POLITECNICO DI MILANO
Dipartimento di Ingegneria Civile, Ambientale e Territoriale

PROJECT OF AN INNOVATIVE PEDESTRIAN BRIDGE

Relatore: Prof. Pier Giorgio Malerba
Correlatore: Ing. Elisa Conti

Tesi di laurea di:
Stefano Gabrieli
Matr. 854453

Anno accademico 2017/2018

Credits

This thesis was written under the administration of the Division of the Structural Engineering at the Universitat Politecnica de Catalunya. It was written during the period November 2017 – July 2018 under the supervision of the Professor Joan Ramon Casas Rius.

I especially want to thank my supervisor, Prof. Joan Casas for all his help with making this Thesis became real and for giving me necessary information regarding this subject, the Prof. Pier Giorgio Malerba for his availability and helps during the revision of this work at the Politecnico di Milano. Finally, I want to thank my friends at UPC and last but not least my family for the moral support given me along all these years.

Synthesis

The motivation for writing this thesis is an interest in bridges that the author has acquired during his life and feed it thank to his studies in structural engineering. Bridges are considered to be state of the art of all civil structures. This is due to the difficulties of the construction aspects and the nature of the problem, in which the boundary conditions play a challenging role; and obviously due to the noble purpose to connect two different shores of a river.

During the time the subject for this thesis was under consideration the author was asked, by a classmate who was developing a bike lane project in its country land, to design a bridge which would cross the El Ter river. Since the author was contacted he was more than willing to help. Thus, the subject of this thesis was clear.

The main objective of this thesis is divided into two parts. First, a preliminary design of three bridge alternatives is made. A rough estimation of quantity of materials is made based on the preliminary design for these three alternatives. Secondly, a more detailed design is made of the most appropriate bridge type. The choice of a bridge type is based on the conclusions from the first part. These conclusions will primarily be based on economy, aesthetics and construction method.

INDEX

INDEX OF FIGURES

INDEX OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Outlines of the thesis

Chapter 2 displays the bridge location and describes the boundary conditions and geometry at the construction site. It also includes information about why this bridge is to be built.

Chapter 3 consists of a general discussion about aesthetics, advantages and disadvantages and other aspects for the three bridge types that are chosen to be analyzed.

Chapter 4 includes preliminary design and a comparison of the three chosen bridge alternatives with respect to the quantity of materials needed for each type.

Chapter 5 includes conclusions of the preliminary design, which type of bridge is chosen for a more detailed design with respect to the limits that are set.

Chapter 6 is the main chapter in which a detailed structural analysis for the superstructure of the chosen bridge alternative in made, all the elements of the bridge with theirs details are designed.

Chapter 7 displays the environmental impact in the environtment around the superstructure and show how to integrate the bridge among the natural background.

Chapter 8 explains the construction process proposed, and in relation with the drawings N° 12 the right sequence of the construction process is shown in the details.

CHAPTER 2
GEOMETRY AND BOUNDARY CONDITIONS

The position of the bridge is in the north-eastern part of Spain, close to border with France.

2.1 Topography

For the drafting of this project, the topography provided by public data sources has been used, in this case, the Cartographic Institute of Catalonia. In this situation, the author has had to resort to databases accessible to the public, using the most detailed and appropriate option for the case, which corresponds to the Topographic base 1: 15000.

2.2 Hydraulics

In this project, the calculation of the maximum flow rates for different periods of return of the basin is carried out thank to a previous study conducted by another student of the Universitat Politecnica de Catalunya, in which it was developed a flow study with a HEC-RAS model for the same river just a pair of kilometers beneath. So, the author has assumed that using these results of the flow rates the problem will be developed on the security side. Then checking the impact of the bridge on the river, it is concluded that the bridge does not mean any variation in the balance of the river and that it does not alter the regime at any time.

2.3 Geotechnical

For the development of this project, it has been used all the geological and geotechnical information corresponding to El Prat de Llobregat. This is due to a lack of knowledge of the geological situation of the area, also due to the little activity that has been carried out in the area, as well as the impossibility of the author to obtain or carry out the necessary studies for the correct elaboration of this study in the area of the project. Due to the nature of this project (which is a Master Thesis), the resources are minimum or nonexistent, therefore, it is totally unfeasible to carry out the pertinent studies to obtain the necessary data to do the geotechnical study that the zone of the project requires.

In view of this situation, it has been chosen to take geology and geotechnics datas from a site of similar characteristics as it would be the Pla del Llobregat, so that the procedure that follows is done in the same way if the data were from the real zones of the project.

2.4 Definitions of the boundary conditions

After the previous studies have been conducted it has been possible to draw the boundary conditions of the problem, as the safety inclination of the slopes and the water levels for different times of no return.

Figure 1 - Boundary conditions

CHAPTER 3
TYPES OF BRIDGES

There are many areas of concern that need to be focused when designing a bridge. In this thesis there are four main subjects considered. They can be listed in order of priority as:

1. Safety
2. Serviceability
3. Aesthetics
4. Economy

These issues and their order of priority may though to be criticized and are merely the author' s preference.

Safety and serviceability are achieved through systematic application of scientific and engineering principles and thus depend on the analytical skills of the engineer. Aesthetics and economy are achieved through nonscientific means and depend almost entirely on the creativity of the designer.

In this master thesis three bridges are investigated as available options for the project, and a choice is established based on the four aforementioned areas of concern. The choice of these alternatives: an arch bridge, a cable-stayed bridge and an extradosed bridge; is based upon the author's interest.

3.1 Arch

Arches have been used throughout the ages as structural elements. A perfect arch, theoretically, is one in which only compressive forces act at the centroid of each element of the arch. The shape of the perfect arch can be thought of as inverse of a hanging chain between abutments. It is pratically impossible to have a perfcet arch bridge, exempt for one loading condition while it is usually subjected to multiple loadings.

For many people, an arch is considered to be one of the most competitive options from the aesthetic perspective and pleasure for a motorist or any user to drive over. Consider the possibility to dispone an appropriate litgh system the arches can also be very attractive during night.

Figure 2 - Arch bridge

The arch type chosen in this paper is a zero hinged concrete arch, which implies no rotation possible at the supports. The deck will be located under the arch itself and it will be supported by several straight cables anchored in the middle line. For this type of bridge the deck will be subjected to a positive axial force, which implies that will be in tension.

Arches can span up to about 550 m and in the case of slender structures of steel, various instability risks such as the risk for torsional buckling of the arch, must be taken into consideration.

3.2 Cable-stayed

The concept of a cable-stayed bridge is simple, despite the loading mechanism is not that easy to define. A bridge carries mainly vertical loads acting on the deck girder. The basic mechanism of the cables is that they provide intermediate supports for the girder so that it is possible to span long distances with this type of bridges.

Figure 3 - Cable-stayed bridge

The basic structural form of a cable-stayed bridge is a series of overlapping triangles that connect the deck with the pylons. Usually in its elements (the deck, the pylons and the cables) the predominant tension is the axial force. Axially loaded member are generally more efficients than flexural members, although high compressive forces increase the risk of lateral buckling. This contributes to the economy of the bridge. They also have less steel consumption compared to the suspension bridges, but on the other hand larger stress variations can occur and their structural behavior is more complex, so a fatigue study of the cables must be taken into account.

Nowadays, this type of bridges are the most common bridge type for long-span bridges and can span up to around 1000 m and come in various forms in respect of economy and of course aesthetic.

They are beautiful structures that appeal to most people. The towers are the most visible elements of a cable-stayed bridge, and therefore contribute the most from an aesthetic point of view. Due to the fact that a simple and clean configuration is preferable, under special circumstances they can also serve as tourist attractions, the author properly choose to design this type of bridge taking inspiration from the famous Calatrava's pedestrian bridges, with only one inclined pylon and Harp cable arrangement. These bridges are really astonishing from an aestitical point of view, but also economically inefficient, so the author put a lot of attention to measure how more expensive could be a bridge with the main purpose to impress the viewer.

3.3 Extradosed

The extradosed bridges are similar to cable-stayed bridges, however the stay cables are used for strengthening. This concept was introduced by J. Mathivat in 1988 and have two main characteristics. One is the allowable stress in the stay cables which is the same as that of internal cables, because in this concept the cables are considered internal cables arranged outside of the box girder. The second is the saddle at the top of the tower which is one third high than what usually is the height of the cable-stayed bridge tower.

Figure 4 - Extradosed bridge

The extradosed bridges are an intermediate type between girder bridges and cable-stayed bridges.

The construction is also easier than for cables-stayed bridges, as the height of the main tower is only around a third that of a cable-stayed bridge with similar size. The main difference from a structural point of view between these two concepts is which member carries the live load more. In the case of extradosed bridges the girder is working more, so for this reason the depth of the deck will be greater.

In this way we can define them like cable-stayed bridge with a shorter tower and relatively stiffer girder, the arrangement of the structure elements will have been chosen to ensure that the girder stiffness is significant compared with that of the cables, such that the girder carries the majority of the live load.

To make this option valuable from and economic and aesthetic point of view the author chose to dispose two pylons equidistants along the span of the bridge, in the way to have a regular and symmetrical look of the bridge.

All the alternatives have in common that are quite impressive, aesthetical speaking, and their shapes lends theirselves to be enriched with special lighting configurations which enhances the beauty and visibility of the bridge at night.

CHAPTER 4
PRELIMINARY DESIGN

4.1 Introduction

This chapter contains preliminary design of the three bridge types, an arch bridge, a cable-stayed bridge and an extradosed one. The aim of the preliminary design is to determine the most suitable bridge type for the purpose of crossing the Ter river with the bike line. The chapter is divided in two different sections. The first section treats factors that are common for all three bridge types, i.e. loads, load combinations and materials. The second treats the three different bridge types respectively. In these section have been sized the important bridge elements for each bridge type.

Finally, in the last section of this chapter, the most suitable bridge type is determined based on the preliminary design and the quantity of materials required.

4.2 Loads

For the preliminary design of this project only three loads are considered. Two permanent loads, selfweight and pavement. The loads are determined according to Eurocode 1 (EC1).

4.2.1 Permanent loads

Self-weight for reinforced concrete is set to 25 kN/m^3. The self-weight of pavement and structural steel are set to 0.1 kN/m^3 (due to the fact that the arch will host a cycle track, the author chosen to propose a wooden pavement) and 78.5 kN/m^3 respectively.

4.2.2 Variable loads

The variable actions, which are taken into account in this project, are traffic loads (bikes) in vertical direction, so only vertical actions are considered in this phase because it seemed reasonable to do this simplification in the preliminary analysis.

Traffic load is defined in EC1-2, section 5 “Actions on footways, cycle tracks and footbridges”.

In which it is explained that loads due to cycle traffic are generally much lower than those due to pedestrian traffic, and the values given in this section are based on the frequent or occasional presence of pedestrians on cycle lanes. Due to the fact this bridge will be also open to pedestrians, it is seemed reasonable to consider the bridge as a footbridge, thus in this preliminary section we are considering overestimating the load, and so we are on the security side.

The EC1-2 explains that we should consider three models, mutually exclusive, to be taken into account as relevant.

They consist of:

- A uniformly distributed load q_{fk}
- A concentrated load Q_{fwk},
- Load representing service vehicles Q_{serv}

For simplicity the last load (representing the service vehicles) will not be taken into account.

The characteristic value q_{fk} load model 4 (crowd loading) defined in the EC1-2, correspond to qfk = 5 kN/m^2 , for dense crowd where such a risk exists. Anyway if this is not the case, the recommended value for q_{fk} is :

$$q_{fk} = 2{,}0 + \frac{120}{L+30} \quad \text{kN/m}^2$$
$$q_{fk} \geq 2{,}5 \text{ kN/m}^2;\; q_{fk} \leq 5{,}0 \text{ kN/m}^2$$

where :

L is the loaded length in [m].

Meanwhile the characteristic value of the concentrated load Q_{fwk} should be taken equal to 10 kN acting on a square surface of sides 0,10 m. Thus we have:

- Q_{fk}= 5 kN/m²
- Q_{fwk}=10 kN on 0.01 m²

4.2.3 Load combinations

Several load combinations need to be taken into account, in the ultimate and serviceability limit states, when a bridge is analyzed and designed. But for simplification only an analysis in the ultimate limit state is made for the preliminary design of all bridge types. The design value of actions in the ultimate limit state is according to EC1, section 6.4.3.2:

$$\sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{"} + \text{"} \gamma_P P \text{"} + \text{"} \gamma_{Q,1} Q_{k,1} \text{"} + \text{"} \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i}$$

Where:

- γ_{Gj} Partial factor for permanent action j
- $G_{k,J}$ Characteristic value of permanent action j
- γ_P Partial factor for prestressing actions

- P Relevant representive value of a prestressing action

- $\gamma_{Q,I}$ partial factor for variable l

Here their values are $\gamma_{G,j}$=1.35, γ_P=1.0 and $\gamma_{Q,l}$=1.5 the partial safety factors for permanent actions, prestress and variable action respectively. The last term in this equation is not required since there is only one principal action

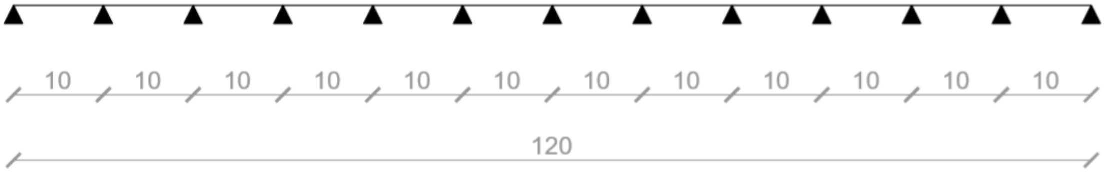
4.3 Girder

The cross section of the deck influences the whole structure, due to its characteristics of self-weight and aerodynamics. The preliminary design is started with some basic assumptions with the aim to make the comparison between the alternatives easier.

In this section a girder proposal will be developed with the aim to design the three bridges alternatives later on, although a proper design of the deck should be developed for each type of bridge the author chosen to design the same girder for both bridges. This is made possible thanks to the choice to span the cables with the same distance (10 meters) and in the same way (anchored in the center line of the deck) for all the alternatives proposed, this makes the first assumption reasonable.

The static configuration proposed for this section and its purpose is the classical continuous beam on supports.

Each support is 10 from the previous one, so the entire span of 120 meters is reach.



Than to evaluate the maximum stress condition in the girder the weight and the geometric properties are required, so the author defined the cross section and the material.

Bearing in mind that the cables are anchored in the mid-lane of the deck, the cross section of the girder needs good torsional capacities. Thus a steel cellular box scheme is been chosen for starting the process of this section. As it is showed in the figure below, the deck is 5.40 m wide, because it is going to host two bicycle lanes of 1.5 m each and two pedestrian lanes of 1 m each, and 20 cm in each side for the rail guard.

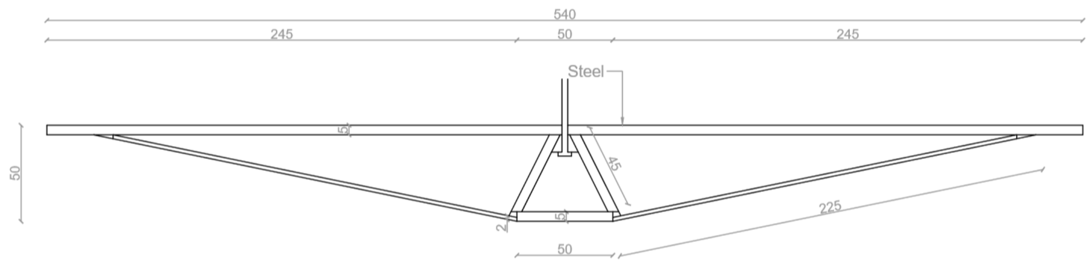


Figure 5 - Box girder proposal

Now it is possible to evaluate the self-weight of the deck, the material chosen for the deck is the common structural steel (fyk=355 MPa), it is known that its own weight is 78.5 kN/m^3 so knowing the area of the section we also know the self-weight of the deck per meter.

Area = (0.05 * 5.4) + (0.05 * 0.5) + 2 * (0.05 * 0.45) + 2 * (0.02 * 2.25) = 0.43 m^2

Qg= Area * 78.5 kN/m^3 = 0.43 * 78.5 = 33.755 [kN/m]

Due to the purpose of this project the author chosen a wooden pavement of 5 cm thick on the whole surface of the deck, considering the own weight of the wood chosen 0.1 kN/m^3 we also know the additional weight of the pavement which has to be taken into account as a dead load during check of the ULS.

$Qg_{pavement}$= (0.05 * 5) * 0.1 = 0.025 [kN/m]

Than it has to be considered the variable load, as explained in the Eurocode (EC2) , it has considered the bridge as a footway bridge for the reason that the load in the case of the pedestrian bridges is higher than the load of the only bicycle bridges. Than considering taking into account the variable load as a footway bridge is in favor of security.

$Qfk = 5\ kN/m^2$

4.3.1 Loads distribution

First, with the aim to evaluate the stresses on the deck in the ultimate limit state (ULS) the permanent and the variable loads have to be combined and multiplied by a security coefficient according to the EC2, so:

$Qg_{uls} = 1.3 * (Qg + Qg_{pavement}) = 1.3 * (33.755 + 0.025) = 1.3 * 33.78 = 43.914$ [kN/m]

$Qfk_{uls} = 1.5 * Qfk = 1.5 \cdot 25 = 37.5$ [kN/m]

$Qg_{uls} + Qfk_{uls} = 43.914 + 7.5 = 81.414$ [kN/m]

Now, to evaluate the maximum stresses in the deck cross section it has to be considered a bunch of load combinations, because the worst scenario is not in the case of a distributed constant load on the whole deck, but a scattered distribution of the variable loads.

All the load combinations are reported on the “Annex 5 – Results”.

The maximum values of the stresses among all the combinations are:

$Mmax^+ = 713.5$ [kN*m]

$Mmax^- = 896.5$ [kN*m]

Tmax = 496.7 [kN]

At this point it is necessary to check the resistant stresses of the cross section, to do so the author considered that the moment stresses are supported by the two parallel flat section (Area 1 and Area 2 on the figure 6), and the shear stresses only by the two inclined flanges in the center of the section. In this way the evaluation of the resistant stresses is easier and on the safety side.

4.3.2 Girder resistance capacities

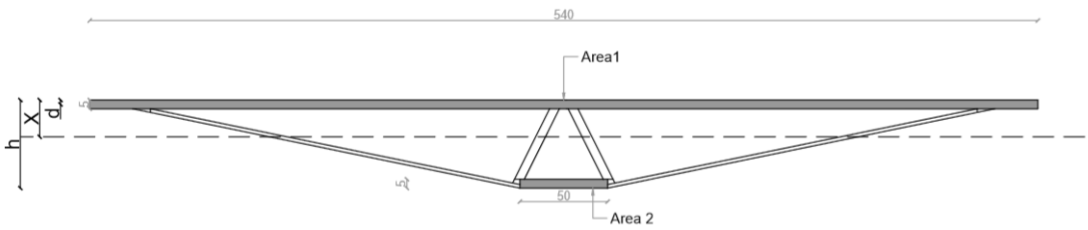


Figure 6 - Box girder, resistance moment evaluation

The resistant moments are evaluated in the case of simply flexion, even if in the cases of the cable-stayed bridge and the extradosed bridge there will be also a compressive force, so the proper condition should be the compressive-flexural case, however as explained before, the aim of this pharagraf is just to do a preliminary design of the bridge alternatives to compare them economically, so it is a reasonable simplification.

To evaluate the forces acting in the two areas in question (Area 1 and Area 2), first the elastic capacity of the material has to be divided by a coefficient Υ_{mo}= 1.5 (as defined in the Eurocode in the case of bridges the values of this coefficient is higher than others, when usually is just 1.15)

$$fyd = \frac{fyk}{1.5} = 236.667\ [MPa]$$

T_{area1}= A1 * Fyd = 270000 [mm^2] * 322.7 [MPa] = 87129 [kN]

T_{area2} = A2 * Fyd = 25000 [mm^2] * 322.7 [MPa] = 8067.5 [kN]

It is indispensable to evaluate the depth of the neutral axis, to do so a equilibrium to traslation due to the forces acting in the cross section is needed, and the result is:

$$X = \frac{\text{Tarea2} * (\text{h} - \text{d}) + \text{Tarea1} \cdot \text{d}}{\text{Tarea2} + \text{Tarea1}} = 83.9\ [mm]$$

Now it is possible to evaluate the resistant moment of the section so:

$$Mrd(\pm) = A1 \cdot fyd \cdot (x - d) + A2 \cdot fyd \cdot (h - x - d) = 4332.2\ [kN \cdot m]$$

As did it to evaluate the moment an approximation is done also for the case of shear, thus only the two inclined flanges are taken into account to support the shear stresses:

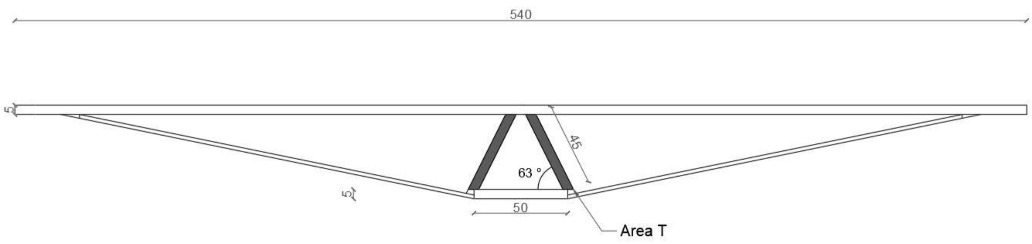


Figure 7 - box girder, shear evaluation

$$Sx = 2 \cdot Area\ T \cdot Dx = 760339.4\ [mm^3]$$

$$Jx = \frac{b \cdot h^3}{12} \cdot \sin(\beta)^2 = 193225.7\ [mm^4]$$

$$Vrd = 2 \cdot \frac{fyd}{\sqrt{3}} \cdot \frac{(Jx \cdot tw)}{Sx} = 1157.8\ [kN]$$

As resulted from the evaluation above, it is showed that the cross section is the way more resistant in respect of the values of the stresses reasonably acting on the deck.

Because a lot of simplifications have been applied during the calculation of the resistant tensions of the section and also due to the fact that the model used to evaluate the stresses acting on the deck was not the proper model for this case (the cables should be considered as springs) we can be satisfied with the results obtained and consider the steel box girder proposed good enough in order to satisfied its purpose.

Later on, for the chosen alternative, a proper composite (concrete-steel) deck will be designed and verified with proper methods and loads (F.E.M.).

4.4 Arch

The first type of bridge is a conventional arch bridge with just one arch above the deck. The arch will be of concrete and will be a zero hinged type. The cross section of the deck influences the whole structure of the bridge due to its characteristics of self-weight, aerodynamics and in this case also thanks to its capabilities to support tension stresses. The bridge deck will be the one just dimensioned in the pervious chapter, also if another type of deck with two lanes of anchors was taken into account (figure 8).

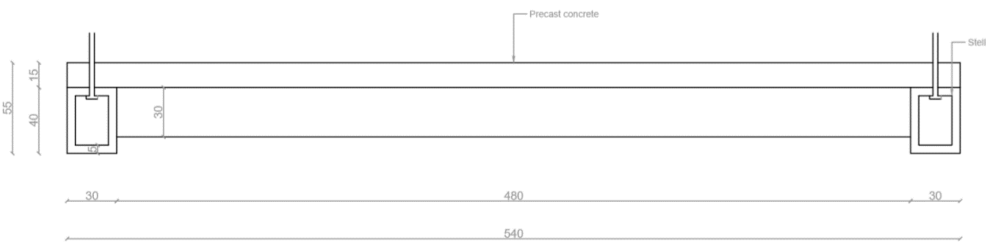


Figure 8 - Arch bridge's deck

However, this deck proposal has been excluded due to aesthetic requirements. Because to suit the aesthetical characteristic asked for this project it has been thought that a single arch centered on the deck ax with central suspension centered in the middle of the girder would be the best option for this case.

As written before with this suspension solution the deck must provide torsional support, so the best proposal which would fit all the requirements is the cellular box scheme designed before.

The arch will be a *Bowstring type*, so the arch and the deck will be connected in the extremities and will work together, so that the arch would be compressed and the deck tensioned.

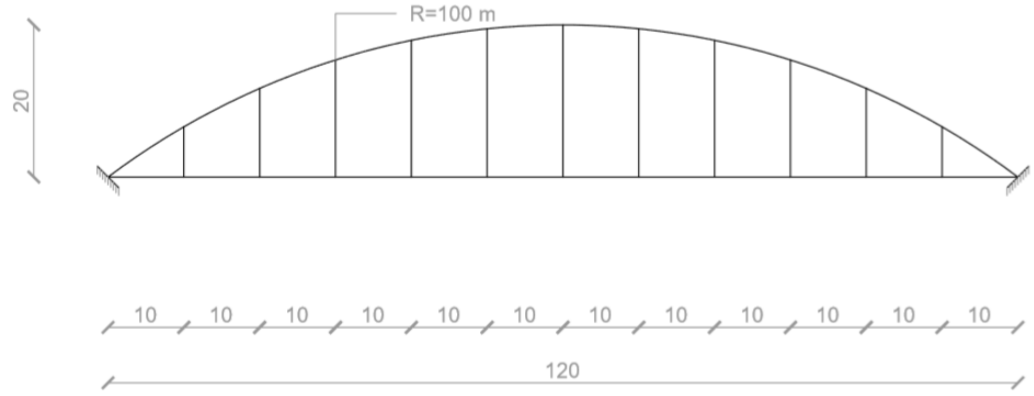


Figure 9 - Arch geometry

As it is possible to see in the figure above the ratio between the bridge span (120 m) and the bridge height (20 m) is within the limits suggested by the literature concerning this topic.

$$4 \leq \frac{span}{rise} \leq 7$$

$$\frac{span}{rise} = \frac{120}{20} = 6$$

4.4.1 Arch section

The process of design the arch section it has been a little iterative, because to design the arch section it would be taken into account also the own arch self-weight but it was not design yet, so the author started with a section proposal based on the reaction forces acting on the two extremities of the arch. The arch will support all the forces acting by the eleven cables, so to evaluate the compression force on the arch first we must evaluate the cable forces.

Each cable will support 10 meters of the deck, so the reactions will be the whole weight of the bridge deck plus the distributed variable load, combined in the ultimate limit state combination in order to provide more safety as the buckling is not taken into account.

