Concessionaria per la progettazione, realizzazione e gestione del collegamento stabile tra la Sicilia e il Continente Organismo di Diritto Pubblico
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# PONTE SULLO STRETTO DI MESSINA

# PROGETTO DEFINITIVO


## EUROLINK S.C.p.A.

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| *Tipo di sistema* | METODI E SISTEMI TEMPORANEI PER LA COSTRUZIONE ED IL MONTAGGIO |
| *Raggruppamento di opere/attività* | FUNE PPWS E SISTEMA DI SOSPENSIONE |
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# INDICE

# Suspension System Construction

The main cable consists of two pairs of main cables apart to each other by 2.0 m center to center with the separation of 52 m center to center, each main cable made of 349 number of pre-fabricated parallel wire strands (PPWS) consisting of 127 number of 5.4 mm in diameter high strength steel wires.

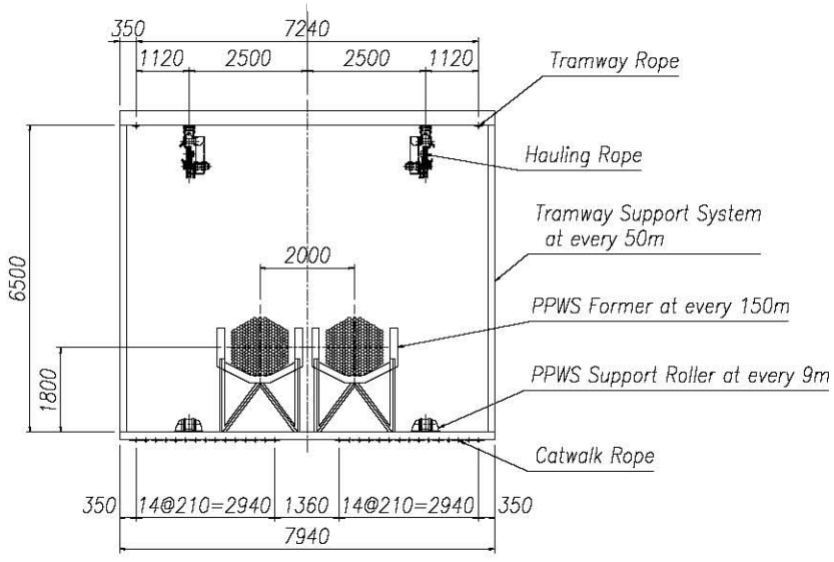
The main cables are supported on the cable saddles at top of the tower and at the anchorage.

The hanger ropes are spaced at every 30 m of the cross girder locations, where two hanger ropes are hung from the main cable via the cable clamp and attached to the hanger anchorage on the cross girder as apart to each other longitudinally typically by 3.75 m.

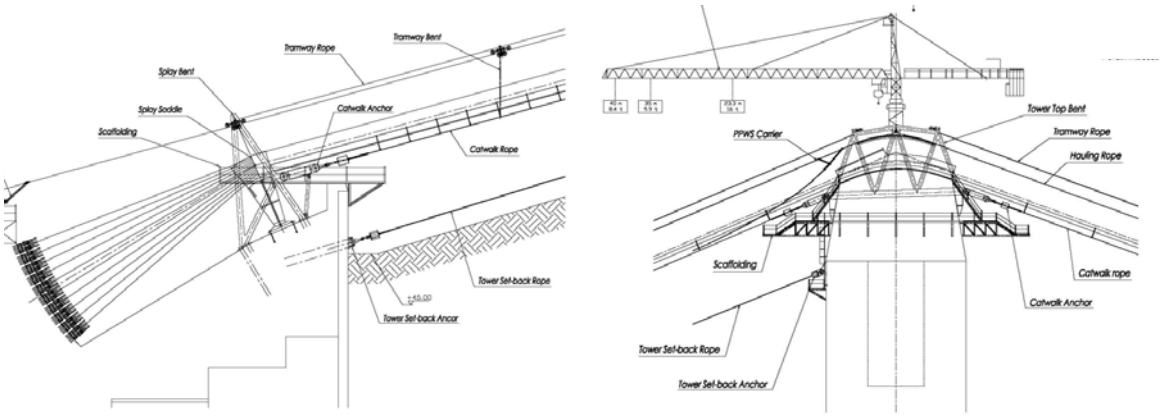
## 1 Catwalk erection and plant installation

The catwalk and plants are designed for the main cable being constructed by the PWS method.

