for installation. Components provided with certification from established European accreditation bodies (e.g. UKAS) may be exempt from testing subject to the approval of the SHMS designer.

13.2.3 Site Acceptance Tests

Immediately following installation, all components of the SHMS, including displays, shall be tested for operation and approved by the SHMS designer before delivery of the relevant structural component to site.

All components of the SHMS shall be tested for operation following erection of the relevant structural component and approved by the SHMS designer.

Before the bridge is opened to the public, and following completion of the SHMS installation, the SHMS shall be proof-tested. This proof-test shall demonstrate that the SHMS runs without the development of errors. The test shall consist of continuous operation of the SHMS, including the performing of designed operation tasks. The test shall be performed for a minimum of 30 continuous days. When an error is discovered it shall be corrected immediately. The test shall demonstrate error-free operation for a minimum of 15 continuous days. The duration of the test shall be extended if required to demonstrate this. The SHMS sub-contractor shall be required to perform the proof-test with sufficient allowance to ensure that the SHMS will be certified prior to the opening of the bridge.

13.2.4 Testing of Embedded Main-cable Sensor

The installation of the embedded main-cable sensors is unproven. The development of the embedded main-cable sensors shall therefore involve proof-testing. The final detailed design shall therefore be proof-tested to demonstrate that function is maintained following, where applicable:

- formation of the sensor as part of a main-cable strand (continuous and multiple sensors)
- positioning of the strand (and sensor) on-site (continuous and multiple sensors)
- compaction of the main-cable on-site (single sensors, and continuous and multiple sensors)
- installation of the main-cable clamps and wrapping-wire (single sensors, and continuous and multiple sensors)

The measurement of relative humidity with fibre-optic cables is not currently well established. The final detailed design shall therefore also be proof-tested to demonstrate function to the minimum requirements.

Development phase proof-testing is discussed further in Appendix 2.

13.2.5 Structural Load Testing

The function of the SHMS, and calibration of the sensors, shall be tested during the structural load tests. Defects that are detected shall be made good.

13.3 Repairs

All defects identified during testing shall be repaired. Components affected by the defects shall be tested following repair. The procedure shall be repeated until the function of the system is demonstrated to be in accordance with the monitoring requirements, and approval is provided by the SHMS designer. All defects identified and repaired shall be formally recorded as part of the quality control documents.

13.4 Labelling and Identification

All hardware (sensors, dataloggers, cables, IDRUs, DAUs, cabinets, portable monitoring equipment, etc) shall be uniquely labelled, and shall be linked to the appropriate element references as will be described in the Inspection and Maintenance Manual for the bridge. Cables shall be labelled at each end and at regular intervals. All labels shall be applied to the equipment before installation. Labelling shall be based on the sensor labelling nomenclature presented in Table 4.4. All labelling shall be subject to the approval of the SHMS designer. Where appropriate and feasible, sensor axis alignment shall be marked onto the adjacent steelwork. Labels and markings shall be permanent, but shall not damage the structure or protective system (e.g. paint system or similar).

All hardware shall be identified in the System Architecture Guide. Photographs shall be presented in the System Architecture Guide recording the position of each component of hardware, including the position and orientation of each sensor. Photographs shall be annotated with the appropriate labelling. The photographs shall be of sufficient quality and layout that it shall be possible to verify changes since installation.

14 Copyright Minimum Requirements

The bridge owner shall share all copyrights to source code of all customised and tailor-made software, and SHMS documentation.

15 Design Life and Warranty Minimum Requirements

The design life of the SHMS shall be 25 years. The SHMS shall function for 25 years provided maintenance activities detailed in the maintenance manual are carried out. After 25 years the SHMS shall require a review and system overhaul.

The minimum warranty on all components of the SHMS shall be 1 year, subject to the exclusions listed below.

The warranty for all components of the SHMS shall be 5 years provided that the SHMS is maintained in accordance with the maintenance manual.

16 Provision for Maintenance

All SHMS equipment, with the exception of 'embedded' sensors, shall be installed such that they can be accessed for maintenance and replacement. Embedded sensors are those sensors that cannot be accessed due to physical restrictions. These include:

- sensors embedded in the main cables
- sensors embedded in the concrete foundations

The DAUs shall be built from hot-swept modules.

17 Maintenance Strategy Development

17.1 Failure Modes, Effects and Criticality Analysis (FMECA)

A failure modes, effects and criticality analysis (FMECA) shall be performed on the SHMS. This analysis shall consider:

- the function of the system in general
- the function of the system in delivering the monitoring requirements
- the components
- the importance of components within the context of the importance of the monitoring requirements, including the importance of sensors to the operation and maintenance of the bridge e.g. identification of high priority safety critical sensors

The FMECA shall drive the development of:

- recommendations for general inspection
- equipment repair and replacement strategy

- spare parts list

The FMECA shall be reviewed:

- following construction of the bridge
- after 5 years of operation of the bridge

Changes identified shall be incorporated into the recommendations for inspection, equipment repair and replacement strategy, and spare parts list.

17.2 Recommendations for General Inspection

Recommendations for general inspection for all components of the SHMS shall be developed based on output from the FMECA.

A preliminary FMECA has identified the following recommendations for inspections:

- Perform regular function checks at 3-month intervals of the standby SHMS MFS
- Verify regularly at 3-month intervals that SHMS data is backed-up from the SCADA database
- Perform regular function checks at 3-month intervals of the back-up wireless communication system
- Perform regular visual inspection at 3-month intervals of the operating conditions of the DAUs and IDRUs
- Perform quick response inspection within 48hrs of lightning fuses following lightning strike
- Perform regular visual inspection at 3-month intervals of remote sensors

17.3 Equipment Repair and Replacement Strategy

An equipment repair and replacement strategy shall be developed based on output from the FMECA. The strategy shall include identification of importance of sensors, prioritisation of sensors to assist the operator in developing and reviewing strategic repair programmes, and permissible response times in the event of failure.

A preliminary FMECA has identified the following considerations:

- Maximum permissible out-of-service time for mid-span GPS receivers is 24-hours
- Maximum permissible out-of-service duration over a year of any tower wind anemometer is 1-month

Due to the branching arrangement of the system, patterns of sensor malfunctions and data loss can be used to identify components requiring repair or replacement e.g. the loss of data from all sensors piping data through an IDRU indicates failure of the IDRU or data-cable leading to the next branch (IDRU or DAU). This type of observation shall be included in the equipment repair and replacement strategy.

17.4 Spare Parts

A spare parts schedule shall be developed based on output from the FMECA.

A preliminary FMECA has identified the following recommendations for spare parts:

- 1 back-up SHMS MFS (included explicitly in the monitoring plan)
- SHMS MFS hardware components (for items most likely to fail and for items that will take excessive time to obtain replacements for)
- 2 mobile DAUs
- 2 mobile IDRUs
- Cabling (in particular for critical sections of the SHMS network)
- 2 GPS receivers (for towers - due to risk of damage from lightening strike)
- 2 GPS receivers (for deck)
- 4 Expansion Joint Linear Displacement Sensors (for positions at towers)
- 4 Expansion Joint Linear Displacement Sensors (for positions at terminal structures)

18 Design for Expansion

18.1 Provision for Immediate Expansion following Delivery

The completed SHMS shall be provided with immediate expansion capability for 20 sensors, to each DAU, of any type included in the SHMS at completion of Progetto Esecutivo.

Specific provision shall be made for the expansion of the SHMS to include acoustic monitoring. Acoustic monitoring may be included almost immediately following completion of the construction of the bridge, if not at a future date. The SHMS should therefore be set-up so that the acoustic monitoring system will be immediately integrated when it is connected. The acoustic monitoring system will be supplied with its own power and communications infrastructure as well as its own DAUs. The DAUs will collect and process all acoustic monitoring data. The only interface between the acoustic monitoring system and the SHMS will be in the form of data transfer between the DAUs and the SHMS MFS. The DAUs will interact with the SHMS MFS as follows:

- send alert signals to the SHMS MFS when crack formation has been identified
- send data files to the SHMS MFS for storage on the SHMS DSS
- send reports to the SHMS MFS for automatic forwarding to the EDMS component of MMS for storage on the MMS database

Provision is to be made for integration of 4no. DAUs. Provisionally, the DAUs are planned to be located in the anchor blocks.

18.2 Future Expansion

The SHMS shall be developed in such a way that future expansion or rearrangement can be easily facilitated. The modularised system architecture, including file architecture, provides a high degree of flexibility where modules can be added, removed or rearranged. The SHMS software shall developed taking into consideration the provision of flexibility for future expansion or rearrangement. The DAU hardware shall also be developed for expansion, for example by the provision of free slots for additional data acquisition cards. Each DAU shall be capable of receiving all sensor types that are included in the SHMS at completion of Progetto Esecutivo.

19 Post-design Technology Advancement

SHMS technologies are rapidly developing. The SHMS development shall adopt, where feasible, new technologies if they represent an improvement on technologies previously specified - subject to the following principles:

- New technologies shall only be adopted if they are demonstrated to be reliable
- New technologies shall only be adopted if they are sufficiently established
- New technologies shall only be adopted if they are demonstrated to be beneficial to the monitoring priorities
- New technologies shall only be adopted if they are financially viable
- New technologies shall only be adopted if they can be demonstrated to be compatible with the SHMS design
- The process of adopting new technologies shall be performed only by the SHMS designer in conjunction with experts with sufficient experience to perform the work to the high standards required

20 Drawings

- CG1000-P1LDPIT-M3SM000000-01: SHMS Overview: Towers and Foundations
- CG1000-P1LDPIT-M3SM000000-02: SHMS Overview: Deck
- CG1000-P1LDPIT-M3SM000000-03: SHMS Overview: Hangers and Main Cables
- CG1000-P1ADPIT-M3SM000000-01: SHMS Sensor Layout: Deck - General
- CG1000-P1ADPIT-M3SM000000-02: SHMS Sensor Layout: Deck - at Towers
- CG1000-P1ADPIT-M3SM000000-03: SHMS Sensor Layout: Deck - at Terminal Structures
- CG1000-P1ADPIT-M3SM000000-04: SHMS Sensor Layout: Deck - Detail 1
- CG1000-P1ADPIT-M3SM000000-05: SHMS Sensor Layout: Deck - Detail 2
- CG1000-P1ADPIT-M3SM000000-06: SHMS Sensor Layout: Deck - Detail 3

- CG1000-P1ADPIT-M3SM000000-07: SHMS Sensor Layout: Towers - General
- CG1000-P1ADPIT-M3SM000000-08: SHMS Sensor Layout: Towers - Detail
- CG1000-P1ADPIT-M3SM000000-09: SHMS Sensor Layout: Main Cables
- CG1000-P1ADPIT-M3SM000000-10: SHMS Sensor Layout: Hangers
- CG1000-P1ADPIT-M3SM000000-11: SHMS Sensor Layout: Anchor Blocks - General
- CG1000-P1ADPIT-M3SM000000-12: SHMS Sensor Layout: Anchor Blocks - Detail
- CG1000-P1ADPIT-M3SM000000-13: SHMS Sensor Layout: Tower Bases
- CG1000-P1ADPIT-M3SM000000-14: SHMS Sensor Layout: Tie-down Piers
- CG1000-P1ADPIT-M3SM000000-15: SHMS Sensor Layout: Countryside
- CG1000-P2ADPIT-M3SM000000-01: SHMS Module Architecture: Deck
- CG1000-P2ADPIT-M3SM000000-02: SHMS Module Architecture: West Tower Leg
- CG1000-P2ADPIT-M3SM000000-03: SHMS Module Architecture: East Tower Leg
- CG1000-P2ADPIT-M3SM000000-04: SHMS Module Architecture: Sicily Anchor Block
- CG1000-P2ADPIT-M3SM000000-05: SHMS Module Architecture: Calabria Anchor Block
- CG1000-PDXDPIT-M3SM000000-01: SHMS Data Architecture Flowchart

21 SCADA Building (Centro Direzionale) Requirements

The SCADA Building (Centro Direzionale) has been described by Component No. 19.

21.1 Design Requirements for SCADA Building

The SCADA building shall support the GPS reference station, against which all GPS vertical data shall be referenced. The SCADA building shall be detailed against settlement.

21.2 Space for SHMS MFS in SCADA Room

A space of 2.5m x 2.5m shall be made available in the SCADA room for the SHMS display screens and SHMS MFS. A minimum of 10 power sockets and 4 LAN sockets shall be provided at the designated location. The SCADA room shall be air-conditioned.

21.3 Space for SHMS Spare Parts in Maintenance Building

A room shall be required in the maintenance building for spare parts and for the portable monitoring equipment.

22 Recommendations for Adopting Other Monitoring Technologies

Although the SHMS is a sophisticated and comprehensive arrangement, bridge investigation techniques have advanced since the development of the original SHMS tender design. In particular, a modern approach to monitoring of the main-cables of suspension bridges is the use of acoustic monitoring. The adoption of acoustic monitoring on the main-cables has been investigated. Acoustic monitoring has not been proposed in the monitoring plan at this time, due to the lack of practical proven experience of this technology when applied to main-cables. Acoustic monitoring for the main-cables will be reviewed at the start of Progetto Esecutivo when more detailed studies and evidence of this technology should be available.

23 Construction Phase Log

A detailed log of the general erection of the bridge during the construction phase shall be created by the constructor to provide a historical record of bridge erection condition. This record will provide a link to the data recorded by the SHMS. All changes to the structure that impact the data recorded shall be logged. The log shall include, for example:

- Date and time of change
- Loads involved
- Location involved
- General schematic of the bridge before and after the change

- General view site photographs

24 Structural Load Testing Requirements

Structural load testing requirements shall be developed during Progetto Esecutivo. This activity does not fall under the SHMS. Data recorded by SHMS shall be used for response verification to the structural load tests.

The structural load testing requirements shall be established by the constructor in collaboration with the bridge structural designers and the SHMS designer. Structural load testing shall include activities such as:

- global structural response to static traffic load tests, using accurately weighed heavy vehicles (trucks, heavy goods vehicles, trains etc) positioned in a variety of arrangements across the bridge
- local structural response to static traffic load tests, using accurately weighed heavy vehicles (trucks, heavy goods vehicles, trains etc) positioned over the local structural element
- global structural response to dynamic traffic load tests, using accurately weighed heavy vehicles (trucks, heavy goods vehicles, trains etc) driven in a variety of arrangements across the bridge
- local structural response to dynamic traffic load tests, using accurately weighed heavy vehicles (trucks, heavy goods vehicles, trains etc) driven over the local structural element
- global structural response to quasi-static wind load tests, reviewing structural behaviour to wind events that develop
- global structural response to dynamic wind load tests, reviewing structural behaviour to wind events that develop
- global structural response to quasi-static temperature load tests, reviewing structural behaviour to temperature conditions that develop

The bridge structural designers shall determine expected output from the SHMS for each of the load tests to be performed.

The structural load tests will verify the structural behaviour of the bridge as well as the function of the SHMS.

25 Detailing Tasks for Progetto Esecutivo

The SHMS plan and general architecture of the SHMS has been developed and presented in this document. This document presents the fundamental principles of the SHMS to be delivered. The detail of the system however requires contributions to be made by numerous different parties, since the system bridges many disciplines, including:

- SHMS sub-contractor – the most efficient choice of software and hardware shall depend on the detailed architecture of the system. Numerous methods are available for delivering the detailed architecture. SHMS sub-contractors will have a preferred system, hence the final architecture will depend on the SHMS sub-contractor chosen. It is therefore recommended that the constructor chooses a sub-contractor to work with the SHMS designer to prepare the detailing in Progetto Esecutivo.
- The bridge structural designers – the SHMS will be installed onto the structure which may require local strengthening. The final positioning of the sensors will depend on those areas of the bridge which are identified as the most critical once the detailed design has been completed. Details on limits and loading are required for the events system to operate effectively. The bridge structural designers have intimate knowledge of all of these details.
- The constructor and sub-contractors – the SHMS will be installed during structural component fabrication so that each sensor can be activated immediately for monitoring during the construction phase, and so that the dead load condition of the structure can be recorded. The constructor and sub-contractors will need to include SHMS installation in the construction programme. .

The following detailing tasks shall be performed during Progetto Esecutivo:

- Set-up SHMS detailed design task force including the SHMS designer, the SHMS sub-contractor, identified preferred SHMS suppliers, the bridge structural designers, the constructor and the sub-contractors.
- Review of the SHMS monitoring plan within the context of the completed structural design, by the SHMS designer in collaboration with the bridge structural designers.

- Review of the calibration strain sensor set within the context of the completed structural design, by the SHMS designer in collaboration with the bridge structural designers.
- Review the inclusion of additional discrete fibre-optic relative humidity sensors to the main-cables to supplement the current arrangement, by the SHMS designer.
- Review the inclusion of additional fibre-optic strain sensors (that span between adjacent cable-clamps) to the main-cables to supplement the current arrangement, by the SHMS designer.
- Review of available technologies for incorporation into the SHMS, by the SHMS designer.
- Identification and detailing of additional sensors that are only required during the construction phase to assist with construction monitoring e.g. equipment that is not part of the SHMS, by the constructor in collaboration with the SHMS designer.
- Final positioning of the sensors by the SHMS designer in collaboration with the bridge structural designers and SHMS sub-contractor.
- Detailing of anemometer supporting structure (boom), by the SHMS designer in collaboration with the bridge structural designers and the SHMS sub-contractor.
- Detailed positioning of the ground movement benchmarks and associated dynamic inclinometers, and detailing of the benchmark structure, by the SHMS designer in collaboration with the local seismological centre.
- Development of the SCADA database structure, by the sub-contractor for the SCADA database in conjunction with the sub-contractors for all of the components of SCADA as well as the designers of the components of SCADA.
- Development of the Database Service Layer, by the sub-contractor for the SCADA database, and development of the SHMS Data Conversion, Delivery, and Query Layer by the SHMS sub-contractor.
- Determine interface details between the various components of SCADA and MMS, including the common format of data files transferred directly between components of SCADA and MMS, by the designers of the components of SCADA and MMS in conjunction with the sub-contractors of the components of SCADA and MMS.