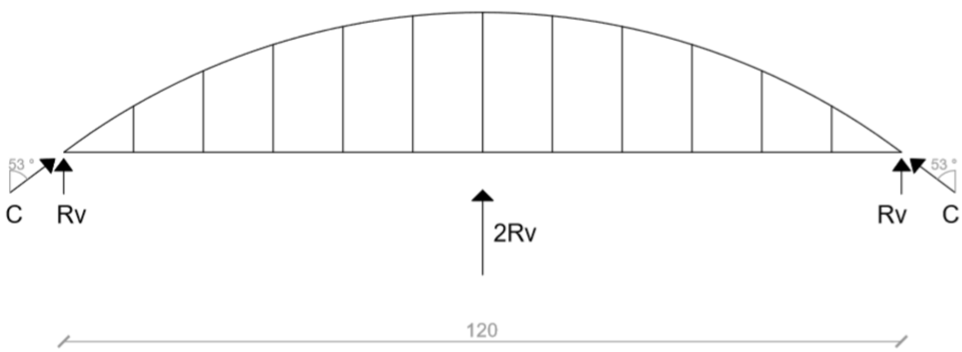


Figure 10 - Arch dynamics

$$Rv = (1.3 \cdot Qg + 1.5 \cdot Qfk) \cdot 10\ m \cdot \frac{11}{2} = 2827.55\ [kN]$$

Thus, now is possible to evaluate the compression force "C" acting on the arch.

$$C = \frac{Rv}{\cos(53°)} = 4698.371\ [kN]$$

Knowing this compression force it is possible to design a first proposal of the acrh section, reminding that this is only a preliminary design, the structure which later on will be defined should be studied will all types of load and with a proper f.e.m. model.

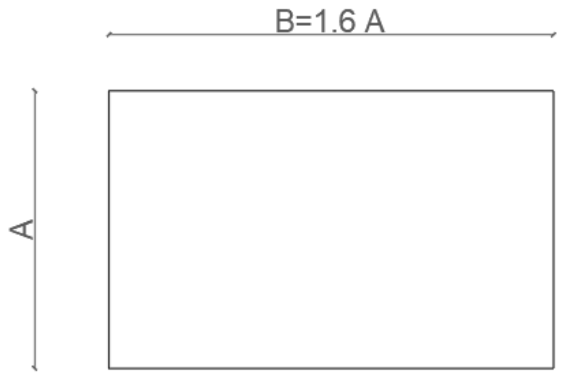
The arch will be made of reinforced concrete, however in order to stay on the safety side the section will be calculated omitting the steel, which has a higher yield limit than the concrete. The concrete chosen is the C35/40 thank to its resistance capacities and its immediate availability on the market, so to consider the stability problems the yield limit of the material is reduced by a coefficient Υ_{mo} = 1.5 and multiplied time a coefficient α_{cd} = 0.85 (long duration structures) as suggested by the Eurocode for this types of structures.

$$fyd = 0.85 \cdot \frac{Rck}{1.5} = 19.83\ [MPa]$$

The minimum area which support this pression is defined by:

$$Amin \geq \frac{c}{fyd} = 236932\ [mm^2]$$

Then a geometry has been chosen



$$A \geq \sqrt{\frac{Amin}{1.6}} = 384.8\ [mm]$$

→ *400 mm*

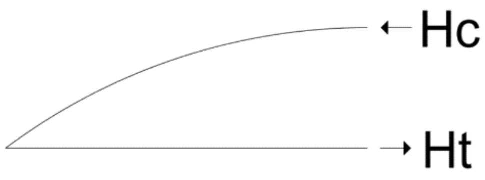
B= 1.6 A = 624 [mm]

→ *650 mm*

$$Area\ = B \cdot A = \ 260000\ \ mm^2$$

The self-weight of this section will be considered in the following calculations with the aim to esteem a better arch section.

The arch is a *Bowstring type* so the value of the compression force in the arch will be the same of the value of the tension force in the deck, in this way it is possible to evaluate these forces by means of a moment equilibrium equation in the middle of the girder (L/2).

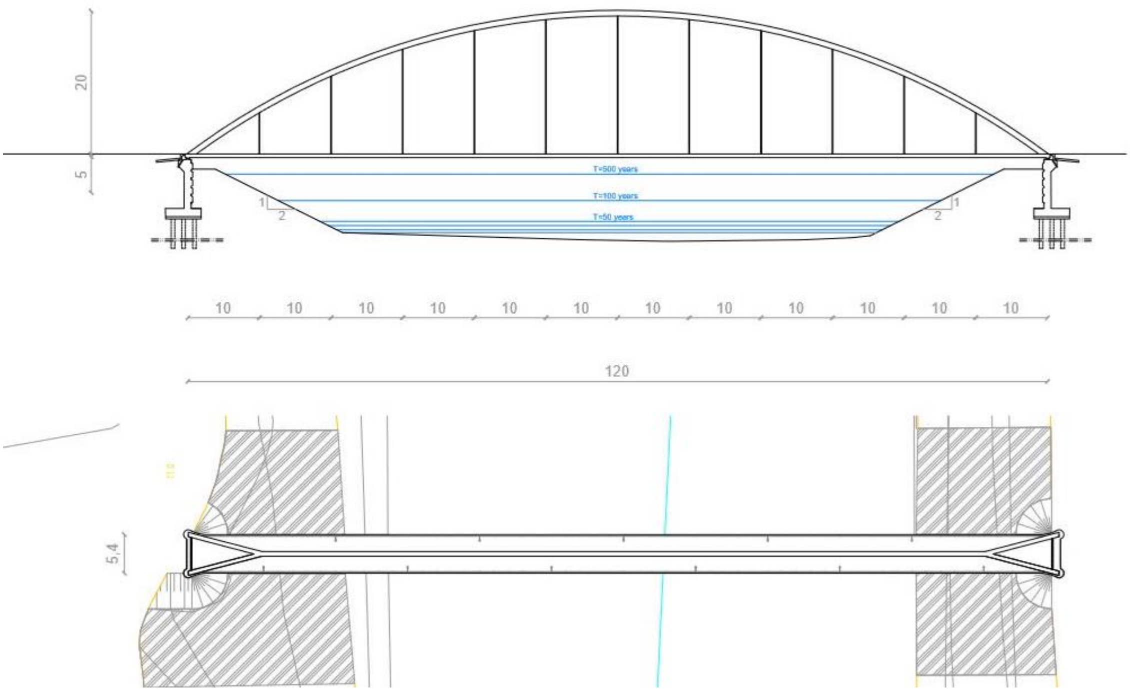


$$M\left(\frac{l}{2}\right) = q \cdot \frac{l^2}{8} = 103133 \quad [kN \cdot m]$$

$$Hc = Ht = \frac{M\left(\frac{l}{2}\right)}{H} = 5156.6 \quad [kN]$$

As we can see the compression force in the arch section is higher than to the previous one, so now it obvious that the designed section has to be verified under these circumstances.

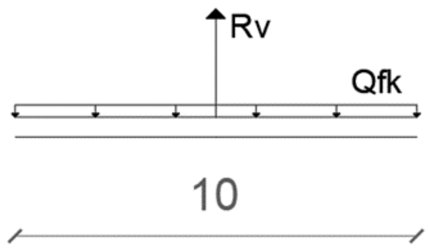
The area calculated before can support a stress of $Crd = Area \cdot fyd = 5156.8\ [kN]$ so the section proposed is going to resist to compression forces without enter in the plastic regime. However this type of bridge is feeble to stability problems, than in order to avoid some buckling problems the arch will be supported by two Y-shape structures on the edges.



4.4.2 Arch cables

Although the main structure has been designed it is missing one of the most delicate phases of this project, i.e. the cables section is not designed yet, and due to the fact that the cables cost affect profoundly the cost of the whole project a particular attention will be put on it.

First, the stresses acting on each cable must be identified, in order to find the minimum section of the cable the following combination will be considered. Each cable must sustain the same tension due to the fact that are equally distributed along the deck.



The material chosen is the same for all the alternatives with the aim to compare the amount of materials needed for each one.

Technical features

$fck = 190\ [MPa]$

$fyd = 170\ [MPa]$

Reducing the material streghteness by a coefficient of 0.45 (from literature papers), the minimum area of the section is defined as follow:

$\sigma_{adm} = 0.45 \cdot fyd = 76.5\ [MPa]$

$Amin = \frac{Rv}{\sigma adm} = 7683.66\ [mm^2]$

This area also means a circle with a radius of

$$Rmin = \sqrt{\frac{Amin}{\pi}} = 49.5\ [mm]$$

$$Reff = 50\ [mm]$$

Summing the length of all the eleven cables of this configuration the total length is:

$$Ltot = 162.4\ [m]$$

4.5 Cable-stayed

This alternative is the most desirable from an aesthetic point of view, and so it will be paid more attention to make it looks more elegant and clean. As already discussed the cable-stayed bridges can span great distances, so there is not problem to cover 120 m span.

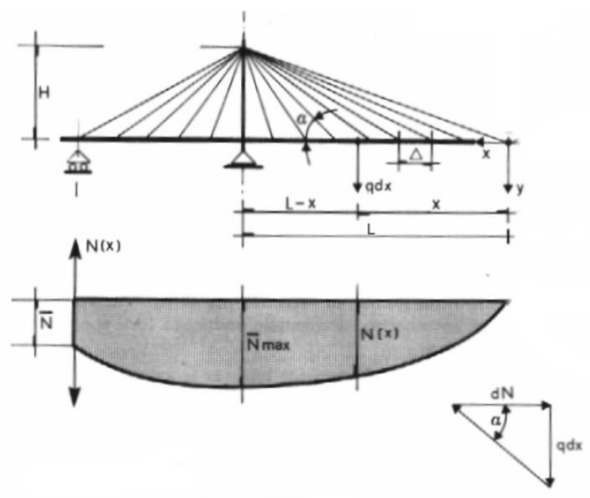
The fisrt step is to choose the cable configuration and the pylons disposition.

Taking advantage of the fact that the cable-stayed bridges can cover up to around 1000 meters span, a simple configuration with just one pylon is chosen, so that the structure appears cleaner. In order to contrast the horizontal forces acting on the pylon, it will be inclined by 60° toward the land exploiting the self-weight of the pylon which will be made by reinforced concrete.

The cable configuration has a fundamental role on how the axial force is distributed in the deck, and how the pylon is charged, we can distinguish two main arrangements:

- *The Fan configuration*
  it is the more efficient from a structural point of view, it minimizes the axial force acting on the deck and centers all the cable forces in the same point of the pylon;

  The angle of the cables is suggested to be within 25° - 65° due to the fact that the cables can resist great axial stresses but almost zero flexural ones.



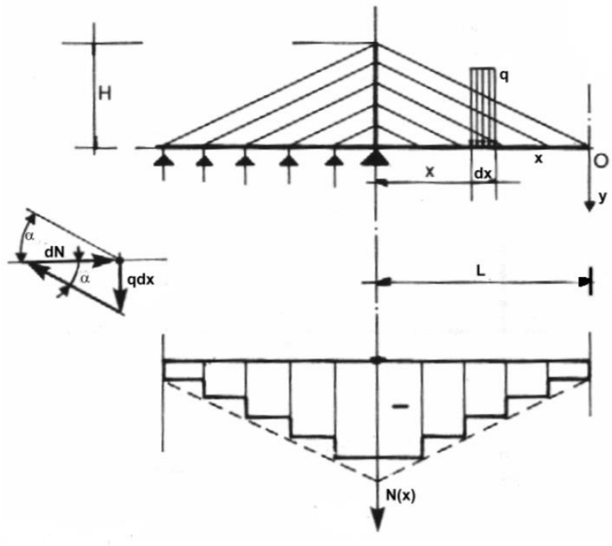
$$N_{max} = \frac{q \cdot L^2}{2H}$$

- *The Harp configuration*

it is undeniable the most attractive option, even if it is not the most efficient solution, as we can see in the scheme on the right, this configuration double the axial stresses on the girder;

so that a lot of material is wasted, however its characteristic permits to dispose all the cables with the optimal angle of 45°;

However, remembering the purpose of this alternative (look gorgeous) this configuration has been selected.



$$N_{max} = \frac{q \cdot L^2}{H}$$

The minimum height of the pylon is approximated by the formula

$$H = L \cdot tg(25°) = 120 \cdot tg(25) = 56\,m$$

anyway this height could be reduced increasing the inclination of the tower or adopting a lighter deck.

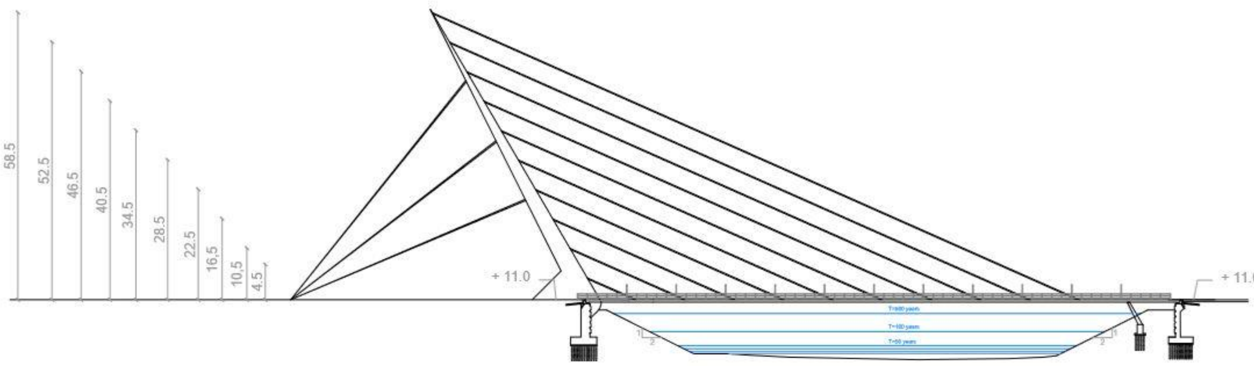
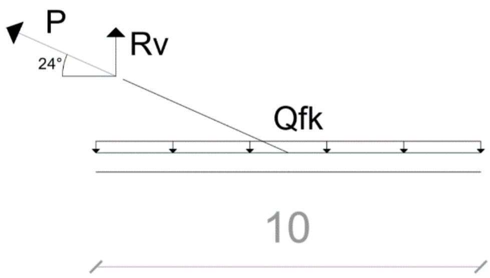


Figure 11 - Cable-stayed bridge proposed

As it is showed in the picture above in this first sketch the main span is reduced by 20 meters, 10 meters on each side, in which the first 10 meters of the bridge works as a double supported beam.

Than it is been evaluated the moment on the foundation of the pylon, because it should not be too high in order to avoid some geotechnical problems.

However, to do so it is necessary to esteem the forces acting on the cables. As did it in the previous case, these forces will be esteemed considering that each cable must sustain a length of 10 meters of the deck.



$$Rv = (Qg + Qfk) \cdot L = (33.78 + 25) \cdot 10 = 587.8\ kN$$

$$P = \frac{Rv}{\sin(24°)} = 1445.16\ kN$$

Now it is possible to calculate the resultant moment on the foundation of the pylon just multiplying these forces time the distance of the segment perpendicular to the direction of the force acting on the cable and the foundations center.

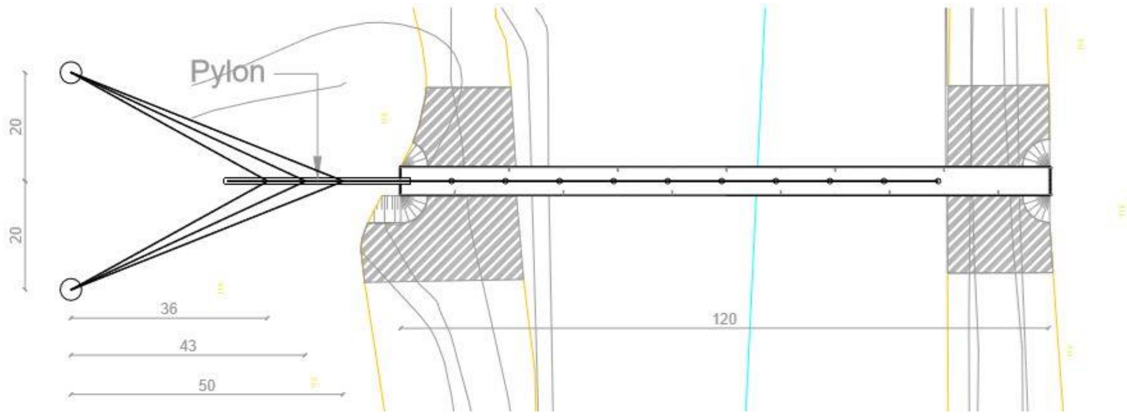
$$M(Q-G) = \sum Pi \cdot \cos(24) \cdot Hi - \sum Fgj \cdot Hj = 322133.8 - 38315 = 283817.9\ [kN \cdot m]$$

Hi and Hj are the distances showed in the figure above and represent the levels of each moment.

Instead, Fgj represent the self-weight force of the two volumes of reinforced concrete of the pylon, and $25\frac{kN}{m^3}$ is the specific weight of this material.

The resultant moment evaluated was too high, so to reduce the moment and so decrease the risks of foundation failure the author chose to install 3 cables on each side of the pylon; so, with a total of 6 cables arranged as showed below the stability and efficiency of the structure have been increased considerably.

In this definitive proposal, the span of the bridge is 120 meters and not 100 meters as the previous one, and so the author abandoned the idea to reduce the total span since in this way the foundations of the pylon and the stirrup can be joined in the same point and so a reduction of the costs is ahead of this choice.



The cables anchored in the land are designed to equilibrate completely the forces coming from the deck, so in this way the pylon is loaded with a centered axial force, this in respect of the average of the load acting on the deck among the frequent combinations and the ULS combinations.

4.5.1 Cables design

The design of the cables will be done in this section following the same steps as before. However the tensions in the cables are already calculated.

$P = 1445.16\ kN$

Technical features

$fck = 190\ [MPa]$

$fyd = 170\ [MPa]$

Reducing the material strength by a coefficient of 0.45 (from literature papers), the minimum area of the section is defined as follow:

$$\sigma_{adm} = 0.45 \cdot fyd = 76.5 \ [MPa]$$

$$Amin = \frac{P}{\sigma adm} = 18891 \ [mm^2]$$

This area also means a circle with a radius of

$$Rmin = \sqrt{\frac{Amin}{\pi}} = 77.6 \ [mm]$$

$$Reff = 78 \ [mm]$$

Summing the length of all the ten cables of this configuration the total length is:

$$Ltot = 777.0 \ [m]$$

Before, for this bridge other cables have been introduced with the aim to reduce the momentum on the foundation and stabilize the tower; for which it must be evaluated the tension on them by means some hypothesis.

The tension acting on these cables has been designed in order to have a null resultant of moments on the center point of the tower, combining the permanent and variable loads as evaluated before.

Knowing the levers of the moment of each cable disposed behind the inclined tower towards the grass, it is easy to evaluate the tension on each cables, because the moment previously calculated will be equally distributed on the back cables.

$$T = \frac{M(Q-G)}{(l1+l2+l3)\cdot 2} = 1321.8 \ [kN]$$

The minimum area of the section is:

$$Amin = \frac{T}{\sigma adm} = 17278.5 \ [mm^2]$$

Equivalent to a circle with a radius of:

$$Rmin = \sqrt{\frac{Amin}{\pi}} = 74.2\ [mm]$$

$$Reff = 75\ [mm]$$

These 6 cables have a total length of

$$Ltot = 335.2\ \ [m]$$

It is already unequivocal that this solution requires an enormous amount of steel compared with the previous one.

4.6 Extradosed

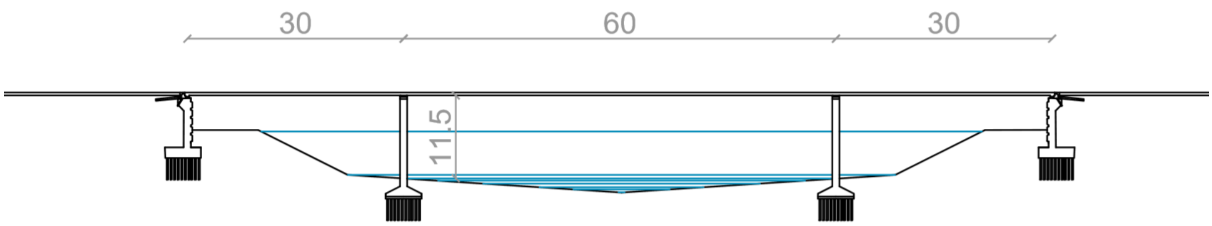
The last solution proposed is an extradosed bridge. This option could be the most favorable due to its efficiency and beauty. The extradosed option can be compared to cable-stayed one for its aesthetical slenderness and clearness, its shape is elegant and the configuration is almost the same of a cable-stayed one but with lower towers.

This makes the solution more desirable in our contest due to the fact that is less invasive towards the surrounding area. Furthermore, this solution is usually cheaper than the cable-stayed or suspended ones.

This is thank mostly to the cable system adopted, for which is possible to install the cables normally used to prestress the concrete and theirs relatives anchoring. This can be seen as the main advantage of this solution compared with the previous one, and the main point is that in the case of the extradosed bridge the girder is stiffer and so the variation of the load in the cables is lower and this permits to consider a higher value of admissible stress in the cable section, because the risk of a fatigue failure is the way lower.

In this proposal the author chose to take advantage of two equidistant pylons in order to reduce the main span of the bridge and thus, also the height of the towers. Two pylons were designed at a distance of 30 meters from each side, so that the central span is now long 60 meters.

This option is been declared as possible after a depth hydrologic study (annex 3) after which it is been verified that the pylons do not compromise the river flow.



Than the height of the towers must be defined, in literature the following rule is suggested

$$\frac{L}{H} = 6 \div 12$$

$$H = 5 \div 10 \quad m$$

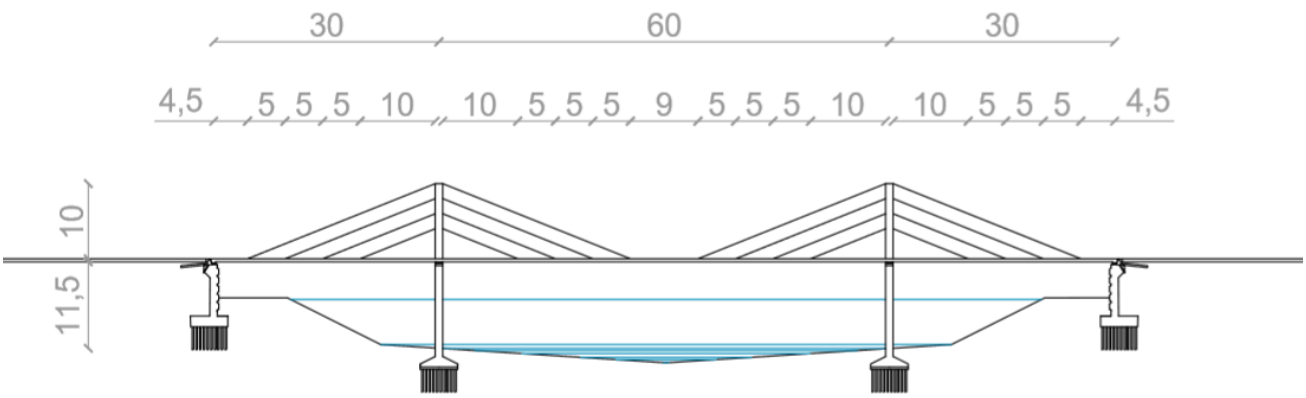
Where L is the main span and H the height of the pylon upon the deck.
In this case, as showed above L is 60 meters, so H should be stay between 5 to 10 meters.

Than, as did it for the cable-stayed case the cables configuration must be selected. For the same reasons of the previous case the author chosen to adopt the harp configuration with a cables angle of 68° and with only a lane of cables arranged in the middle of the deck.

Besides, the literatures' articles about this topic suggest to respect the rule that the first cable outstanding from the pylon has to be anchored at a distance between

$$(0.18 \div 0.25) \cdot L = 10.8 \div 15 \ [m]$$

With the aim to make match the harp configuration with the chosen angle of 68° (in respect to the zenit), the height of the pylon and the first anchor distance, the following draw has been developed.



A compromise has been found, and so all the lengths have been properly defined. The first anchor is arranged at a distance of 10 meters from the pylon, then each 5 meters a cable is been installed and so a tower's height of 10 meters has been reached.

The shape of the tower is as simple as possible, later on a further study will be done in order to accomplish the aesthetical requirements.

In this section the girder under consideration is the same as the previous cases in order to compare the solutions, but the requirements of the girder for this bridge are different from the others, due to the fact that a strong axial force will be acting on the deck and it has to be also flexurally stiffer in order to reduce the variation of the stresses on the cables. Although, the proposal has been developed with this cellular box girder, in the case this option will be the one which better fit all the requirements, another deck will be properly studied and designed.

4.6.1 Foundations

The foundation under each pylon will consist of concrete footings and cohesive piles. The number of piles needed under each pylon is determined due to the largest vertical reaction force and moment under the pylon.

4.6.2 Construction

The foundations are to be constructed fist, afterwards the pylons can start to be build. They will be constructed up to the height where the lowest cable will be connected. Then the construction of the deck can start, where the deck is connected to the cables in segments while the pylons are constructed further up. After the segments of the main girder are in place the trapezoidal profiles are fastened on the upper edges of the beams.

This process is done for each cable row with segments of the main girders welded togethere until the top row is reached and the deck structure meets in the middle of the span. In this way, the structure works as a self-anchored system with the deck hanging from the cables on each side of the pylons. The figure below display how this principle works.

4.6.3 Cables design

In order to express a preliminary design of the cables sections, it has been considered that each set of four cables spanned in the same direction and from the same tower will support half of the main span of the deck, so 30 meters. Taking into account the permanent and variable loads without any coefficient.

$$Rv = \frac{(Qg+Qfk)\cdot 30}{4} = 44.085\ [kN]$$

Then considering the angle of 65°

$$T = \frac{Rv}{sen(65°)} = 486.42\ [kN]$$

And so a minimum area must be guaranteed

$$Amin = \frac{T}{\sigma adm} = 4402.03\ [mm^2]$$

Equivalent to a circle with a radius of:

$$Rmin = \sqrt{\frac{Amin}{\pi}} = 37.4\ [mm]$$

$$Reff = 38\ [mm]$$

The total length of the cables is:

$Ltot = 309.32$

4.6.4 Pylons preliminary design

The pylons will be made of reinforced concrete, so knowing all the vertical loads acting on the deck is easy to define the minimum area required for the pylons section. Due to the symmetry of the cables disposition for both pylons, it can be considered that the they are loaded with a centered axial force, therefore applying the ultimate limit state combinations, in order to preserve security of the project the minimum area will be calculated.