The catwalk is approximately 8m wide aerial walkway, made of 30 numbers of 37mm diameter spiral strands for the floor and 2 numbers of the same strands each for the two side walls as shown below, to cover the erection of the PPWS (pre-fabricated parallel wire strand) of a pair of main cable separated by 2.0m centre to center. Each spiral strand is made of 37 number of the same high strength cable wire as used for the main cable.




The catwalk is divided into three spans, the Sicilia side span, the main span and the Calabria side span, each connected to the catwalk anchor structure at the tower top and at the splay saddle as shown below. The catwalks for each cable plane are connected by the cross bridge, which provides access between them and stability, at approximate 150m interval. The storm system is not adopted, since only shallow rise is achieved hence does not works effectively.

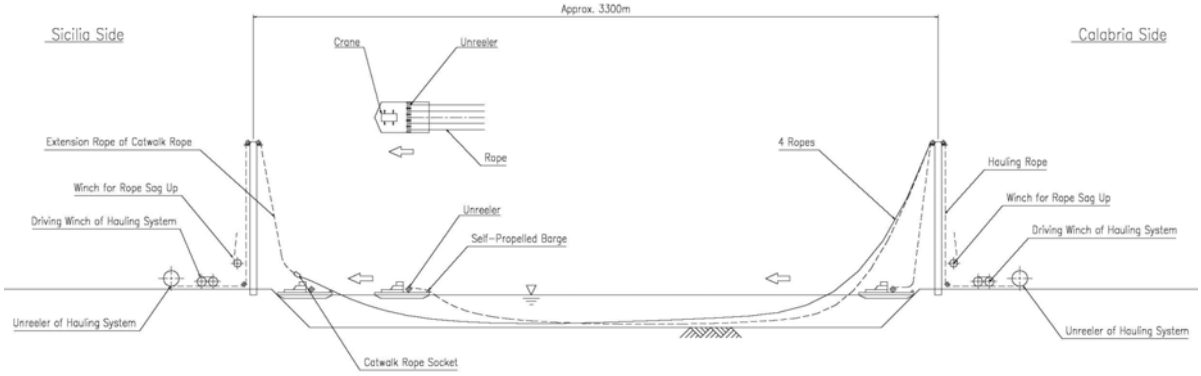



## 1.1 Sea Crossing

The erection of the catwalk system usually starts with passing of a small diameter rope called as “pilot rope” on a sea or in a air between two towers and the erection of the catwalk ropes is carried out using the hauling system which is made by replacing a smaller diameter “pilot rope” with a bigger diameter “hauling rope”, however, this method is not feasible thus not adopted, and the erection of the catwalk system of this project starts with passing of the catwalk ropes directly on a sea between two towers

A half number of the catwalk ropes and the hauling ropes, the total 16 number of ropes, of each catwalk in the main span cross the Strait of Messina as divided to four (4) operation. Each operation is such that four ropes pulled out from a un-reeler on the Calabria side over the Calabria tower top are carried by a tag boat from the Calabria side toward the Sicilia side in a sea, connected to the extension ropes coming from a un-reeler on the Sicilia side over the Sicilia tower top when they come close to the Sicilia side, and raised up by tensioning them at the both sides as shown below.