- Development of software strategy and system assembly, including identification of the software, hardware, data-loggers and sensors, by the SHMS sub-contractor in collaboration with the SHMS designer.
- Development of the SHMS displays by the SHMS sub-contractor in collaboration with the SHMS designer.
- Development of the SHMS reports by the SHMS sub-contractor in collaboration with the SHMS designer.
- Continued review of feasibility of full-length main-cable internal fibre-optic sensors by the SHMS designer.
- Development of fibre-optic humidity sensor, including proof testing, by preferred supplier.
- Development of full-length main-cable internal fibre-optic sensors, including proof testing, by preferred supplier.
- Detailing of the SHMS support steelwork by the SHMS sub-contractor.
- Detailing of the connection of the SHMS support steelwork to the bridge by the SHMS designer in collaboration with the bridge structural designers.
- Detailing of the local strengthening of the bridge design for the addition of the SHMS support steelwork by the bridge structural designers in collaboration with the SHMS designer.
- Identification of data-channels for definition of triggers and warnings, by the SHMS designer in collaboration with the bridge structural designers.
- Definition of trigger threshold limits and de-trigger threshold levels for all events, warnings, and serviceability warnings, by the SHMS designer in collaboration with the bridge structural designers.
- Definition of triggering parameters for seismic events, by the SHMS designer consulting the local seismological centre.
- Definition of criteria for bridge event warnings (including matrix of associations of warnings and events, impact of condition, and bridge status categorisation) as well as matrix of

anticipated outcomes for automatic assessment, by the SHMS designer in collaboration with the bridge structural designers.

- Definition of association of data channels to be recorded when an event is triggered on each data channel, by the SHMS designer in collaboration with the bridge structural designers.
- Finalise procedures to be adopted in the calculation of fatigue utilisations and maintenance utilisations, including choice of initial weighting parameters, by the SHMS designer in collaboration with the bridge structural designers.
- Definition of configuration parameters by the SHMS designer in collaboration with the SHMS sub-contractor.
- Perform a failure modes, effects and criticality analysis (FMECA) to support the development of maintenance recommendations, including identification of importance, prioritisation and maintenance timescales for each sensor, by the SHMS sub-contractor in collaboration with the SHMS designer and the bridge structural designers.
- Develop recommendations for inspection of the SHMS, by the SHMS sub-contractor in collaborations with the SHMS designer.
- Develop an equipment repair and replacement strategy for the SHMS, by the SHMS sub-contractor in collaborations with the SHMS designer.
- Develop a spare parts schedule, by the SHMS sub-contractor in collaboration with the SHMS designer.
- Develop structural load testing requirements, including assessment of expected output, by the constructor in collaboration with the SHMS designer and the bridge structural designers
- Initial drafting of all manuals and guides by the SHMS sub-contractor in collaboration with the SHMS designer.
- Preparation of the sensor identification lookup sheets by the SHMS designer in collaboration with the SHMS sub-contractor.
- Initial drafting of the installation programme by the constructor and sub-contractors in collaboration with the SHMS sub-contractor and the SHMS designer.

- Preparation of the installation method statements by the SHMS sub-contractor in collaboration with the constructor, sub-constructors and the SHMS designer.
- Preparation of the 25-year over-haul plan, by the SHMS sub-contractor.

26 Comments on Construction Phase

During the construction phase all parties shall contribute to the delivery of the completed structure and accessories including the SHMS.

The SHMS sub-contractor shall work with the constructor and sub-contractors to deliver the SHMS within the fabrication and erection programme.

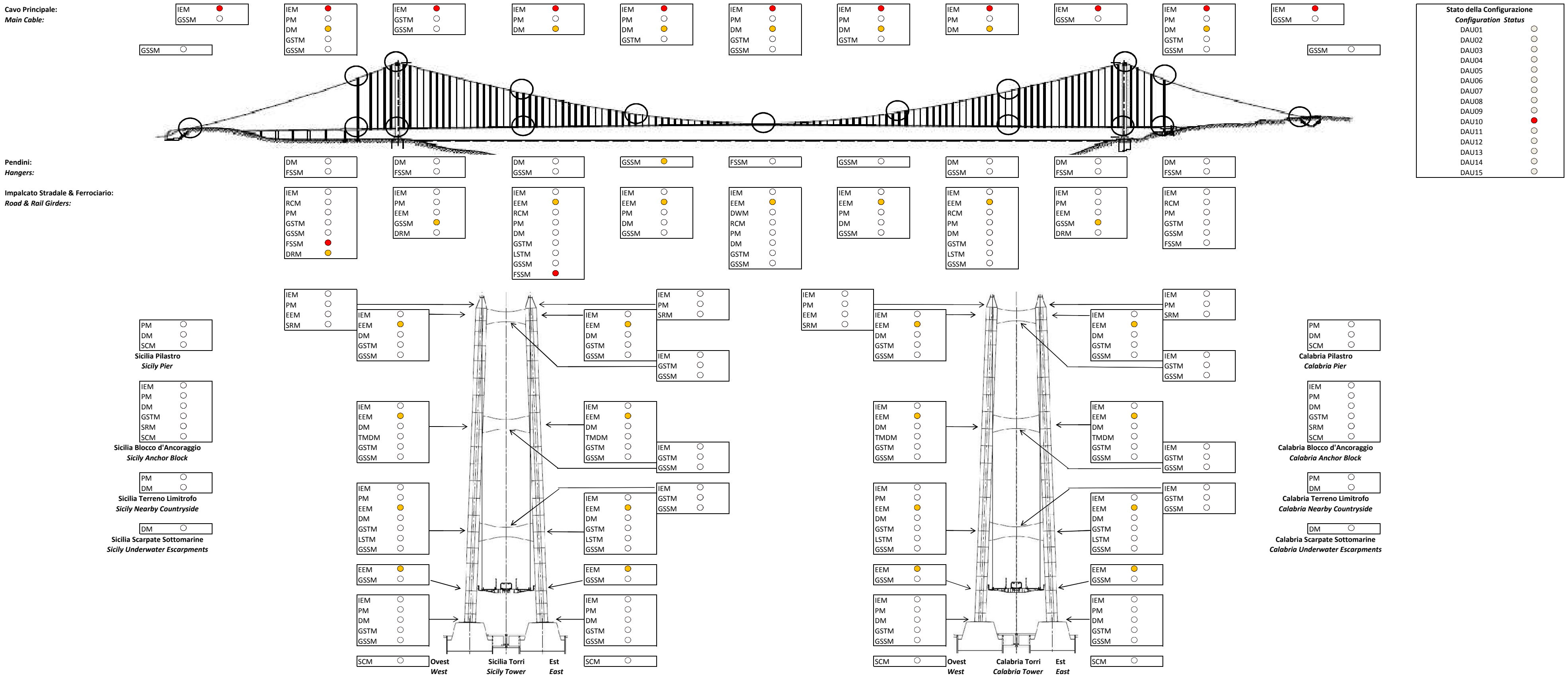
The constructor and sub-contractors shall facilitate the installation of the SHMS equipment at the appropriate time in the fabrication and erection programme.

Following installation of SHMS equipment, the constructor and sub-contractors shall at all times exercise reasonable care towards the SHMS equipment. The constructor and sub-contractors shall be responsible for damage caused by construction activities following installation of the SHMS equipment.

The bridge structural designers shall provide timely data predictions, and appropriate warning and event trigger limits for the erection phase.

The bridge structural designers shall provide accurately assessed initial predictions for main-cable stress data at various stages of bridge deck erection including the initial condition of the main-cable without suspended deck segments.

Appendix 1 Example Display Screens

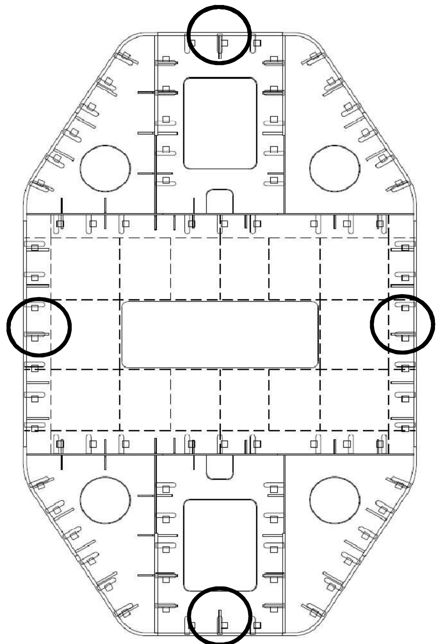


Cavo Principale:
Main Cable:
IEM
GSSM
IEM
PM
DM
GSTM
GSSM
IEM
GSTM
GSSM
IEM
PM
DM
IEM
PM
DM
GSTM
IEM
PM
DM
GSTM
GSSM
IEM
PM
DM
GSTM
IEM
PM
DM
IEM
GSSM
IEM
PM
DM
GSTM
GSSM
IEM
GSSM
GSSM
GSSM
Stato della Configurazione
Configuration Status
DAU01
DAU02
DAU03
DAU04
DAU05
DAU06
DAU07
DAU08
DAU09
DAU10
DAU11
DAU12
DAU13
DAU14
DAU15
Pendini:
Hangers:
DM
FSSM
DM
FSSM
DM
GSSM
GSSM
FSSM
GSSM
DM
GSSM
DM
FSSM
DM
FSSM
Impalcato Stradale & Ferrociario:
Road & Rail Girders:
IEM
RCM
PM
GSTM
GSSM
FSSM
DRM
IEM
PM
EEM
GSSM
DRM
IEM
EEM
RCM
PM
DM
GSTM
LSTM
GSSM
FSSM
IEM
EEM
PM
DM
GSSM
IEM
EEM
DWM
RCM
PM
DM
GSTM
GSSM
IEM
EEM
PM
DM
GSSM
IEM
EEM
RCM
PM
DM
GSTM
LSTM
GSSM
IEM
PM
EEM
GSSM
DRM
IEM
RCM
PM
GSTM
GSSM
FSSM
PM
DM
SCM
Sicilia Pilastro
Sicily Pier
IEM
PM
DM
GSTM
SRM
SCM
Sicilia Blocco d'Ancoraggio
Sicily Anchor Block
PM
DM
Sicilia Terreno Limitrofo
Sicily Nearby Countryside
DM
Sicilia Scarpate Sottomarine
Sicily Underwater Escarpments
IEM
PM
EEM
SRM
IEM
EEM
DM
GSTM
GSSM
IEM
EEM
DM
GSTM
GSSM
IEM
PM
SRM
IEM
GSTM
GSSM
IEM
EEM
DM
TMDM
GSTM
GSSM
IEM
EEM
DM
TMDM
GSTM
GSSM
IEM
GSTM
GSSM
IEM
PM
EEM
DM
GSTM
LSTM
GSSM
IEM
EEM
DM
GSTM
LSTM
GSSM
IEM
GSTM
GSSM
EEM
GSSM
EEM
GSSM
IEM
PM
DM
GSTM
GSSM
IEM
PM
DM
GSTM
GSSM
SCM
SCM
Ovest
West
Sicilia Torri
Sicily Tower
Est
East
IEM
PM
EEM
SRM
IEM
EEM
DM
GSTM
GSSM
IEM
EEM
DM
GSTM
GSSM
IEM
PM
SRM
IEM
GSTM
GSSM
IEM
EEM
DM
TMDM
GSTM
GSSM
IEM
EEM
DM
TMDM
GSTM
GSSM
IEM
GSTM
GSSM
IEM
PM
EEM
DM
GSTM
LSTM
GSSM
IEM
EEM
DM
GSTM
LSTM
GSSM
IEM
GSTM
GSSM
EEM
GSSM
EEM
GSSM
IEM
PM
DM
GSTM
GSSM
IEM
PM
DM
GSTM
GSSM
SCM
SCM
Ovest
West
Calabria Torri
Calabria Tower
Est
East
PM
DM
SCM
Calabria Pilastro
Calabria Pier
IEM
PM
DM
GSTM
SRM
SCM
Calabria Blocco d'Ancoraggio
Calabria Anchor Block
PM
DM
Calabria Terreno Limitrofo
Calabria Nearby Countryside
DM
Calabria Scarpate Sottomarine
Calabria Underwater Escarpments

Sopra la Traversa:
Above Cross-Beam:

Nord
North

GSSM03-TMP-E-UNSG -165,0



GSSM03-TMP-E-UWSG -177,0

Ovest
West

GSSM03-TMP-E-UESG -177,0

Est
East

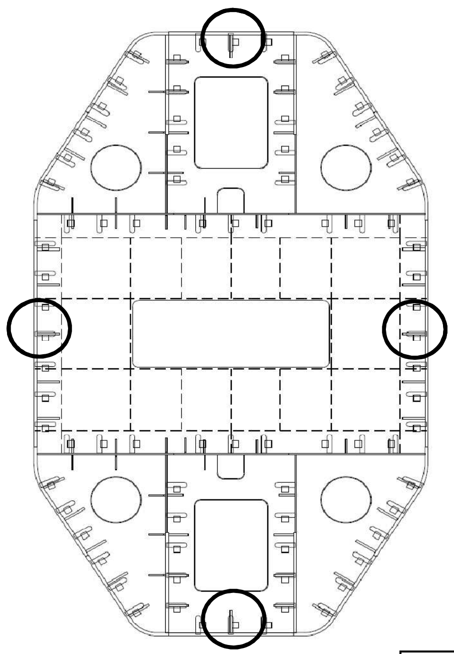
GSSM03-TMP-E-USSG -164,0

Sud
South

Sotto la Traversa:
Below Cross-Beam:

Nord
North

GSSM03-TMP-E-LNSG -170,0



GSSM03-TMP-E-LWSG -157,0

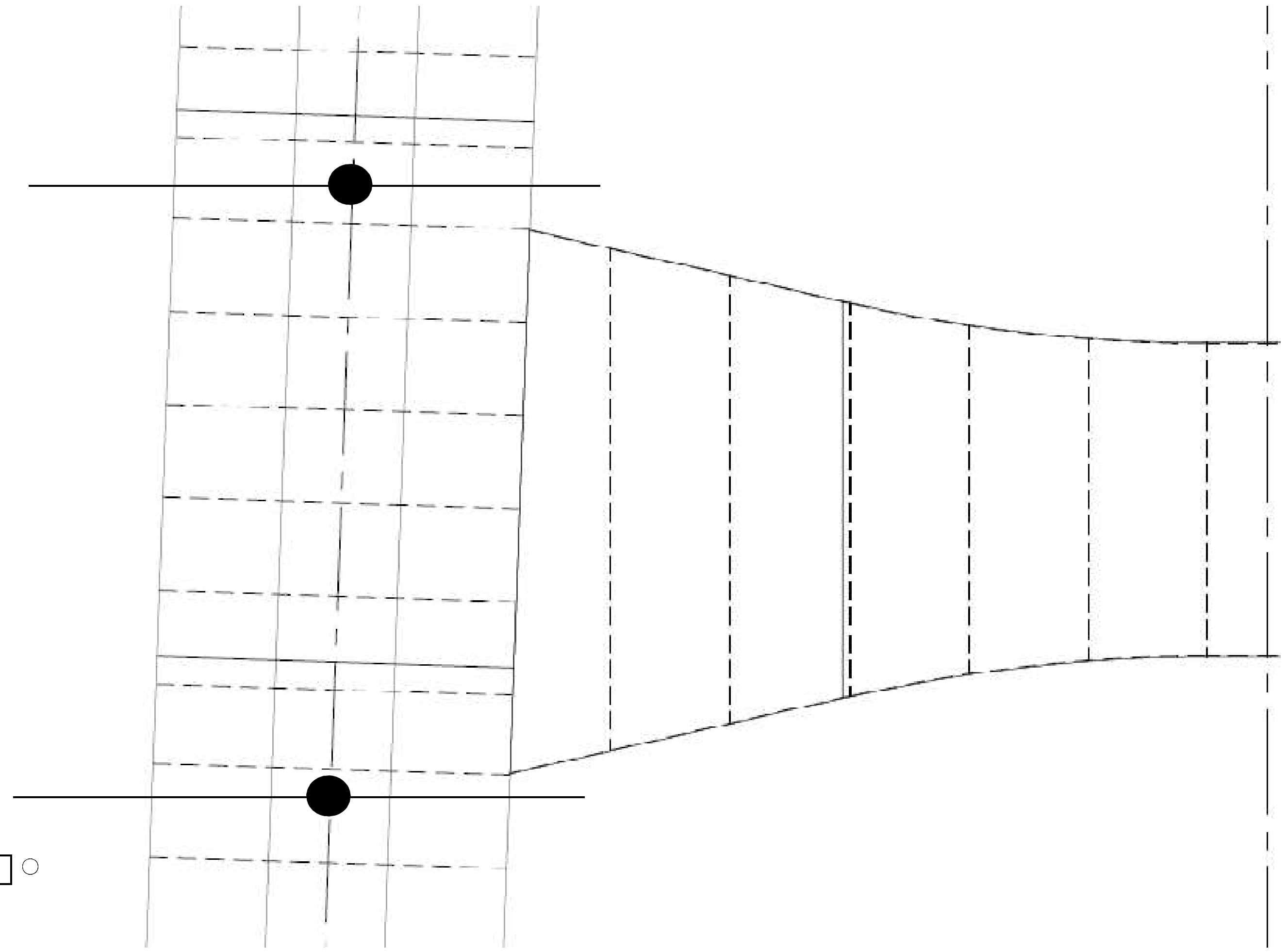
Ovest
West

GSSM03-TMP-E-LESG -164,0

Est
East

GSSM03-TMP-E-LSSG -163,0

Sud
South

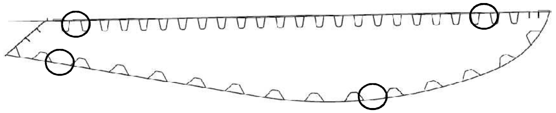


Sicilia Torri - Gamba Est - Presso la Traversa 2
Sicily Tower - East Leg - at Cross-Beam 2