The most desirable type of concrete for this project is the C40/45 due to its resistant capacities and its immediate availability on the project area. Furthermore, even if the pylons will be made of reinforced concrete, the amount of steel inside of the section will not be taken into account in this phase, so as to guarantee more reliability of the structure. Remind that the horizontal forces are not considered in this section it is safer to overestimate the loads and reduce the material capabilities.

Dividing the yield limit by a factor of Υ_c=1.5 and multiplying time α_{cd} = 0.85 (long duration structures) as defined by the Eurocode, the yield limit considered will be the following:

$$\sigma_{cd} = \alpha \cdot \frac{fck}{\Upsilon} = 0.85 \cdot \frac{35}{1.5} = 19.83\ [MPa]$$

The axial load on each pylon will be evaluated as follow:

$$Nmax = (1.3 \cdot Qg + 1.5 \cdot Qk) \cdot L = 4884\ [kN]$$

$$L = 60\ [m]$$

Therefore respecting the inequality Nrd ≥ Nmax the minimum area will be:

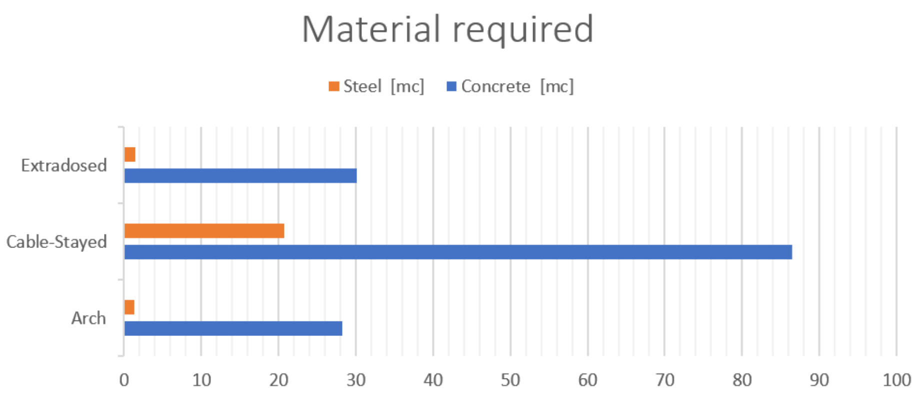
$$Amin \geq \frac{Nmax}{\sigma cd} = 246293.5\ [mm^2]$$

and it is about equivalent to a square section with a side of 500 mm.

CHAPTER 5 ALTERNATIVES COMPARISON

The purpose of this section is to evaluate which one of the three alternatives is the most competitive, for which a proper and detailed design will be carried out afterwards.

A summary table with all the materials required for each bridge will be showed in order to compare numerically the options. Due to the fact that has been proposed the same girder for all the bridge alternatives is useless to consider the amount of material of this element, therefore the amount of steel for the girder will be omitted.



	Arch	Cable-Stayed	Extradosed
Steel [mc]	1.28	20.77	1.41
Concrete [mc]	28.25	86.5	30.1

Table 1 - materials required for each alternative

It’s clear that the cable-stayed alternative is the way more expensive than the others two, for which less than the half of the material is required.

The arch and the extradosed alternatives require almost the same amount of material, however it has to be said that the construction of the arch requires more effort and it is more complex. As a matter of fact it is not easy to cast in situ an arch of that dimension and mostly there is no need to suggest a complex solution when there is another which satisfied all the requirements.

The extradosed bridges could be defined as the structures being between the girder bridge and the cable-stayed bridge, the key feature of these structures is their charming shape which remind us the elegance of the cable-stayed ones, however with lower towers and lower prices, therefore considering the aim of this project the extradosed solution is the best option possible.

Also because the cable-stayed bridges usually strongly dominate surrounding, meanwhile the extradosed ones characterized by horizontal lines are more neutral and have less aggressive visual impact on the surroundings. Nevertheless, they can be visually more attractive related to the simple girder bridge.

The only weak point of the extradosed option, in respect with the others two, is that two foundations are needed, this could increase marginally the costs because of the need of two other excavations.
However, pondering the advantages of the extradosed solution this is not completely relevant.

CHAPTER 6
FINAL DESIGN

6.1 Introduction

In this chapter the final design of the selected alternative will be carry out. As explained in the previous chapters, after different considerations taking into account the ahestetic, the serviceability and the cost of realization, the extradosed solution is resulted as the most competitive option.

6.2 Girder

The most important element of a bridge is the girder, for this reason a lot of attention will be put on this phase. In the preliminary design a box-shaped steel girder was proposed in order to do a preliminary design of the three alternatives and afterwards compare them economically.

However, that solution had never been related as the best option available. Considering the economic effort to build a tailored box girder, there are other options which better fit our necessities. So the author proposed another girder option which is cheaper and fit all the necessities of aesthetic and serviceability.

The selected option is a mix structure, made up of concrete and steel. The composite structure represent the most effective utilization of materials, because as we already know, the steel can be subjected to tensile tensions whereas the concrete do is best with compressive tensions. These particular solutions take advantages of the best capabilities of both materials. Besides, the high ductility of the steel leads to better seismic resistance of the composite section. Steel component can be deformed in the ductile regime without premature failure and so can withstand numerous loading cycles before fracture. Remember the unique property of the steel called ductility, which permits to absorb the energy released due to seismic forces.

Furthermore, these composite structures can be made of pre-fabricated components, which make the construction faster, and so facilitates a quicker return on the invested capital. Another advantage of this solution is the quality of the steel used, in effect the quality of the steel is assured since it is produced under controlled environment in the factory under strict quality controls.

Summing up this solution is cheaper, the realization is faster, the quality of the components is assured and is more ductile so it has a better behavior under seismic forces.

In order to exploit all these performances, the author suggested a solution with pre-fabricated steel beams. However, because of the nature of the project, the girder must have a good torsional stiffness, thing that regular pre-fabricated beam does not dispose. So, in order to make the steel part of the girder torsionally stiffer the author suggested to weld two HE shaped sections at a certain distance, so that will be created a closed profile which better fit the torsional requirements.

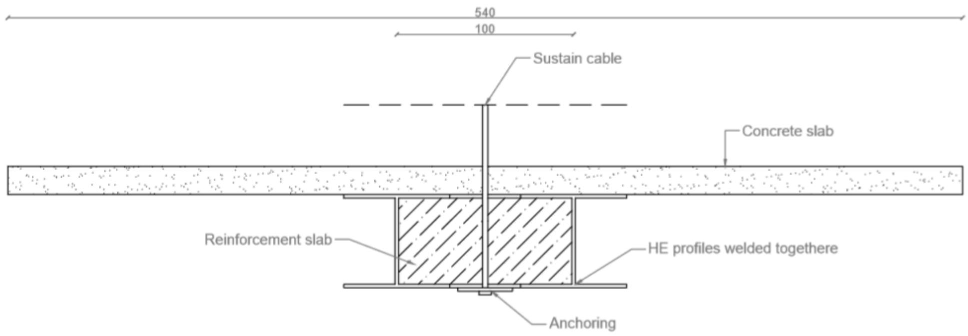


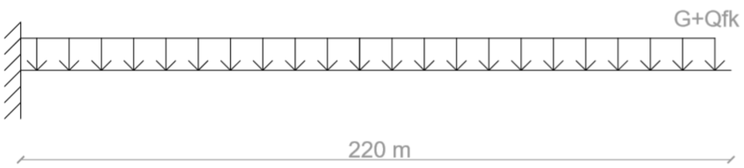
Figure 12 - Girder proposal

The only dimensions proposed are the width of the concrete slab which is 540 cm, as the project requires and the distance between two centers of the HE beams, which has been proposed a distance of 100 cm in order to increase the torsional capacity. The picture also shown the reinforcement slab, this steel slab will be welded in each section where the cables are anchored, with the aim to reduce the local buckling problems. The steel slab situated in the middle of the two steel beams will be of the same thickness and the same steel type of the beams' flanges. Afterwards the welding process of these parts will be explained.

In order to design the two HE profiles which has to be welded by means of a steel plate, which has the same thickness of the beams' flanges, the author considered the construction process, and so, taking into account that the river flow is quite small and the height of the bridge is just 11,5 meters on the river's bed level. The best construction solution is to adopt the scaffoldings system and build the bridge's deck 10 meters at a time. So the welded profiles should support its self-weight and in addiction the weight of the concrete which will be cast in situ.

The worst condition for the steel beam is during the phase of construction, when the concrete will be cast in situ, because the HE profiles will have to support the highest tensions in their lifetime, because when the bridge will be completed the span between each cable anchor is 5 meters while during the casting of the concrete the span between of two supports will be of 10 meters. So it easy to understand that this will be the worst condition for the beams. For this reason the author used this static scheme to preliminary design the two HE beams.

First, in order to consider the weight of the concrete, the thickness of the concrete slab has to be dimensioned; to do that the transversal section has to be designed. We consider a one meter wide slab and exploiting the symmetry of the deck we have just to solve a 2.20 m cantilever beam, due to the fact that the concrete slab and the steel beams will be connected by steel studs aligned in the center of the beams. Actually, the proper isostatic system is not a 2.20 m cantilever but something shorter, due to the fact that the slab is also supported by the beams' flanges, anyway consider a longer slab is safer. With the aim to design the thinner slab possible and considering that the moment depends by the thickness of the slab, the author chose to evaluate the moments and so, the minimum steel needed in the transversal section for thickness starting from 10 cm to 22 cm.



The evaluation is been done by the use of a ExCell file, so below are showed the algorithm used, and then a table will shows the results. The material chosen is concrete C40/45 and steel S450 for the reinforcements, the concrete cover will be 30 mm, and for guarantee the ductility behavior ξ_{lim}= 0.25, the reinforcement will consist in one bar each 20 cm, in order to guarantee at least 4 bars in one meter of slab.

$$Med = (G + Qfk) \cdot \frac{L^2}{2}$$

$$Xlim = \xi lim \cdot d$$

$$Cc, lim = 0.8 \cdot Xlim \cdot b \cdot \sigma cd$$

$$Mrd, lim = Cc, lim \cdot (d - 0.8 \cdot \frac{Xlim}{2})$$

$$Asmin = \frac{Mrd.lim}{(d-0.4 \cdot Xlim) \cdot Fyd}$$

$$Aeff$$

$$Xeff = \frac{Aeff \cdot Fyd}{0.8 \cdot \sigma cd \cdot b}$$

$$Mrd, eff = 0.8 \cdot b \cdot \sigma cd \cdot Xeff \cdot (d - 0.4 \cdot Xeff)$$

h [mm]	Med [kN*m]	Mrd,lim [kN*m]	Asmin [mm^2]	Φmin [mm]	Φeff [mm]	Mrd,eff [kN*m]
100	18.15	32.79	1459.73	21.56	22	33.84
120	19.36	54.20	1876.80	24.44	25	56.13
140	20.57	80.96	2293.87	27.02	28	85.53
160	21.78	113.08	2710.93	29.38	30	116.83
180	22.99	150.55	3128.00	31.55	32	153.87
200	24.2	193.38	3545.07	33.59	34	197.04
220	25.41	241.55	3962.13	35.51	36	246.72

Table 2 - Girder transversal reinforcement

As showed in the table above, the 10 cm thick slab with one Φ18 bar every 20 cm is enough to sustain the self-weight and the variable load.

However, in order to guarantee completely safety of the object, as explained in the Eurocode, the worst load condition is when we consider a vehicle passing through the deck, even if this is not allowed we can consider this event as a “accidental action”. So in order to verify this load condition the evaluation of the moments and shear are needed. For such a situation, the following load model should be used, consisting of a two axle load group of 80 and 40 kN, separated by a wheel base of 3 m as showed in the figure below.

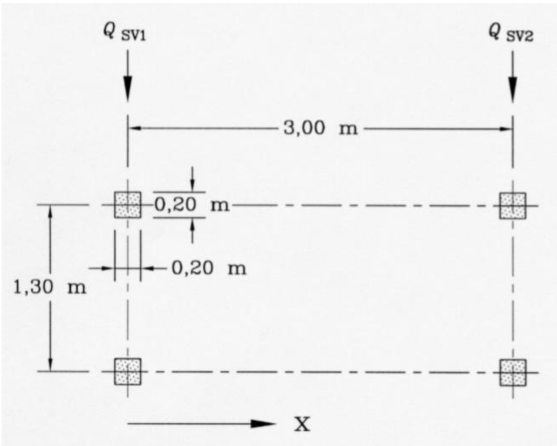


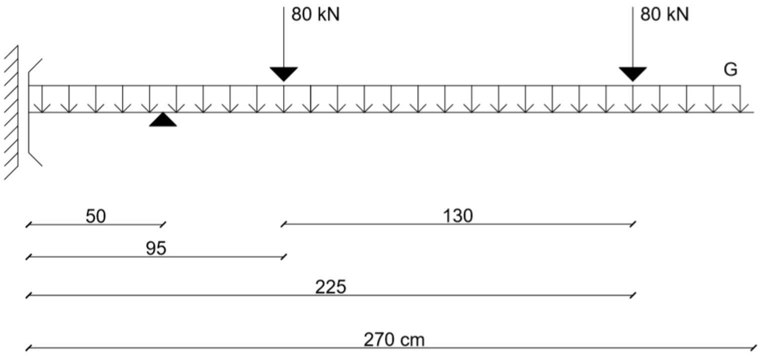
Figure 13 - Accidental load, Spanish legislation

Where:

$$Q\ sv1 = 80\ \frac{kN}{m^2}$$

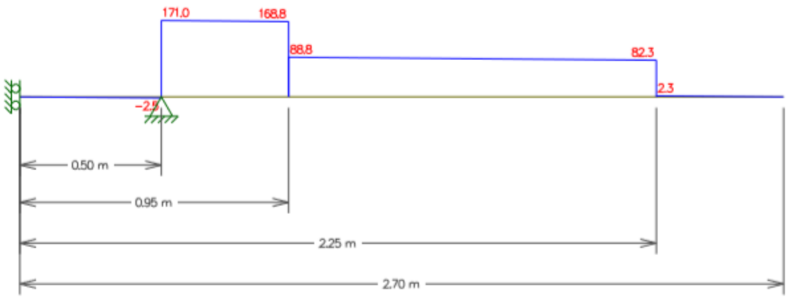
$$Q\ sv2 = 40\ \frac{kN}{m^2}$$

To evaluate this condition the author solved a isostatic problem which comes out from exploiting the symmetry of the deck and considering the center of the HE beam as a vertical support (a line of connectors will be implemented between the concrete slab and the steel beam on this line), and the midline of the deck as clamped edge in which the vertical displacement is permitted (in order to stay on the security side).

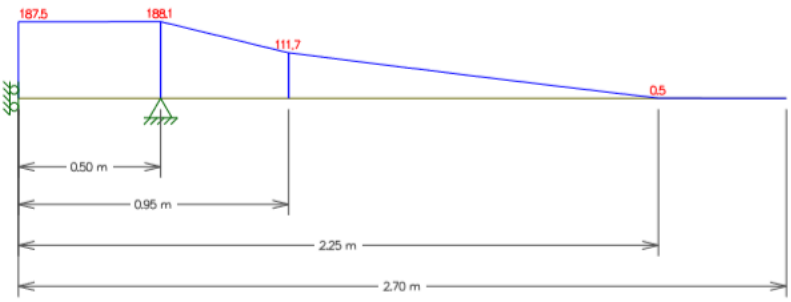


The moments, shear and deformation diagrams are the following:

Shear [kN]



Moment [kN·m]

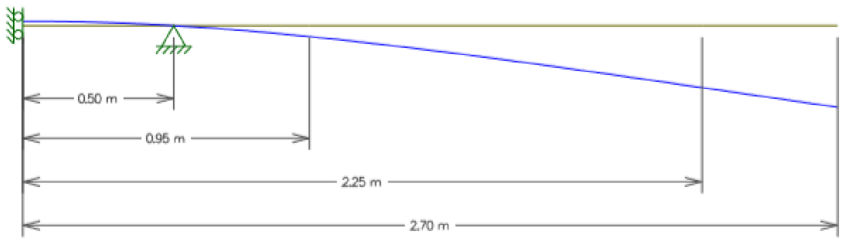


Deformation $[-]$

As showed the maximum moment is greater that ho one considered before, so a different reinforcement is needed.

Having these new condition implemented Mmax = 188.1 $[kN \cdot m]$ and Vmax= 168.8 $[kN]$.

the author calculated, with the same algorithm as before, the minimum thickness of the deck



and the reinforcement which support these tensions and respect the ductility requirements ("rottura bilanciata").

It resulted that the minimum thickness possible is 20 cm with Φ36 bars spaced by 20 cm as showed in te figure below.

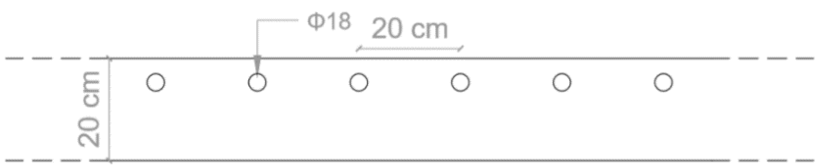


Figure 14 - Transversal reinforcement

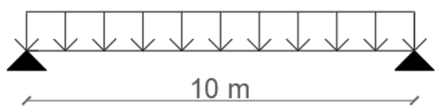
Now, that the slab thickness is defined it is possible to define the other dimensions of the girder, the next step is to define the steel beams and then create a digital model on the software SAP2000 in order to evaluate all the stresses conditions.

The worst condition for the steel beam is during the phase of construction, when the concrete will be cast in situ, and so the concrete slab do not contribute to resist the tensions; besides in this phase the HE profiles will have to support the highest tensions in their lifetime, due to the fact that when the bridge will be completed the span between each cable anchor is 5 meters while during the casting of the concrete the span considered between two supports is 10 meters. For these reasons it easy to understand that this will be the worst condition for the beams. Hence the author used this static scheme to preliminary design the two HE beams.

In order to preliminary design the beams slab it is better to stay on the security side, so the slab between the two steel beams is omitted in these calculations, besides this choice makes the calculations easier.

The steel used is a S355, so with $fyk = 355\ MPa$, the specific weight of the steel is 78.5 kN/m^3 while the specific weight of the reinforced concrete can be assumed as 25 kN/m^3 , now we can esteem the load that the beams have to support. In order to evaluate the self-weight of the steel beam is supposed to be used a HE340B section which could resist the already mentioned loads, so now that the area section of the steel and concrete are known it is possible to make some calculations.

$q = 30.74 \quad kN/m$



$$M\left(\frac{l}{2}\right) = q \cdot \frac{l^2}{8} = 384.3253 \quad kN \cdot m$$

$$Wmin \geq \frac{M \cdot \Upsilon mo}{fyk} = 1136.74 \quad \cdot 10^3\ mm^3$$

Thus the section chosen (HE340B) is resulted appropriate because its bending properties consist $Wmin = 1678 \cdot 10^3 \quad m^3$.

6.3 Pylons

The pylons have been predesigned according to the Eurocode legislation with the M-N Diagrams, afterwards the check with the ultimate limit state has been performed with the software SAP2000, thus the lower section has been increased in order to have less displacements at the top of the pylons, which compromise the correct bridge behavior.

In this chapter will be showed how the preliminary design has been carried out. These section properties and capacities have been used to create a first model in the software used for the analysis. However the final section which comply all the checks and verifications for the ULS and ELS is a little different and it will be showed in the next chapters.

6.3.1 Acting tensions

These values are taken from the worst load condition (ULS) according to the Spanish legislation, coming out from the digital 3D model (on SAP2000).

$$Ned = 5130\ kN$$

$$Mx,ed = 3148\ kN \cdot m$$

$$My,ed = 2945\ kN \cdot m$$

$$Ved = 200\ kN$$

6.3.2 Materials properties

- Concrete: C40/45

$$\sigma ck = 40\ MPa$$

$$\sigma cd = \alpha cc \cdot \frac{\sigma ck}{\gamma s} = 0.85 \cdot \frac{40}{1.5} = 22.67\ MPa$$

- steel (reinforcement): B450B

$$fyk = 450\ MPa$$

$$fyd = \frac{fyk}{\gamma si} = \frac{450}{1.15} = 391.3\ MPa$$

6.3.3 Geometry

With the axial force it is possible to define a section which is able to support that tension, so:

$$Amin \geq \frac{Ned}{\sigma cd} = \frac{5130}{22.67} = 226323.5\ mm^2$$

Whereby a square section of 800 mm could be a good option, taking in to account the fact that the moments are now not considered, even if they will represent the major condition for designing the steel bars reinforcements. In this phase a square section has been proposed, however afterwards the iterative analysis the section will be changed to a rectangular one, which better fit the deflection requirements and the correct bridge behavior.

$$Ac = l^2 = 800^2 = 640000\ mm^2$$

$$d'a = d'b = 0.1 \cdot 800 = 80\ mm$$

6.3.3.1 Longitudinal reinforcement design

The first thing to check is if the eccentricity $e = \frac{Ned}{Med}$ is greater than $\max(20\ mm; 0.05 \cdot l(500) = 25\ mm)$

$$ex = \frac{5130}{3148} = 61\ mm$$

$$ey = \frac{5130}{2945} = 57\ mm$$

Now that this has been verified, it is possible to evaluate the normalized values for bending moments and axial force, and through the M-N diagrams (for the correct properties of the section and materials) evaluate the minimum of reinforcement needed.

$$V = \frac{Ned}{Ac{\cdot}fcd} = 0.35 \qquad \mu x = \frac{Mx,ed}{Ac{\cdot}fcd} = 0.27 \qquad \mu y = \frac{My,ed}{Ac{\cdot}fcd} = 0.25$$

From the Table 3 has been possible to define the minimum of steel reinforcement

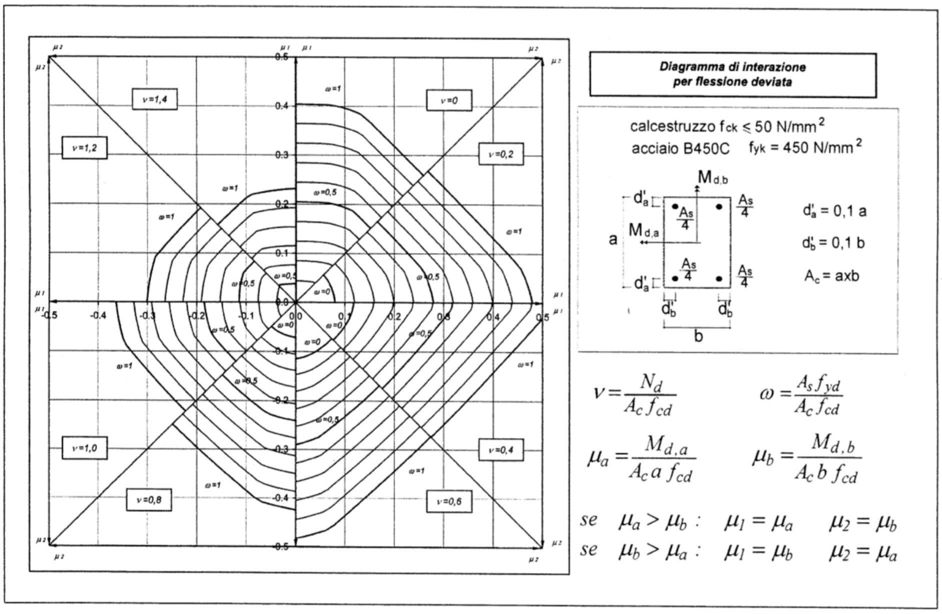


Diagramma U.23 Sez. rettangolare; armature nei 4 angoli; $f_{ck} \leq 50$ N/mm^2

Table 3 - M N diagram

$$w = \frac{As{\cdot}fyd}{Ac{\cdot}fcd} = 0.725$$

$$As = 0.725 \cdot \frac{Ac{\cdot}fcd}{fyd} = 24097{,}185\ mm^2$$

Checking the minimum and maximum values of the steel reinforcement needed recommended from the Italian legislation "NTC-2008".

$$As,min = \max(0.003 \cdot Ac = 1920\ mm^2; 0.1 \cdot \left(\frac{Ned}{fyd}\right) = 1311\ mm^2)$$

$$As,max = 0.04 \cdot Ac = 25600\ mm^2$$

6.3.3.2 Shear reinforcement design

$$ted = \frac{Ved}{b \cdot d' \cdot \sigma cd} = 0.138$$

However, this value has to respect a minimum of $tedmin = 0.172$

$$B = \frac{v \cdot \alpha c}{ted} = 3.63$$

$$cotg\theta = \frac{B}{2} + \sqrt{\left(\frac{B}{2}\right)^2 - 1} = 3.33$$

$$cotg\theta = 2.5$$

$$Wsw = \frac{ted}{cotg\theta} = 0.05515$$

Applying the following inequality

$$\frac{Asw}{s} \geq Wsw \cdot \frac{b \cdot \sigma c}{fyd}$$

bars	Asw	s max [mm]
2Ø8	100.5	39
2Ø10	157.1	61
2Ø12	226.2	89
2Ø14	307.9	120
2Ø16	402.1	157
2Ø18	508.9	199
2Ø20	628.3	246

Table 4 - Pylons, shear reinforcements

The author choice to use 2Ø16 bars each 150 mm; in order to have a Vrd higher than the design shear force Ved.

Now it is possible to introduce a pylon section with which the analysis will be made.

The reinforcement disposition proposed is the following:

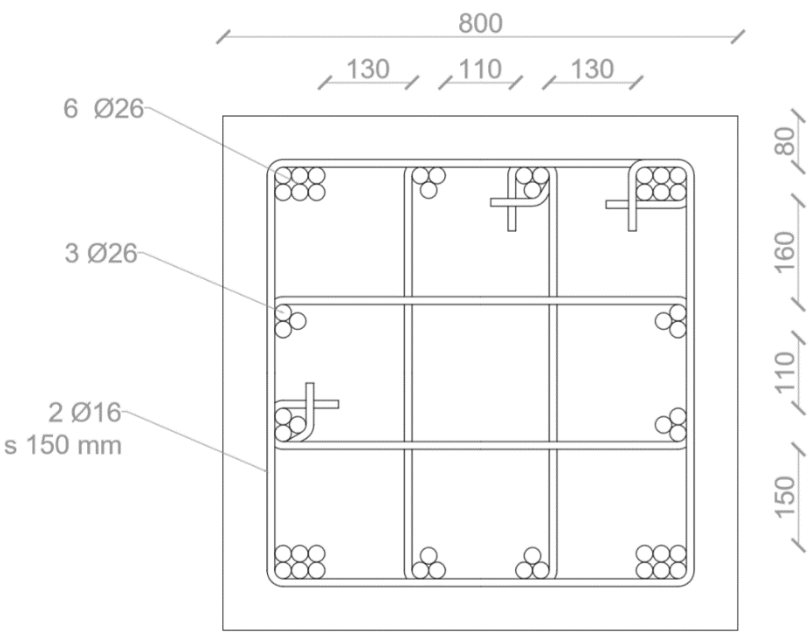


Figure 15 - Pylon reinforcement proposal

6.4 3D Model

Throughout the design process, plenty iterations have been realized in order to define the optimal sections of the bridge elements, this have affected also the girder model, which after a lot of calculations and ELS and ULS verifications the optimal girder section has been designed. Thus, the beams' dimensions mentioned in this section are related to the final model, the one which respect and verify all the ELS and ULS conditions and not the sections mentioned in the previously chapters.