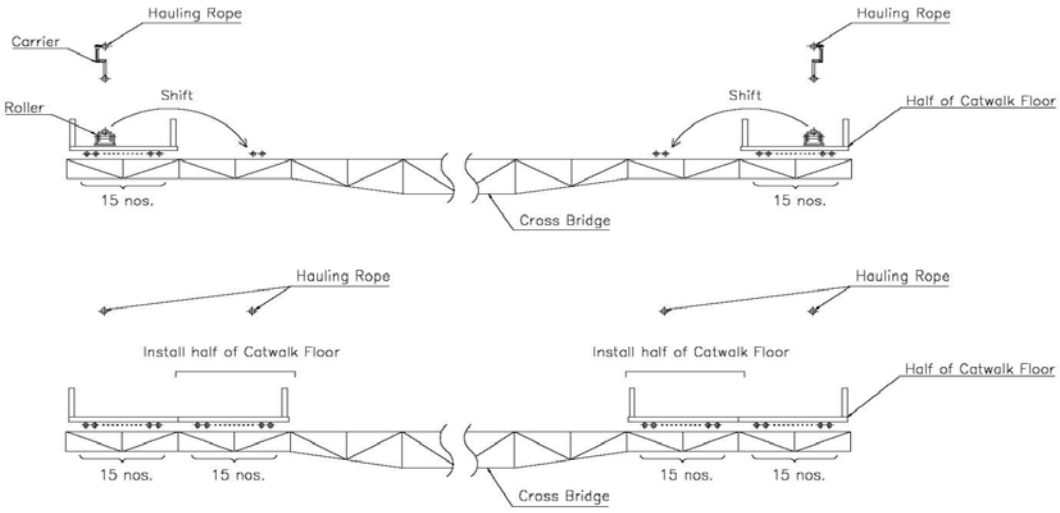
Prior to the sea crossing of the catwalk ropes, the catwalk rope anchor structure and the working platform shall be provided and attached to the tower top.



This operation requires a close of the strait for 3~4 hours for each time; the total 8 times if the sea crossing for the east side and the west side are made separately, which needs permission by the marine authority, however, definitely save the construction time hence cost.

## 1.2 Catwalk Erection

In the main span, a half width of the planned catwalk is made using a half number of the catwalk ropes and the hauling ropes crossed on a sea between two towers followed by erecting the cross bridges and the floor system, the rest of the catwalk ropes and the hauling ropes, the total 16 numbers of ropes, is erected on the catwalk erected earlier using the hauling rope also erected and shifted to their final positions laterally as shown below, thereby the catwalk in the main span is completed with the floor system for the latter half, the hand strands and the wall mesh erected.



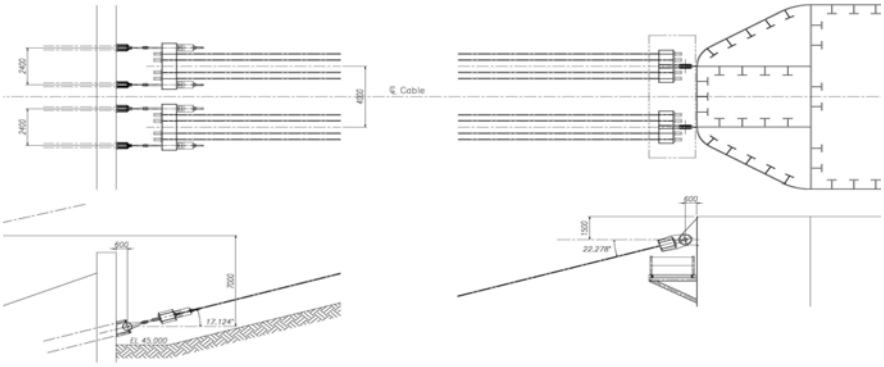

In the side span, a loop type hauling system is installed separately between the anchorage and the tower each at the Sicilia side and at the Calabria side, the splay bent, the catwalk rope anchor structure and the working platform shall be provided and set to the anchor block, the catwalk ropes are erected using the hauling system, thereby the catwalks in the side spans are completed with the floor system, the hand strands and the wall mesh erected.