Calabria 1/3 Posizione - Impalcato Stradale Est - Estremo della Campata di 30m
Calabria 1/3 Point - East Road Girder - End of 30m span

Est
East

GSSM12-D-E-ETESG -110,0
GSSM12-D-E-ETWSG -120,0

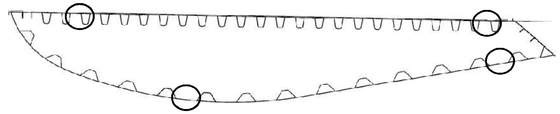


GSSM12-D-E-EBESG 45,0
GSSM12-D-E-EBWSG 201,0

Calabria 1/3 Posizione - Impalcato Stradale Ovest - Estremo della Campata di 30m
Calabria 1/3 Point - West Road Girder - End of 30m span

Ovest
West

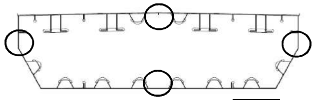
GSSM12-D-W-ETESG -112,0
GSSM12-D-W-ETWSG -105,0



GSSM12-D-W-EBESG 207,0
GSSM12-D-W-EBWSG 60,0

Calabria 1/3 Posizione - Impalcato Ferroviario- Estremo della Campata di 30m
Calabria 1/3 Point - Rail Girder - End of 30m span

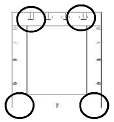
GSSM12-D-C-ETSG -120,0
GSSM12-D-C-EESG -14,0
GSSM12-D-C-EWSG 1,0



GSSM12-D-C-EBSG 211,0

Calabria 1/3 Posizione - Traversa - Est
Calabria 1/3 Point - Cross Beam - East

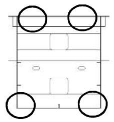
GSSM12-CG-E-TSSG -101,0
GSSM12-CG-E-TNSG -93,0



GSSM12-CG-E-BSSG 101,0
GSSM12-CG-E-BNSG 102,0

Calabria 1/3 Posizione - Traversi - Centro
Calabria 1/3 Point - Cross Beam - Centre

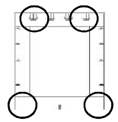
GSSM12-CG-C-TSSG -92,0
GSSM12-CG-C-TNSG -90,0



GSSM12-CG-C-BSSG 110,0
GSSM12-CG-C-BNSG 99,0

Calabria 1/3 Posizione - Traversi - Ovest
Calabria 1/3 Point - Cross Beam - West

GSSM12-CG-W-TSSG -95,0
GSSM12-CG-W-TNSG -90,0

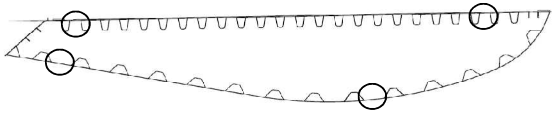


GSSM12-CG-W-BSSG 93,0
GSSM12-CG-W-BNSG 94,0

Calabria 1/3 Posizione - Impalcato Stradale Est - Messaria della Campata di 30m
Calabria 1/3 Point - East Road Girder - Middle of 30m span

Est
East

GSSM12-D-E-MTESG -103,0
GSSM12-D-E-MTWSG -130,0

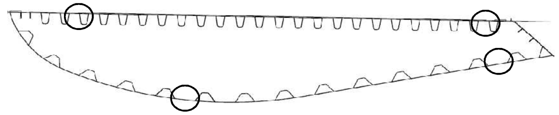


GSSM12-D-E-MBESG 47,0
GSSM12-D-E-MBWSG 192,0

Calabria 1/3 Posizione - Impalcato Stradale Ovest - Messaria della Campata di 30m
Calabria 1/3 Point - West Road Girder - Middle of 30m span

Ovest
West

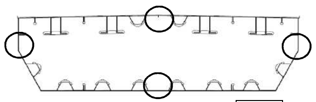
GSSM12-D-W-MTESG -106,0
GSSM12-D-W-MTWSG -107,0



GSSM12-D-W-MBESG 193,0
GSSM12-D-W-MBWSG 49,0

Calabria 1/3 Posizione - Impalcato Ferroviario - Messaria della Campata di 30m
Calabria 1/3 Point - Rail Girder - Middle of 30m span

GSSM12-D-C-MTSG -118,0
GSSM12-D-C-MESG -51,0
GSSM12-D-C-MWSG -35,0



GSSM12-D-C-MBSG 205,0

Ambiente Interno
Internal Environment

Identificativo del canale dati:
Data-channel identifier:

Sicilia Blocco d'Ancoraggio
Sicily Anchor Block

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM01-AB-E	59,0		25,0	16,8	11,0
IEM01-AB-W	48,0		24,0	13,6	19,0

Cavo Principale Est
East Main Cable

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM01-MC-01-E-E1	33,0				
IEM01-MC-01-E-E2	44,0				
IEM01-MC-02-E-E1	45,0				
IEM01-MC-02-E-E2	44,0				
IEM01-MC-03-E-E1	55,0				
IEM01-MC-03-E-E2	38,0				
IEM01-MC-04-E-E1	34,0				
IEM01-MC-04-E-E2	48,0				
IEM01-MC-05-E-E1	39,0				
IEM01-MC-05-E-E2	30,0				
IEM01-MC-06-E-E1	39,0				
IEM01-MC-06-E-E2	51,0				
IEM01-MC-07-E-E1	33,0				
IEM01-MC-07-E-E2	52,0				
IEM01-MC-08-E-E1	38,0				
IEM01-MC-08-E-E2	60,0				
IEM01-MC-09-E-E1	41,0				
IEM01-MC-09-E-E2	47,0				
IEM01-MC-10-E-E1	39,0				
IEM01-MC-10-E-E2	31,0				
IEM01-MC-11-E-E1	50,0				
IEM01-MC-11-E-E2	60,0				
IEM01-MC-01-E-W1	56,0				
IEM01-MC-01-E-W2	36,0				
IEM01-MC-02-E-W1	30,0				
IEM01-MC-02-E-W2	33,0				
IEM01-MC-03-E-W1	43,0				
IEM01-MC-03-E-W2	47,0				
IEM01-MC-04-E-W1	50,0				
IEM01-MC-04-E-W2	30,0				
IEM01-MC-05-E-W1	48,0				
IEM01-MC-05-E-W2	45,0				
IEM01-MC-06-E-W1	46,0				
IEM01-MC-06-E-W2	32,0				
IEM01-MC-07-E-W1	30,0				
IEM01-MC-07-E-W2	42,0				
IEM01-MC-08-E-W1	46,0				
IEM01-MC-08-E-W2	57,0				
IEM01-MC-09-E-W1	36,0				
IEM01-MC-09-E-W2	30,0				
IEM01-MC-10-E-W1	31,0				
IEM01-MC-10-E-W2	45,0				
IEM01-MC-11-E-W1	43,0				
IEM01-MC-11-E-W2	31,0				

Identificativo del canale dati:
Data-channel identifier:

Calabria Blocco d'Ancoraggio
Calabria Anchor Block

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM02-AB-E	48,0		24,0	13,6	18,0
IEM02-AB-W	47,0		21,0	10,4	15,0

Cavo Principale Ovest
West Main Cable

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM02-MC-01-W-E1	39,0				
IEM02-MC-01-W-E2	35,0				
IEM02-MC-02-W-E1	48,0				
IEM02-MC-02-W-E2	32,0				
IEM02-MC-03-W-E1	59,0				
IEM02-MC-03-W-E2	46,0				
IEM02-MC-04-W-E1	32,0				
IEM02-MC-04-W-E2	39,0				
IEM02-MC-05-W-E1	48,0				
IEM02-MC-05-W-E2	32,0				
IEM02-MC-06-W-E1	57,0				
IEM02-MC-06-W-E2	30,0				
IEM02-MC-07-W-E1	40,0				
IEM02-MC-07-W-E2	55,0				
IEM02-MC-08-W-E1	39,0				
IEM02-MC-08-W-E2	58,0				
IEM02-MC-09-W-E1	41,0				
IEM02-MC-09-W-E2	57,0				
IEM02-MC-10-W-E1	47,0				
IEM02-MC-10-W-E2	57,0				
IEM02-MC-11-W-E1	39,0				
IEM02-MC-11-W-E2	46,0				
IEM02-MC-01-W-W1	60,0				
IEM02-MC-01-W-W2	54,0				
IEM02-MC-02-W-W1	35,0				
IEM02-MC-02-W-W2	48,0				
IEM02-MC-03-W-W1	55,0				
IEM02-MC-03-W-W2	43,0				
IEM02-MC-04-W-W1	39,0				
IEM02-MC-04-W-W2	30,0				
IEM02-MC-05-W-W1	42,0				
IEM02-MC-05-W-W2	33,0				
IEM02-MC-06-W-W1	36,0				
IEM02-MC-06-W-W2	44,0				
IEM02-MC-07-W-W1	48,0				
IEM02-MC-07-W-W2	52,0				
IEM02-MC-08-W-W1	33,0				
IEM02-MC-08-W-W2	59,0				
IEM02-MC-09-W-W1	48,0				
IEM02-MC-09-W-W2	59,0				
IEM02-MC-10-W-W1	30,0				
IEM02-MC-10-W-W2	60,0				
IEM02-MC-11-W-W1	34,0				
IEM02-MC-11-W-W2	32,0				

Identificativo del canale dati:
Data-channel identifier:

Impalcato Stradale Est
East Road Girder

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM07-D-E	38,0	85,0	24,0	11,6	11,0
IEM08-D-E	42,0	75,0	24,0	12,4	10,0
IEM09-D-E	37,0	84,0	27,0	14,4	20,0
IEM10-D-E	52,0	92,0	20,0	10,4	18,0
IEM11-D-E	37,0	95,0	30,0	17,4	16,0
IEM12-D-E	46,0	82,0	29,0	18,2	18,0
IEM13-D-E	53,0	93,0	22,0	12,6	11,0
IEM14-D-E	59,0	79,0	24,0	15,8	16,0
IEM15-D-E	50,0	82,0	20,0	10	16,0

Impalcato Ferroviario
Rail Girder

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM07-D-C	32,0	94,0	28,0	14,4	11,0
IEM08-D-C	30,0	84,0	28,0	14	12,0
IEM09-D-C	31,0	95,0	29,0	15,2	18,0
IEM10-D-C	54,0	90,0	28,0	18,8	14,0
IEM11-D-C	35,0	77,0	29,0	16	18,0
IEM12-D-C	39,0	89,0	21,0	8,8	10,0
IEM13-D-C	36,0	77,0	25,0	12,2	15,0
IEM14-D-C	41,0	77,0	30,0	18,2	20,0
IEM15-D-C	44,0	91,0	24,0	12,8	17,0

Impalcato Stradale Ovest
West Road Girder

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM07-D-W	35,0	91,0	21,0	8	11,0
IEM08-D-W	34,0	100,0	21,0	7,8	16,0
IEM09-D-W	35,0	92,0	29,0	16	15,0
IEM10-D-W	53,0	73,0	20,0	10,6	14,0
IEM11-D-W	33,0	92,0	23,0	9,6	17,0
IEM12-D-W	52,0	78,0	30,0	20,4	12,0
IEM13-D-W	42,0	90,0	27,0	15,4	14,0
IEM14-D-W	46,0	71,0	20,0	9,2	19,0
IEM15-D-W	35,0	93,0	29,0	16	10,0

Traversa
Cross Beam

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM07-CG-C	54,0	94,0	21,0	11,8	12,0
IEM08-CG-C	31,0	90,0	25,0	11,2	10,0
IEM09-CG-C	52,0	73,0	22,0	12,4	19,0
IEM10-CG-C	39,0	72,0	29,0	16,8	12,0
IEM11-CG-C	47,0	94,0	24,0	13,4	10,0
IEM12-CG-C	59,0	72,0	26,0	17,8	16,0
IEM13-CG-C	53,0	79,0	28,0	18,6	10,0
IEM14-CG-C	44,0	94,0	25,0	13,8	14,0
IEM15-CG-C	44,0	97,0	29,0	17,8	12,0

Identificativo del canale dati:
Data-channel identifier:

Sicilia Torri - Gamba Est
Sicily Tower - East Leg

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM03-TT-E	49,0		30,0	19,8	15,0
IEM03-TUP-E	36,0		26,0	13,2	20,0
IEM03-TMP-E	46,0		22,0	11,2	18,0
IEM03-TLP-E	55,0		21,0	12	13,0
IEM03-TB-E	31,0		22,0	8,2	19,0

Sicilia Torri - Gamba Ovest
Sicily Tower - West Leg

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM04-TT-E	55,0		24,0	15	15,0
IEM04-TUP-E	34,0		25,0	11,8	11,0
IEM04-TMP-E	48,0		30,0	19,6	10,0
IEM04-TLP-E	37,0		29,0	16,4	20,0
IEM04-TB-E	32,0		25,0	11,4	12,0

Sicilia Torri - Traversa
Sicily Tower - Cross Beam

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM04-UP-C	35,0		30,0	17	17,0
IEM04-MP-C	32,0		25,0	11,4	17,0
IEM04-LP-C	48,0		29,0	18,6	18,0

Calabria Torri - Gamba Est
Calabria Tower - East Leg

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM05-TT-E	32,0		20,0	14,8	20,0
IEM05-TUP-E	36,0		23,0	6	14,0
IEM05-TMP-E	44,0		26,0	19,2	20,0
IEM05-TLP-E	30,0		20,0	-20	13,0
IEM05-TB-E	51,0		29,0	-20	18,0

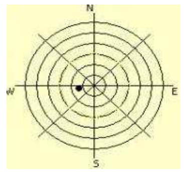
Calabria Torri - Gamba Ovest
Calabria Tower - West Leg

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM06-TT-E	31,0		21,0	19,4	19,0
IEM06-TUP-E	47,0		22,0	13,6	17,0
IEM06-TMP-E	47,0		30,0	17,6	16,0
IEM06-TLP-E	58,0		22,0	-20	16,0
IEM06-TB-E	53,0		27,0	-20	15,0

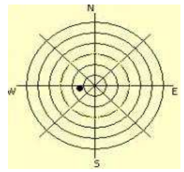
Calabria Torri - Traversa
Calabria Tower - Cross Beam

Data-channel identifier	RH (%)	SH (%)	AT (degC)	DPT (degC)	min ST (degC)
IEM06-UP-C	40,0		28,0	15,2	17,0
IEM06-MP-C	44,0		21,0	#REF!	16,0
IEM06-LP-C	51,0		25,0	#REF!	10,0

Condizioni del Vento
Wind Conditions

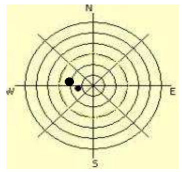


EEM04-TT-W-PGWS	7,0	m/s (gust)
EEM04-TT-W-PMWS	5,5	m/s (mean)
EEM04-TT-W-PGWD	203,0	deg E (plan)

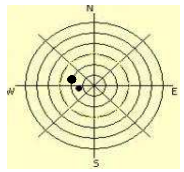


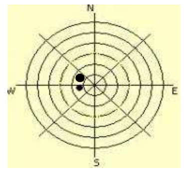
EEM06-TT-W-PGWS	7,0	m/s (gust)
EEM06-TT-W-PMWS	5,5	m/s (mean)
EEM06-TT-W-PGWD	194,0	deg E (plan)

EEM03-TUP-E-PGWS	7,0	m/s (gust)
EEM03-TUP-E-PMWS	5,5	m/s (mean)
EEM03-TUP-E-PGWD	200,0	deg E (plan)
EEM03-TMP-E-PGWS	7,0	m/s (gust)
EEM03-TMP-E-PMWS	5,5	m/s (mean)
EEM03-TMP-E-PGWD	200,0	deg E (plan)

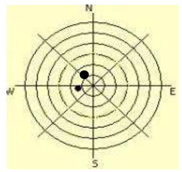


EEM04-TUP-W-PGWS	11,0	m/s (gust)
EEM04-TUP-W-PMWS	9,5	m/s (mean)
EEM04-TUP-W-PGWD	203,0	deg E (plan)
EEM04-TMP-W-PGWS	10,0	m/s (gust)
EEM04-TMP-W-PMWS	8,5	m/s (mean)
EEM04-TMP-W-PGWD	180,0	deg E (plan)



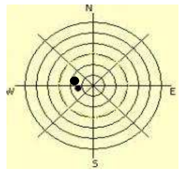


EEM05-TUP-E-PGWS	10,0	m/s (gust)
EEM05-TUP-E-PMWS	8,5	m/s (mean)
EEM05-TUP-E-PGWD	207,0	deg E (plan)
EEM05-TMP-E-PGWS	8,0	m/s (gust)
EEM05-TMP-E-PMWS	6,5	m/s (mean)
EEM05-TMP-E-PGWD	180,0	deg E (plan)