The software "SAP2000 v19" has been used to make all the analysis, which permits a lot of different ways to evaluate a structure, however the author and the prof. Joan Ramon Casas thought that the most realistic model for this case was a 3D model constituted by shell and plate elements.

6.4.1 HE beams

The HE beams to be modelized are the HE800AA sections (S355), these have been modelized through 6 "shell- thick" area elements with 2 different thickness which represent the flanges and the core plate of the HE-shaped beams.

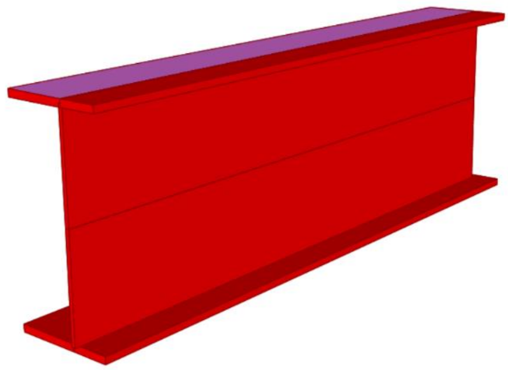


Figure 16 - HE Beam model

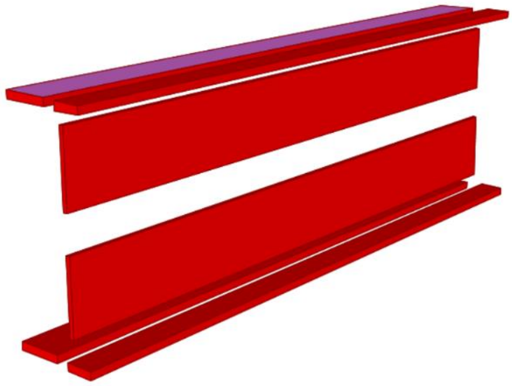


Figure 17 - HE beam shrink view

The two HE-shaped sections are welded throught a plate with the same properties and thickness of the HE800AA beams' flanges, in the model these plates have been modelized with 4 "shell-thick" elements, the same elements used to modelize the beams' flanges.

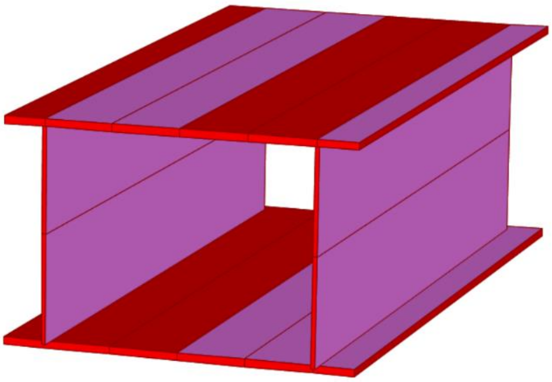


Figure 18 - Girder box section

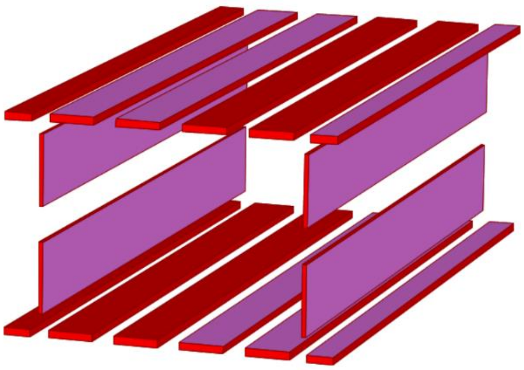


Figure 19 - Girder box section shrink view

In order to modeling adequately the connection between the concrete slab and the steel section another shell element has been used on the line in which the connectors will be installed. The longitudinal dimension of all these area elements adopted is 5 meters, in such way that the results will be trusted without further increase the computing requirements of the processor.

6.4.2 Concrete slab

The concrete slab (C40/45, B450B) has been associated to 4 "plate-thick" area elements due to the fact that is thicker than the steel elements and so its behavior is different. This choice has been forced and suggested by the physical behavior of shells and plates models defined in literature, and so these choices have been taken in order to exploit their advantages and minimize the disadvantages in the computing calculation.

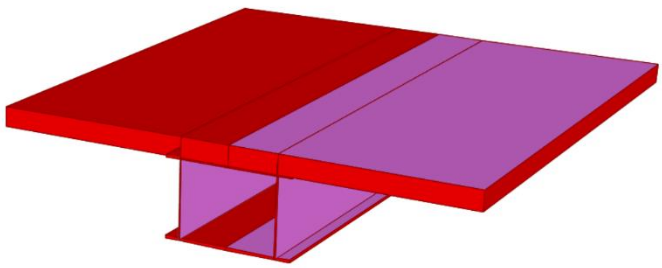


Figure 20 - Complete deck section

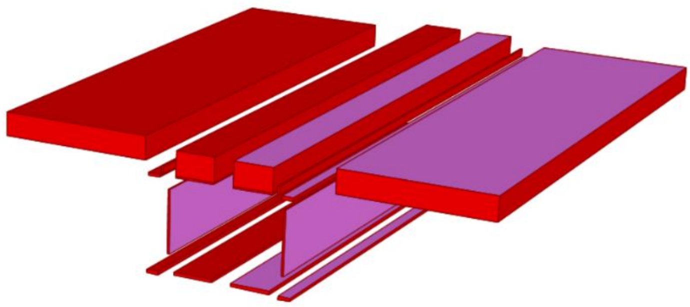


Figure 21 - Complete deck section shrink view

Furthermore, with the aim to improve the quality of the model, in the sections in which the deck is more stressed, so in the center of the main span and in the first 5 meters around the pylons the area of the shell and plate elements have been reduced by a factor of four. In this way the displacements and stress results have more accuracy.

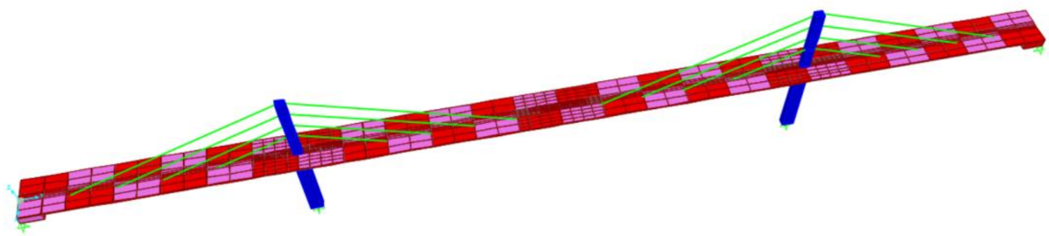


Figure 22 - Complete bridge model

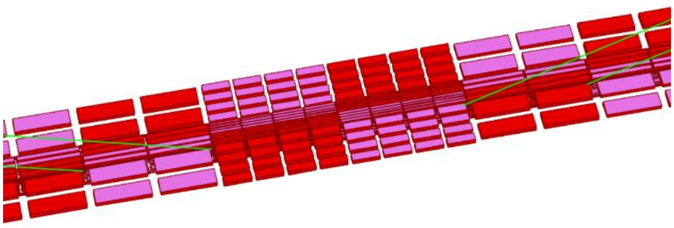


Figure 23 - Details of the discretization of the model

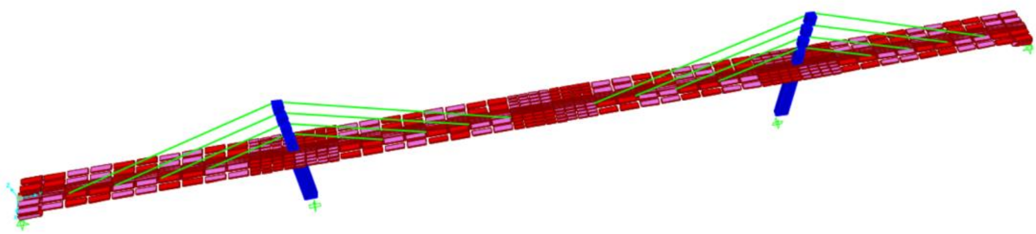


Figure 24 - complete model shrink view

6.4.3 Pylons

In the spatial model the cables and the pylons have been modelized with their proper elements available in the software which represent perfectly the physical behavior of each element.

6.5 Cables design process

This phase is one of the most important due to the fact the structural behavior of the bridge is highly influenced by the cables sections and the axial tensions applied on each cable, so in order to define these properties the following method has been applied.

Furthermore, the design process respects the requirements of the European legislation:

- Eurocode 3 part 1 – 11 : Design of steel structures (prEN 1993 1-1, 2004)

Material properties

One of the advantages of the extradosed bridges is that the cables are considered as external post-tensioned tendons, so their properties are:

- $fyd = 170\ MPa$

- $fyk = 190\ MPa$

- $Ai = 150\ mm^2$

6.5.1 Design process

First, we run the analysis with vertical supports on each point where the cables will be anchored.

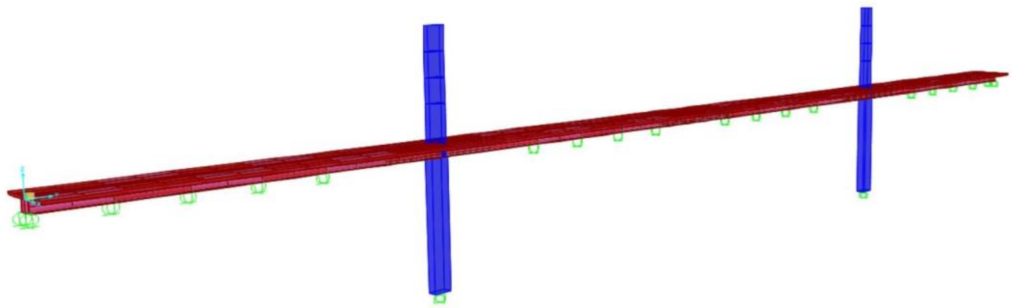


Figure 25 - Cables design: supports position

Whereupon, for each vertical support it has been evaluated the highest vertical reaction force among all the load combinations (all the ULS have been considered).

With the highest reaction force the respectively axial tension on the cable has been defined, and considering the maximum between the 65% of the nominal resistance (as suggested on the Phd Thesis "Comportamiento Estructural y Criterios de Diseño de los Puentes con Pretensado Extradosado" of Gustavo Chio Cho under the direction of the Professor Angel C. Aparicio), and the values recommended by the EC3 the minimum area section of each cable has been defined.

$$Frd = \min\left[\frac{fyk}{\psi o \cdot \Upsilon r}; \frac{fud}{\Upsilon r}\right] = \frac{190}{1.5 \cdot 1} = 126.67\ MPa$$

$$frd = 0.65 \cdot fyk = 123.5\ MPa$$

Then, because on the market the post-tension cables available are constituted by elements with a section of $150\ mm^2$, the effective area section of each cable has been defined as the minimum multiple number of this amount, in such a way that the following inequality was satisfied.

$$Aeff \ \geq Amin = \frac{Tmax}{0.65 \cdot fyk}$$

In this way, with the worst load combination less than the 65 % of the strength capacity has been reached.

Now that each cable section is defined, the tension to apply on each cable during the construction process to make sure that the bridge respects all the ELS need to be defined.

The tension applied on each cable will have a vertical component equal to the reaction force on each "provisional vertical support" with the load case in which the self-weight and the dead loads are considered without any coefficient.

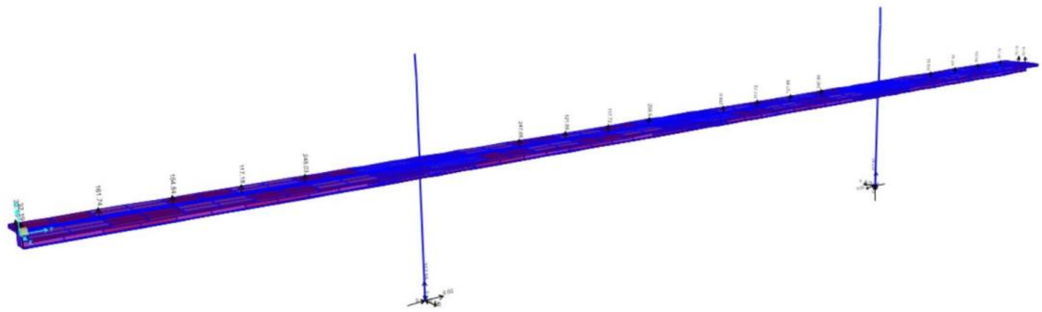


Figure 26 – Cables design: supports recation forces

With this design process the bridge will experiments low displacements which respects all the ELS, and the cable sections are the minimum required which respect the ULS.

Furthermore, the cables will lean on the pylons where a proper space will be left in order to simplify the construction process.

All the calculation and results are gathered in the annex 1 – "Model and results".

6.6 Load conditions

The reference regulations used in order to evaluate all the load combinations and to check the safety (uls) and serviceability (els) of the bridge have been

- Actions:

  "IAP-11 Instruccion sobre las acciones a considerar en el proyecto de puentes de carretera"

  "EC-1 part 2 Eurocode"

- Steel:

  "EAE Instrucción de Acero estructural"

  "Eurocode 3: Design f Steel structures Part 1-1"

- Concrete:

  "EHE-08 Instrucción de Hormigon Estructural"

- Composite structures:

  "Eurocode 4: Design f composite Steel and Concrete structures "

- Seismic:

  "NCSP-07 Norma de Construccion Sismorresistente – Puentes"

6.6.1 Permanent

As permanent loads the author considered the same loads defined in the previously chapters referred to the preliminary design of the girder, in which the Eurocode is been respected.

Specific weight of the reinforced concrete 25 $\frac{kN}{m^3}$ and specific weight of structural steel 78.5 $\frac{kN}{m^3}$.

6.6.2 Variable

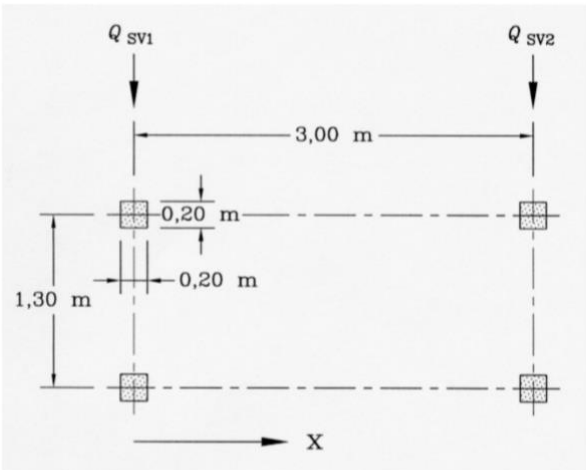
The variable action suggested by the Spanish legislation in the chapter 4.1.8 is the same as the one recommended by the Eurocode (EC-2), so with $qfk = 5 \left[\frac{kN}{m^2}\right]$.

6.6.3 Accidental presence of the vehicles on the bridge

In order to evaluate the worst condition the Eurocode EC-1 section 5.6.3 is been taken in consideration for evaluate the effects of an accidental presence of a vehicles on the bridge, even if the bridge is a footway with a cycle track, so this load rarely will act on the deck surface, anyway is been considered.

The Eurocode suggest to evaluate this model in the case in which no permanent obstacle prevents a vehicle from being driven onto the bridge deck.

The model recommended is te following:



Key
x : Bridge axis direction
Q_{sv1} = 80 kN
Q_{sv2} = 40 kN

Besides, these punctual forces will be applied in the worst condition possible, so in the middle on the longest span of the bridge on the most lateral position.
This configuration will also male experience a great torsional tension on the deck, and this is one of the main problem of the deck, section.

Due to the fact that the anchors are applied in the center line of the deck, the girder has have a proper torsional stiffness in order to sustain these tension, which can induce the supports fail on the bridge ends, and so in this will happen the bridge could collapse.

6.6.4 Wind

In pursuance to evaluate the wind effects on the structure the Spanish legislation (IAP-11, “Instruccion sobre las acciones a considerar en puentes de carretera”) is been considered, in which the wind forces will be determined as an equivalent static load, depending on the wind velocity.
The first step is to define the basic velocity of the wind for the location in which the bridge will be built, which is defined as follow:

$$V_b = C_{dir}\, C_{season}\, V_{b,0}$$

donde:

v_b velocidad básica del viento para un periodo de retorno de 50 años [m/s]

c_{dir} factor direccional del viento que, a falta de estudios más precisos, puede tomarse igual a 1,0

c_{season} factor estacional del viento que, a falta de estudios más precisos, puede tomarse igual a 1,0

$v_{b,0}$ velocidad básica fundamental del viento [m/s] (según el mapa de isotacas de la *figura 4.2-a*)

However for a period of no return different from 50 years the velocity to consider is:

$$v_b(T) = v_b\, c_{prob}$$

for which in the case where a specific study is missing a value of $Cprob = 1.04$ is suggested.

The basic velocity is defined by the "mapa de isotacas para la obtencion de la velocidad basica fundamental del viento $Vb.0$ " which is attached below.

Because the bridge is located in the north of Catalunya the "Zona C" has to be contemplated. So with the basic velocity of $Vb,0 = 29\ \frac{m}{s}$.

$$Vb(T) = 29 \cdot 1.04 = 30.16\,\frac{m}{s}$$

The second step is to evaluate the average velocity of the wind with the suggested equation

$$V_m(z) = c_r(z)\ c_o\ V_b(T)$$

where the coefficients represent the "topography factor" and the "rugosity factor" as elucidated in the legislations as follow:

$v_b(T)$ velocidad básica del viento [m/s] para un periodo de retorno T

c_o factor de topografía, que se tomará habitualmente igual a 1,0. En valles en los que se pueda producir un encauzamiento del viento actuante sobre el puente, se tomará para c_o un valor de 1,1. Cuando existan obstáculos naturales susceptibles de perturbar apreciablemente el flujo del viento sobre el puente, el valor de c_o se determinará mediante un estudio específico

$c_r(z)$ factor de rugosidad obtenido de la siguiente fórmula:

$$c_r(z) = k_r \ln\left(\frac{z}{z_0}\right) \quad \text{para } z \geq z_{min}$$

$$c_r(z) = c_r(z_{min}) \quad \text{para } z < z_{min}$$

Where

z altura del punto de aplicación del empuje de viento respecto del terreno o respecto del nivel mínimo del agua bajo el puente [m]

k_r factor del terreno, según *tabla 4.2-b*

z_0 longitud de la rugosidad, según *tabla 4.2-b*

z_{min} altura mínima, según *tabla 4.2-b*

The “table 4.2-b” is attached below and the type of zone our location is related is “Tipo II”

TABLA 4.2-b **COEFICIENTES k_r, z_0, Y z_{min} SEGÚN EL TIPO DE ENTORNO**

TIPO DE ENTORNO	k_r	z_0 [m]	z_{min} [m]
0	0,156	0,003	1
I	0,170	0,01	1
II	0,190	0,05	2
III	0,216	0,30	5
IV	0,235	1,00	10

Table 5 - Load definition: wind coefficients

Thus, $Kr = 0.190$ $Zo = 0.05\ [m]$ $Zmin = 2\ [m]$

Due to the fact all the deck bridge is higher than Zmin $Cr(z) = 0.19 \cdot \ln\left(\frac{z}{0.05}\right)$ and

$$Vm = 0.19 \cdot \ln\left(\frac{z}{0.05}\right) \cdot 1 \cdot 30.16 = 5.7304 \cdot \ln\left(\frac{z}{0.05}\right)$$

The last step consist in evaluate the push force on each bridge element (deck and pylons) as showed:

$$F_w = \left[\frac{1}{2}\rho\, v_b^2(T)\right] c_e(z)\, c_f\, A_{ref}$$

F_w	empuje horizontal del viento [N]
$\frac{1}{2}\rho\, v_b^2(T)$	presión de la velocidad básica del viento q_b [N/m^2]
ρ	densidad del aire, que se tomará igual a 1,25 kg/m^3
$v_b(T)$	velocidad básica del viento [m/s] para un periodo de retorno T
c_f	coeficiente de fuerza del elemento considerado (*figura 4.2-b*)
A_{ref}	área de referencia, que se obtendrá como la proyección del área sólida expuesta sobre el plano perpendicular a la dirección del viento [m^2]
$c_e(z)$	coeficiente de exposición en función de la altura z calculado según la fórmula siguiente[1]:

$$c_e(z) = k_r^2\left[c_o^2\ \ln^2\left(\frac{z}{z_0}\right) + 7\,k_l\,c_o\,\ln\left(\frac{z}{z_0}\right)\right] \qquad \text{para } z \geq z_{min}$$

Kl is the turbulence coefficient and is suggested to use it Kl = 1 as the topography coefficient C_o, so:

$$Ce(z) = 0.19^2 \cdot [\ln^2\left(\frac{z}{0.05}\right) + 7 \cdot \ln\left(\frac{z}{0.05}\right)]$$

The push has to be evaluated for each element, so first we evaluate the push on the bridge deck:

$$Fw = [0.5\ \cdot 1.25 \cdot 30.16^2] \cdot 0.19^2 \cdot [\ln^2\left(\frac{z}{0.05}\right) + 7 \cdot \ln(\frac{z}{0.05})] \cdot 2 \cdot\ 1.25 =\ \ 3.47\,\frac{kN}{m}$$

Where A_{ref}=1.25 due to the fact that if the bridge is crowded of people the wind forces act also on the pedestrians, and $Cf\ = 2$ as written in the "Tabla 4.2-b coeficiente de ocultamiento para las secciones mas habituales".

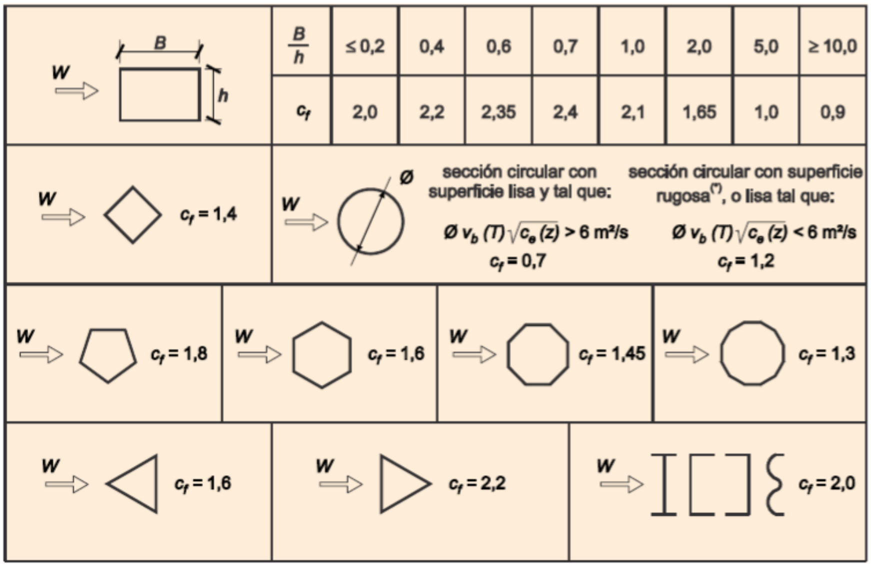


Table 6 - Load definition: aeroelastic coefficients

While for the pylons the push is

$$Fw = [0.5 \cdot 1.25 \cdot 30.16^2] \cdot 0.19^2 \cdot [\ln^2\left(\frac{z}{0.05}\right) + 7 \cdot \ln(\frac{z}{0.05})] \cdot 1 \cdot 1 = 1.39\,\frac{kN}{m}$$

Direction of the wind forces:

- Perpendicular to the deck
- Parallel to the longitude of the bridge

Transversal wind

$$Cf,x = 2.5 - 0.3\left(\frac{B}{heq}\right) = 2.5 - 0.3\left(\frac{5.4}{1.25}\right) = 1.204$$

Where: $B = 5.4\,m,\ heq = 1.25\,m$

however the minimum value of this coefficient is 1.3, so $Cf,x = 1.3$ is been taken.

6.6.4.1 Vertical effects

$$F_{w,z} = \left[\frac{1}{2}\,\rho\,v_b^2(T)\right] c_e(z)\,c_{f,z}\,A_{ref,z}$$

Where

$F_{w,z}$	empuje vertical del viento [N]
$\frac{1}{2}\rho\, v_b^2(T)$	presión de la velocidad básica del viento definida en el *apartado 4.2.3* [N/m^2]
$c_e(z)$	coeficiente de exposición definido en el *apartado 4.2.3*
$c_{f,z}$	coeficiente de fuerza en la dirección vertical Z, que se tomará igual a ±0,9
$A_{ref,z}$	área en planta del tablero [m^2]

$$Fw,z = \left[\frac{1}{2}\cdot 1.25\cdot 30.16^2\right]\cdot 0.19\cdot 0.9 = 0.97\,\frac{kN}{m^2}$$

6.6.4.2 Longitudinal wind

In the Spanish legislation (IAP-11) recommend to use a fraction of the horizontal push to evaluate the vertical forces acting on the bridge's deck, so for footbridges this fraction consist of the 25% of the vertical force, and the direction will be along the y axis.

Than in the 4.2.8 section of the IAP-11 is written that some simplifications can be adopted if the deck and the pylons are included between 10 and 20 meters, so this is our case so a linear interpolation will be adopted during the analysis.

6.6.5 Aeroelastic effects

The aeroelastic study can be omitted according to the Spanish legislation (Chapter 4.2.9 of the IAP-11) due the fact that the bridge respects the followings conditions:

- Main span shorter than 100 m

- Effective span (maximum distance between points with null moment with the selfweight) lower than 30 times the girder thickness, so 30 meters.
- Girder's width higher than 1/10 the distance between points of null transversal moment under the trsnaversal wind condition: in our case the deck's width should be greater than 3.6 meters and so it is respected

Since all these conditons are respected the aerolastic study of the bridge can be omitted.