On the catwalk, the tramway system consisting of the tramway ropes, the support struts and the pulley boxes which support the hauling rope and the other necessary facilities including the PPWS guide rollers, lighting, communication system and etc. are erected and installed to be ready for the erection of the PPWS.

## 1.3 Tie Back System

The tower is tie back prior to commencing the erection of the PPWS in order that the PPWS adjusted to the design sag does not move over the tower saddle.

The tie back of the towers is carried out using eight (8) numbers of PPWS, which is determined as taking temperature and vibration effect on top of the tie back force, for each tower leg spun between the tower top (at EL 383.5m on the tower leg segment No.21) and the anchorage (4.0m below IP on the front face of the anchorage) to achieve the tie back amount of about 3.9 m for the Sicilia tower and 3.3 m for the Calabria tower from those erected vertically as shown below. (see Attachment 1)



## 1.4 Plant Installation

Not similarly to the main cable being constructed by AS method, no much plants nor equipment are required for the erection of the strands of the main cable constructed by PWS method.

The erection of the PPWS is carried out using the hauling system, which requires turning sheave towers, driving winches and un-reelers both on the Sicilia and Calabria anchorage to work as reciprocating system. Two hauling systems are provided for each catwalk, thus four (4) sets of those plants are installed both on the Sicilia and Calabria anchorages.

The PPWS is supplied, most likely as coil horizontal laid, to the hauling system on the Sicilia anchorage, which requires un-coiler and tensioner if necessary on the Sicilia anchorage. Two hauling systems are provided for each catwalk, thus four (4) sets of those plants are installed on the Sicilia anchorage.

## 1.5 Aerodynamic

The catwalk itself is considered to be aerodynamically stable since it is very porous structure, however, is expected to be exposed to tower driving vibration.

In order to mitigate the possible vibration below such amplitude as corresponds to acceleration of 0.5 m/s$^2$ under working wind speed of 15 m/s at the ground level, the tunnel mass damper (TMD) is so designed and installed to the tower.

# 2 Erection of main cable

The main cable apart by 52m to each other and consists of a pair of main cable, each consists of 349 numbers of pre-fabricated parallel wire strands (PPWS) consisting of 127 numbers of 5.40mm diameter high strength steel wire of the breaking stress of 1860Mpa. The breaking stress of 1860Mpa has been chosen to reduce the forces to the cable anchorage and the tower, and the number of strands, and the wire diameter of 5.33mm has been chosen to optimize the sectional area for the design force. In addition to 324 numbers of strands in the main span, there are 8 numbers of extra strands for the Sicily side span and 6 numbers of extra strands in the Calabria side span for each main cable.

At the cable anchorage, four strands are anchored at similar area to that for one strand constructed by AS method, and the center-to-center distance of a group of four strands is widened to secure the minimum working space.

## 2.1 Manufacturing of PPWS

The pre-fabricated parallel wire strands (PPWS) are manufactured in a new plant established near the construction site or in the existing plant in Asia, in any case, by a series of operations listed below.

- Installation of wire coils of 2ton supplied by wire manufacturers on 127 numbers of pay-off equipped with a break giving minimum tension to wire,
- Pulling of 127 number of wires from coils on pay-off in slow speed and under even tension through a series of low friction pulleys,
- Forming of 127 number of wire into hexagon shape using a series of templates then using three pair of roller pressing in 120 degree difference alternately,
- Putting marks on the formed strand at where it will comes to the cable saddles and at the mid center enabling to erect PPWS without sag adjustment,
- Coiling of the formed strand banded by plastic tape with the internal diameter of 3.5m tightly with a minimum tension of 1 ton,
- Socketing of the both ends of the strand free from the coil into cast steel cylindrical socket using copper-zinc or resin socketing material.

The length of PPWS is achieved in such a way that the gauge wires accurately measured and marked separately are pulled together with other wires and bundled into the strands.