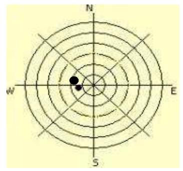


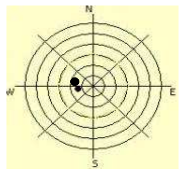
EEM06-TUP-W-PGWS	11,0	m/s (gust)
EEM06-TUP-W-PMWS	9,5	m/s (mean)
EEM06-TUP-W-PGWD	193,0	deg E (plan)
EEM06-TMP-W-PGWS	10,0	m/s (gust)
EEM06-TMP-W-PMWS	8,5	m/s (mean)
EEM06-TMP-W-PGWD	201,0	deg E (plan)

EEM03-TLP-E-PGWS	8,0	m/s (gust)
EEM03-TLP-E-PMWS	6,5	m/s (mean)
EEM03-TLP-E-PGWD	193,0	deg E (plan)
EEM03-TD-E-PGWS	11,0	m/s (gust)
EEM03-TD-E-PMWS	9,5	m/s (mean)
EEM03-TD-E-PGWD	208,0	deg E (plan)

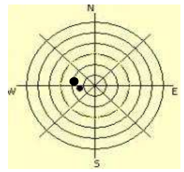


EEM04-TLP-W-PGWS	11,0	m/s (gust)
EEM04-TLP-W-PMWS	9,5	m/s (mean)
EEM04-TLP-W-PGWD	193,0	deg E (plan)
EEM04-TD-W-PGWS	7,0	m/s (gust)
EEM04-TD-W-PMWS	5,5	m/s (mean)
EEM04-TD-W-PGWD	197,0	deg E (plan)





EEM05-TLP-E-PGWS	8,0	m/s (gust)
EEM05-TLP-E-PMWS	6,5	m/s (mean)
EEM05-TLP-E-PGWD	203,0	deg E (plan)
EEM05-TD-E-PGWS	9,0	m/s (gust)
EEM05-TD-E-PMWS	7,5	m/s (mean)
EEM05-TD-E-PGWD	183,0	deg E (plan)

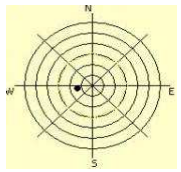


EEM06-TLP-W-PGWS	8,0	m/s (gust)
EEM06-TLP-W-PMWS	6,5	m/s (mean)
EEM06-TLP-W-PGWD	193,0	deg E (plan)
EEM06-TD-W-PGWS	12,0	m/s (gust)
EEM06-TD-W-PMWS	10,5	m/s (mean)
EEM06-TD-W-PGWD	188,0	deg E (plan)

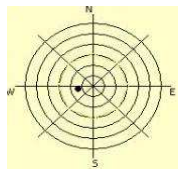
Sicilia
Sicily

Calabria
Calabria

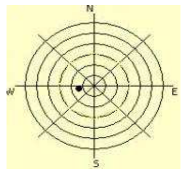
DWM11-D-E-1XWS	7,0	m/s
DWM11-D-E-1YWS	0,0	m/s
DWM11-D-E-1ZWS	0,0	m/s
DWM11-D-E-2XWS	12,0	m/s
DWM11-D-E-2YWS	3,0	m/s
DWM11-D-E-2ZWS	1,0	m/s
DWM11-D-W-1XWS	8,0	m/s
DWM11-D-W-1YWS	1,0	m/s
DWM11-D-W-1ZWS	2,0	m/s
DWM11-D-W-2XWS	11,0	m/s
DWM11-D-W-2YWS	2,0	m/s
DWM11-D-W-2ZWS	1,0	m/s



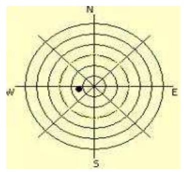
EEM08-D-E-PGWS	9,0	m/s (gust)
EEM08-D-E-PMWS	7,5	m/s (mean)
EEM08-D-E-PGWD	199,0	deg E (plan)



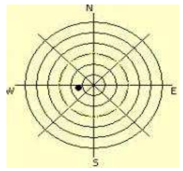
EEM08-D-W-PGWS	7,0	m/s (gust)
EEM08-D-W-PMWS	5,5	m/s (mean)
EEM08-D-W-PGWD	199,0	deg E (plan)



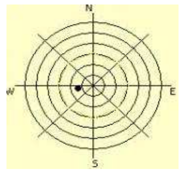
EEM09-D-E-PGWS	8,0	m/s (gust)
EEM09-D-E-PMWS	6,5	m/s (mean)
EEM09-D-E-PGWD	189,0	deg E (plan)



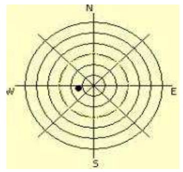
EEM09-D-W-PGWS	12,0	m/s (gust)
EEM09-D-W-PMWS	10,5	m/s (mean)
EEM09-D-W-PGWD	208,0	deg E (plan)



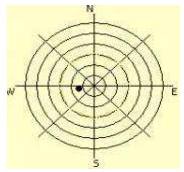
EEM10-D-E-PGWS	9,0	m/s (gust)
EEM10-D-E-PMWS	7,5	m/s (mean)
EEM10-D-E-PGWD	202,0	deg E (plan)



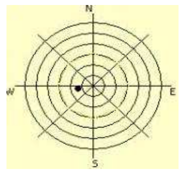
EEM10-D-W-PGWS	11,0	m/s (gust)
EEM10-D-W-PMWS	9,5	m/s (mean)
EEM10-D-W-PGWD	191,0	deg E (plan)



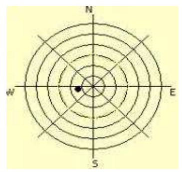
EEM11-D-E-PGWS	12,0	m/s (gust)
EEM11-D-E-PMWS	10,5	m/s (mean)
EEM11-D-E-PGWD	204,0	deg E (plan)



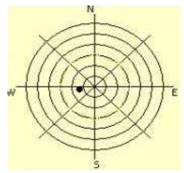
EEM11-D-W-PGWS	9,0	m/s (gust)
EEM11-D-W-PMWS	7,5	m/s (mean)
EEM11-D-W-PGWD	187,0	deg E (plan)



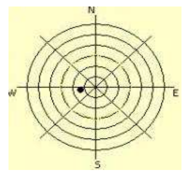
EEM12-D-E-PGWS	12,0	m/s (gust)
EEM12-D-E-PMWS	10,5	m/s (mean)
EEM12-D-E-PGWD	183,0	deg E (plan)



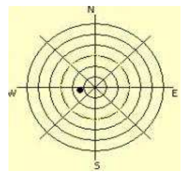
EEM12-D-W-PGWS	9,0	m/s (gust)
EEM12-D-W-PMWS	7,5	m/s (mean)
EEM12-D-W-PGWD	198,0	deg E (plan)



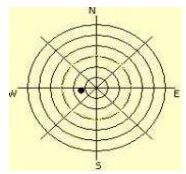
EEM13-D-E-PGWS	12,0	m/s (gust)
EEM13-D-E-PMWS	10,5	m/s (mean)
EEM13-D-E-PGWD	208,0	deg E (plan)



EEM13-D-W-PGWS	7,0	m/s (gust)
EEM13-D-W-PMWS	5,5	m/s (mean)
EEM13-D-W-PGWD	203,0	deg E (plan)



EEM14-D-E-PGWS	9,0	m/s (gust)
EEM14-D-E-PMWS	7,5	m/s (mean)
EEM14-D-E-PGWD	184,0	deg E (plan)



EEM14-D-W-PGWS	8,0	m/s (gust)
EEM14-D-W-PMWS	6,5	m/s (mean)
EEM14-D-W-PGWD	182,0	deg E (plan)

DWM11-D-E-3XWS	9,0	m/s
DWM11-D-E-3YWS	0,0	m/s
DWM11-D-E-3ZWS	0,0	m/s
DWM11-D-E-4XWS	11,0	m/s
DWM11-D-E-4YWS	0,0	m/s
DWM11-D-E-4ZWS	0,0	m/s
DWM11-D-W-3XWS	12,0	m/s
DWM11-D-W-3YWS	3,0	m/s
DWM11-D-W-3ZWS	2,0	m/s
DWM11-D-W-4XWS	11,0	m/s
DWM11-D-W-4YWS	3,0	m/s
DWM11-D-W-4ZWS	0,0	m/s

Condizioni dell'Ambiente Esterno
External Environment Conditions

Identificativo del canale dati: **Sicilia** … **Calabria**
Data-channel identifier: ***Sicily*** … ***Calabria***

	EEM08-D-E	EEM09-D-E	EEM10-D-E	EEM11-D-E	EEM12-D-E	EEM13-D-E	EEM14-D-E
PGWS Plan Gust Wind Speed (m/s)	10,0	10,0	9,0	7,0	9,0	7,0	9,0
PGWD Plan Gust Wind Dirn (degE)	208,0	202,0	203,0	187,0	197,0	186,0	191,0

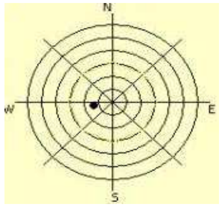
	EEM08-D-W	EEM09-D-W	EEM10-D-W	EEM11-D-W	EEM12-D-W	EEM13-D-W	EEM14-D-W
PGWS Plan Gust Wind Speed (m/s)	12,0	11,0	8,0	9,0	11,0	7,0	9,0
PGWD Plan Gust Wind Dirn (degE)	193,0	199,0	196,0	201,0	203,0	202,0	198,0

	EEM04-TT-W	EEM06-TT-W
RH Rel Humidity (%)	46,0	52,0
CT Air Temp (degC)	27,0	29,0
SR Solar Radiation (W/m2)	1191,0	1142,0
B Air Pressure (hPa)	995,0	994,0
SH Surface Humidity (%)		

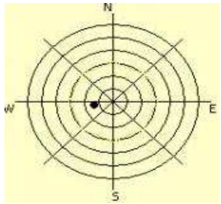
	EEM04-TD-W	EEM08-D-W	EEM09-D-W	EEM10-D-W	EEM11-D-W	EEM12-D-W	EEM13-D-W	EEM14-D-W	EEM06-TD-W
RH Rel Humidity (%)	49,0				50,0				49,0
CT Air Temp (degC)	26,0		29,0		28,0		27,0		27,0
SR Solar Radiation (W/m2)					1072,0				
B Air Pressure (hPa)	998,0								995,0
SH Surface Humidity (%)			0,0				0,0		

	RCM07-D-E	RCM08-D-E	RCM09-D-E	RCM10-D-E	RCM11-D-E	RCM12-D-E	RCM13-D-E	RCM14-D-E	RCM15-D-E
RT Road Temp (degC)	36,0		40,0		35,0		35,0		38,0
RG Rain Gauge (mm/hr)			0,0				0,0		

	RCM07-D-W	RCM08-D-W	RCM09-D-W	RCM10-D-W	RCM11-D-W	RCM12-D-W	RCM13-D-W	RCM14-D-W	RCM15-D-W
RT Road Temp (degC)	36,0		38,0		35,0		37,0		38,0
RG Rain Gauge (mm/hr)			0,0				0,0		



EEM09-D-W-PGWS	*7,0*	*m/s (gust)*
EEM09-D-W-PMWS	5,5	m/s (mean)
EEM09-D-W-PGWD	185,0	deg E (plan)



EEM12-D-W-PGWS	*11,0*	*m/s (gust)*
EEM12-D-W-PMWS	9,5	m/s (mean)
EEM12-D-W-PGWD	208,0	deg E (plan)

Posizione
Position

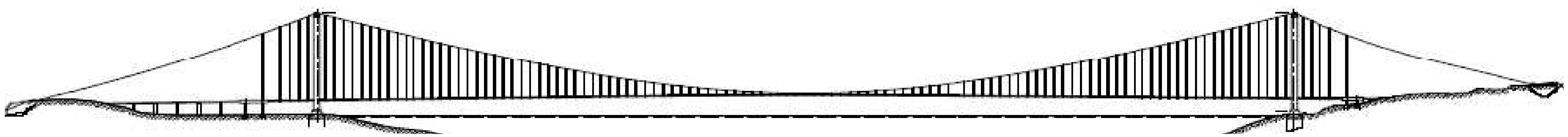
PM07-MC-E-XGPS	0,000	m
PM07-MC-E-YGPS	-29,000	m
PM07-MC-E-ZGPS	260,000	m
PM03-TT-E-XGPS	183,100	m
PM03-TT-E-YGPS	-29,000	m
PM03-TT-E-ZGPS	382,600	m
PM09-MC-E-XGPS	733,100	m
PM09-MC-E-YGPS	-29,000	m
PM09-MC-E-ZGPS	250,000	m
PM10-MC-E-XGPS	1283,100	m
PM10-MC-E-YGPS	-29,000	m
PM10-MC-E-ZGPS	110,000	m
PM11-MC-E-XGPS	1833,100	m
PM11-MC-E-YGPS	-29,000	m
PM11-MC-E-ZGPS	81,100	m
PM12-MC-E-XGPS	2383,100	m
PM12-MC-E-YGPS	-29,000	m
PM12-MC-E-ZGPS	110,000	m
PM13-MC-E-XGPS	2933,100	m
PM13-MC-E-YGPS	-29,000	m
PM13-MC-E-ZGPS	250,000	m
PM05-TT-E-XGPS	3483,100	m
PM05-TT-E-YGPS	-29,000	m
PM05-TT-E-ZGPS	382,600	m
PM15-MC-E-XGPS	3666,200	m
PM15-MC-E-YGPS	-29,000	m
PM15-MC-E-ZGPS	260,000	m

DM03-TUP-E-XSIN2	0,020	°
DM03-TUP-E-YSIN2	0,020	°
DM05-TUP-E-XSIN2	0,020	°
DM05-TUP-E-YSIN2	0,020	°

PM07-MC-W-XGPS	0,000	m
PM07-MC-W-YGPS	29,000	m
PM07-MC-W-ZGPS	260,000	m
PM04-TT-W-XGPS	183,100	m
PM04-TT-W-YGPS	29,000	m
PM04-TT-W-ZGPS	382,600	m
PM09-MC-W-XGPS	733,100	m
PM09-MC-W-YGPS	29,000	m
PM09-MC-W-ZGPS	250,000	m
PM10-MC-W-XGPS	1283,100	m
PM10-MC-W-YGPS	29,000	m
PM10-MC-W-ZGPS	110,000	m
PM11-MC-W-XGPS	1833,100	m
PM11-MC-W-YGPS	29,000	m
PM11-MC-W-ZGPS	81,100	m
PM12-MC-W-XGPS	2383,100	m
PM12-MC-W-YGPS	29,000	m
PM12-MC-W-ZGPS	110,000	m
PM13-MC-W-XGPS	2933,100	m
PM13-MC-W-YGPS	29,000	m
PM13-MC-W-ZGPS	250,000	m
PM06-TT-W-XGPS	3483,100	m
PM06-TT-W-YGPS	29,000	m
PM06-TT-W-ZGPS	382,600	m
PM15-MC-W-XGPS	3666,200	m
PM15-MC-W-YGPS	29,000	m
PM15-MC-W-ZGPS	260,000	m

DM04-TUP-W-XSIN2	0,020	°
DM04-TUP-W-YSIN2	0,020	°
DM06-TUP-W-XSIN2	0,020	°
DM06-TUP-W-YSIN2	0,020	°

PM04-TLP-W-XGPS	183,100	m
PM04-TLP-W-YGPS	36,000	m
PM04-TLP-W-ZGPS	120,000	m
PM06-TLP-W-XGPS	3483,100	m
PM06-TLP-W-YGPS	36,000	m
PM06-TLP-W-ZGPS	120,000	m



Sicilia
Sicily

Calabria
Calabria

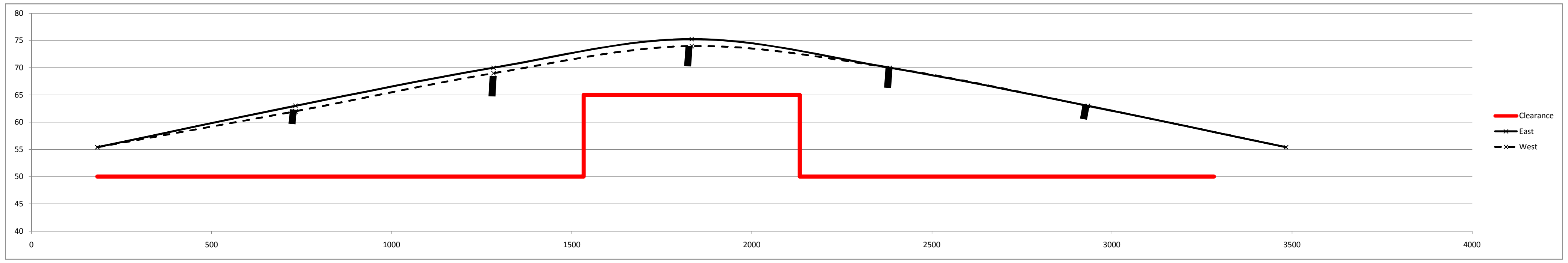
PM07-D-E-XGPS	0,000	m
PM07-D-E-YGPS	-29,000	m
PM07-D-E-ZGPS	52,650	m
PM08-D-E-XGPS	183,100	m
PM08-D-E-YGPS	-29,000	m
PM08-D-E-ZGPS	55,400	m
PM09-D-E-XGPS	733,100	m
PM09-D-E-YGPS	-29,000	m
PM09-D-E-ZGPS	63,000	m
PM10-D-E-XGPS	1283,100	m
PM10-D-E-YGPS	-29,000	m
PM10-D-E-ZGPS	70,000	m
PM11-D-E-XGPS	1833,100	m
PM11-D-E-YGPS	-29,000	m
PM11-D-E-ZGPS	75,260	m
PM12-D-E-XGPS	2383,100	m
PM12-D-E-YGPS	-29,000	m
PM12-D-E-ZGPS	70,000	m
PM13-D-E-XGPS	2933,100	m
PM13-D-E-YGPS	-29,000	m
PM13-D-E-ZGPS	63,000	m
PM14-D-E-XGPS	3483,100	m
PM14-D-E-YGPS	-29,000	m
PM14-D-E-ZGPS	55,400	m
PM15-D-E-XGPS	3666,200	m
PM15-D-E-YGPS	-29,000	m
PM15-D-E-ZGPS	52,650	m