6.6.6 Thermal effects

With the aim to evaluate the thermal effects on the deck, the "Tipo 2" of the chapter 4.3.1 af the IAP-11 will be used, due the fact the deck is a composite element composed by steel and concrete.

First the maximum and minimum values of the temperature on the bridge location have to be defined, these values are defined in the 4.3.1.1 section of the IAP-11, from the "table 4.2-a" and "table 4.2-b" and then the following equations will be applied.

$$T_{max,p} = T_{max} \{k_1 - k_2 \ln [-\ln (1 - p)]\}$$
$$T_{min,p} = T_{min} \{k_3 + k_4 \ln [-\ln (1 - p)]\}$$

With $k1 = 0.781;$ $k2 = 0.056;$ $k3 = 0.393;$ $k4 = -0.156;$ and $p = \frac{1}{100};$

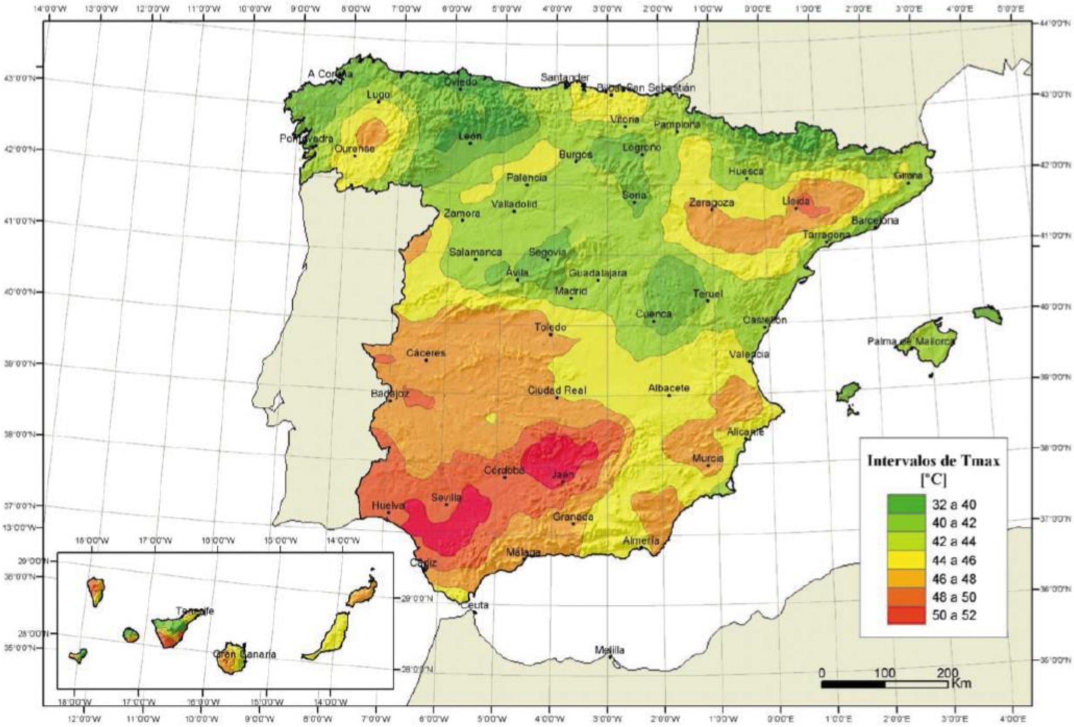


Table 7 - Thermal load: Spain temperature map

Taking the highest value of the bridge location $Tmax$ = 42° .

For the minimum value, first the zone has to be identified according to the "Tabla 4.3-b", in which Catalunya is represented by the "ZONA 2", so because of the fact the altitude of the bridge location is 0 meters $Tmin = -11°$.

Table 8 - Thermal effects: country suddivision

TABLA 4.3-a **TEMPERATURA MÍNIMA ANUAL DEL AIRE, T_{min} [°C]**
(Coincide con la tabla correspondiente del Código Técnico de la Edificación)

ALTITUD [m]	ZONA DE CLIMA INVERNAL (SEGÚN FIGURA 4.3-b)						
	1	2	3	4	5	6	7
0	-7	-11	-11	-6	-5	-6	6
200	-10	-13	-12	-8	-8	-8	5
400	-12	-15	-14	-10	-11	-9	3
600	-15	-16	-15	-12	-14	-11	2
800	-18	-18	-17	-14	-17	-13	0
1000	-20	-20	-19	-16	-20	-14	-2
1200	-23	-21	-20	-18	-23	-16	-3
1400	-26	-23	-22	-20	-26	-17	-5
1600	-28	-25	-23	-22	-29	-19	-7
1800	-31	-26	-25	-24	-32	-21	-8
2000	-33	-28	-27	-26	-35	-22	-10

Table 9 - Thermal effect: Minimum temperatures

Afterward the uniform component of the temperature need to be calculated:

$$T_{e,min} = T_{min} + \Delta T_{e,min}$$
$$T_{e,max} = T_{max} + \Delta T_{e,max}$$

Where the values of $\Delta Te, \min$; $\Delta Te, max$ are defined by the “Tabla 4.3-b” where for the case of a composite deck the values to be adopted are:

$\Delta Te, \min = +4$; $\Delta Te, \max = +4$;

TABLA 4.3-b **VALORES DE $\Delta T_{e,min}$ Y $\Delta T_{e,max}$ PARA EL CÁLCULO DE LA COMPONENTE UNIFORME DE TEMPERATURA**

TIPO DE TABLERO	$\Delta T_{e,min}$ [ºC]	$\Delta T_{e,max}$ [ºC]
Tipo 1: Tablero de acero	-3	+16
Tipo 2: Tablero mixto	+4	+4
Tipo 3: Tablero de hormigón	+8	+2

Table 10 - Thermal effects: temperature variation

$$Te, min = -11 + 4 = 7°$$

$$Te, min = 40 + 4 = 44°$$

The thermal expansion coefficient for both materials, concrete and structural steel are $\alpha tconcrete = 10 \cdot 10^{-6}\ C^{-1}$ and $\alpha tsteel = 12 \cdot 10^{-6}\ C^{-1}$.

In order to evaluate the displacements for the thermal actions the characteristic value of the maximum variation has to be defined, so:

$\Delta Tn, exp = Te, max - To = 48 - 15 = 33°C$

When To ca be assumed $To = 15°C$

Differential thermal component

Because the bridge is a composite structure it is referred to the “Tipo 2 - puentes mixtos” by which the differential thermal condition for the two materials has to be taken in account, and so the values recommended by the 4.3.1.2.1 section of the IAP-11 for this case are:

- Cooling condition

$$\Delta Tm, cool = -10°C$$

- Heating condition

$$\Delta Tm, heat = +18°C$$

Differential thermal condition between cables and the girder

The Spanish legislation also define the positive and negative differential among the cables and the bridge's girder

- Positive differential

$$Tcables - Tdeck = +20°C$$

- Negative differential

$$Tcables - Tdeck = -10°C$$

6.6.7 Snow

The location in which the bridge is located is considered as a maritime zone, such that the snow load can be omitted by the evaluation. Anyway, for stay on the security side the bridge will be considered as referred in the IAP-11 section 4.4.

$$qk = 0.8 \cdot 0.4 = 0.32 \left[\frac{kN}{m^2}\right]$$

As it is clear, the value of the snow load is really low.

6.6.8 Hydrostatic and hydrodynamic

Because of the fact the pylons are in the river, the hydrostatic and hydrodynamic pressure on the pylons need to be considered.

6.6.8.1 Hydrodynamic pressure

$$E = \left[\frac{1}{2}\rho\, v^2(T)\right] c_f\, A(T)$$

where:

6.6.8.2 Hydrostatic pressure

- E empuje total [N]
- ρ densidad del agua, igual a 1000 kg/m^3
- $v(T)$ velocidad de la corriente correspondiente al caudal de avenida de periodo de retorno de T años [m/s]
- c_f coeficiente de fuerza (o de arrastre) de la sección que soporta el empuje de la corriente, según la *figura 4.2-b*; en el caso de una sección circular, el valor límite de $\phi\, v_b(T)\sqrt{c_e(z)} = 6\text{m}^2/\text{s}$ definido en la *figura 4.2-b*, se debe sustituir por $\phi\, v(T) = 0{,}4\text{m}^2/\text{s}$
- $A(T)$ área de la superficie del elemento proyectada sobre un plano perpendicular a la corriente correspondiente a la sección mojada de la avenida de periodo de retorno de T años [m^2]

This value is evaluated as a linear uniformed pressure on the pylons considered the density specific weight of the water equal to $9.8\ kN/m^3$

6.6.9 Seismic

The seismic evaluation is an important condition to be evaluated, mostly for structures as the bridge under study, because a dangerous earthquake could prejudice the normal behavior of the bridge and its utility.
With the aim to evaluate this possible dangerous condition the Spanish legislation “Norma de construccion sismorresistente – Puentes NCSP-07” is been taken in consideration.

6.6.9.1 Horizontal seismic action

The NCSP-07 defines in the chapter 3.4 the acceleration to be taken in consideration.

$$a_c = S\ \rho\ a_b$$

This values is defined in the follwing map, dependig on the location of the structure

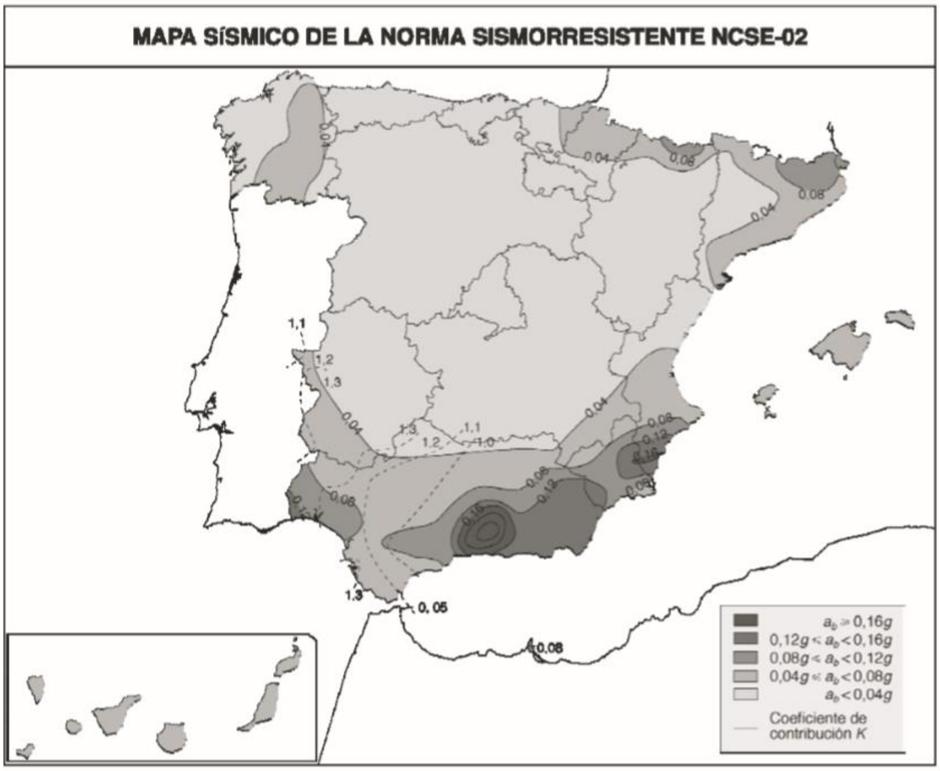


Table 11 - Seismic load: Spanish sesmic map

Fortunately the location of the bridge is in the safest zone possible, in which the acceleration to be considered is the lowest.

$$ab < 0.04g$$

Therefore, as explained in the section 2.8 of the Spanish legislation the seismic actions can be omitted by the calculation of the external forces action on the structure.

6.6.10 Combinations

In the chapter 6 of the Spanish legislation IAP-11 are defined the representative values for the combinations of the actions. In which distinguish 3 main conditions:

- Valor de combinacion
- Valor frecuente

- Valor casi-permanente

And then the table "6.1-a" defines the values of the combination coefficients, which are gathered in the following table.

	ψo	ψ1	ψ2
Wind	0.3	0.2	0
Thermal action	0.6	0.6	0.5
Water pressure	1	1	1
Vertical actions	0.75	0.75	0

Table 12 - Load combination coefficients

6.6.10.1 Partial coefficients

The approach of the Spanish legislation is the well-known partial coefficients method, in order to consider all the loads combinations possible and stay on the security side. So to define these coefficients gathered in a table and distinguished from "ultimate limit state- Υ_{uls}" and "exercise limit state-Υ_{els}".

	ϒuls	ϒels
Self-weight	1.35	1
Dead load	1.35	1
Variable loads	1.35	1
Thermal	1.5	1
Wind	1.5	1
Hydrostatic	1.5	1
Hydrodynamyc	1.5	1

Table 13 - load combination partial coefficients

These values have been taken from the tables in the IAP-11

TABLA 6.2-b COEFICIENTES PARCIALES PARA LAS ACCIONES γ_F
(PARA LAS COMPROBACIONES RESISTENTES)

ACCIÓN		EFECTO	
		FAVORABLE	DESFAVORABLE
Permanente de valor constante (G)	Peso propio	1,0	1,35
	Carga muerta	1,0	1,35
Permanente de valor no constante (G^*)	Pretensado P_1	1,0	1,0 / 1,2(1) / 1,3(2)
	Pretensado P_2	1,0	1,35
	Otras presolicitaciones	1,0	1,0
	Reológicas	1,0	1,35
	Empuje del terreno	1,0	1,5
	Asientos	0	1,2 / 1,35(3)
	Rozamiento de apoyos deslizantes	1,0	1,35
Variable (Q)	Sobrecarga de uso	0	1,35
	Sobrecarga de uso en terraplenes	0	1,5
	Acciones climáticas	0	1,5
	Empuje hidrostático	0	1,5
	Empuje hidrodinámico	0	1,5
	Sobrecargas de construcción	0	1,35

Table 14 - Spanish legislation: load combinations partial coefficients

TABLA 6.2-c COEFICIENTES PARCIALES PARA LAS ACCIONES γ_F (ELS)

ACCIÓN		EFECTO	
		FAVORABLE	DESFAVORABLE
Permanente de valor constante (G)	Peso propio	1,0	1,0
	Carga muerta	1,0	1,0
Permanente de valor no constante (G^*)	Pretensado P_1	0,9(1)	1,1(1)
	Pretensado P_2	1,0	1,0
	Otras presolicitaciones	1,0	1,0
	Reológicas	1,0	1,0
	Empuje del terreno	1,0	1,0
	Asientos	0	1,0
	Rozamiento de apoyos deslizantes	1,0	1,0
Variable (Q)	Sobrecarga de uso	0	1,0
	Sobrecarga de uso en terraplenes	0	1,0
	Acciones climáticas	0	1,0
	Empuje hidrostático	0	1,0
	Empuje hidrodinámico	0	1,0
	Sobrecargas de construcción	0	1,0

Table 15 - Spanish legislation: partial coefficients ELS

6.6.11 Summary of the load actions

A summary table with all the actions considered for the evaluation and the check of the structure is showed below:

Self weight	automatic (SAP2000)	
Dead loads	pavement	0.025 kN/m^2
Variable loads	vertical	5 kN/m^2
	horizontal	0.5 kN/m^2
Wind	Fw,z	0.97 kN/m^2
	Fw,deck	3.47 kN/m
	Fw,pylon	1.39 kN/m
Snow	qk	0.32 kN/m^2

Table 16 - Load actions: summary table

6.6.12 Load combinations

Two main differences have to be defined, while considering the loads acting on the structure there will be two checks to be done, the first is related to the Ultimate Limit State, meanwhile the second concerns the Exercise Limit State. Checking these two conditions, the safety and serviceability of the structure is secured.

The combinations for the Ultimate limit state are the following:

$$\sum_{j\geq 1}\gamma_{G,j}\,G_{k,j} + \sum_{m\geq 1}\gamma_{G,m}\,G^{*}_{k,m} + \gamma_{Q,1}\,Q_{k,1} + \sum_{i>1}\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i}$$

Where the Legislation defines

$G_{k,j}$ valor característico de cada acción permanente
$G^{*}_{k,m}$ valor característico de cada acción permanente de valor no constante
$Q_{k,1}$ valor característico de la acción variable dominante
$\psi_{0,i}\, Q_{k,i}$ valor de combinación de las acciones variables concomitantes con la acción variable dominante
γ_G, γ_Q coeficientes parciales

And so the loads combinations for the Ultimate limit state have been the following:

I) $1.35 \cdot G + 1.35 \cdot variable + 1.35 \cdot dead + 1.5 \cdot wind(trasv + vert)$

II) $1.35 \cdot G + 1.35 \cdot variable + 1.35 \cdot dead + 1.5 \cdot wind(long)$

III) $1.35 \cdot G + 1.35 \cdot variable + 1.35 \cdot dead + 1.5 \cdot snow + 1.5 \cdot 0.6\, Temperature$

IV) $1.35 \cdot G + 1.35 \cdot dead + 1.5 \cdot snow + 1.5 \cdot 0.3\, wind(trans + vert)$

V) $1.35 \cdot G + 1.35 \cdot dead + 1.5 \cdot snow + 1.5 \cdot 0.3\, wind(long)$

VI) $1.35 \cdot G + 1.35 \cdot dead + 1.5 \cdot snow + 1.5 \cdot 0.6\, temperature$

VII) $1.35 \cdot G + 1.35 \cdot dead + 1.5 \cdot 0.8\, snow + 1.5\, wind(trans + vert)$

VIII) $1.35 \cdot G + 1.35 \cdot dead + 1.5 \cdot 0.8\, snow + 1.5\, temperature$

IX) $1.35 \cdot G + 1.35 \cdot dead + 1.5 \cdot 0.4\, variable + 1.5\, temperature$

X) $1.35 \cdot G + 1.35 \cdot dead + 1.5 \cdot\, accidental$

XI) $1.35 \cdot G + 1.35 \cdot dead + 1.5 \cdot\, accidental + 1.5 \cdot 0.3\, wind(trans + vert)$

Meanwhile for the accidental situations the IAP-11 suggest

$$\sum_{j\geq 1} G_{k,j} + \sum_{m\geq 1} G^{*}_{k,m} + \psi_{1,1}\, Q_{k,1} + \sum_{i>1} \psi_{2,i}\, Q_{k,i} + A_d$$

The load combinations for the Exercise limit state are:

- Characteristic combination

$$\sum_{j\geq 1} \gamma_{G,j}\, G_{k,j} + \sum_{m\geq 1} \gamma_{G,m}\, G^{*}_{k,m} + \gamma_{Q,1}\, Q_{k,1} + \sum_{i>1} \gamma_{Q,i}\, \psi_{0,i}\, Q_{k,i}$$

- Frequent combination

$$\sum_{j\geq 1}\gamma_{G,j}\,G_{k,j}+\sum_{m\geq 1}\gamma_{G,m}\,G^{*}_{k,m}+\gamma_{Q,1}\psi_{1,1}\,Q_{k,1}+\sum_{i>1}\gamma_{Q,i}\,\psi_{2,i}\,Q_{k,i}$$

I) $1.0 \cdot G + 1.0 \cdot dead + 1.0 \cdot 0.4\ variable$

II) $1.0 \cdot G + 1.0 \cdot dead + 1.0 \cdot 0.4\ variable + 1.0 \cdot 0.5\ temperature$

III) $1.0 \cdot G + 1.0 \cdot dead + 1.0 \cdot 0.4\ variable + 1.0 \cdot 0.2\ wind$

IV) $1.0 \cdot G + 1.0 \cdot dead + 1.0 \cdot 0.6\ temperature$

- Almost-permanent combination

$$\sum_{j\geq 1}\gamma_{G,j}\,G_{k,j}+\sum_{m\geq 1}\gamma_{G,m}\,G^{*}_{k,m}+\sum_{i>1}\gamma_{Q,i}\,\psi_{2,i}\,Q_{k,i}$$

I) $1.0 \cdot G + 1.0 \cdot dead$

II) $1.0 \cdot G + 1.0 \cdot dead + 1.0 \cdot 0.5\ temperature$

Each combination has its main purpose to evaluate a specific displacement limit or the proper capacities of the sections.

6.7 Deformation limit state

In the 7.1.1 section the IAP-11 defines the limits of deformations for the footways bridges, so this limit has to be respected with the ELS load combinations.

$$\delta max \leq \frac{L}{1200} = 0.05\ m = 50\ mm$$

6.8 Vibration limit state

According to the spanish legislation (chapter 7.2.1 of the IAP-11) the dynamic study for the vibration limit state, in the case of pedestrian bridges, can be omitted if the previously mentioned deformation limit state is respected and there are not the following conditions:

- Urban traffic conditions with intense pedestrian traffic;
- New structural type with new materials.

Anyway, for footbridges the critical rank of vibrations to be avoided in order to preserve the minimum degree of confort is defined by the "tabla 7.2-a" of the aforementioned legislation, from which the following values were taken:

- Vertical and longitudinal 1.25 – 4.60 [Hz]
- Lateral 0.50 – 1.20 [Hz]

Even tought the previosly conditions were met, and so it was not necessary to check the values of the frequencies related to the first modal mode of the structure, it has been checked that these values of frequencies were lower than the aforementioned limits.
In the "results' annex" a table shows the values of all the frequencies related at each mode.

6.9 Foundations

6.9.1 Methodology employed

In the study phase, geotechnical surveys have been carried out beneath the supports, although there are areas not studied due to difficulties in accessing research points.

Based on the geotechnical analysis carried out, the dimension, geometry and the typology of the foundations are established. Below are the formulations and fundamental theories that will be taken into account.

6.9.2 Foundation typology

For this structure the typology chosen is to install the deep foundations. Due to the fact they are suggested in cases when the compressed floor could cause problems in a direct foundation, and so the right number of piles will be concrete in situ just beneath the bridge pylons and the abutments.

The minimum number of these elements depends by the soil characteristics and the tensions applied to the soil.

At the beginning a minimum of 5 piles are proposed.

The sink load of each pile is obtained as a sum of a tip and shaft resistance:

$$Q_h = q_p A_p + \Sigma\, q_{fi} A_{fi}$$

Where:

- Ap = area of the tip
- Afi = lateral area on each soil layer
- qp = unitary tip resistance, depends on the soil
- qfi = unitary shaft resistance, depends on the soil

for granular soil (C = 0) the tip resistance is given by the expression

$$q_p = \sigma'_v N_{qp} = \gamma\, h\, N_{qp}$$

where:

- Nqp is the factor of the load capacity, function of the angle of internal rubbing, and according to Caquot Kerisel, can be adopted the value

$$Nqp = 10^{3.04 tg\Phi}$$

- ϒ is the soil density
- h the length of the pile

however, when the information about the soils come from SPT trials, the tip resistance can be expressed with the expression of Meyerhorf (1976)

$$qp\ (KN/m^2) = 40 * Nspt * L/D \quad <= 400 N_{SPT}$$

the static penetration resistance Rp is between 2NSPT (lime-clays) and 5NSPT (sands).
Usually the coefficient μ decreases increasing the static penetration resistance Rp and the diameter of the pile. Thus the unitary resistance for the tip will be:

- $qp = 4N_{30}$ for $D \leq 0.5$ m
- $qp = 2N_{30}(3\text{-}d)$ for $0.5 < D \leq 2$ m
- $qp = 2N_{30}$ for $D \geq 2$ m

In the case of clean gravels, it is usually adopted: qp= 120 kg/cm^2 , for sandy lands 80 kg/cm^2 and clays or limes 50 kg/cm^2.
Instead, for cohesive soils, the unitary resistance of the tip is obtained with the following expression:

$$qp = c_u\ Ncp \sim 4.5\ q_u$$

Where:

- Cu = shear resistance not drained
- Ncp = 9 for Φ = 0

- Qu = simple compression resistance

The number of piles needed in order to sustain the load only with the tip resistance change with the soil capacities, so the resistances of upper and lower layers must be considered.

Meanwhile the shaft resistance is expressed by:

$$q_{fi} = P'_h \tan \delta' + C'_a$$

According to Burland, it can be adopted the value $\delta' = \Phi' - 5°$

- Ks = 0.5 (fine sands)
- Ks = 1.0 (dense sands)

On granular soil the legislation establish a relation

$$q_f = \varepsilon \, Rp$$

For orientation purposes, the most usual values of this coefficient in function of the SPT results are showed below:

Nspt	5	11	18	30	40
qf (t/m2)	3.0	4.5	6.0	8.5	10.0

For the calculation of the admissible load, a safety coefficient of not less than 2 for the shaft and 3 for the tip may be adopted.

6.9.3 Design forces

First of all, the reaction forces at the base of the pylon have been gathered, and the highest reactions will be considered for the design process.

TABLE: Joint Reactions at the base of the pylons						
Combination	F1	F2	F3	M1	M2	M3
Text	KN	KN	KN	KN-m	KN-m	KN-m
FREQUENT1	-6.823E-12	16.608	2272.384	-18.4759	-5.3E-10	7.62E-12
FREQUENT2	-1.101E-11	109.58	2214.511	-451.764	-6.5E-10	3.02E-12
FREQUENT3	-32.352	21.007	2433.021	-29.9399	-328.059	5.6687
FREQUENT4	-1.116E-11	115.507	1740.001	-505.426	-4.3E-10	-1.9E-12
ULS1	-242.638	99.142	5201.868	-237.092	-2460.44	42.5154
ULS2	-0.026	235.846	3999.715	-936.309	1.754	-0.0308
ULS3	-72.817	35.642	2902.915	-70.8253	-736.379	12.7238
ULS4	-0.026	193.094	2437.309	-824.949	1.754	-0.0308
ULS5	-242.659	58.266	3724.9	-129.956	-2459.04	42.4908
ULS6	-0.02	304.192	2346.502	-1343.84	1.4032	-0.0247
ULS7	-2.02E-11	321.317	2955.467	-1389.11	-1.3E-09	1.26E-12
ULS10	1.867	95.16	2637.432	-313.117	-124.181	2.8761
ULS11	-70.924	105.057	2998.866	-338.911	-862.314	15.6308
G+DEAD+CABLES	-6.136E-12	3.941	1809.449	14.5196	-3E-10	3.59E-12
TORSION+WIND	-236.786	63.692	4173.965	-134.129	-2898.46	49.8229

Table 17 - Foundation design: Joint reactions

The highest values are highlighted in yellow:

- Vertical reaction

$$Ved = 5201.868\ kN$$

- Horizontal reaction

$$Hed = 321.317\ kN$$

- Moment reaction

$$Med = 2898.46\ kNm$$

Proposing a piles distribution as showed in the picture below, the design will consist to find the right dimensions of D (diameter) and L (length) of the piles.