## 2.2 Transportation of PPWS

PPWS coil, horizontally raid of steel shipping plate, will be delivered to a storage area as fully covered by plastic film, oil cloth and wrapped by tape protect against any damage and corrosion.

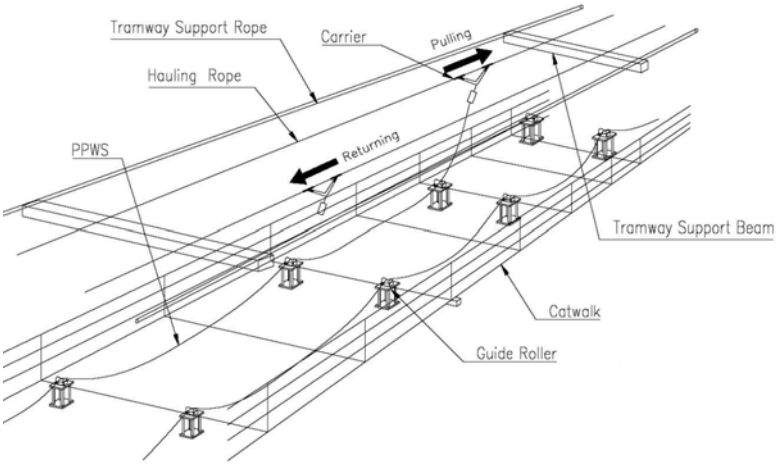
The coils of the PPWS are transported on a barge from a storage area, where the PPWS is delivered form the manufacturing plant and at least 200 coils are always stored on wooden supports or the like off from ground but in un-covered area, at 4 hour sailing time to the temporary quay furnished for discharging goods in front of the tower at the Sicilian side. Loading and unloading will be made using 150 ton movable crane as lifting the PPWS coil with slings connected to the shipping plate, and transportation will be carried out with modular trailer truck at the storage yard and from the temporary quay to the anchorage.

As the erection of the PPWS is planned to be performed by 8 strands per day hence 48 strands per week, 48 coils occupying 90ft x 300 ft barge and weighting to some 5500ton are transported every 7 calendar days.

## 2.3 Erection of PPWS

On each catwalk, two PPWS are pulled out in parallel at one time from the coils installed on the un-coiler set on the back of the Sicily anchorage and brought as laying on a series of the guide rollers provided on the catwalk without twisting to the Calabria anchorage by the hauling system. Once those strands arrive at the Calabria anchorage, they are lifted by tensioning at the anchorage and at the tower top, shifted sideway toward their final position, lowered down into the groove of the tray of the cable saddles, and temporary anchored to the anchorage. Traveling of the PPWS on the

catwalk tilts the catwalk significantly between the cross bridges, and it is preferable that two PPWS travel in parallel on each catwalk.




The PPWS pulled in the day time are adjusted to its design sag hence design lengths at the same night. The distance of those strands to be moved on the cable saddle for sag adjustment is determined by measuring the spans and sag of those strands between the cable saddles and their temperature and by comparing their present un-stressed length in each span calculated based on the measured data with their design un-stressed length. Those strands are then moved on the cable saddles using grip and jacking system and at the anchorage using jacking system to their targeted position. The sag adjustment is completed when their span and sag representing the design length is finally confirmed by the measurement to be the design value within the permitted tolerance. If it is confirmed that the marks on the strand put during the manufacturing the PPWS come to their design position within the permitted tolerance, the erection of the PPWS will be carried out using the “Marking System” without sag adjustment.

The PPWS is about 5300m long and 118 ton in weight. The PPWS is expected to be pulled at the speed of 40-50 m/min; therefore it will take 2 and a half hour for the PPWS to travel from the Sicily anchorage to the Calabria anchorage. Four (4) PPWS are therefore planned to be completed on each catwalk per day hence eight (8) per day in total, and the production of the PPWS per day is expected to be 944 tons.