PM07-D-W-XGPS	0,000	m
PM07-D-W-YGPS	29,000	m
PM07-D-W-ZGPS	52,650	m
PM08-D-W-XGPS	183,100	m
PM08-D-W-YGPS	29,000	m
PM08-D-W-ZGPS	55,400	m
PM09-D-W-XGPS	733,100	m
PM09-D-W-YGPS	29,000	m
PM09-D-W-ZGPS	62,000	m
PM10-D-W-XGPS	1283,100	m
PM10-D-W-YGPS	29,000	m
PM10-D-W-ZGPS	69,000	m
PM11-D-W-XGPS	1833,100	m
PM11-D-W-YGPS	29,000	m
PM11-D-W-ZGPS	74,000	m
PM12-D-W-XGPS	2383,100	m
PM12-D-W-YGPS	29,000	m
PM12-D-W-ZGPS	70,000	m
PM13-D-W-XGPS	2933,100	m
PM13-D-W-YGPS	29,000	m
PM13-D-W-ZGPS	63,000	m
PM14-D-W-XGPS	3483,100	m
PM14-D-W-YGPS	29,000	m
PM14-D-W-ZGPS	55,400	m
PM15-D-W-XGPS	3666,200	m
PM15-D-W-YGPS	29,000	m
PM15-D-W-ZGPS	52,650	m

PM07-PB-E-XGPS	0,000	m
PM07-PB-E-YGPS	-29,000	m
PM07-PB-E-ZGPS	52,650	m
PM03-TB-E-XGPS	183,100	m
PM03-TB-E-YGPS	40,000	m
PM03-TB-E-ZGPS	18,000	m
PM05-TB-E-XGPS	3483,100	m
PM05-TB-E-YGPS	40,000	m
PM05-TB-E-ZGPS	18,000	m
PM15-PB-E-XGPS	3666,200	m
PM15-PB-E-YGPS	-29,000	m
PM15-PB-E-ZGPS	52,650	m

PM07-PB-W-XGPS	0,000	m
PM07-PB-W-YGPS	29,000	m
PM07-PB-W-ZGPS	52,650	m
PM04-TB-W-XGPS	183,100	m
PM04-TB-W-YGPS	40,000	m
PM04-TB-W-ZGPS	18,000	m
PM06-TB-W-XGPS	3483,100	m
PM06-TB-W-YGPS	40,000	m
PM06-TB-W-ZGPS	18,000	m
PM15-PB-W-XGPS	3666,200	m
PM15-PB-W-YGPS	29,000	m
PM15-PB-W-ZGPS	52,650	m

Zona di Libero del Canale di Navigazione
Navigation Channel Clearance



DM01-AB-E-1XSIN2	0,020	°
DM01-AB-E-1YSIN2	0,020	°
DM01-AB-E-2XSIN2	0,020	°
DM01-AB-E-2YSIN2	0,020	°
DM01-AB-E-3XSIN2	0,020	°
DM01-AB-E-3YSIN2	0,020	°
DM01-AB-E-4XSIN2	0,020	°
DM01-AB-E-4YSIN2	0,020	°
DM02-AB-E-1XSIN2	0,020	°
DM02-AB-E-1YSIN2	0,020	°
DM02-AB-E-2XSIN2	0,020	°
DM02-AB-E-2YSIN2	0,020	°
DM02-AB-E-3XSIN2	0,020	°
DM02-AB-E-3YSIN2	0,020	°
DM02-AB-E-4XSIN2	0,020	°
DM02-AB-E-4YSIN2	0,020	°

PM01-AB-E-XGPS	-776,900	m
PM01-AB-E-YGPS	-29,000	m
PM01-AB-E-ZGPS	53,500	m
PM01-R-1XGPS	-1461,000	m
PM01-R-1YGPS	370,000	m
PM01-R-1ZGPS	35,000	m
PM01-R-2XGPS	-1787,000	m
PM01-R-2YGPS	269,000	m
PM01-R-2ZGPS	39,000	m
PM02-R-1XGPS	6590,000	m
PM02-R-1YGPS	152,000	m
PM02-R-1ZGPS	50,000	m
PM02-R-2XGPS	6331,000	m
PM02-R-2YGPS	232,000	m
PM02-R-2ZGPS	46,000	m
PM02-AB-E-XGPS	4443,100	m
PM02-AB-E-YGPS	-29,000	m
PM02-AB-E-ZGPS	53,500	m

SRM01-AB-E-LD	-1475,000	mm
SRM01-AB-W-LD	-1499,000	mm
SRM03-TT-E-LD	-1448,000	mm
SRM04-TT-W-LD	-1453,000	mm
SRM02-AB-E-LD	-1426,000	mm
SRM02-AB-W-LD	-1474,000	mm
SRM05-TT-E-LD	-1493,000	mm
SRM06-TT-W-LD	-1458,000	mm

DM01-AB-W-1XSIN2	0,020	°
DM01-AB-W-1YSIN2	0,020	°
DM01-AB-W-2XSIN2	0,020	°
DM01-AB-W-2YSIN2	0,020	°
DM01-AB-W-3XSIN2	0,020	°
DM01-AB-W-3YSIN2	0,020	°
DM01-AB-W-4XSIN2	0,020	°
DM01-AB-W-4YSIN2	0,020	°
DM02-AB-W-1XSIN2	0,020	°
DM02-AB-W-1YSIN2	0,020	°
DM02-AB-W-2XSIN2	0,020	°
DM02-AB-W-2YSIN2	0,020	°
DM02-AB-W-3XSIN2	0,020	°
DM02-AB-W-3YSIN2	0,020	°
DM02-AB-W-4XSIN2	0,020	°
DM02-AB-W-4YSIN2	0,020	°

PM01-AB-W-XGPS	-776,900	m
PM01-AB-W-YGPS	29,000	m
PM01-AB-W-ZGPS	53,500	m
PM01-R-3XGPS	-1874,000	m
PM01-R-3YGPS	373,000	m
PM01-R-3ZGPS	32,000	m
PM01-R-4XGPS	-2130,000	m
PM01-R-4YGPS	106,000	m
PM01-R-4ZGPS	35,000	m
PM02-R-3XGPS	6759,000	m
PM02-R-3YGPS	219,000	m
PM02-R-3ZGPS	33,000	m
PM02-R-4XGPS	6114,000	m
PM02-R-4YGPS	470,000	m
PM02-R-4ZGPS	34,000	m
PM02-AB-W-XGPS	4443,100	m
PM02-AB-W-YGPS	29,000	m
PM02-AB-W-ZGPS	53,500	m

Dinamica del Impalcato, Torri, e Cavi Principale

Deck, Tower and Main-cable Dynamics

DM07-MC-E1-XA3	0,517	g
DM07-MC-E1-YA3	0,875	g
DM07-MC-E1-ZA3	0,001	g
DM07-MC-E2-XA3	0,486	g
DM07-MC-E2-YA3	0,852	g
DM07-MC-E2-ZA3	0,005	g
DM07-MC-E-TA3	0,012	g
DM07-MC-W1-XA3	0,516	g
DM07-MC-W1-YA3	0,862	g
DM07-MC-W1-ZA3	0,001	g
DM07-MC-W2-XA3	0,508	g
DM07-MC-W2-YA3	0,875	g
DM07-MC-W2-ZA3	0,008	g
DM07-MC-W-TA3	-0,007	g

DM09-MC-E1-XA3	0,485	g
DM09-MC-E1-YA3	0,859	g
DM09-MC-E1-ZA3	0,007	g
DM09-MC-E2-XA3	0,494	g
DM09-MC-E2-YA3	0,875	g
DM09-MC-E2-ZA3	0,006	g
DM09-MC-E-TA3	-0,008	g
DM09-MC-W1-XA3	0,513	g
DM09-MC-W1-YA3	0,854	g
DM09-MC-W1-ZA3	0,005	g
DM09-MC-W2-XA3	0,483	g
DM09-MC-W2-YA3	0,848	g
DM09-MC-W2-ZA3	0,002	g
DM09-MC-W-TA3	0,003	g

DM10-MC-E1-XA3	0,250	g
DM10-MC-E1-YA3	0,942	g
DM10-MC-E1-ZA3	0,004	g
DM10-MC-E2-XA3	0,258	g
DM10-MC-E2-YA3	0,942	g
DM10-MC-E2-ZA3	0,010	g
DM10-MC-E-TA3	0,000	g
DM10-MC-W1-XA3	0,265	g
DM10-MC-W1-YA3	0,964	g
DM10-MC-W1-ZA3	0,005	g
DM10-MC-W2-XA3	0,253	g
DM10-MC-W2-YA3	0,948	g
DM10-MC-W2-ZA3	0,004	g
DM10-MC-W-TA3	0,008	g

DM11-MC-E1-XA3	0,001	g
DM11-MC-E1-YA3	0,990	g
DM11-MC-E1-ZA3	0,005	g
DM11-MC-E2-XA3	0,005	g
DM11-MC-E2-YA3	1,016	g
DM11-MC-E2-ZA3	0,003	g
DM11-MC-E-TA3	-0,013	g
DM11-MC-W1-XA3	0,005	g
DM11-MC-W1-YA3	0,990	g
DM11-MC-W1-ZA3	0,006	g
DM11-MC-W2-XA3	0,003	g
DM11-MC-W2-YA3	0,993	g
DM11-MC-W2-ZA3	0,007	g
DM11-MC-W-TA3	-0,002	g

DM12-MC-E1-XA3	0,232	g
DM12-MC-E1-YA3	0,945	g
DM12-MC-E1-ZA3	0,001	g
DM12-MC-E2-XA3	0,240	g
DM12-MC-E2-YA3	0,958	g
DM12-MC-E2-ZA3	0,006	g
DM12-MC-E-TA3	-0,007	g
DM12-MC-W1-XA3	0,231	g
DM12-MC-W1-YA3	0,950	g
DM12-MC-W1-ZA3	0,003	g
DM12-MC-W2-XA3	0,254	g
DM12-MC-W2-YA3	0,974	g
DM12-MC-W2-ZA3	0,008	g
DM12-MC-W-TA3	-0,012	g

DM13-MC-E1-XA3	0,482	g
DM13-MC-E1-YA3	0,878	g
DM13-MC-E1-ZA3	0,006	g
DM13-MC-E2-XA3	0,508	g
DM13-MC-E2-YA3	0,859	g
DM13-MC-E2-ZA3	0,001	g
DM13-MC-E-TA3	0,010	g
DM13-MC-W1-XA3	0,513	g
DM13-MC-W1-YA3	0,868	g
DM13-MC-W1-ZA3	0,008	g
DM13-MC-W2-XA3	0,507	g
DM13-MC-W2-YA3	0,863	g
DM13-MC-W2-ZA3	0,004	g
DM13-MC-W-TA3	0,003	g

DM15-MC-E1-XA3	0,504	g
DM15-MC-E1-YA3	0,840	g
DM15-MC-E1-ZA3	0,007	g
DM15-MC-E2-XA3	0,505	g
DM15-MC-E2-YA3	0,860	g
DM15-MC-E2-ZA3	0,009	g
DM15-MC-E-TA3	-0,010	g
DM15-MC-W1-XA3	0,490	g
DM15-MC-W1-YA3	0,859	g
DM15-MC-W1-ZA3	0,000	g
DM15-MC-W2-XA3	0,514	g
DM15-MC-W2-YA3	0,857	g
DM15-MC-W2-ZA3	0,006	g
DM15-MC-W-TA3	0,001	g

DM03-TUP-E-XA3	0,004	g
DM03-TUP-E-YA3	0,985	g
DM03-TUP-E-ZA3	0,001	g
DM04-TUP-W-XA3	0,004	g
DM04-TUP-W-YA3	1,010	g
DM04-TUP-W-ZA3	0,009	g
DM03-TUP-TA3	0,000	g
DM03-TMP-E-XA3	0,006	g
DM03-TMP-E-YA3	1,008	g
DM03-TMP-E-ZA3	0,000	g
DM04-TMP-W-XA3	0,005	g
DM04-TMP-W-YA3	0,983	g
DM04-TMP-W-ZA3	0,010	g
DM03-TMP-TA3	0,001	g
DM03-TLP-E-XA3	0,003	g
DM03-TLP-E-YA3	0,987	g
DM03-TLP-E-ZA3	0,009	g
DM04-TLP-W-XA3	0,010	g
DM04-TLP-W-YA3	1,003	g
DM04-TLP-W-ZA3	0,010	g
DM03-TLP-TA3	-0,004	g

TMDM03-TMP-E-1LD	0,006	mm
TMDM03-TMP-E-2LD	0,009	mm
TMDM03-TMP-E-3LD	0,002	mm
TMDM03-TMP-E-4LD	0,002	mm
TMDM03-TMP-E-5LD	0,004	mm
TMDM03-TMP-E-6LD	0,002	mm
TMDM03-TMP-E-7LD	0,000	mm
TMDM03-TMP-E-8LD	0,000	mm
TMDM04-TMP-W-1LD	0,006	mm
TMDM04-TMP-W-2LD	0,004	mm
TMDM04-TMP-W-3LD	0,001	mm
TMDM04-TMP-W-4LD	0,003	mm
TMDM04-TMP-W-5LD	0,010	mm
TMDM04-TMP-W-6LD	0,006	mm
TMDM04-TMP-W-7LD	0,002	mm
TMDM04-TMP-W-8LD	0,002	mm

TMDM05-TMP-E-1LD	0,005	mm
TMDM05-TMP-E-2LD	0,001	mm
TMDM05-TMP-E-3LD	0,006	mm
TMDM05-TMP-E-4LD	0,000	mm
TMDM05-TMP-E-5LD	0,009	mm
TMDM05-TMP-E-6LD	0,008	mm
TMDM05-TMP-E-7LD	0,006	mm
TMDM05-TMP-E-8LD	0,008	mm
TMDM06-TMP-W-1LD	0,007	mm
TMDM06-TMP-W-2LD	0,005	mm
TMDM06-TMP-W-3LD	0,009	mm
TMDM06-TMP-W-4LD	0,000	mm
TMDM06-TMP-W-5LD	0,001	mm
TMDM06-TMP-W-6LD	0,000	mm
TMDM06-TMP-W-7LD	0,004	mm
TMDM06-TMP-W-8LD	0,002	mm

DM05-TUP-E-XA3	0,000	g
DM05-TUP-E-YA3	1,018	g
DM05-TUP-E-ZA3	0,008	g
DM06-TUP-W-XA3	0,008	g
DM06-TUP-W-YA3	0,988	g
DM06-TUP-W-ZA3	0,001	g
DM05-TUP-TA3	-0,004	g
DM05-TMP-E-XA3	0,004	g
DM05-TMP-E-YA3	0,981	g
DM05-TMP-E-ZA3	0,006	g
DM06-TMP-W-XA3	0,005	g
DM06-TMP-W-YA3	0,999	g
DM06-TMP-W-ZA3	0,000	g
DM05-TMP-TA3	-0,001	g
DM05-TLP-E-XA3	0,004	g
DM05-TLP-E-YA3	1,003	g
DM05-TLP-E-ZA3	0,008	g
DM06-TLP-W-XA3	0,008	g
DM06-TLP-W-YA3	1,018	g
DM06-TLP-W-ZA3	0,009	g
DM05-TLP-TA3	-0,002	g

DM09-CG-E-XA3	0,006	g
DM09-CG-E-YA3	0,989	g
DM09-CG-E-ZA3	0,003	g
DM09-CG-W-XA3	0,001	g
DM09-CG-W-YA3	0,986	g
DM09-CG-W-ZA3	0,008	g
DM10-CG-E-XA3	0,009	g
DM10-CG-E-YA3	0,997	g
DM10-CG-E-ZA3	0,007	g
DM10-CG-W-XA3	0,005	g
DM10-CG-W-YA3	0,984	g
DM10-CG-W-ZA3	0,007	g
DM11-CG-E-XA3	0,000	g
DM11-CG-E-YA3	0,989	g
DM11-CG-E-ZA3	0,003	g
DM11-CG-W-XA3	0,008	g
DM11-CG-W-YA3	0,987	g
DM11-CG-W-ZA3	0,000	g
DM12-CG-E-XA3	0,008	g
DM12-CG-E-YA3	1,016	g
DM12-CG-E-ZA3	0,008	g
DM12-CG-W-XA3	0,010	g
DM12-CG-W-YA3	0,985	g
DM12-CG-W-ZA3	0,003	g
DM13-CG-E-XA3	0,010	g
DM13-CG-E-YA3	0,986	g
DM13-CG-E-ZA3	0,007	g
DM13-CG-W-XA3	0,004	g
DM13-CG-W-YA3	1,002	g
DM13-CG-W-ZA3	0,008	g