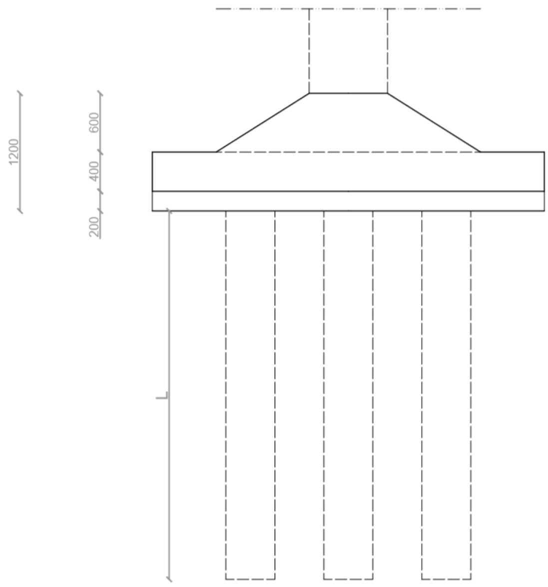


Figure 27 - Foundation geometry

The author proposed to install 5 piles symmetrically distributed under the two pylons. The following step will be to find the distribution of the forces acting on each pile under the worst load condition, and so how the moments will be redistributed on each pile, which will sustain the whole structure with vertical forces.

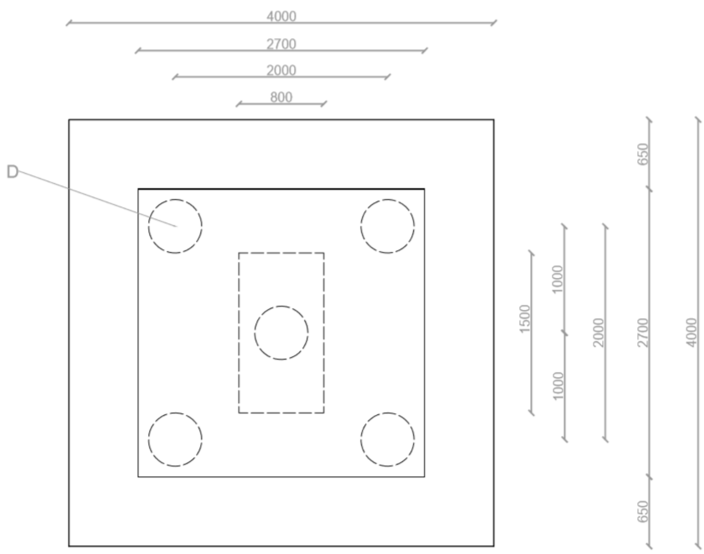


Figure 28 - Foundation geometry top view

6.9.4 Maximum forces acting on one single element (ULS - load combinations):

Combination with maximum vertical Ved

- Vertical due to vertical

$$Vved1 = \frac{Ved}{5} = 1040.37\ kN$$

- Vertical due to moment

$$Vmed1 = \frac{Med}{4 \cdot 1\ m} = \frac{2460.64}{4} = 615.16\ kN$$

$$Vtot1 = 1040.37 + 615.16 = 1655.53\ kN$$

Combination with maximum Moment Med

- Vertical due to vertical

$$Vved2 = \frac{Ved}{5} = \frac{4173.965}{5} = 834.793\ kN$$

- Vertical due to moment

$$Vmed2 = \frac{Med}{4 \cdot 1\ m} = \frac{2898.46}{4} = 724.615\ kN$$

$$Vtot2 = 834.793 + 724.615 = 1559.408\ kN$$

Max horizontal force

$$Hed = \frac{321.317}{5} = 64.26\ kN$$

6.9.5 Maximum forces acting on one single element (Geo - load combinations) NTC2008:

Combination with maximum vertical Ved

- Vertical due to vertical

$$Vved1 = \frac{Ved}{5} = \frac{2272.384}{5} = 454.48 \ kN$$

- Vertical due to moment

$$Vmed1 = \frac{Med}{4 \cdot 1 \ m} = \frac{18.76}{4} = 4.69 \ kN$$

$$Vtot1 = 454.48 + 6.69 = 459.17 \ kN$$

Combination with maximum Moment Med

- Vertical due to vertical

$$Vved2 = \frac{Ved}{5} = \frac{1740.001}{5} = 348.00 \ kN$$

- Vertical due to moment

$$Vmed2 = \frac{Med}{4 \cdot 1 \ m} = \frac{505.426}{4} = 126.36 \ kN$$

$$Vtot2 = 348.00 + 126.36 = 474.36 \ kN$$

Max horizontal force

$$Hed = \frac{115.507}{5} = 23.10 \ kN$$

Maximum design forces:

- ULS

$$Vedi = 1655.53\ kN$$

- ELS

$$Vedi = 474.36\ kN$$

6.9.6 Soil properties

Due to the fact the information about the soil come from an SPT analysis, it is possible to define the tip resistance of the pile with the expression of Meyerhorf (1976) previously mentioned. Following a table show the tip resistance for each layer and with various dimensions of the pile's diameter (D).

Soil characteristics			D (m)				qp (kN/m^2)			Ap (m^2)		
z1 (m)	z2 (m)	Nspt	D1	D2	D3	L (m)	qp(D1)	qp(D2)	qp(D3)	Ap1	Ap2	Ap3
3.0	3.6	4	0.4	0.6	0.8	3	1200	800	600	0.125664	0.282743	0.502655
6.0	6.6	14	0.4	0.6	0.8	3	4200	2800	2100	0.125664	0.282743	0.502655
9.0	9.6	17	0.4	0.6	0.8	3	5100	3400	2550	0.125664	0.282743	0.502655
12.0	12.6	32	0.4	0.6	0.8	3	9600	6400	4800	0.125664	0.282743	0.502655
15.0	15.6	24	0.4	0.6	0.8	3	7200	4800	3600	0.125664	0.282743	0.502655
18.0	18.6	53	0.4	0.6	0.8	3	15900	10600	7950	0.125664	0.282743	0.502655
21.0	21.6	70	0.4	0.6	0.8	3	21000	14000	10500	0.125664	0.282743	0.502655
14.0	24.6	60	0.4	0.6	0.8	3	18000	12000	9000	0.125664	0.282743	0.502655
27.0	27.6	72	0.4	0.6	0.8	3	21600	14400	10800	0.125664	0.282743	0.502655
30.0	30.6	17	0.4	0.6	0.8	3	5100	3400	2550	0.125664	0.282743	0.502655

Table 18 - Foundations: soil capacity

Meanwhile, the values of the shaft resistance have been defined by an interpolation from the SPT trials results.

Soil characteristics			qfi
z1 (m)	z2 (m)	Nspt	(kN/m^2)
3.0	3.6	4	3.1
6.0	6.6	14	5.2
9.0	9.6	17	5.8
12.0	12.6	32	8.9
15.0	15.6	24	7.3
18.0	18.6	53	13.3
21.0	21.6	70	16.8
14.0	24.6	60	14.8
27.0	27.6	72	17.3
30.0	30.6	17	5.8

Table 19 - Foundations: shaft resistance from SPT trials

6.9.7 Ultimate load resistance

At this point, the two resistances (qp and qf) are added up for difference values of the pile's diameters (D1, D2 and D3) and afterwards the optimal dimensions of the pile (D, L) has been chosen.

Soil characteristics			D (m)				qp (kN/m^2)			qfi	Qh (kN/m^2)		
z1 (m)	z2 (m)	Nspt	D1	D2	D3	L (m)	qp(D1)	qp(D2)	qp(D3)	(kN/m^2)	Qh1(z)	Qh2(z)	Qh3(z)
3.0	3.6	4	0.4	0.6	0.8	3	1200	800	600	3.1	162.4	243.6	324.8
6.0	6.6	14	0.4	0.6	0.8	3	4200	2800	2100	5.2	558.9	838.3	1117.8
9.0	9.6	17	0.4	0.6	0.8	3	5100	3400	2550	5.8	693.8	1040.7	1387.6
12.0	12.6	32	0.4	0.6	0.8	3	9600	6400	4800	8.9	1292.9	1939.4	2585.8
15.0	15.6	24	0.4	0.6	0.8	3	7200	4800	3600	7.3	1018.7	1528.0	2037.3
18.0	18.6	53	0.4	0.6	0.8	3	15900	10600	7950	13.3	2162.0	3243.1	4324.1
21.0	21.6	70	0.4	0.6	0.8	3	21000	14000	10500	16.8	2866.4	4299.6	5732.8
14.0	24.6	60	0.4	0.6	0.8	3	18000	12000	9000	14.8	2545.0	3817.5	5090.0
27.0	27.6	72	0.4	0.6	0.8	3	21600	14400	10800	17.3	3062.4	4593.6	6124.8
30.0	30.6	17	0.4	0.6	0.8	3	5100	3400	2550	5.8	1010.8	1516.2	2021.6

Table 20 - Foundations: Ultimate load resistance for different pile's diameters and lentgh

Therefore, it was chosen to adopt 5 piles with a diameter $60\ cm$ of and a length of $12\ m$ which can sustain a total vertical load of $Qh = 1934.4\ kN$ each.

6.9.8 Verifications of the foundation resistance

Applying the method of the "approach-1 combination-2" of the Italian legislation (NTC 2008) is resulted as follow:

$$Rc, k, punta = \frac{1809.56}{1.7} = 1064.45\ kN$$

$$Rc, klaterale = \frac{129.826}{1.7} = 76.37\ kN$$

$$Rd = \frac{Rc, k, p}{1.7} + \frac{Rc, k, l}{1.45} = 679\ kN$$

The verification is satisfied as showed below:

$$Rd = 679\ kN \quad > \quad Ed = 474.6\ kN$$

It can be possible also to do another type of verification with the security coefficients and with the uls load combinations and summing the weight of the pile. Taking a security coefficient of 3:

$$Qadm = \frac{Qh}{FS} - W = \frac{1934.4}{3} - 81.4 = 563.4\ kN$$

Which is still higher than

$$Ed = 474.6\ kN$$

6.9.9 Horizontal Balast coefficient – seismic risk

With the aim to estimate the horizontal balast coefficient (Kh) for different geological units detected during the execution of the soundings, the expressions proposed by Terzaghi (1955) is considered. The expression for the horizontal balast module in granular materials is as follows

$$K_h = nh^*z/D$$

Nh is a value which depends by the depth

For clay soils the expression to be used is as follow:

$$K_h = 66.7 \cdot \frac{C_U}{D}$$

And so applying the values obtained from the soil trials, it is possible to define this coefficient with the depth as showed in the “table 21” below:

Prof	LITOLOGÍA	Kh (T/m^3)
8,0	sorres	1600
10,0	Argiles llimoses	333
14,0	sorres	1120
17,8	sorres	7120
18,1	sorres	1450
26,3	Argiles	600
27,8	sorres	2226
44,6	Argiles	600
50,8	sorres	20328
52,8	Graves sorres	21128
54,8	Graves sorres	21928

Table 21 - Litology and soil's layers

6.9.10 Seismic risk

According to the "Norma sismorresistente (NCSR-02)" the municipal term of the zone in question presents the following coefficients:

Acceleració sísmica bàsica	$a_b/g = 0.04$
Coeficient de contribució	k = 1

And the soils are defined by their type to which is given a coefficient C

	Tipus de terreny	Coeficient C
Reblerts antròpics (RA)	IV	2.0
Sorres fines (Q_1)	IV	2.0
Argiles llimoses (Q_2)	IV	2.0
Sorres llimoses (Q_3)	III	1.6
Graves sorrenques (Q_4)	III	1.6

6.10 Connectors

The connection between the concrete slab and the steel frame is made up by a line of steel studs welded on center of the beam flange. In this way there will be two lines of connectors on the whole deck section. The choice to install the studs on the same line of the beam center makes work the entire deck as a whole element, even if they actually are two different elements made of two different materials.

The chosen connection is a rigid type connection, which permits the section to reach its maximum allowable flector moment and so the maximum shear tension between the slab ad the steel frame.

In this way increasing the number of studs per meter the resistant moment of the deck will not increase, due to the fact the maximum capacities of the elements which compose the composite section are already reached. So the hypothesis of perfect interaction have been considered in the calculations.

First, it has to be defined the maximum shear stress on the critical sections with the elastic theory, afterwards, once the stud type has been selected, and so the ultimate resistance of the selected stud is known just remain to define the minimum number of connectors for each length.

According to the Eurocode 4 (EN 1994-1-1) the ultimate resistance of the stud will consist in:

$$\min(PrdStud; PrdConcrete)$$

Taking in mind the geometry of the girder and its elements a stud with the following dimensions has been proposed $d = 16\ mm$ y $h = 80\ mm$.

$$PrdStud = 0.8 \cdot fu \cdot \frac{\frac{\pi \cdot d^2}{4}}{\gamma_v} = 0.8 \cdot 350\ MPa \cdot \left(\frac{\frac{\pi \cdot 16^2}{4}}{1.25}\right) = 45\,037.87\ N$$

$$PrdConcrete = 0.29 \cdot \alpha \cdot d^2 \cdot \frac{\sqrt{fck \cdot Ecm}}{\gamma_v} = 0.29 \cdot 1 \cdot 16^2 \cdot \frac{\sqrt{40 \cdot 35500}}{1.25} = 70\,773.74\ N$$

Where for C40/45 concrete type

$$fck = 40\ MPa$$

$$Ecm = 35.5\frac{kN}{mm^2}$$

$$\Upsilon v = 1.25$$

$$\alpha = 1$$

$$h, d = height\ and\ diameter\ of\ the\ stud$$

Therefore, the ultimate resistance of the stud is defined by the resistance of the steel element

$$PrdStud = 45\ 037.87\ N$$

Afterwards the minimum number of studs per unit length is defined as:

$$N = \frac{Vl}{Prd}$$

The highest value of shear tension is on the pylons and its value is

$$Vmax = 422.6\ kN$$

And so

$$N = \frac{Vl}{Prd} = \frac{422\ 600}{45\ 037.87} = 9.38 \quad \rightarrow \quad N = 10\ \text{studs every meter of slab}$$

<u>The minimum space between the studs</u>:

Longitudinally

$$l \geq 5 \cdot d = 80\ mm$$

Transversally

$$l \geq 4 \cdot d = 64\ mm$$

The author chosen to install two lines of connectors above each HE-shaped beam, and so with a total on 2 lines of connectors spaced as showed below in “figure 29”:

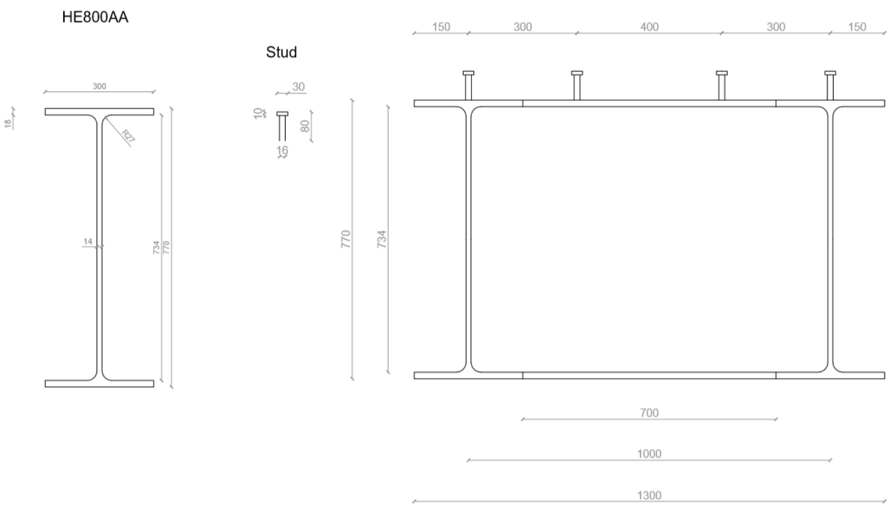


Figure 29 - Connectors distribution

6.11 External supports

The external supports at the ends of the deck of the bridge are some important elements because influence the behavior of the whole structure. The author chosen to exploit the properties of the neoprene supports and so to leave free rotations on the deck ends, however confer horizontal restrains which assure the stability of the deck.

Th main problem in these cases is to check the stability of the deck with the worst condition regard torsional effects. Because if the deck rise up from just one of the supports the entire bridge could fail. The worst condition with which this can happen is when the structure experiments the worst torsional load, so in order to consider this load a proper load combination has been created.

This load combination gathers all the possible loads which could make this happen, and for which a new load case has been create with the name of “torsion”. This load pattern is featured by the sum of all variable loads applied on just one side of the deck.

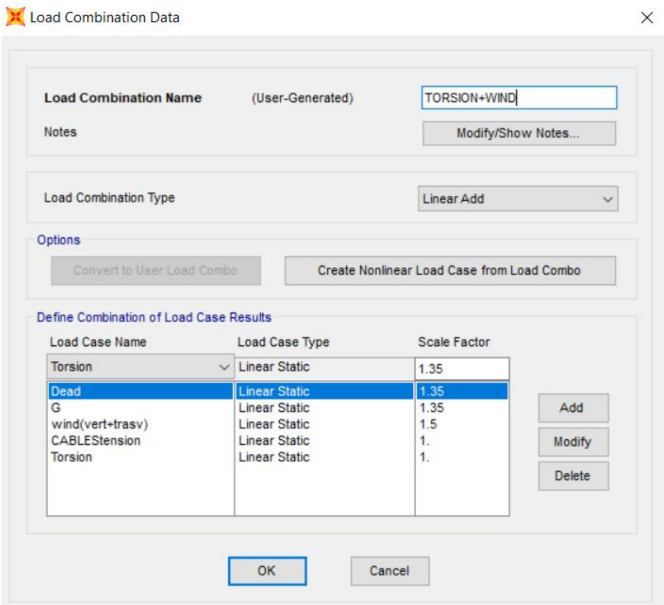


Figure 30 - External support design: Torsion load condition

In this load combination also the wind effects have been summarized and the ULS coefficients have been applied as usual.

At the beginning the supports were put just beneath the center of the HE-shaped beams but as we can see one reaction force is downward, this means that the bridge would rise up, and we must avoid this.

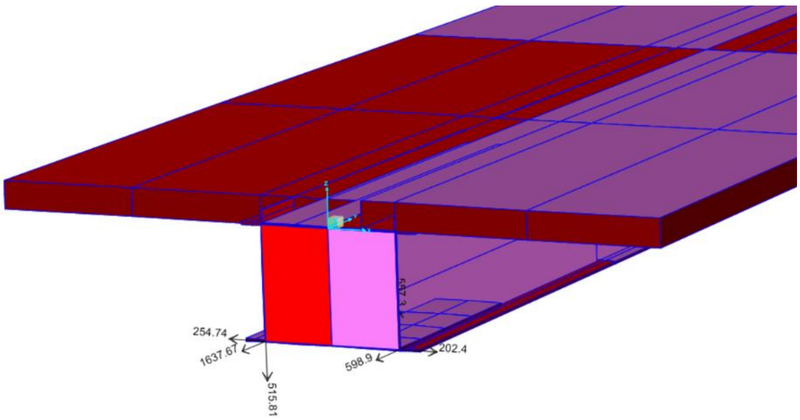


Figure 31 - External supports: Vertical reactions

With the aim to reduce this vertical reaction the supports have been enlarged in accord to the width on the deck section obtaining a downward vertical reaction of 35 Kn.

Now there are two choices to prevent the bridge from rising, or we clamp it at the edge, totally changing the type of support; or in order to maintain the same type of support, apply in the same point another downward vertical force higher than this reaction.

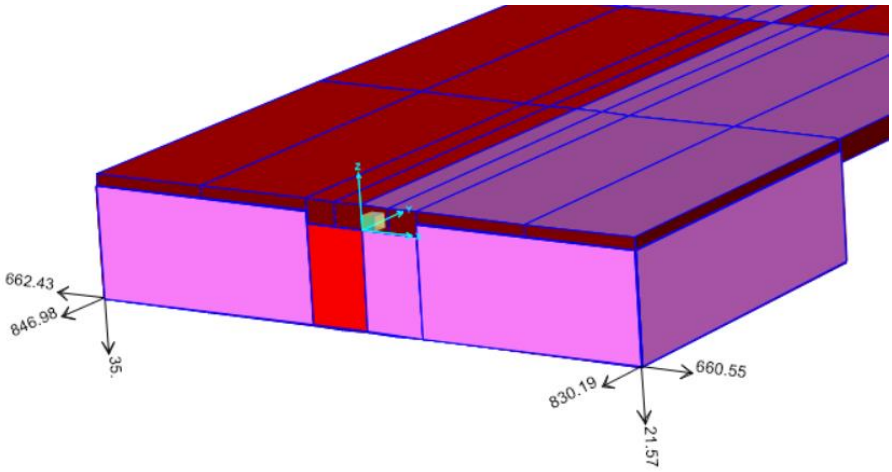


Figure 32 - External supports: Vertical reaction forces with the concrete beam

So in order to counteract this force the author chosen to cast at the ends of the bridge a concrete beam perpendicular to the direction of the deck, in which the steel section of the deck will be clamped in it. The mass of this beam will be great enough in order to counteract the downward reaction force, and so impede any torsional problem on the supports.

The concrete beam dimensioned will add a downforce on the support of 67.5 kN, and so the final reaction will be 32.5 kN upward.

6.11.1 Support devices

This section has been developed according to:

- Eurocode 3, part 3, Structural bearings: elastomeric bearings (EN 1337-3 2005)

In the following table all the reaction forces on the supports are summarized:

Vertical max	198.61 kN
Vertical min	69.3 kN
Transversal max	3276.57 kN
Longitudinal max	3008.76 kN
Rotation max	0.00717 rad

Table 22 - External supports: Reation forces

6.11.1.1 Design proposal

Fisrt device proposal

There are 2 support devices on each end, separated from 5 meters as previously showed. With the aim to select the appropriate support devices, it is necessary to know the maximum and minimum loads on the abutments, these loads were already summarized.

As the maximum reactions supported by the support devices do not exceed 15000 kN, the neoprene support devices can be used.

the criteria adopted to pre-dimensioning these elements is the criteria established in the book “Aparatos de apoyos para puentes y estructuras” of the Ángel Aparicio Engineering Doctor, which establishes for the calculation of the area of the plate.

$$A_n \geq \frac{N_{máx}}{\sigma_n \, adm}$$

Where:

$N_{máx}$: maximum vertical force

σ_n *adm*: average compression force available

As a criterion for pre-dimensioning $\sigma_n\ adm = 12\ N/mm^2$ is considered as the average compressive pressure of the neoprene (in some specific cases can reach the value of 15 MPa)

$$A_n \geq \frac{131\ 110\ N}{15\ \frac{N}{mm^2}} = 8740.67\ mm^2$$

For a rectangular geometric solution, a support device of 100x150 mm^2 is obtained and the area required by the pre-dimensioning is fulfilled.

On the other hand, a minimum load condition must be met on the support to prevent the neoprene plate and concrete from taking off due to the fact it seeks to avoid phenomena of plate creep.

$$15000\ mm^2 = A_n \leq \frac{N_{min}}{3\ \frac{N}{mm^2}} = \frac{69\ 300\ N}{3\ \frac{N}{mm^2}} = 23100\ mm^2$$

The maximum thickness of the neoprene will be limited by a condition of stability, so the thickness of rubber should not exceed the fifth of the smallest dimension in plan.

For the estimation of the thickness of the neoprene and the steel plates, the criteria established in the *"table 3 of the EN 1337"* are followed:

	a (mm)	b (mm)	A (m^2)	a' (mm)	b' (mm)	A' (m^2)	n	$e_{neoprene}$ (mm)	e_{steel} (mm)
Neoprene	100	150	0,015	90	140	0,0126	3	8	3

6.11.1.2 Support devices checks

The checks that are detailed below have been made on the support devices previously pre-dimensioned. The values of the parameters used in each of the checks are detailed in the explanation of each of them.

To obtain the perimeter and the effective area, 5 mm are subtracted on each side corresponding to the coating zone without steel. With these parameters the form factor is obtained:

$$S = \frac{A'}{lp * te} = \frac{12600\ mm^2}{2 \cdot (90 + 140)\ mm \cdot 8\ mm} = 6.06$$

Deformation checks

The strains have to comply the inequality:

$$\varepsilon_{t,d} = K_L * (\varepsilon_{c,d} + \varepsilon_{q,d} + \varepsilon_{\alpha,d}) \leq 7$$

Besides

$$\varepsilon_{c,d} \leq 4$$

$$\varepsilon_{q,d} \leq 1$$

$$\varepsilon_{\alpha,d} \leq 2$$

Deformation due to compression

$$\varepsilon_{c,d} = \frac{1{,}5 \cdot F_{z,d}}{G \cdot S \cdot A_{\gamma}}$$

Where

- A_{γ} is the effective area reduced due to load effects

$$A_{\gamma} = A' \cdot \left(1 - \frac{u_{x,d}}{a'} - \frac{u_{y,d}}{b'}\right) = 12\,600\ mm^2$$

- G is the shear module of the neoprene

$$G = 0.9\ MPa$$

- S is the shape factor
- $F_{z,d}$ the maximum vertical reaction

For which

$$\varepsilon_{c,d} = \frac{1{,}5 \cdot F_{z,d}}{G \cdot S \cdot A_{\gamma}} = \frac{1{,}5 \cdot 131\,110\ N}{0{,}9\ MPa \cdot 6.06 \cdot 12600\ mm^2} = 2.86 \ \leq 4$$

Shear deformation

This deformation is due to the transversal displacements and is expressed by this equation:

$$\varepsilon_{q,d} = \frac{u_{xy,d}}{T_q} = \frac{28.7}{30} = 0.96 \ \leq 1$$

Where $u_{xy,d}$ is the resultant horizontal displacement w

hich in our case is 28.7 mm, and T_q is the thickness of the elastomeric deviceso 30 mm.

This value of strain is too close to the limits and could cause problems along the life of the neoprene support. Therefor, with the aim to reduce the problems caused by horizontal displacements on the supports, it has been chosen to increase the dimension of the supports, even because the professionals with the experience in this sector suggest to design the thickness of the device according to the maximum horizontal forces.

So this first design proposal has been rejected and another device was proposed in accordance with the aforementioned questions.