The cable saddle is made of a number of trays each having groove for the PPWS which are piled up one another, therefore, the tray is piled one another after all gloves of the previous tray are occupied by the PPWS.

For the cable erection, all worker necessary on the catwalk will be transported by lifts provided along the tower to the tower top and to their position by their own foot if not far from the tower top or by a transporter (moving on the catwalk) if far from the tower top.

## 2.4 Strand Deformation Control

Since all strands of each of two main cables splay outward in one direction laterally, many strands stay in their horizontal curvature in the tray of the splay saddle even after leave their vertical curvature, which cause strand deformation in the tray of the splay saddle.

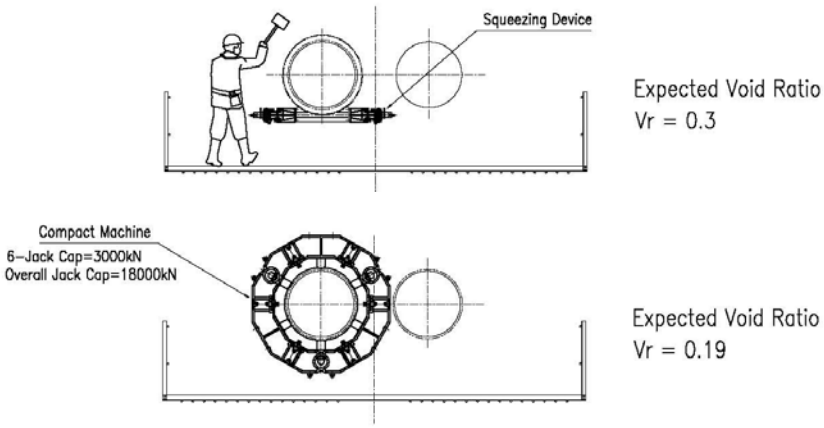
In order to control the strand deformation, special care is taken when the PPWS is placed into the groove of the tray of the splay saddle using stopper prepared for the groove and holding-down clamp prepared on the back of the splay saddle to keep the strand within the tray of the splay saddle.

## 2.5 Cable Compaction

In order to obtain a circular (slightly elliptical) shape of the main cable, as required for the installation of the cable clamps, the main cables consisting of 349 numbers of the PPWS are compacted. Since the separation of two main cables is 2.0m, although it is a big improve that the separation is enlarged from 1.75 m to 2.0 m, the main cable is preliminary squeezed using a simple tool toward a target void ratio of 30% enabling the compact machine to be installed, then the main cable is compacted using a specially manufactured compacting machine equipped with a series of hydraulic jacks of 300 tf each having “shoe” at head of their cylinders toward a void ratio of 19% as shown below.

The cable compaction is carried out on a pair of main cable in parallel but one slightly ahead to the other not to disturb the operation to each other.

Before the main cable is compacted, plastic tape tightening the PPWS put during the manufacturing are removed from the outer strands to allow wires to move freely. Once the main cable is compacted, before releasing jacking force, the main cable is wrapped with steel strap firmly to maintain the compacted shape and size at every 2m.


Squeezing Device
Expected Void Ratio
Vr = 0.3
Compact Machine
6–Jack Cap=3000kN
Overall Jack Cap=18000kN
Expected Void Ratio
Vr = 0.19

# 3 Erection of cable clamp and hanger ropes

The cable clamp is of a horizontally split integrated type consists of one top half and two bottom halves which can clamp a pair of main cable together. The hanger ropes are spaced at every 30 m where the cross girders are located, and there are two ropes at each hanger rope location each of which is anchored to the hanger anchorage in line of the web plate of the cross girder.

## 3.1 Erection of Cable Clamp

Prior to the erection of the cable clamps, the geometry of the completed main cable is carefully measured at night under steady temperature and calm wind and the locations of each cable clamp are marked on the main cable.