Dinamica del Terreno
Ground Dynamics

DM03-TB-E-XA3	0,000	g
DM03-TB-E-YA3	0,985	g
DM03-TB-E-ZA3	0,001	g
DM03-TB-E-XDIN2	0,007	°
DM03-TB-E-YDIN2	0,001	°

DM04-TB-W-XSA3	0,007	g
DM04-TB-W-YSA3	1,008	g
DM04-TB-W-ZSA3	0,007	g
DM04-TB-W-XDIN2	0,008	°
DM04-TB-W-YDIN2	0,001	°

DM05-TB-E-XA3	0,003	g
DM05-TB-E-YA3	1,002	g
DM05-TB-E-ZA3	0,005	g
DM05-TB-E-XDIN2	0,009	°
DM05-TB-E-YDIN2	0,009	°

DM06-TB-W-XSA3	0,006	g
DM06-TB-W-YSA3	1,009	g
DM06-TB-W-ZSA3	0,005	g
DM06-TB-W-XDIN2	0,008	°
DM06-TB-W-YDIN2	0,004	°

DM01-AB-C-XSA3	0,000	g
DM01-AB-C-YSA3	1,002	g
DM01-AB-C-ZSA3	0,009	g
DM01-AB-C-XDIN2	0,001	°
DM01-AB-C-YDIN2	0,008	°

DM07-PB-C-XDIN2	0,003	°
DM07-PB-C-XDIN2	0,008	°

DM15-PB-C-XDIN2	0,000	°
DM15-PB-C-XDIN2	0,002	°

DM02-AB-C-XSA3	0,008	g
DM02-AB-C-YSA3	0,989	g
DM02-AB-C-ZSA3	0,007	g
DM02-AB-C-XDIN2	0,009	°
DM02-AB-C-YDIN2	0,009	°

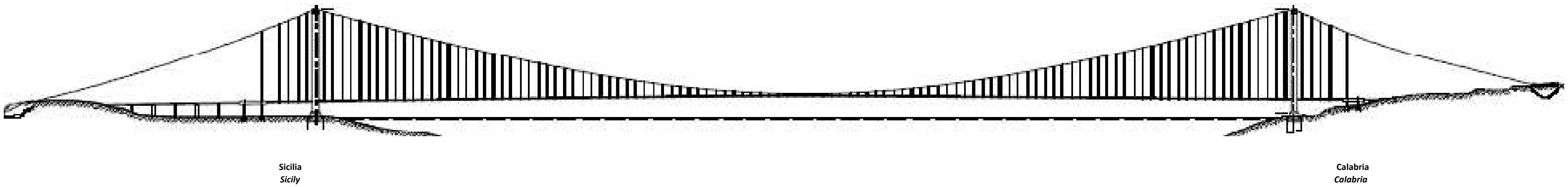
DM01-R-1XSA3	0,003	g
DM01-R-1YSA3	1,012	g
DM01-R-1ZSA3	0,003	g
DM01-R-2XSA3	0,003	g
DM01-R-2YSA3	0,998	g
DM01-R-2ZSA3	0,005	g
DM01-R-3XSA3	0,002	g
DM01-R-3YSA3	0,993	g
DM01-R-3ZSA3	0,001	g
DM01-R-4XSA3	0,007	g
DM01-R-4YSA3	1,012	g
DM01-R-4ZSA3	0,009	g

DM01-UE-1XDIN2	0,003	°
DM01-UE-1YDIN2	0,006	°
DM01-UE-2XDIN2	0,009	°
DM01-UE-2YDIN2	0,006	°
DM01-UE-3XDIN2	0,009	°
DM01-UE-3YDIN2	0,010	°
DM01-UE-4XDIN2	0,003	°
DM01-UE-4YDIN2	0,007	°
DM01-UE-5XDIN2	0,003	°
DM01-UE-5YDIN2	0,006	°

DM02-UE-1XDIN2	0,008	°
DM02-UE-1YDIN2	0,004	°
DM02-UE-2XDIN2	0,006	°
DM02-UE-2YDIN2	0,008	°
DM02-UE-3XDIN2	0,002	°
DM02-UE-3YDIN2	0,005	°
DM02-UE-4XDIN2	0,003	°
DM02-UE-4YDIN2	0,005	°
DM02-UE-5XDIN2	0,005	°
DM02-UE-5YDIN2	0,001	°

DM02-R-1XSA3	0,010	g
DM02-R-1YSA3	0,986	g
DM02-R-1ZSA3	0,001	g
DM02-R-2XSA3	0,008	g
DM02-R-2YSA3	0,993	g
DM02-R-2ZSA3	0,005	g
DM02-R-3XSA3	0,009	g
DM02-R-3YSA3	0,995	g
DM02-R-3ZSA3	0,001	g
DM02-R-4XSA3	0,004	g
DM02-R-4YSA3	1,008	g
DM02-R-4ZSA3	0,007	g

Tensione Medio di Pendini
Hanger-Cable Average Stress



Pendini Est
East Hangers

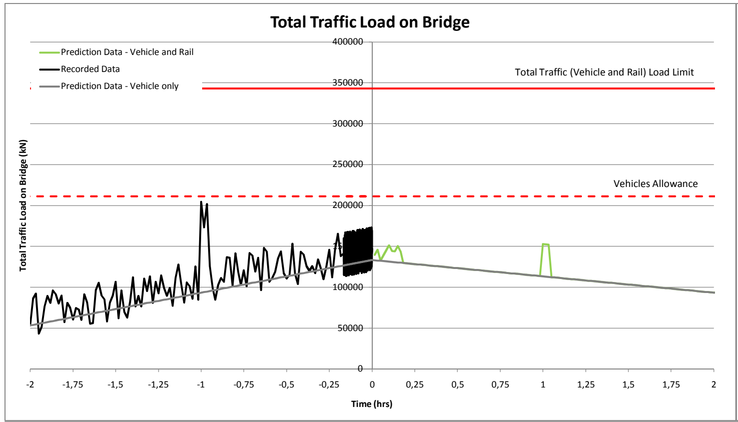
FSSM07-H-E-1NEFFSG	100,0	MPa	○
FSSM07-H-E-1SEFFSG	122,0	MPa	○
FSSM08-H-E-5NEFFSG	115,0	MPa	○
FSSM08-H-E-5SEFFSG	130,0	MPa	○
FSSM08-H-E-6NEFFSG	109,0	MPa	○
FSSM08-H-E-6SEFFSG	112,0	MPa	○
GSSM09-H-E-18NEFFSG	122,0	MPa	○
GSSM09-H-E-18SEFFSG	112,0	MPa	○
GSSM09-H-E-19NEFFSG	109,0	MPa	○
GSSM09-H-E-19SEFFSG	106,0	MPa	○
GSSM10-H-E-41NEFFSG	100,0	MPa	○
GSSM10-H-E-41SEFFSG	104,0	MPa	○
GSSM10-H-E-42NEFFSG	127,0	MPa	○
GSSM10-H-E-42SEFFSG	119,0	MPa	○
GSSM10-H-E-43NEFFSG	122,0	MPa	○
GSSM10-H-E-43SEFFSG	114,0	MPa	○
FSSM11-H-E-59NEFFSG	103,0	MPa	○
FSSM11-H-E-59SEFFSG	124,0	MPa	○
FSSM11-H-E-60NEFFSG	110,0	MPa	○
FSSM11-H-E-60SEFFSG	102,0	MPa	○
FSSM11-H-E-61NEFFSG	101,0	MPa	○
FSSM11-H-E-61SEFFSG	120,0	MPa	○
GSSM13-H-E-101NEFFSG	120,0	MPa	○
GSSM13-H-E-101SEFFSG	118,0	MPa	○
GSSM13-H-E-102NEFFSG	129,0	MPa	○
GSSM13-H-E-102SEFFSG	111,0	MPa	○
GSSM12-H-E-79NEFFSG	105,0	MPa	○
GSSM12-H-E-79SEFFSG	125,0	MPa	○
GSSM12-H-E-78NEFFSG	130,0	MPa	○
GSSM12-H-E-78SEFFSG	104,0	MPa	○
GSSM12-H-E-77NEFFSG	115,0	MPa	○
GSSM12-H-E-77SEFFSG	108,0	MPa	○
FSSM15-H-E-119NEFFSG	114,0	MPa	○
FSSM15-H-E-119SEFFSG	101,0	MPa	○
FSSM14-H-E-115NEFFSG	105,0	MPa	○
FSSM14-H-E-115SEFFSG	100,0	MPa	○
FSSM14-H-E-114NEFFSG	129,0	MPa	○
FSSM14-H-E-114SEFFSG	119,0	MPa	○

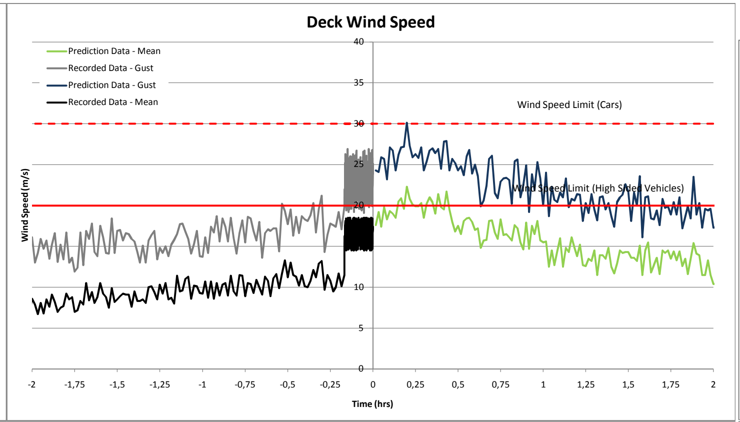
Pendini Ovest
West Hangers

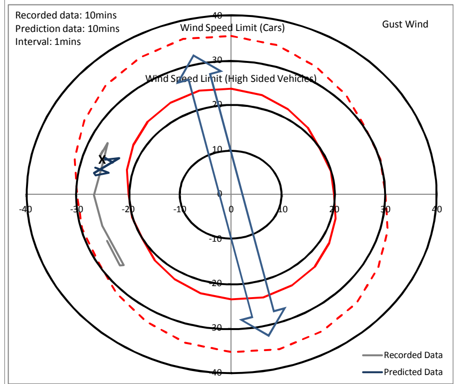
FSSM07-H-W-1NEFFSG	106,0	MPa	○
FSSM07-H-W-1SEFFSG	105,0	MPa	○
FSSM08-H-W-5NEFFSG	104,0	MPa	○
FSSM08-H-W-5SEFFSG	103,0	MPa	○
FSSM08-H-W-6NEFFSG	118,0	MPa	○
FSSM08-H-W-6SEFFSG	119,0	MPa	○
GSSM09-H-W-18NEFFSG	102,0	MPa	○
GSSM09-H-W-18SEFFSG	101,0	MPa	○
GSSM09-H-W-19NEFFSG	118,0	MPa	○
GSSM09-H-W-19SEFFSG	107,0	MPa	○
GSSM10-H-W-41NEFFSG	117,0	MPa	○
GSSM10-H-W-41SEFFSG	100,0	MPa	○
GSSM10-H-W-42NEFFSG	110,0	MPa	○
GSSM10-H-W-42SEFFSG	116,0	MPa	○
GSSM10-H-W-43NEFFSG	123,0	MPa	○
GSSM10-H-W-43SEFFSG	124,0	MPa	○
FSSM11-H-W-59NEFFSG	125,0	MPa	○
FSSM11-H-W-59SEFFSG	109,0	MPa	○
FSSM11-H-W-60NEFFSG	107,0	MPa	○
FSSM11-H-W-60SEFFSG	106,0	MPa	○
FSSM11-H-W-61NEFFSG	104,0	MPa	○
FSSM11-H-W-61SEFFSG	115,0	MPa	○
GSSM13-H-W-102NEFFSG	127,0	MPa	○
GSSM13-H-W-102SEFFSG	116,0	MPa	○
GSSM13-H-W-101NEFFSG	106,0	MPa	○
GSSM13-H-W-101SEFFSG	126,0	MPa	○
GSSM12-H-W-79NEFFSG	112,0	MPa	○
GSSM12-H-W-79SEFFSG	128,0	MPa	○
GSSM12-H-W-78NEFFSG	105,0	MPa	○
GSSM12-H-W-78SEFFSG	129,0	MPa	○
GSSM12-H-W-77NEFFSG	112,0	MPa	○
GSSM12-H-W-77SEFFSG	107,0	MPa	○
FSSM15-H-W-119NEFFSG	117,0	MPa	○
FSSM15-H-W-119SEFFSG	113,0	MPa	○
FSSM14-H-W-115NEFFSG	117,0	MPa	○
FSSM14-H-W-115SEFFSG	120,0	MPa	○
FSSM14-H-W-114NEFFSG	122,0	MPa	○
FSSM14-H-W-114SEFFSG	124,0	MPa	○

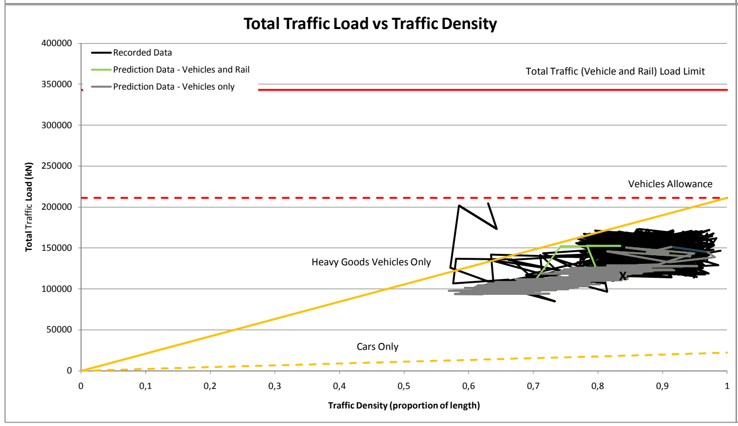
Carichi Applicati
Applied Loads

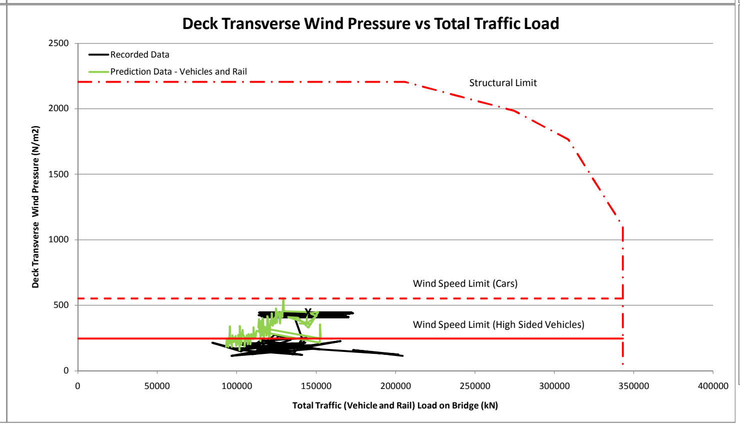
Sensor used for Deck Wind Speed: EEM09-D-W

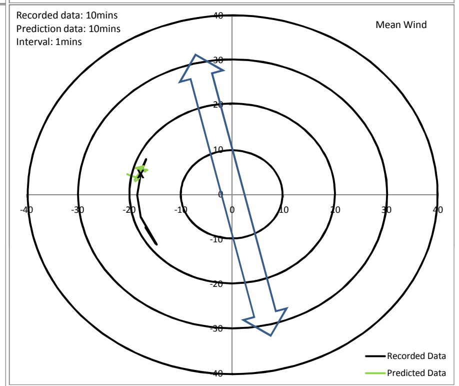












Appendix 2 Discussion concerning Main-cable Fibre-optic Sensors, and Plan for Testing

This appendix presents a general introduction on the fibre-optic techonology proposed for the main-cables of the Messina bridge. It discusses the considerations leading to the selection of each type of fibre-optic sensor identified for monitoring of the main-cables. A general plan for sensor and system testing is presented. The development and the proof-testing phase that is associated with the embedded main-cable sensors is presented in more detail; a development and test programme is included.

General

Sensors for the measurement of structural parameters, that are based on fibre-optic technology, have been developed and applied in the monitoring of structures over recent decades. A fibre-optic sensor is a sensor that uses an optical fibre either as the sensing element or as a means of relaying signals from a remote sensor to the electronics that process the signals. Measurements are taken by measuring changes between the input and output/reflected signals. Numerous types of fibre-optic sensors have been developed; these can be divided into a number of categories according to different principles of operation. If the sensors are categorised according to the transduction mechanism that affects the property of light, then the categories are as follows; intensiometric, interferometric, polarimetric, modalmetric and spectrometric. The most common short-gauge and long-gauge sensors used in civil engineering applications are Fibre-Bragg Gratings (FBG), Fabry-Perot Interferometers, Michelson and Mach-Zehnder Interferometers. Distributed sensors based on Brillouin, Raman or Rayleigh scattering are also available. These measure distributed parameters from metres up to tens of kilometres with a spatial resolution from tens of millimetres up to a few metres, depending on the technology and application. Distributed sensors based on Raman and Brillouin scattering do not require the inclusion of modifications to the glass fibre.

A fibre-optic sensory system typically consists of fibre-optic sensors based typically around a glass fibre core with cladding, transmitting cables and data-acquisition systems based around a light transmitter and receiver. Fibre-optic sensors allow for reliable monitoring due to benefits including insensitivity to electro-magnetic fields as well as high temperatures, accurate measurement with no need for re-calibration, no drift in measurement signal, transmission over long distances without amplifiers, and wide bandwidth. As with electronic sensors, the measurement of certain parameters such as stress requires a correction for temperature effects. Temperature correction is easily applied through measurement of temperature with fibre-optic sensors, in conjunction with data processing. Many modern fibre-optic sensors however also offer automatic temperature compensation.