Second device proposal

This time the device was pre-dimensioned according to the horizontal strain of the elastometric device. In order to respect the value of

$$\varepsilon_{q,d} = \frac{u_{xy,d}}{T_q} = 0.5 \leq 1$$

And due to the fact that the maximum horizontal displacemnt amount at 28.7 mm, a neoprene device with a thickness of 60 mm has been chosen. So that, respecting the "*table 3 of the EN 1337*" it has been chosen a device with dimensions 300x400 mm with 4 layers of neoprene with 12 mm of thickness and 3 of reinforcement with 4 mm of thickness.

Tabla 3
Tamaños normalizados para los apoyos tipo B

Dimensiones a x b (mm) o D	Espesor en mm						Número de capas n	
	Apoyo sin carga		Elastómero (total*)		Capas de elastómero	Placas de refuerzo	Mín.	Máx.
	Mín.	Máx.	Mín.	Máx.				
100 × 150	30	41	16	24	8	3	2	3
100 × 200	30	41	16	24	8	3	2	3
150 × 200	30	52	16	32	8	3	2	4
ϕ 200	30	52	16	32	8	3	2	4
150 × 250	30	52	16	32	8	3	2	4
150 × 300	30	52	16	32	8	3	2	4
ϕ 250	30	52	16	32	8	3	2	4
200 × 250	41	74	24	48	8	3	3	6
200 × 300	41	74	24	48	8	3	3	6
200 × 350	41	74	24	48	8	3	3	6
ϕ 300	41	74	24	48	8	3	3	6
200 × 400	41	74	24	48	8	3	3	6
250 × 300	41	85	24	56	8	3	3	7
ϕ 350	41	85	24	56	8	3	3	7
250 × 400	41	85	24	56	8	3	3	7
300 × 400	57	105	36	72	12	4	3	6
ϕ 400	57	105	36	72	12	4	3	6
300 × 500	57	105	36	72	12	4	3	6
ϕ 450	57	105	36	72	12	4	3	6
300 × 600	57	105	36	72	12	4	3	6
350 × 450	57	121	36	84	12	4	3	7
ϕ 500	57	121	36	84	12	4	3	7
400 × 500	73	137	48	96	12	4	4	8
ϕ 550	73	137	48	96	12	4	4	8
400 × 600	73	137	48	96	12	4	4	8
450 × 600	73	153	48	108	12	4	4	9
ϕ 600	73	153	48	108	12	4	4	9
500 × 600	73	169	48	120	12	4	4	10
ϕ 650	73	169	48	120	12	4	4	10
600 × 600	94	199	64	144	16	5	4	9
ϕ 700	94	199	64	144	16	5	4	9
600 × 700	94	199	64	144	16	5	4	9
ϕ 750	94	199	64	144	16	5	4	9
700 × 700	94	220	64	160	16	5	4	10
ϕ 800	94	220	64	160	16	5	4	10
700 × 800	94	220	64	160	16	5	4	10
ϕ 850	94	220	64	160	16	5	4	10
800 × 800	110	285	80	220	20	5	4	10
ϕ 900	110	285	80	220	20	5	4	10
900 × 900	110	285	80	220	20	5	4	11

* Espesor total sin cubierta superior e inferior de 2,5 mm.

Table 23 - Support devices:Table 3 of EN1337

The checks that are detailed below have been made on the support devices previously pre-dimensioned. The values of the parameters used in each of the checks are detailed in the explanation of each of them.

To obtain the perimeter and the effective area, 5 mm are subtracted on each side corresponding to the coating zone without steel. With these parameters the form factor is obtained:

$$S = \frac{A'}{lp * te} = \frac{113100\ mm^2}{4 \cdot (390 + 290)\ mm \cdot 12\ mm} = 3.47$$

6.11.1.3 Deformation checks

The strains have to comply the inequality:

$$\varepsilon_{t,d} = K_L * (\varepsilon_{c,d} + \varepsilon_{q,d} + \varepsilon_{\alpha,d}) \leq 7$$

Besides

$$\varepsilon_{c,d} \leq 4$$

$$\varepsilon_{q,d} \leq 1$$

$$\varepsilon_{\alpha,d} \leq 2$$

<u>Deformation due to compression</u>

$$\varepsilon_{c,d} = \frac{1{,}5 \cdot F_{z,d}}{G \cdot S \cdot A_Y}$$

Where

- A_Y is the effective area reduced due to load effects

$$A_Y = A' \cdot \left(1 - \frac{u_{x,d}}{a'} - \frac{u_{y,d}}{b'}\right) = 113100 \cdot \left(1 - \frac{22}{290} - \frac{28.7}{390}\right) = 96690\ mm^2$$

- G is the shear module of the neoprene

$$G = 0.9\ MPa$$

- S is the shape factor

- $F_{z,d}$ the maximum vertical reaction

For which

$$\varepsilon_{c,d} = \frac{1{,}5 \cdot F_{z,d}}{G \cdot S \cdot A_{\gamma}} = \frac{1{,}5 \cdot 131\ 110\ N}{0{,}9\ MPa \cdot 3.47 \cdot 96690\ mm^2} = 0.65 \ \leq 4$$

<u>Shear deformation</u>

This deformation is due to the transversal displacements and is expressed by this equation:

$$\varepsilon_{q,d} = \frac{u_{xy,d}}{T_q} = 0.5 \leq 1$$

<u>Deformation due to rotation</u>

this deformation id defined through the following expression

$$\varepsilon_{\alpha,d} = \frac{\left(a'^2 \cdot \alpha_{a,d} + b'^2 \cdot \alpha_{b,d}\right) \cdot t_i}{2 \cdot \Sigma\left(t_i^3\right)} \leq 2$$

Where

- $\alpha_{a,d}$ y $\alpha_{b,d}$ are the rotations in radiant

- t_i is the thickness of a single layer of neoprene

$$\varepsilon_{\alpha,d} = \frac{\left(a'^2 \cdot \alpha_{a,d} + b'^2 \cdot \alpha_{b,d}\right) \cdot t_i}{2 \cdot \Sigma\left(t_i^3\right)} = \frac{(290^2 \cdot 0.00717) \cdot 8}{2 \cdot 3 \cdot 8^3} = 1.57 \ \leq 2$$

Global check of deformations

$$\varepsilon_{t,d} = K_L \cdot (\varepsilon_{c,d} + \varepsilon_{q,d} + \varepsilon_{\alpha,d}) = 1 \cdot (0.65 + 0.5 + 1.57) = 2.72 \leq 7$$

As observed the limitations of maximum deformations are verified.
Tension check

Tension in the steel plate

When the load is applied, the elastomer tends to compress in the direction of the force and to expand in the other two directions. The objective of the steel plates is to prevent these deformations by decreasing the neoprene thickness between plates, but for this. The plate will suffer some tensile stresses, therefore in the verification this stress must not exceed the steel plasticizing value established at $fyk = 355 \frac{N}{mm^2}$.

So in order to not exceed this value of plasticizing stress, the minimum thickness of the plates have the following expression:

$$t_{s,min} = \frac{K_p \cdot F_{Z,d} \cdot (t_1 + t_2) \cdot K_n \cdot \gamma_m}{A_\gamma \cdot f_y}$$

Where

- $t_1\ y\ t_2$ are the thickness of the elastomer
- $K_n = 1$ is the value for the induced tensile stresses
- $K_p = 1.3$ is a correction factor for the stresses
- γ_m is a partial safety factor which is taken equal to 1

Thus

$$t_{s,min} = \frac{K_p \cdot F_{Z,d} \cdot (t_1 + t_2) \cdot K_n \cdot \gamma_m}{A_\gamma \cdot f_y} = \frac{1.3 \cdot 131\ 110 \cdot (12 + 4) \cdot 1 \cdot 1}{12\ 600 \cdot 355} = 0.6097\ mm$$

Therefor the adopted value ($4\ mm$) comply perfectly this requirement.

Condition of no glide

This check will be carry out with two verifications. The first is to check that the result of horizontal reactions do not exceed the friction force and the second is to verify that there is a minimum tension. So it is necessary to evaluate:

$$F_{xy,d} \leq \mu_e \cdot F_{z,d\,min}$$

$$\sigma_{c,d\,min} = \frac{F_{z,d\,min}}{A_\gamma} \geq 3\ N/mm^2$$

The friction force coefficient is defined as

$$\mu_e = 0{,}1 + \frac{1{,}5 \cdot K_f}{\sigma_{c,d\,min}}$$

Where

- $K_f = 0.6$ is the friction factor

- $\sigma_{min,d}$ is the minimum tension

$$\sigma_{c,d\,min} = \frac{F_{z,d\,min}}{A_\gamma} = \frac{69\ 300\ N}{12\ 600\ mm^2} = 5{,}5\ N/mm^2\ \geq 3\ N/mm^2$$

So that

$$\mu_e = 0{,}1 + \frac{1{,}5 \cdot 0.6}{5.5} = 0.264$$

Taking all this in mind it is possible to follow on the verification with

$$F_{xy,d} = 4\ 443.\ 4\ N \leq 0{,}264 \cdot 69\ 300\ N = 18\ 296.2\ N$$

Torsion stability

The limit condition of rotation verifies that the steel plates and the neoprene layers do not detach due to the rotation of the bridge. This condition is checked with the following expression:

$$\sum u_z \geq \frac{\left(a' \cdot \alpha_{a,d} + b' \cdot \alpha_{b,d}\right)}{K_{r,d}} = \frac{(290\ mm \cdot 0{,}00717)}{3} = 0.6931\ mm$$

$$\sum u_z = \frac{F_{z,d\ max} \cdot n_e}{A'} \cdot \left(\frac{1}{5 \cdot G \cdot S^2} + \frac{1}{E_b}\right)$$

$$\sum u_z = \frac{198\,610\ N \cdot 48\ mm}{113100\ mm^2} \cdot \left(\frac{1}{5 \cdot 0{,}9\ MPa \cdot 3.47^2} + \frac{1}{2000\ MPa}\right) = 1.6\ mm \geq 0{,}6931\ mm$$

The last condition of the abutment support devices is verified, so it can be concluded that the support devices are well dimensioned.

6.11.2 Conclusions

After the whole process for the calculation and determination of the requests on the support devices, a solution has been obtained which has complied the verifications established by the EN1337. Therefore, this justifies that they are the most optimal and economic dimensions.

6.12 Verifications

6.12.1 Exercise limit state

The exercise limit states have been the most restrictive conditions to be verified, and they have conditioned all the design process for the whole structure. The major condition to be checked was the deformation limit state, for which a maximum displacement of $50\,mm$ was allowed under the frequent load case combinations.

As already said before, this condition has been the most difficult to be verified, and in order to respect this displacement limit the deck section could seems over designed, due to the fact we are actually speaking of a steel section, even if is a composite section the main resistance element is the steel box girder; and as it is well known the major problem with the steel elements is to check the ELS. Thanks to the fact they have great ductility capacities, the ULS do not affect largely the design process. The design process have been a sort of iterative process, by which starting with the minimum steel section allowable (HE340B, designed by the uls conditions) the section has been progressively increased until the exercise limit states were satisfied.

In the following table the maximum displacements of the most critical sections are showed for all the ELS load combinations, the complete table with all the results is attached in the proper annex.

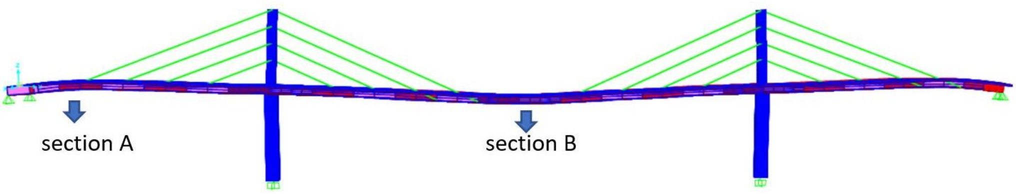


Figure 33 - Bridge deformation with the worst load case

Load condition	Displacements [mm]	
	section A	section B
Frequent1	-1	-19
Frequent2	7	-29
Frequent3	-2	-23
Frequent4	10	-20

Table 24 - ELS: Displacements values

6.12.2 Ultimate limit state

The check of the ultimate limit state has been verified for each element by mean of the results coming out from the SAP2000 model, and according with the European legislation. All the tables containing the values of the stresses of the critical sections are attached in the proper annex, in the following chapter the attention is focused on the methods adopted.

6.12.2.1 Steel

The ultimate limit state verifications adopted for the steel elements, and so for the box girder section constituted by two HE-shaped beams welded together, has been developed according to the following legislation:

- Eurocode 3 Design of steel structures part 1-1 (EN1993 1-1)

Which recommend the following rule:

$$\left(\frac{\sigma_{x,Ed}}{f_y/\gamma_{M0}}\right)^2+\left(\frac{\sigma_{z,Ed}}{f_y/\gamma_{M0}}\right)^2-\left(\frac{\sigma_{x,Ed}}{f_y/\gamma_{M0}}\right)\left(\frac{\sigma_{z,Ed}}{f_y/\gamma_{M0}}\right)+3\left(\frac{\tau_{Ed}}{f_y/\gamma_{M0}}\right)^2\leq 1$$

First the critical sections have been selected. This has been possible thank to the SAP2000 interface, by which is possible to see which elements are the most stressed for each load combination. In order to do that the author chosen to exploit the interface instruments which permit to see the normalized stresses, and so to have an idea of which elements are the most stressed and how stressed they are in respect to their $fyk\ (355\ MPa)$ and $fyd\ (338\ MPa)$ values.

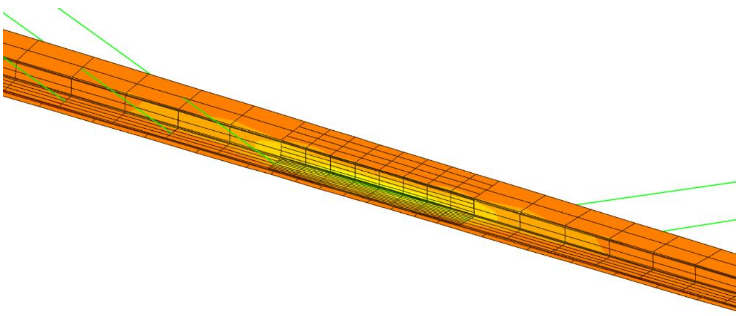


Figure 34 - Von Mises stresses on the deck

Although the author realized that the highest values of stresses where around 35-45 % of the maximum stress available, a proper verification has been carried out for these critical elements.

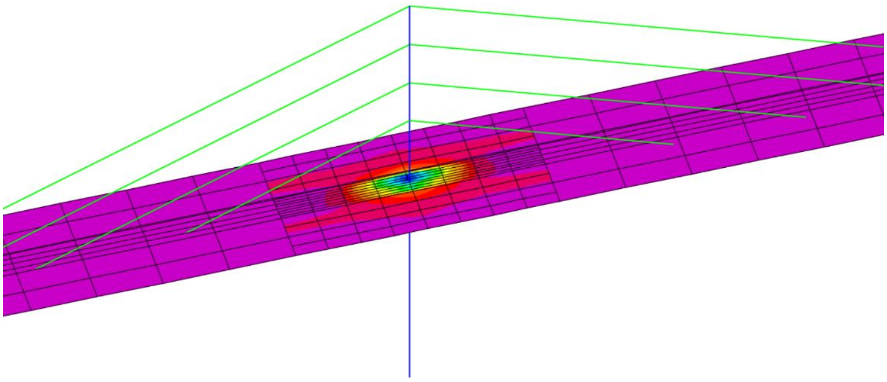


Figure 35 - highest stresses o the element around the pylons

For which first the principal stresses have been evaluated and then with the Von Mises criteria the has been checked.

$$\sigma_{id,VM} = \sqrt{\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2}$$

Which has to be lower than the $fyd\ (338\ MPa)$.

As an example the following element will be analyzed (element n°10):

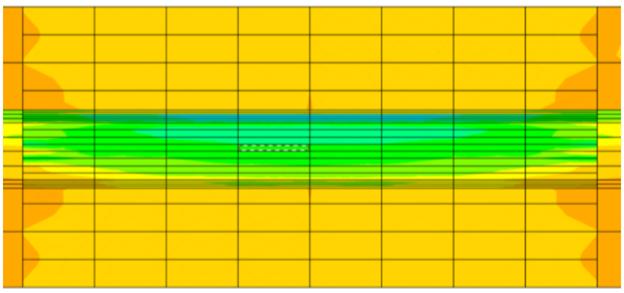


Figure 36 - Verifications: stresses on element n°10

AreaElem	OutputCase	S11	S22	S12	Smax	Smin	SAngle	SVM
Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
10	ULS1	-1.896	-84.787	28.162	6.766	-93.45	17.098	97.01
	ULS2	2.183	-120.321	12.737	3.493	-121.631	5.874	123.415
	ULS3	1.026	-36.068	9.59	3.358	-38.401	13.67	40.185
	ULS4	2.002	-95.412	10.207	3.06	-96.471	5.918	98.036
	ULS5	-2.089	-61.268	25.726	7.531	-70.888	20.502	74.937
	ULS6	1.765	-141.927	15.213	3.357	-143.52	5.978	145.228
	ULS7	1.856	-151.609	16.243	3.557	-153.309	5.976	155.118
	ULS10	2.583	-27.344	9.018	5.09	-29.851	15.538	32.695
	ULS11	1.247	-38.292	15.944	6.875	-43.92	19.443	47.73
	TORSION+WIND	3.643	-65.889	37.701	20.161	-82.406	23.66	94.12
							Max VM	155.118

Table 25 - Stress check for the element n° 10

6.12.2.2 Concrete slab

The same approach has been applied to the "plate-thick" elements which constitute the concrete slab, for which has been checked that the compressive stresses do not exceed the σcd of the concrete.

Meanwhile, if the transversal reinforcement was already designed according to the European legislation, the longitudinal bars were not. And so, analyzing the higher tensile stresses acting on the concrete part of the composite deck, it has been possible to design the longitudinal reinforcement. These values have been found exploiting the instruments of the SAP2000 interface as did for the steel shell elements.

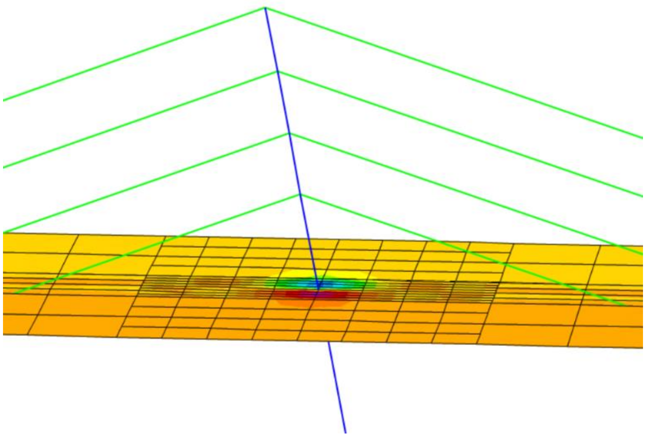


Table 26 - Highest stress values on the concrete slab

The worst load condition which induce the highest tensile stresses on the concrete slab is the UL1, and the most stressed elements have been selected.

$$\sigma \max = 424.76 \frac{N}{mm^2}$$

With this value, which is extended in a very little segment, meanwhile the other stresses around this point are about $\approx 350 \frac{N}{mm^2}$, is now possible to define the longitudinal bars.

However, considering the low value of the tensile stresses acting on the critical section (close to the pylons) the minimum amount of steel reinforcement is already enough to guarantee the resistance of the section. It is easy to realize thinking of the properties of the steel bars $fyk = 450 \frac{N}{mm^2}$.

6.12.2.3 Pylons

The same process has been applied to the pylons, however this element is not homogeneous because is made of reinforced concrete, so another type of verification has been carried out. The software used permits to design and check the RC (reinforced concrete) elements, for this reason the good behavior of the pylons has been checked by means of this instrument.

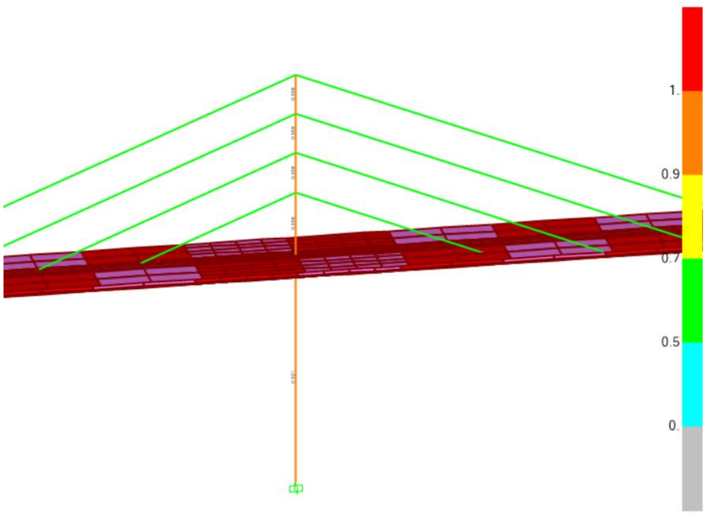


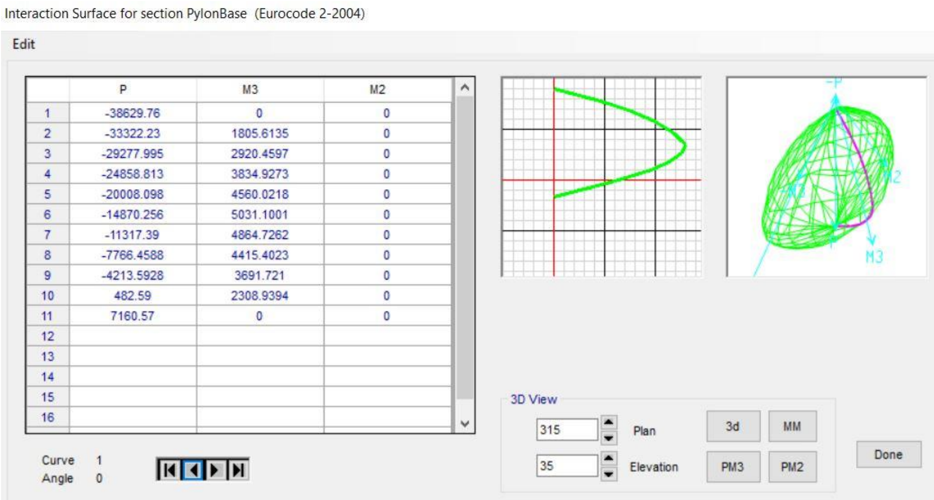
Figure 37 - Pylons design/check process

The best solution which fit the ductility requirements of the Eurocode has been carried out thank to the software interface which permits to find the best section possible, once defined the materials properties. The SAP2000 interface for the design process shows which elements are optimized and which are over dimensioned or on the contrary the ones which are undersized.


```
Eurocode 2-2004 COLUMN SECTION DESIGN  Type: DC HIGH MRF  Units: KN, m, C  (Summary)

L=10.700
Element      : 2                B=1.500          D=0.800          dc=0.068
Section ID   : PylonBase        E=35000000       fck,cyl=40000.   Lt.Wt. Fac.=1.000
Combo ID     : DCON5            fyk=413685.473   fywk=413685.47
Station Loc  : 10.700           RLLF=1.000       SOM: Nominal Curvature
Combo Eq.    : Eq. 6.10

Gamma(Concrete): 1.500          AlphaCC=1.000    AlphaCT=1.000
Gamma(Steel)   : 1.150          AlphaLCC=0.850   AlphaLCT=0.850


AXIAL FORCE & BIAXIAL MOMENT CHECK FOR NEd, MEd2, MEd3
            Capacity     Design      Design      Design     Minimum     Minimum
               Ratio        NEd        MEd2        MEd3          M2          M3
               0.893   5960.845    2333.597    3298.539     298.042     158.956

AXIAL FORCE & BIAXIAL MOMENT FACTORS
                           MOEd        Madd     Minimum        Beta           L
                         Moment      Moment         Ecc      Factor      Length
   Major Bending(M3)   3298.539       0.000       0.027       1.000      10.700
   Minor Bending(M2)   2333.597       0.000       0.050       1.000      10.700

SHEAR DESIGN FOR V2,V3
                          Rebar       Shear       Shear       Shear  Tan(Theta)
                          Asw/s         VEd        VRdc        VRds       Ratio
   Major Shear(V2)        0.000     211.154    1482.177       0.000       0.000
   Minor Shear(V3)        0.000     298.387    1469.860       0.000       0.000


AXIAL COMPRESSION RATIO
                      Conc.Capa   CompRatio   CompRatio     Seismic   CompCheck       Ratio
                          A*fcd Ned/(A*fcd)       Limit       Load?     Needed?         OK?
                      32000.000       0.186       0.550          No          No         Yes
```

Figure 38 - Pylons: Design/ check details

Thus, after an iterative process the best solution has been found and consist on two different section for the pylons. The section below the deck will be a little bigger due to the fact have to support higher tensions, meanwhile the pylon section above the deck will be loaded mostly with axial stresses, and so, a smaller section fit perfectly its duties. Besides with a thinner pylon above the deck, the bridge will look better, improving the aesthetic of the whole structure.



	P	M3	M2
1	-38629.76	0	0
2	-33322.23	1805.6135	0
3	-29277.995	2920.4597	0
4	-24858.813	3834.9273	0
5	-20008.098	4560.0218	0
6	-14870.256	5031.1001	0
7	-11317.39	4864.7262	0
8	-7766.4588	4415.4023	0
9	-4213.5928	3691.721	0
10	482.59	2308.9394	0
11	7160.57	0	0
12			
13			
14			
15			
16			

Figure 39 - Pylons desegn/check tensions iteraction

CHAPTER 7
ENVIROMENTAL IMPACT

In the homonym annex, an analysis of the actions or aspects that affect, from an environmental point of view, the area of the structure during the construction process and in the exploitation phase of the work.

The environmental aspects set out in the analysis involve the production of dust or noise emissions generated by the machinery, as well as the possible reduction in the quality of the river waters during the construction phase. In addition, protective and preventive measures are specified in the aforementioned annex.

CHAPTER 8
CONSTRUCTION PROCESS

The construction process is the most delicate phase of a project, and can compromise the entire structure behaviour, also due to the fact that if it will not be developed in a proper way, the elements could sustain tensions for which are not designed for, or the equilibrium can not be assured; so a great attention must be paid to this phase.