The installation of the cable clamps starts from the mid center in the main span. The cable clamps are lifted to the tower top by the crane mounted on top of the tower and transported to their positions using a bogie running on the main cable as guided by the tramway rope to stabilize. The cable clamp is split into one top half and two bottom halves, and transported as the one top half is on the bogie and two bottom halves are hung under the main cable from the bogie.

When the cable clamp arrive their position, the bogie is removed as one top half and two bottom halves are hung by the tramway, and one top half and two bottom halves are attached to the main cable with the screwed rods. After four gaps between one top half and two bottom halves are observed to be even, the screwed rods are tensioned gradually as maintaining those gap being evenly reduced, and further tensioned to the design value once the main cable becomes stiff enough.

## 3.2 Erection of Hanger Rope

The erection of the hanger ropes are carried out by different methods for their location hence length.

The hanger ropes shorter than 30m are delivered to the site in unreeled condition. Those hanger ropes are lifted to the tower top by the crane mounted on top of the tower and transported to their locations using the two carriers running on the tramway system as each end of the hanger rope are attached to each carrier. When the hanger ropes arrives their locations, the bottom end is lowered down through a opening on the catwalk floor then the top end is connected to the cable clamp.

The hanger ropes longer than 30m but except those close to the tower are delivered to the site on drum. Those hanger ropes are lifted to the tower top by the crane mounted on top of the tower and transported to their locations using the two carriers running on the main cable as each end of the

hanger rope are attached to each carrier and the mid part is supported on a series of the roller provided between a pair of the main cable. When the hanger ropes arrives their locations, the bottom end is lowered down through a opening on the catwalk floor then the top end is connected to the cable clamp.

The hanger ropes close to the tower location are delivered to the site on drum. Those hanger ropes are lifted direct toward their cable clamp in vertical position and connected to the cable clamp when the top socket arrive their height.

## 3.3 Erection of Tie- Down Hanger

The tie-down hanger ropes are not installed prior to commencing the girder erection but installed after a half of the suspended girder in the main span is completed but without those in the side span.

The tie-down hanger ropes are delivered to the site on drum. The tie-down hanger ropes are placed on the deck of the terminal structure, unreeled from the drum and lifted to the cable clamp using strand jack or winch line provided on the main cable. When the top end of the tie-down hanger ropes arrive their height, the sockets are connected to the cable clamp, the rest of the rope is unreeled completely from the drum. The bottom end of the tie-down hanger ropes are then lowered down through a hole in the deck into the anchor position at the mid of the concrete pier. When the bottom end of the tie-down hanger ropes arrive the anchor position, using temporary tension rod the tie-down hanger ropes are tensioned down and anchored to their anchorage.

# 4 Cable wrapping

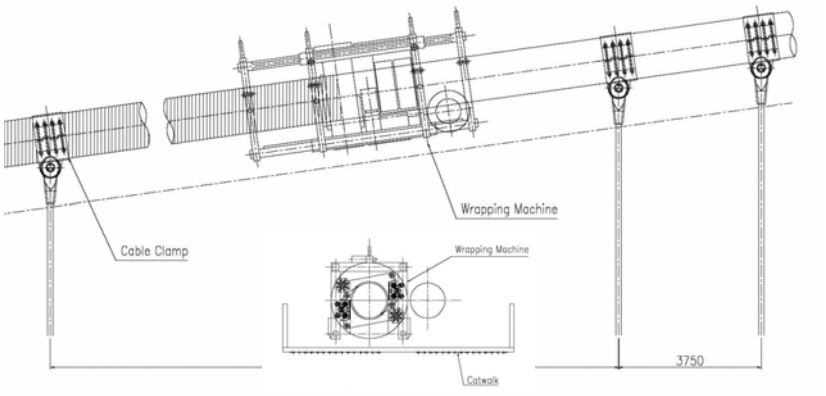
The main cable is wrapped by 3.5 mm diameter soft steel wire providing physical protection and by elastomeric tape providing air tight for the dehumidification. The elastomeric tape is made of chlorosulfonated polyethylene polymer manufactured by three layers (polymer - fabric reinforcement – polymer) laminated construction.