As with all monitoring equipment, but particularly important with fibre-optic sensors, successful installation and application of fibre-optic sensors requires the work to be performed by people with appropriate knowledge, education as well as experience with working with fibre-optic sensors. The involvement of suppliers with successful experience of fibre-optic sensors shall therefore be a requirement of the project.

Fibre-optic sensors based on Fibre-Bragg Gratings and the Raman Scattering Method, for discrete and distributed measurements respectively, have been identified for the Messina bridge project.

Fibre-Bragg Gratings (FBG)

Fibre-optic sensors based on FBGs are well-established. FBGs offer a wide range of application. FBGs can then be used as direct sensing elements for strain (and thus stress with temperature compensation) and temperature. They can also be used for measuring pressure, humidity, in-line flow, vibration as well as corrosion in many kinds of various applications. Significant advantages over traditional electronic gauges used for these applications include lower sensitivity to vibration, heat and electro-magnetic fields. Consequently FBGs are more reliable than electronic sensors. Although fibre-optic sensors based on FBGs are well-established, research and further development continues and new products constantly enter the market.

Raman Scattering Method

Distributed sensing based on Raman scattering consists of a single optical fibre that is used to measure temperature along the fibre, for distances of up to tens of kilometres. There is good experience in the fibre-optic sensor market with the use of this sophisticated technique. These sensors have been installed on dams, pipelines, bridges, highways and other large structures and buildings where there is need for distributed monitoring over long distances. Due to limited experience, currently a challenge exists with the installation of these sensors inside main-cables or stay-cables; however the latest developments inidicate that these sensors are now sufficiently developed for installastion in more demanding environments such as that presented by the main-cables.

Current Experience

Sensors based on FBGs are well-established. The more recent development of distributed temperature measurement using the Raman scattering process has also been applied successfully with experience based for example on dam monitoring in harsh environments. The main challenge for the adoption of these sensors in the main-cables is the installation.

The installation of fibre-optic sensors to new forms of structure, without previous experience, is challenging. Research on fibre-optic sensors has however reached the point where installation procedures are now practical. Some companies have already made installations with FBG arrays on stay-cables and main-cables, and a lot of research around this specific subject is ongoing. Of particular note, the coatings to fibre-optic sensors and cables have been developed to produce a durable cable that can survive harsh environments.

Examples of companies involved in fibre-optic sensor development include Applied Geomechanics, SMARTEC S/A , and FOS & S.

Examples of complicated fibre-optic sensor installations can be found at the following Internet links:

http://www.carboceramics.com/attachments/contentmanagers/2708/Fiber_Optic_Sensing_Solutions_for_the%20FAA_Case%20Study.pdf

http://www.fos-s.be/projectsadv/be-en/0/detail/item/20/cat/4/

http://smartec.ch/HTMLFiles/Manhattan_Bridge_Monitoring.htm

Examples of current research and development can be found at the following Internet links

http://lib.semi.ac.cn:8080/tsh/dzzy/wsqk/spie/vol7293/72930I.pdf

http://www.nbshangong.com/upload/papers/paper_g4.pdf

An example of a distributed fibre-optic temperature sensor can be found at the following Internet link:

http://www.carboceramics.com/attachments/files/47/DSS_DTS_Fiber_Optic.pdf

Fibre-optic relative humidity sensors are not as well developed as those for measuring temperature or stress. Therefore in addition to the challenge presented by installation, the development of the sensor itself shall be a challenge. Current research has developed a number of sensors that are based around FBGs, with special coatings applied that are responsive to humidity. Hygrometer cells in fibre-optic cables that have been developed include, for example:

- spliced segment of polymer optical fibre, based on polymethyl methacrylate (PMMA), with Fibre-Bragg-Grating
- Fibre-Bragg-Grating coated with polyimide
- long-period Fibre-Bragg-Grating coated with a thin film of silica nanospheres

Although concept sensors exist, achieving long-term durability will also be a signficiant challenge. The relative humidity of air flowing out of the main-cables shall be monitored at the exhaust ducts of the dehumidification system. Establishing the initial internal environment following construction as well as monitoring the initial period of main-cable drying is of most interest. Short-term monitoring of relative humidity within the main-cables with internal sensors is therefore of importance; long-term monitoring with internal sensors is not so important.

The approach that shall be adopted for the Messina bridge shall be that approach that is demonstrated to be the most reliable. Proving tests shall be required for this assessment.

Selection of Sensors for Measurements taken from the Main-Cables

Strain sensors require bonding to the main-cable wires and straining with the main-cable in order to register the straining of the main-cable. The associated straining requirements are at the limits of fibre-optic sensors. Furthermore the measurement of strain is most reliably achieved with FBGs, and current available systems limit the number of FBGs on a fibre-optic cable. Measurement of strain is only required at key positions in the main-cables, primarily at the tower tops, anchor blocks, where access to cabling is feasible via the splay of the main-cable strands as they pass into the saddles. There is therefore limited benefit in developing a strain sensor that is installed over the full-length of the main-cable, a limited benefit that is also offset by economy and risk of not being successful. It is practical and also appropriate to install strain sensors discretely at the appropriate point in main-cable erection sequence. This would limit the strain that is applied to the sensor to reasonable levels. The sensors would however only pick-up changes in main-cable strain from the point at which they were installed in the straining sequence of the main-cable strands. Additional strain sensors could be installed to the main-cable strands prior to erection to record the straining history up to the point at which the main sensors are installed. These additional sensors would be considered sacrificial and would not be planned for inclusion in the final SHMS. Stress measurement shall therefore be performed with temperature-compensated single fibre-optic sensors with FBGs.

Unlike strain sensors, temperature sensors do not require bonding to the main-cable wires. They can be detailed to be placed within a sleeve that allows flexibility of the fibre-optic strand relative to the main-cable. It is therefore feasible to install a fibre-optic sensor at strand fabrication, that runs the full-length of the main-cable. In order to obtain the full potential of the full length fibre-optic cable, distributed readings using the method based on Raman-scattering has been proposed. This method would allow temperature readings to be obtained at every position along the main-cable. Temperature measurement shall therefore be performed with stress-free fibre-optic cabling installed over the full-length of the main cable with readings based on the Raman Scattering process.

Similarly, the measurement of relative humidity does not require bonding to the main-cable, therefore the adoption of a full-length fibre-optic cable is feasible. However current technology requires humidity to be measured at discrete positions using special coatings applied around the fibre optic strand where FBGs have been created. The use of discrete monitoring has therefore been proposed for the fibre-optic humidity sensors. Relative humidity measurement shall therefore be performed with stress-free fibre-optic cabling installed over the full-length of the main-cable with numerous FBGs and local application of special coatings.

Measurement of Relative Humidity

The measurement of relative humidity with fibre-optic sensors is not currently well established. Also, the installation of fibre-optic sensors into the main-cables represents an advancement in technology. The embedded fibre-optic relative humidity sensors shall be developed and tested for this project.

Redundancy of relative humidity measurements has been provided in the monitoring plan by the installation of two fibre-optic relative humidity sensors per main-cable. Additional redundancy is provided by the measurement of relative humidity of air emerging from the outlets of the de-humidification system.

Additional redundancy would be beneficial due to the required development of the sensor. The provision of additional redundancy, in the form of embedded fibre-optic single relative humidity sensors positioned in the main-cables adjacent to the tower tops and the anchor blocks, shall be considered at Progetto Esecutivo.

Measurement of Stress

The measurement of stress with temperature-compensated fibre-optic sensors is well established. However, the installation of fibre-optic sensors into the main-cables represents an advancement in technology. The embedded fibre-optic single strain sensors shall be developed and tested for this project.

Redundancy of stress measurements has been provided in the monitoring plan by the installation of fibre-optic strain sensors to the surface of the main-cables in addition to those installed within the main-cables.

These sensors are intended to be installed directly onto the main-cable wires with a bonded length of less than 100mm. For the surface mounted sensors, these short bonded lengths will allow the sensors to be accessible for maintenance through port-holes in bespoke cable-bands. The short bonded lengths will also allow local bending stresses in the main-cable to be picked-up next to the cable.clamps. However there may be concern that the bonding of the fibre-optic strain sensors directly to the main-cable wires over a short length may not allow the straining of the main-cable wires to be completely registered by the sensors. The effectiveness of the bonding length shall be verified by proof-testing.

An alternative approach for installing fibre-optic strain sensors would be to use the two adjacent main-cable clamps at a hanger location to hold the ends of the fibre-optic strain sensor in place. For internal strain sensors, as well as surface mounted strain sensors, that are extended past the clamps, the clamping effect would restrain the sensor. However this method would not allow the sensor to be accessed for maintenance or replacement. An alternative method that allows access for maintenance or replacement would be to fix the ends of the fibre-optic strain sensors to the clamps with bolted end fittings. However, this approach would require a special cover to be created for the main-cable to provide access over the full length between adjacent cable-clamps.

The measurement of stress over a long gauge length defined by two adjacent clamps would not allow local bending stresses of the main-cable to be well-registered; only the axial stress of the main-cable is likely to be registered.

Clearly the addition of fibre-optic strain sensors between adjacent cable clamps would provide additional redundancy for measurement of axial stress that would be beneficial. The addition of these sensors shall be considered at Progetto Esecutivo, following the conclusions drawn from proof-testing of the proposed bonded sensors.

Measurement of Temperature

The distributed measurement of temperature with fibre-optic sensors using the Raman-scattering process is well established. However, the installation of these sensors in main-cables represents an advancement in technology. The embedded distributed fibre-optic temperature sensors shall be developed and tested for this project.

Redundancy of temperature measurements has been provided in the monitoring plan by the inclusion of discrete fibre-optic temperature sensors based on FBGs installed both inside as well as to the surface of the main-cables. This method of installation has been successfully applied to the main-cables of other major suspension bridges, albeit using electronic sensors. The use of fibre-optic temperature sensors instead of electronic temperature sensors will not reduce the success of this installation.

Sheave of Embedded Fibre-Optic Cables

Due to the installation conditions (including compaction of the main-cable) as well as due to the forces expected to be experienced at the tower top saddles, the sheave of the fibre-optic cable will need to be appropriately detailed for survivability of the installation process as well as function. A kevlar sheave (coating) is expected to provide sufficient durability, although this will need to be proven. Designs, particularly involving metals, will need to be appropriately detailed so as not to influence cathodic deterioration of the main-cable. Installing the fibre-optic cable within a thin metal tube is not expected to be sufficient or successful. Proving trials will be required to ensure development of a fibre-optic cable that will survive the installation process and function as required.

Plan for Testing

The Messina bridge will be the longest bridge in the world, and experience with installation of fibre-optic sensors in the main-cables of suspension bridges is limited.

A thorough testing schedule and procedure will therefore be established. Testing must prove feasibility of the installation as well as verify functionality of the sensors, passive cables, hardware, software and other data acquisition equipment for the completed installation. Testing must also verify sensor performance and accuracy in relation to expected (calculated) values while maintaining high levels of measurement repeatability.

A testing team is to be established with members who are qualified, experienced and competent. A testing task force will also be formed from representatives from the SHMS designer, SHMS sub-contractor, cable manufacturer, sensor manufacturer, external experts with key skills, constructor and owner. The testing task force will establish the requirements of testing to be undertaken by the testing team. An outline procedure for testing is presented below:

1. A focused technical specification for these sensors is established, presenting measurement parameters and prospective measuring techniques.
2. Data is collected, evaluated and presented to support technologies that shall be developed for the Messina bridge. Data shall include information on previous testing and verification of the technologies. Data will include material presented in papers.
3. The testing aims are established.
4. Plans are established around the testing aims and a testing schedule is established.
5. Testing is performed at a variety of stages in the development and delivery process.
6. Proof-tests of the sensors are to be performed during development. Proof-testing shall also be performed on the sensors subjected to the conditions of installation and service.
7. Development phase proof-tests shall be evaluated. The results shall be verified against the technical specification and the testing aims. A decision shall be made by the testing team panel on whether to approve the sensors, continue sensor development, or abandon sensor development and establish alternative measurement techniques.
8. If sensors have been demonstrated as acceptable, the sensors shall be manufactured as approved.

9. The development and proof-testing phase shall be completed prior to the commencement of Progetto Esecutivo.
10. Manufactured sensors and support equipment shall be subjected to Factory Acceptance Tests (FAT).
11. The FAT shall be evaluated for approval. The results shall be verified against the technical specification. Unapproved sensors shall be rejected or subject to repair.
12. If sensors are approved by FAT, they shall be incorporated into the bridge construction.
13. Sensors that are installed within the strand of the main-cable shall be subject to further FAT following construction of the main-cable strand and prior to erection of the strand on-site.
14. The FAT shall be evaluated for approval. The results shall be verified against the technical specification. Unapproved sensors shall be rejected or subject to repair. If unapproved sensors are rejected replacement sensors can be installed in other strands.
15. If sensors are approved by FAT, they shall be incorporated into the bridge construction.
16. Following bridge construction, installed sensors and support equipment shall be subjected to Site Acceptance Tests (SAT).
17. The SAT shall be evaluated for approval. The results shall be verified against the technical specification. Unapproved sensors shall be rejected or subject to repair. If installed sensors are rejected, alternative measurement techniques shall be established.
18. A second phase of SAT shall be performed to review long-term function. A report on performance is prepared by the testing team panel.
19. At all stages of testing, appropriate quality records shall be established and submitted to the testing team panel, which shall be retained as a permanent record of testing.

Development and Proof-Testing Phase

The fibre-optic cables that will be embedded inside the main-cables will need to be developed for durability and function, to avoid damage during main-cable erection; the core of a fibre optic cable, which is made of silica and is very fragile, can be provided with a protective coating such as kevlar. Furthermore the embedded fibre-optic relative humidity sensor itself will need to be developed for this project. A phase of development and proof-testing will therefore be required to ensure that appropriate sensor designs are adopted. Development and proof-testing will also enable the sensors to be made more economical, more reliable, and of longer life. Proof-testing will enable the development of a simple and effective solution for installing the sensors to the main-cables, and will provide data to evaluate and thus confirm the correct function of the sensors and associated hardware. particularly within the installation environment.

The durability and function of the Linear Polarization Resistance sensors that will be embedded inside the main-cables will also need to be demonstrated, and if required modified such that appropriate sensor designs are adopted.

In addition, testing of the function of the general fibre-optic sensors, including bond-length, is required to demonstrate suitability to Stretto di Messina.

Tests will also be performed to demonstrate the physical behaviour and performance of the dehumidification system.

The sensors may be modified by the SHMS designers depending on the outcome of the proof-testing, Furthermore, if Stretto di Messina remains unconvinced by the adoption of fibre-optic sensors, the fibre-optic sensors could be replaced with equivalent electronic sensors; however the following drawbacks and important considerations should be noted:

- electronic sensors can be prone to drift
- electronic sensors are sensitive to electromagnetic disturbance and stray currents
- electronic sensors are expected to have a shorter life
- the risk of sensor failure during main-cable erection and compaction is expected to be increased due to the soft data-cable
- electronic sensors are single sensors, and therefore each sensor will require its own data-cable
- near to each splay of the main-cable strands, the data-cables can be fed along the alignment of the main-cable wires. However, remote from the splay of the main-cable strands, the data-cables would need to be fed out of the main-cables and sealed cable-guard wrap. Running soft data-cables across the alignment of the main-cable wires increases the risk of damage

to the data-cables and failure of the sensor. Access holes, added to the sealed cable-guard wrap, risks compromising the seal of main-cables and the effectiveness of the dehumidification system

- the monitoring system should not in any way compromise the structural integrity of the main-cables or indeed introduce cathodic deterioration

The above list is not exhaustive.

An outline inventory of development phase proof-tests is proposed below. The development and proof-tesing phase will need to be formed into a programme of 9-12 months duration, completing prior to the commencement of Progetto Esecutivo, The proof-testing programme will consist of function tests, durability tests, as well as condition simulation tests. Where feasible, final proving tests will be repeated a minimum of 3 times to demonstrate reliable performance. In order to reliably establish sensor performance, a number of different sensor types for monitoring the same or equivalent parameters will need to be installed on the test specimens. For example, testing of the fibre-optic sensors will involve the addition of appropriate electrical sensors. Tests will be performed on a variety of specimens of varying scale, from single wires to a complete mock-up of the main-cable. The characteristic conditions that will be experienced by the sensors during installation, construction and service will be simulated; including the fabrication process of the strands, the erection of the strands, the erection of subsequent strands, the compaction of the main-cable, and the applied stresses whilst in service, Collaboration from the outset, between the fabricator of the main-cable and the manufacturer(s) of the sensors, is essential in order to meet the technical requirements.

Columbia University have already performed numerous tests on a variety of sensors using a main-cable mock-up appropriate to the Manhattan suspension bridge, New York. Various environmental conditions have been simulated in these tests. The following website presents a good overview of the set-up and testing performed by Columbia University:

http://www.civil.columbia.edu/carleton/research/suspension.html for information.

There may be significant advantages and benefit in performing full-scale proof-testing through Columbia University, as they have experience with and the facilities for testing on full-scale section model mock-ups of main-cables, The following proof-tests shall be performed in addition to any additional tests presented in the monitoring plan. Note that a "function test" represents a test to verify the function of the sensors. This test not only verifies that a reading is obtained from the sensor, it also verifies the quality and accuracy of data produced. The test programme will need to be detailed by the Testing Task Force, following meetings with the chosen supplier of the fibre-optic sensors and the chosen supplier of the main-cable wire, site visits to structures with working fibre-optic sensors including discussions with the owners/responsible consultants, and visits to and discussions with potential research facilities.

Development phase proof-testing - no specimen:

- function test for newly developed fibre-optic relative humidity sensor (repeatable)
- minimum radius bend test for all fibre-optic sensor types, to verify continued function following bending to specified minimum bend radius (repeatable)
- tension test for all main-cable fibre-optic sensors, to verify continued function following applied tension to minimum requirements (repeatable)
- mechanical shock test for all fibre-optic sensor types, to verify continued function following a drop of 1.5m (5ft) (repeatable)
- durability test (simulation of strand fabrication conditions including pulling from bobbin) for all full-length embedded fibre-optic sensors, to verify continued function following fabrication into the main-cable strand (repeatable), including but not limited to
  - tension of the sensor
  - bending of the sensor

Development phase proof-testing - wire specimen:

- function test for all embedded fibre-optic sensors (repeatable)
- compatibility test, to demonstrate compatibility of the sensor materials with the main-cable wire without inducing deterioration of the main-cable wire (repeatable)

Development phase proof-testing - strand specimen:

- function test under simulated physical conditions for full-length embedded main-cable sensors (repeatable), including but not limited to
  - tension of the strand
  - radial stresses due to installation of the strand over the tower/anchor block saddle
- minimum strand radius bend test for all full-length embedded fibre-optic sensors, to verify continued function following bending to specified minimum bend radius (repeatable)
- durability test (simulation of strand fabrication conditions) for all full-length embedded fibre-optic sensors, to verify continued function following fabrication into the main-cable strand (repeatable), including but not limited to
  - compaction of the strand
- durability test (simulation of strand storage, transport and erection conditions), to verify continued function following strand erection (repeatable), including but not limited to
  - impact onto the strand
  - pulling a strand over the installed strand with sensor
  - moving a strand across the installed strand with sensor
- bond test for all main-cable and hanger fibre-optic sensors, to demonstrate suitability of method of bonding and required bond length (repeatable) , including but not limited to
  - tension of the strand

Development phase proof-testing - plate specimen:

- bond test for all general fibre-optic sensors, to demonstrate suitability of method of bonding and required bond length (repeatable), including but not limited to
  - tension of the plate
  - compression of the plate

Development phase proof-testing - multi-strand specimen (7 strands):

- function test under simulated physical conditions for all embedded main-cable sensors (including LRP sensors). Note that the testing of the LRP sensors must include the expected length of data-cable required. (repeatable). Testing will include but not be limited to
  - tension of the multi-strand
  - differential tension across the multi-strand
  - radial compression stresses due to clamping of the main-cable
- function test under simulated environmental conditions for all main-cable sensors (including LRP sensors) (repeatable), including but not limited to
  - moisture
  - uniform heat in conjunction with different moisture levels
  - distributed heat in conjunction with different moisture levels
  - rain simulation
  - solar radiation

Development phase proof-testing - 30m long mock-up section specimen (full-scale including dehumidification system):

- function test under simulated physical erection conditions for all main-cable sensors (including LPR sensors) (not repeatable but to be demonstrated by quantity of test sensors), including but not limited to
  - radial stresses due to compaction of the main-cable
- function test under simulated physical conditions for all main-cable sensors (including LPR sensors) (not repeatable but to be demonstrated by quantity of test sensors), including but not limited to
  - radial compression stresses due to clamping of the main-cable

- function test under simulated environmental conditions for all main-cable sensors (including LPR sensors), including but not limited to
  - moisture
  - uniform heat in conjunction with different moisture levels
  - distributed heat in conjunction with different moisture levels
  - performance test of the dehumidification system, to demonstrate and understand the progression of air dehumidification and air flow through the main-cable. Note that although this test needs to be performed on a full-scale section model of appropriate length, the wires of the model need not be created from the steel wires specified in the design. Equivalent section model wires can be adopted provided that these do not absorb or modify the characteristics for the formation of humidity. (repeatable). Testing will include but not be limited toairflow along the main-cable
  - airflow across the main-cable
  - dehumidification along the main-cable
  - dehumidification across the main-cable

Appendix 3 List of Example Equipment

This list is not a specification. This list represents a list of exar

Example real-time operating system: National Instruments - I
Example programming enviroment: National Instruments - N
Example graphical interface software: National Instruments -
Example hardware platform: National Instruments - NI Crio

Section	***Title***
5.2.1	Tri-axial Sonic Anemometer
5.2.2	Tri-axial Mechanical Anemometer
5.2.3	GPS Receiver
5.2.4	Air Temperature Sensor (1)
5.2.5	Air Temperature Sensor (2)
5.2.6	Pyrometer
5.2.7	Hygrometer (1)
5.2.8	Hygrometer (2)
5.2.9	Fibre-Optic Relative Humidity Sensor
5.2.10	Barometer
5.2.11	Rain Gauge
5.2.12	Surface Hygrometer (1)
5.2.13	Surface Hygrometer (2)
5.2.14	Road Temperature Sensor
5.2.15	1D Accelerometer (1)
5.2.16	1D Accelerometer (2)
5.2.17	2D Accelerometer (1)
5.2.18	2D Accelerometer (2)
5.2.19	3D Accelerometer (1)
5.2.20	3D Accelerometer (2)
5.2.21	2D Static Inclinometer
5.2.22	2D Dynamic Inclinometer
5.2.23	Fibre-Optic Temperature Sensor (1)

5.2.24 Fibre-Optic Temperature Sensor (2)
5.2.25 Fibre-Optic Temperature Sensor (3)
5.2.26 Fibre-Optic Temperature Sensor (4)
5.2.27 Fibre-Optic Strain Sensor (1)
5.2.28 Fibre-Optic Strain Sensor (2)
5.2.29 Fibre-Optic Strain Sensor (3)
5.2.30 Fibre-Optic Strain Sensor (4)
5.2.31 Fibre-Optic Strain Sensor (5)
5.2.32 Fibre-Optic Strain Sensor (6)
5.2.33 Fibre-Optic Strain Sensor (7)
5.2.34 Fibre-Optic Strain Sensor in Delta Formation
5.2.35 Linear Displacement Sensor (1)
5.2.36 Linear Displacement Sensor (2)
5.2.37 Linear Displacement Sensor (3)
5.2.38 Linear Displacement Sensor (4)
5.2.39 Linear Displacement Sensor (5)
5.2.40 Hydraulic Pressure Gauge (1)
5.2.41 Hydraulic Pressure Gauge (2)
5.2.42 Oil Temperature Sensor
5.2.43 Concrete Corrosion Sensor
5.2.44 Ground Pressure Sensor
5.2.45 Interstitial Ground-Water Pressure Sensor
5.2.46 Video Displacement Sensor
5.2.47 Half-cell Potentiometer and Studs
5.2.48 Benchmark
5.2.49 Railway Track Temperature Sensor
5.2.50 Corrosion Rate Sensor
5.2.51 Microwave Interferometric Radar
5.2.52 Calibration Strain Sensor

nple equipment that could be used to satisfy the "Sensor Minimum Requirements" that are set out in section 5.0.

NI Labview
I Labview
NI Labview

Example Sensor

Gill Instruments - Three Axis Anemometer - WindMaster Pro
Young - Marine Wind Monitor - 05106 WITH Young - Gill Propeller Anemometer - 27106
Leica - High precision GNSS monitoring receiver - GMX902
Young - Relative Humidity/Temperature Probe - 41382   OR   Young - Temperature Probe - 41342   WITH Young - Multi-Plate Radiation Shield - 41003
Young - Relative Humidity/Temperature Probe - 41382   OR   Young - Temperature Probe - 41342
Aanderaa - Solar Radiation Sensor - 2770
Young - Relative Humidity/Temperature Probe - 41382   WITH Young - Multi-Plate Radiation Shield - 41003
Young - Relative Humidity/Temperature Probe - 41382
To be developed - Refer to discussion in Appendix 2
Lambrecht - Air Pressure Sensor - 00.08128.093 072
Young - Tipping Bucket Rain Gauge - 52202
Thermokon Sensortechnik - Condensation Detector - WK01
Thermokon Sensortechnik - Condensation Detector - WK01
Fiber sensing - BraggMETER Industrial Multipurpose Measurement Unit WITH Fibersensing - High Performance FBG Temperature sensor - FS6300-50110301
Silicon Designs - accelerometer module - 2210-002
Silicon Designs - accelerometer module - 2210-002
Silicon Designs - accelerometer module - 2210-002 - 1 required for each axis
Silicon Designs - accelerometer module - 2210-002 - 1 required for each axis
Silicon Designs - accelerometer module - 2210-002 - 1 required for each axis
Columbia Research Laboratories - Servo Accelerometer - SA-307LN
Columbia Research Laboratories - Biaxial Force Balance Inclinometer - SI-726BIHPC
Schaevitz - DC-Operated Gravity-Referenced Servo Inclinometer - LSOC/LSOP
Fiber sensing - BraggMETER Industrial Multipurpose Measurement Unit WITH Fibersensing - High Performance FBG Temperature sensor - FS6300-20110301

Smartec - Reading Unit Raman OTDR - 14.2012 Ditemp WITH Smartec - Temperature Sensing Cable - DiTeSt-DiTemp
Fiber sensing - BraggMETER Industrial Multipurpose Measurement Unit WITH Fibersensing - High Performance FBG Temperature sensor - FS6300-20110301
Fiber sensing - BraggMETER Industrial Multipurpose Measurement Unit WITH Fibersensing - High Performance FBG Temperature sensor - FS6300-20110301
Fiber sensing - BraggSCOPE Dynamic Measurement Module with NI platform WITH Fibersensing - High Performance FBG Strain sensor - FS6200-20110301
Fiber sensing - BraggSCOPE Dynamic Measurement Module with NI platform WITH Fibersensing - High Performance FBG Strain sensor - FS6200-20110301
Fiber sensing - BraggSCOPE Dynamic Measurement Module with NI platform WITH Fibersensing - High Performance FBG Strain sensor - FS6200-20110301
Fiber sensing - BraggSCOPE Dynamic Measurement Module with NI platform WITH Fibersensing - High Performance FBG Strain sensor - FS6200-20110301
Fiber sensing - BraggSCOPE Dynamic Measurement Module with NI platform WITH Fibersensing - High Performance FBG Strain sensor - FS6200-20110301
Fiber sensing - BraggSCOPE Dynamic Measurement Module with NI platform WITH Fibersensing - High Performance FBG Strain sensor - FS6200-20110301
Fiber sensing - BraggSCOPE Dynamic Measurement Module with NI platform WITH Fibersensing - High Performance FBG Strain sensor - FS6200-20110301
Fiber sensing - BraggSCOPE Dynamic Measurement Module with NI platform WITH Fibersensing - High Performance FBG Strain sensor - FS6200-20110301
Leuze Electronic - Optical Laser Distance Sensor - ODS96
To be supplied by Buffer Manufacturers
Penny and Giles - Linear Position Transducer - SLT190
Penny and Giles - Linear Position Transducer - SLT190
To be supplied by Tuned Mass Damper Manufacturers
To be supplied by Buffer Manufacturers
To be supplied by Buffer Manufacturers
To be supplied by Buffer Manufacturers
Roctest - Concrete Corrosion Sensor - SensCore 16.1010
Roctest - Total Pressure Cell - TPC
Roctest - Vibrating Wire Piezometer - CL1
Toshiba - hi-def camera - IK-HR1D WITH National Instruments - NI Labview data processing facilities
Elcometer - Reading Unit - Elcometer 331SH WITH Elcometer - Half Cell Kit - TW331CUKIT
To be developed - bespoke design
Fiber sensing - BraggMETER Industrial Multipurpose Measurement Unit WITH Fibersensing - High Performance FBG Temperature sensor - FS6300-20110301
Analatom - Linear Polarisation Resistance (LPR) Corrosion sensor with 150µm interdigitation gap
IDS Ingegneria Dei Sistemi - Microwave Interferometric Radar - IBIS-S
Gage Technique International - Vibrating Wire Surfacing Mounting Strain Gauge - TSR/5.5/T

Appendix 4 Microwave Interferometric Radar - Brochure

IBIS-S: Preventing Structural Failures Utilizing Microwave Interferometry

IBIS-S

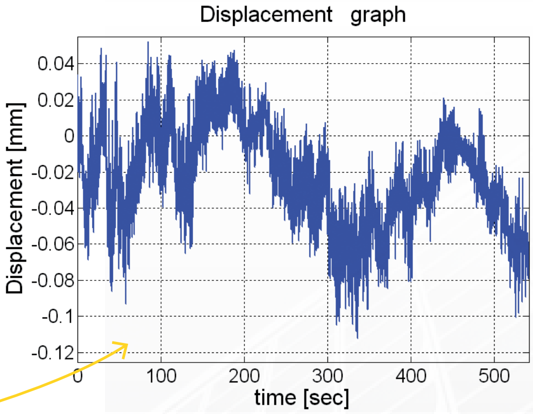
An innovative sensor for remote monitoring of structural movements and deformations

IDS
INGEGNERIA DEI SISTEMI

Go101S9

GeoRadar Division

Monitoring applications:

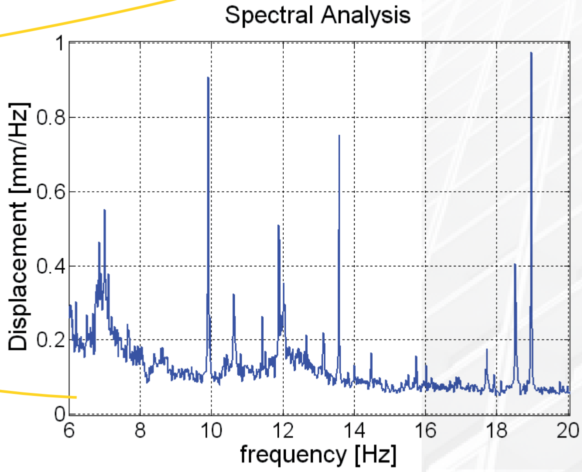


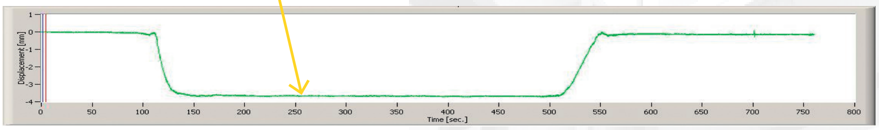
Static

- Structural load testing
- Structural displacement and collapse hazards
- Cultural heritage preservation

Dynamic

- Structural resonance frequency measurement
- Structural modal shape analysis
- Real time monitoring of deformation





Advantages Over Traditional Techniques:

- Remote sensing at a distance of up to 1 km.
- Displacement accuracy up to 1/100 mm.
- Real-time simultaneous mapping of deformations
- Fast installation and operation
- Static and dynamic monitoring
- Structural vibration sampling up to 100 Hz
- Operates day-night, in all weather conditions
- Provides direct displacements, not derived quantities

IDS INGEGNERIA DEI SISTEMI

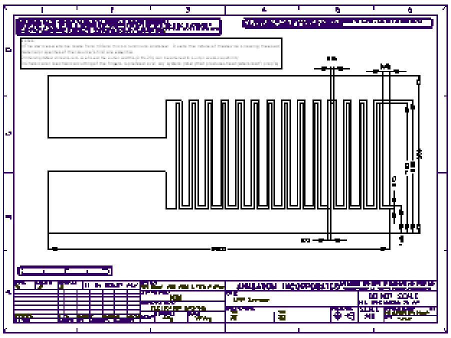
IDS Ingegneria Dei Sistemi S.p.A.
Pisa Branch Office
via Sterpulino 20, 56121 Pisa, Italy
tel. +39 050 967111
fax +39 050 967121

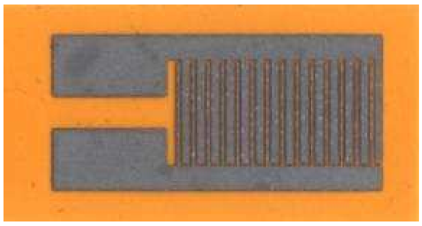
For further information contact
e-mail: sales.gpr@ids-spa.it
tel. +39 050 967123
www.idsgeoradar.com

Appendix 5 LPR Corrosion sensor - Information

Analatom
A Structural Health Monitoring Company

LPR Corrosion Sensor





The Analatom Inc. corrosion sensor is a Linear Polarization Resistor (LPR) that works on the same principle as macro LPR systems do. It is a device that corrodes at the same rate as the structure on which it is placed. The sensor is made up of two micromachined electrodes that are interdigitated at 150mm apart. The corrosion reaction – both oxidation and reduction – produces a corrosion current that can be pre determined empirically for each sensor type, this I/V (Current/Voltage) form is called a Tafel plot.

The sensor itself is made from shim stock of the same material as the structure that is being monitored. The shim is usually 25mm thick (0.001") and is attached to a Kapton backing sheet of similar thickness. This gives the sensor a total thickness in the 50mm range, although a thickness of up to 200mm are possible if required. The shim is machined (pattered) using a photolithography technique, this allows for a varied design layout so that sensors can be fitted deep into tight structures such as bridge cables and lap joints.

The sensor can be placed directly on the metal surface of the structure to be monitored. Painting and other surface preparations can be performed on top of the sensor with no damage to the sensor or coating. In operation the sensors are unobtrusive and require no maintenance or inspection. The system that monitors the sensor is low powered and both sensors and system are robust. The system is designed to be easily installed and operated with an indefinite operating life. The autonomous battery powered version of the system can run for over a decade without need for replacement. A solar powered unit will also be available. The GUI and user interface all load onto a standard Windows PC and are easy to use and interface with other sensors and systems.

Please contact us for detail quote.