The main cable compacted and maintained to its shape with steel straps is wrapped tightly by the 3.5 mm diameter soft steel wire as those steel straps are removed from the main cable, and by the elastomeric tape as half width overlapped to each other and chemically integrated by heating given from a specially made blanket.

Since the separation of two main cables is extended to 2.0m, the conventional type wrapping machine is able to work to warp the main cable by steel wire, and the special wrapping machine also work the main cable by the elastomeric tape without any difficulty.

The interface between the wrapping wire and the cable clamp is completely sealed using elastic compound and that between the elastomeric tape and the cable clamp is firmly sealed using a neoprene sleeve with steel strap to secure the air tightness.

In the current erection method, the main cable of less than 3m being wrapped by soft wire followed by elastomeric tape is assumed. however, a possibility of such main cable being covered by steel sleeve will be investigated in a later stage.




# 5 Erection of Hand Ropes

The hand ropes are provided to each main cable. Since the cable maintenance cradle is designed so that it move on the hand ropes, the hand ropes are designed so that they can support the cable maintenance cradle as supported by the struts at every cable clamp locations. The hand ropes are terminated and anchored on top of the tower and at the anchorage.

The hand ropes in the main span are extended from drum on the suspended girder and lifted to their height as two ends are griped and pulled using winch line mounted on top of the tower. When the hand ropes arrive their height, the hanger ropes are shifted to their position laterally, connected to their anchor on the tower top, now appear in higher position, and pulled down toward the main cable, and connected to the struts attached to the cable clamps, which gives the design tension.

The hand ropes in the side span are extended from drum as one end is gripped and pulled toward the tower top using winch line mounted on top of the tower and the other end is left near the anchorage. When the hand ropes arrive their height, he hanger ropes are shifted to their position laterally, connected to their anchor on the tower top and on the anchorage, now appear in higher position, and pulled down toward the main cable, and connected to the struts attached to the cable clamps, which gives the design tension.

# 6 Attachment 1



## *Tie-back system*

The tie-back system is installed prior to the PPWS erection in order that the PPWS adjusted to the design sag does not slip on the tower saddle.

### 1. Tie-back position

The tie-back positions of the tower are defined as the cable completion stage of the bridge and are 3.92m for Sicilia tower and 3.30m for Calabria tower at the main cable IP, where the horizontal components of the continuous main cable in the main span and in the back span is almost the same.

### 2. Tie-back system

The tie-back system consists of the tie-back strands, the anchor girders, the tension jacks, the anchor plates at the tower leg segment No.21 at the elevation of 383.5m and the anchor assembly at the anchorage. Eight (8) strands having their properties below for each strand are planned for the tie-back system on each tower leg and their arrangement between the tower and the anchorage are shown below.

Strand properties

| Type | Area | Breaking strength | Unit weight |
|---|---|---|---|
| PPWS 127-$\varphi$5.0 | 2490 mm$^2$ | 4400 kN | 0.1922 kN/m |

Configuration between anchors

| | Sicilia | Calabria |
|---|---|---|
| Height difference | 337.0m | 272.5m |
| Horizontal distance | 937.5m | 788.0m |

Since the Sicilia back span requires more tie-back forces than Calabria, the tie-back system is designed for the forces in the Sicilia back span.

With this arrangement, the tension of strand to obtain the required tie-back at the main cable IP is calculated based on the 180 days design tower taking the tower vibration and temperature variation into account, and are ensured within the permissible tension as shown below.

1.0*PP+1.0*VV+1.0*VT = 1836+256+44 = 2136kN/strand < 4400/2.0=2200kN

where

PP : the tension in normal condition,
VV: the tension due to the vortex-induced vibration of tower
TT: the tension due to the temperature variation (-15°C from a design temperature.)