The foundations are to be constructed first. After that, the work with the pylons can start where each pylon will be constructed up to the height to the deck. Afterwards the provisional pylons can be constructed in the river's bed up to the height of the deck. The provisional pylons will be positioned at ten meters of distance each, and will be able to support the whole transversal deck's section. All the pylons will be protected from the water flow by a cyrcle metal barrier.
Once the two pylons and all the nine provisional pillars are build the construction of the formwork can start. The height of the formwork is about the thickness of the deck, so 1 meter and the span between of the provisional pillars is 10 meters.

At this point the formwork should be completed for all the bridge length, so the steel components of the deck can be positioned in their final location and welded toghether in order to form the steel box girder composed by the two HE-shaped beams.
Then, the joint between the pylons and the deck will be carried out as is showed in the Drawings (N° 10).

At this point is possible to start cast the concrete slab which compose the composite girder. The concrete slab will be carry out ten meters at a time.

Afterward, the pylons will be constructed up to the height where the lowest cable is connected paying attention during the realization of the special part (showed in the drawing n° 9–D), and than further up until the end of the pylons. During its realizations the 4 cables will be put inside their own spaces inside the two pylons.

After the segments of the girder and the pylons are set in place the trapezoidal profiles are fastened on the upper edges of the beams. This process is done for each cable row with the segments of the main girders welded together until the top row is reached and the deck structure meets in the middle of the span.

This way, the structure will works as a self-anchored system with the deck hanging from the cables on each side of the pylons, so starting with the *cable 4, the* previously calculated tension will be applied at the cable and subsequently the formwork and provisional pillars where will be removed.

In the drawings (N°12) is showed the specific order with wich each element has to be construted, with the aim to do not compromise final behaviour of the structure and do not change the flow of the river due to the space occupied from the provisional pillars.

BIBLIOGRAPHY

3562 febrero 2015 – “Puentes arco (III). Los puentes en la actualidad” - La revista de los Ingenieros de Caminos, Canales y Puertos – ROP

Kasuga, A. (2006). “Extradosed bridges in Japan. Struct. Concr. 7, 91-103.

Jiri Strasky (2011) – “Stress Ribbon and Cable-supported Pedestrain Bridges (Structures and Buildings)”

Mermigas, K. K. (2008) “Behaviour and Design of Extradosed Bridges.” Canada: University of Toronto.

EN 1990:2002. Eurocode- Basis of Structural Design. CEN, 2002

EN 1991:2002 Eurocode – Actions on Structures. CEN, 2002

EN 1991:2004 Eurocode – Design of Concrete Structures. CEN, 2004

EN 1993:1992 Eurocode – Design of Steel Structures. CEN, 1992

EN 1994-1-1 Eurocode 4 – Design of composite steel and concrete structures. CEN, 2004

IAP-11 “Instruccion sobre las acciones a considerar en el proyecto de puentes de carretera”

NCSE-02 “Norma de construcction sismoresistente”

NCSP-07 “Norma de construccion sismorresistente: Puentes”

UNE-EN 1337-3 “Norma Apoyos estructurales: Apoyos elastoméricos”

Angel C. Aparicio and Juan J. Arenas, “Aparatos de apoyo para puentes y estructuras”

PhD. Thesis “Puentes Extradosados, concepcion y criterios de diseno” – Gustavo Chio Cho

Bunner, M. and Wright, K, (2006), “Selecting the Shape of a Steel Arch”, Bridgeline, Volume 15, NO. 1, April 2006.

Austin, W.J., (1971), “IN-PLANE BENDING AND BUCKLING AF ARCHES”, Journal of the Structural Division, May 1971, pp. 1575-1591

Chen, W. and Duan, L., (2000), “Bridge Engineering Handbook”, CRC Press LLC, Florida.

Jan Biliszczuk, “Extradosed Bridges in Poland . Design and Construction” Warsaw, Poland

Manabu ITO “Aesthetic Design of Large Bridges – From some personal involvement” Univerity of Tokyo, Japan

L. M. C. Simoes and J. H. O. Negrao – “Sizing and Geometry optimization of cable-stayed bridges” Universidade de Coimbra, Portugal

Jiri Strasky, Ph.D. “Design and Construction of Cable-Stayed Bridges in Czech Republic” T. Y. Lin International, San Francisco, California.

S Ikeda and A KAsuga “Development of Extradosed structures in the bridge Construction” , Yokohama National University, Japan and Sumitomo Construction Co. Ltd, Japan.

Carlos Miguel Cabecadas Calado “ Structural Design of Cable-stayed Bridges”, Universidade Técnica de Lisboa, Potugal, Outubro 2001.

Computer programs

AutoCAD 2009, Autodesk

CSI SAP2000 Version 19.1, Computers and Structures

Miscrosoft Office Excel 2007, Microsoft.

Microsoft Office Word 2007, Microsoft.

Ftool, 2016.

ANNEX 1 GENERAL BACKGROUND

The present project corresponding the construction of a footbridge on the Ter River for the passage of pedestrians and bicycles is written up and given the author's goal to deepen structural and design aspects, the author requested the tutoring of this project to Professor Joan Ramon Casas Dius, who kindly agreed to provide the necessary tools and guidance for its development.

The objective of this project is to link a network of roads and rural roads that surround the urban center of Torroella de Montgrí and connect with the area of L'Estartit, on both sides of the river. Allowing in this way the possibility of crossing the river by another point apart from the existing bridge in Torroella, providing more possibilities for trips and shortening the journeys that were strictly limited to the only option to cross the river. On the northern side of the river we find the urban areas of Torroella de Montgrí and L'Estartit as well as the whole number of roads that surround them, and along the south side, more roads connect the different farms and fields in addition to the facilities of Camping Verde Delfin that becomes the area closest to the river, on the south side, where there live, even temporarily, a considerable amount of people who must be taken into account as they will use the catwalk Access to Torroella or L'Estartit.

The bridge shown in this project consists of 120 meters extradosed bridge, with a main central span of 60 meters and others two symmetrical in dimensions and geometry of 30 meters.

The information necessary for the development of this project has been sought by the author himself (hydrological data, cartography, etc.) and obtained from different collaborating sources as well as public sources of data collection thanks to which the author has been able to develop this document that aims at all the necessary information for the execution of the bridge located in Torroella de Montgrí.

In the General Ordering Plan, the area occupied by the pedestrian bridge appears as non-rustic residential land. There is a clear lack of action in an area that is so far away from the urban nucleus that is very far from the urban area or where actions can be carried out, then it is necessary to break some barriers between the two areas of the river that are so only connected by the bridge of Torroella. We should also mention that it is a very suitable area for practicing sports such as running, cycling or walking pets, and that the existence of the bridge would give more impetus to these activities.

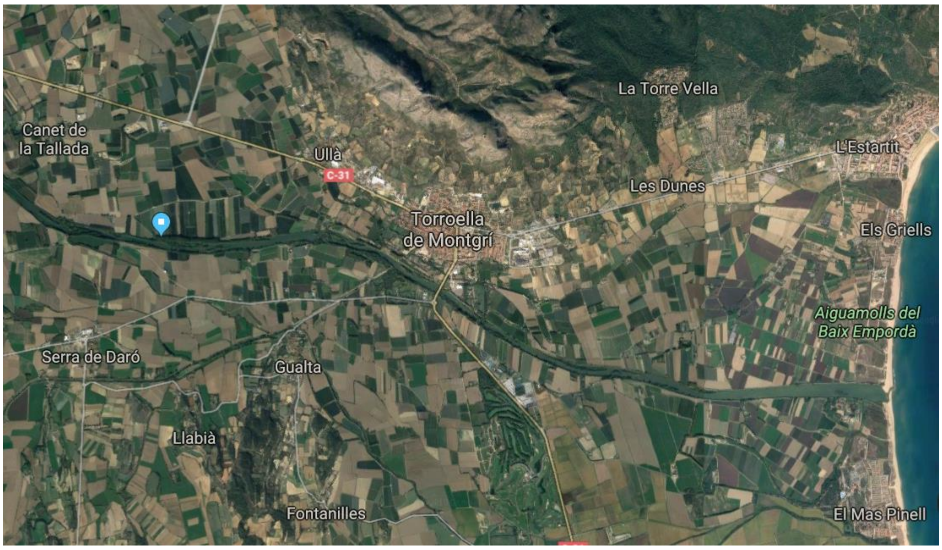


Figure 40 - Bridge location on map

The bridge is located approximately 4 km from the mouth of the river and in respect to the bridge of Torroella at 2 km. Despite the existence of this bridge, the construction of the catwalk has been deemed advisable since it is only aimed at pedestrians and cyclists and it makes cultural and social nexus while integrating with the environment. In addition, it emphasizes the fact of redirecting the traffic of cyclists and pedestrians in a way that is able to cross the river by another point, and thus to diminish by the bridge of Torroella that is destined basically to the rolled traffic of vehicles of motor.

Therefore, this bridge acts as a cultural and social link, joining the two bands of river in which the practice of sport is habitual, aside from the purely functional use to move around the area making use of the same.

Figure 41 - view of the location from close distance

I.1 Adminastrive background

Regarding the administrative background, they are totally nonexistent. It is true that when projecting the variant that connected the C31 to the junction between Ullà and Verges with the GI-643 between Gualta and Serra de Daró, it was necessary to build a bridge for cross the river, giving an alternative to the existing bridge in Torroella to communicate both bands of the river.

Although, this variant that was designed but never completed along with the bridge, located above Torroella, can not be considered as ending satisfied or had the same objective as the present project, since They differ considerably and communicate both bands of the river at very different points and which entail needs to satisfy completely different.
Therefore, it is considered that the antecedents are practically nonexistent in this sense.

I.2 Cartography anf topography

The study area, where the bridge will be located, corresponds to a section of the Ter river between the municipality of Torroella de Montgrí and its mouth, about 5 km and 2 km, respectively. The fact of being in an area classified according to the General Plan for Municipal Urban Planning, as a rustic, non-urban land, as well as the nature of the project (a master thesis) in which resources and means of which It is available all those provided by the school or public information sources, causing the cartography and topography to be used for this project will be the most accurate that can be obtained from any of these available sources.

Thus, once the various options have been studied, the one that offers more precision and detail in this case is the "Topographic Base 1: 5000" provided by the Cartographic Institute of Catalonia, which from its own web application, the "VISSIR" allows the download of the necessary sheets.

Therefore, due to the various factors, one of which, and most notably, the lack of means to try to use more detailed and detailed mapping and topography for this project, public databases should be made available, In this case, as it has been said, the Topographic Base 1: 5000.

Figure 42 - distance from the sea

ANNEX 2 GEOTECHNICAL

II.1 Introduction

First of all, due to the various circumstances of the project, either due to the inexistence of economic resources or the lack of databases, this study of geology and geotechnics can not be carried out in the area where the project is located, just as it should be. Before this situation, tutor and author agree to use data from a similar location, which is the Plana del Llobregat, specifically in the municipality of El Prat de Llobregat, which has sufficient data to properly perform this study, thanks to projects that are available to the public. Despite taking different data to those that should really be taken, the procedure, calculations and criteria to be used for this study are considered suitable for this particular case and the study area.

In the Municipal Term of Torroella de Montgrí, province of Girona, the previous studies are being carried out for the construction of a catwalk to cross the river Ter. This work includes the cycling network as it will act as a connector of the two bands of the river, connected only by the Torroella bridge, from the estuary, improving the existing routes and offering new ones.

The study area is located from the geological point of view on the Ter river's alluvial plain covering rocky substrates of Tertiary age. Also due to the construction of infrastructures there are anthropic filler with variable thicknesses, sometimes compacted (embankments of existing infrastructures), and without compacting associated to uncontrolled dumps. Hydrogeologically, the Miocene substrate behaves imperviously, making it a barrier lower than the aquifer associated with the graves and sands of the Ter river. The zone of analysis coincides with the so-called Pla de l'Empordà.

This plan is a morphological platform, which corresponds to a Piedmont plain, gently inclined towards the sea.

II.2 Objectives

The objective of this report is to describe and analyze the geological characteristics and geotechnical parameters of the soils and geological formations at the sites of the walls, which will support the embankments of the planned viaduct that will cross the River Ter. The study includes the data, recommendations and geotechnical conclusions necessary for the execution of the aforementioned structures.

The geotechnical study of stirrups and walls basically includes the following aspects:

1. General and specific geological characteristics of the site.
2. Determination of the thickness of each of these materials throughout the study area.
3. Geotechnical parameters representative of each one of the different formations.
4. Estimation of the admissible tensions and the depth of foundation of the planned structures.

II.3 Procedure

The project area is located, from the geological point of view, on the Quaternary deposits of deltaic origin formed at the mouth of the Llobregat river, which, after crossing the Cordillera-Catalana range, enters the coastal depression or coastal platform. These delta deposits of variable thickness (75 to 100 m), are available on the Pliocene base, and they appear material corresponding to very varied sedimentary environments (common feature of delta deposits): river type (sand and bass well rolled), materials of ancient river terraces buried by the most modern alluvial, and sediments of coastal influence.

For the realization of this section, the information gathered in the following documents was based:

- Mapa Geològic i Geomorfològic d'Espanya a escala 1:50.000; IGME Full 420, Hospitalet de Llobregat

- Fotografia aèria de la zona a escala 1:5.000, editada per l'ICC.

- Estudi Informatiu I Estudi d´impacte ambiental " Millora general. Nova carretera Port-Aeroport. Tram entre la rotonda amb la nova carretera de la platja i la ZAL del Port carrer A. Tram; El Prat de Llobregat".

The works carried out to characterize the materials in the study area are summarized below:

Field work was carried out during the month of April 2006, and consisted of a detailed observation of the surface area of the entire area of influence of the study. These field work has included an "on-site" research campaign, consisting of performing 2 rotation drills (S-1 and S-2) with continuous extraction of a witness, near the stirrups, which have reached depths Study levels of 60.0 and 54.22 m respectively. In addition, two dynamic sprockets of type Borrós (P-1 and P-2) have been carried out for the study of the walls that will support the embankments of the stirrups. The penetrometers have reached maximum depths of study of 20.0 and 16.0 m respectively. This campaign should be coordinated with the detailed geotechnical mapping in which all the observations carried out both on the surface and in the previously described investigations must be reflected. Special attention will be given to the presence of unstable areas, soft floors, poor drainage points, presence of anthropic cracks, etc.

II.4 Analysis on site

A TP-50 probe mounted on a truck was used to execute the soundings. In the interior of the surveys a total of 28 SPT trials have been performed and 16 unchanged samples have been extracted.

The penetration test SPT consists in the encapsulation of a bipartite sample cam in percussion through a mass of 63.5 kg that falls from a height of 75 cm. The penetration test SPT allows, by counting the number of blows necessary to penetrate the cam samples, get an idea of the consistency or compactness of the terrain at the level in which the test is performed.

The spoon length of the SPT test is 60 cm. The Nspt index (number of hits) is obtained by adding the blows obtained in two sections of 15 cm (the power stations) of carry embedded samples. This type of test is finished when the sample is carried out completely (60 cm), or when more than 50 strokes are needed for any of the 15 cm stretches, it will be considered as a waste.

The following table summarizes the sampling extracted in each of the surveys.

Assaig	Profunditat (m)	Mostres	Colpeig N_{30}	Material
S-1	60.0	SPT-1 (3.0-3.6 m)	5	Sorres fines (Q_1)
		SPT-2 (5.4-6.0 m)	15	Sorres fines (Q_1)
		SPT-3 (8.0-8.6 m)	19	Sorres fines (Q_1)
		MI-1 (10.5-11.1m)	6	Sorres fines (Q_1)
		MI-2 (13.0-13.6 m)	11	Sorres fines (Q_1)
		SPT-4 (15.5-16.1 m)	8	Sorres fines (Q_1)
		SPT-5 (18.0-18.6 m)	26	Sorres fines (Q_1)
		MI-3 (21.0-21.6 m)	7	Argiles llimoses (Q_2)

		SPT-6 (23.4-24.0 m)	8	Argiles llimoses (Q_2)
		MI-4 (26.0-26.6 m)	12	Argiles llimoses (Q_2)
		SPT-7(28.5-29.1 m)	7	Argiles llimoses (Q_2)
		MI-5 (31.0-31.6 m)	10	Argiles llimoses (Q_2)
		SPT-8 (33.0-33.6 m)	8	Argiles llimoses (Q_2)
		MI-6 (36.0-36.6 m)	16	Argiles llimoses (Q_2)
		SPT-9 (38.4-39.0 m)	4	Argiles llimoses (Q_2)
		MI-7 (41.0-41.6 m)	16	Argiles llimoses (Q_2)
		SPT-10 (43.5-44.1 m)	7	Argiles llimoses (Q_2)
		MI-8 (46.0-46.6 m)	16	Argiles llimoses (Q_2)
		SPT-11 (48.5-49.1 m)	8	Argiles llimoses (Q_2)
		MI-9 (51.0-51.6 m)	22	Sorres llimoses (Q_3)
		SPT-12 (53.4-54.0 m)	48	Sorres llimoses (Q_3)
		SPT-13 (56.4-57.0 m)	36	Graves sorrenques (Q_4)
		SPT-14 (59.4-60.0 m)	58	Graves sorrenques (Q_4)
		SPT-1 (2.4-3.0 m)	13	Sorres fines (Q_1)
		SPT-2 (5.0-5.6 m)	4	Sorres fines (Q_1)
		SPT-3 (7.5-8.1 m)	13	Sorres fines (Q_1)
		MI-1 (10.0-10.6 m)	5	Sorres fines (Q_1)
		SPT-3 (12.5-13.1 m)	5	Sorres fines (Q_1)
		SPT-4 (15.0-15.6 m)	30	Sorres fines (Q_1)
S-2	54.22	SPT-5 (18.0-18.6 m)	6	Sorres fines (Q_1)
		SPT-7 (21.0-21.6 m)	10	Argiles llimoses (Q_2)
		MI-2 (23.4-24.0 m)	16	Argiles llimoses (Q_2)
		SPT-8 (26.0-26.6 m)	8	Argiles llimoses (Q_2)
		MI-3 (28.5-29.1 m)	15	Argiles llimoses (Q_2)
		SPT-9 (31.0-31.6 m)	29	Argiles llimoses (Q_2)

		MI-4 (33.5-34.1 m)	17	Argiles llimoses (Q_2)
		SPT-10 (36.0-36.6 m)	9	Argiles llimoses (Q_2)
		MI-5 (38.4-39.0 m)	14	Argiles llimoses (Q_2)
		SPT-11 (41.0-41.6 m)	5	Argiles llimoses (Q_2)
		SPT-12 (46.0-46.6 m)	10	Argiles llimoses (Q_2)
		MI-7 (48.5-49.1 m)	31	Sorres llimoses (Q_3)
		SPT-13 (51.0-51.6 m)	49	Sorres llimoses (Q_3)
		SPT-14 (54.0-54.22 m)	R	Graves sorrenques (Q_4)

Table 27 - Geological: SPT trials results

II.4.1 Campaign of type penetrometer Borros

For the dynamic penetration tests "Borros", a device mounted on a mobile chassis (manual trolley) was used. During the test, the number of strokes required to nail a rod is recorded 20 cm. This N20 data is considered rejection if it exceeds the value of 100. A total of 2 dynamic spots such as "Borros" have been performed, one of which has reached the maximum planned depth of study (20.0 m) and the other has been rejected at 16.0 m. Below is a summary picture with the depth reached:

Assaig	PROFUNDITAT (m)
Penetròmetre P-1	16
Penetròmetre P-2	20

Informative, which is summarized below:

Complementarily to the exhaustive superficial field recognition that has allowed to characterize the Geology existing in the sector covered by the Project as well as the elaboration of geological cartography, a research campaign has been carried out along the track that consisted in conducting a survey, three trials of dynamic penetration and five coves by means of retroexcavadora machine.The situation of all the research points has been represented in the geological cartography.

The survey, of S-1 nomenclature and 35 m depth, is followed by a table that relates the results obtained to the different SPT tests carried out:

SONDEIG	PROFUNDITAT (m)	N_{spt}	Materials
S-1	3.00 – 3.60	4	Llim de consistència tova ML.(0.0-3.0m.). Llim amb quelcom de sorra ML.(3.0-6.0 m.).
	6.00 – 6.60	14	Sorra amb força llim. SM (6.0-7.8 m.).
	9.00 – 9.60	17	Sorra amb quelcom de llims SP.(7.8-9.6 m.).
	12.00 – 12.60	32	Sorra amb quelcom de llim (SM-SP) (9.6-17.4 m.). Argila negra, CL (17.4-17.6 m.)
	15.00 – 15.60	24	
	18.00 – 18.60	53	Sorra amb quelcom de llims SP.(17.6-24.6 m.). Argila de consistència tova-molt tova ML (24.6-25.5 m.)
	21.00 – 21.60	70	
	24.00 – 24.60	60	
	27.00 – 27.60	72	Sorra amb força de llim (SM). (25.5-27.6 m.)
	30.00 – 30.60	17	Llim de consistència tova-molt tova (ML) (27.9-35 m.)

Table 28 - Geological: Nspt results from the trials

II.5 Geological description of the project's zone and its environment

From the geological point of view, the Barcelona environment is located in the extensive context that affected the neogenic times of the western margin of the Catalan-Balearic Sea. This tectonic process implies a presence of a series of normal faults approximately parallel to the coastline, which delimits a set of sunken blocks (trenches or semi-trenches) along with other elevations (orchards).Of schematic form, the oldest materials are those that appear in the coastal mountain range, that is to say, in Collserola, where they appear Paleozoic metasedimentary rocks, mainly slates and to a lesser degree gres, limestone and conglomerates among others, more or less affected by the metamorphism of contact associated with the granitoids that arise at the foot of the mountain.In the direction of the sea, in the area closest to the coast of the plain, the Paleozoic rocks are covered by tertiary sediments, represented by margins and sewers of the Montjuic block, of myocene age, and by clayey and sandstone pliocens In the peatonal area of the Empordà, most of the sediments mentioned are discordantly covered by deposits of colonial origin of the Pleistocene age (Old Quaternary). They are basically clays, slimes and limestone crusts, which sometimes form a sequence of three levels known as the Tricicle of the Llobregat plain.

In particular, the study area is located on deposits of the Llobregat river delta. This is mainly constituted by alternatives of recent quaternary granular and cohesive levels, which present in general relatively unfavorable geotechnical characteristics and cover the tertiary substrate formed by clayey marbles.

II.5.1 Lithological characteristics

The materials that emerge at the location of the planned viaduct correspond, according to the two surveys carried out, to quaternary floors of the Holocene and the Pleistocene. Superimposed to these natural materials, they are fitted out. In this way the differentiated lithological units are the following:

- Reparation lands (R)
- Alluvial quaternary floors (Q)
    1. Fine sand (Upper aquifer) (Q1)
    2. Gray Limes (False Intermitja) (Q2)
    3. Sandy Limes and Serious Sandstones (Lower Aquifer) (Q3 and Q4)

The following are described geologically the differentiated lithological units.

II.5.2 Fine sand (Q1)

The most superficial sand deposits are detected at this level, detected in the two surveys beneath the re-lands (R), and up to a depth ranging between 18.5 and 21.0 m according to the surveys carried out.

These deposits are mainly formed by fine sand with a low content in clay fraction and some gravel. Closers appear clay horizons with thicknesses between 0.2 and 1.2 m. The following images show the appearance of the sand in question

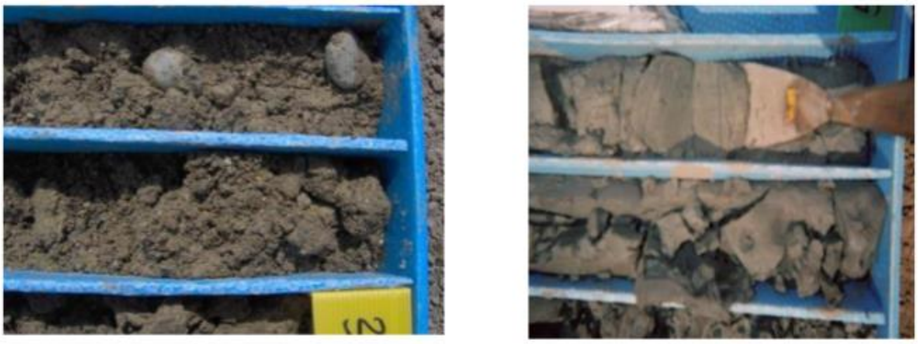


Figure 43 - Sands' picture

The sands of this unit exhibit a moderate-elevated permeability and form the so-called superior aquifer of the Llobregat whose water level is detected at about 2-3 m depth with respect to the level of execution of the surveys.

II.5.3 Gray Limes (Q2)

This level is located between the fine sand of the upper aquifer and the sandy lemons and sandy graves of the lower aquifer. It is a very consistent, gray-leaved clay that has a thickness of about 32 m. This unit is also called intermittent wedge because it is waterproof materials that separate the two aquifers (upper and lower) existing in the Llobregat delta.

In the following images the aspect of the limy clays in question is observed:

Figure 44 - Geological: Grey lime's picture

The sands of this unit have a moderate-elevated permeability and form the so-called lower aquifer of the Llobregat.

II.6 Geomorphology

The road object of the present study is carried out in its entirety by the deltaica plain of the Llobregat river, on its right bank. The plain deltaica del Llobregat, of the order of 92 km of surface, is a sector of very soft morphology, with a slope of the order of 1%. However, it is advisable to note the anthropogenic morphology that is so present in the area as the Llobregat channeling activities. The project area is located in the Llobregat delta. This area is characterized mainly by presenting a fluvial geomorphology modeled by the alluvial dynamics of the Llobregat river. The relief of the area is generally flat and the tertiary substrate is covered by the alluvial sediments deposited in the Llobregat which have thicknesses exceeding 60 m.

- Delta morphology: A delta is a sedimentary tank built at the mouth of a river in front of the coastline. The sedimentations in the deltas are very powerful, several hundred meters. The thicker fragments are deposited near the mouth, while the ends reach more remote areas. The tanks with thicker particles form the bottom layers and the front layers. They form a flattened with sand and slime.

II.7 Embankment

Below, the embankments present in the project are designed.

The trace has two rehashes with inclination 2H:1V, on both sides of the bridge with maximum heights of between 10.0 and 11.5 m. which will have differents lengths and will be supported both on alluvial terrain of the Ter River and on anthropic reforms of current roads.

II.8 Stability analysis

The stability analysis of the reworkings for the most unfavorable situation has been carried out, with 11 m in height in the case of not carrying out the treatment with drains and fast loading and in the case of carrying out the load progressive with improvement of properties for the consolidation of the material when draining.

The analysis was carried out with the SLIDE program using the simplified Bishop method valid for circular type breaks in soils.

In both cases, the embankment has a stability security factor of 1.35 and 1.75, which is good enough for this case.

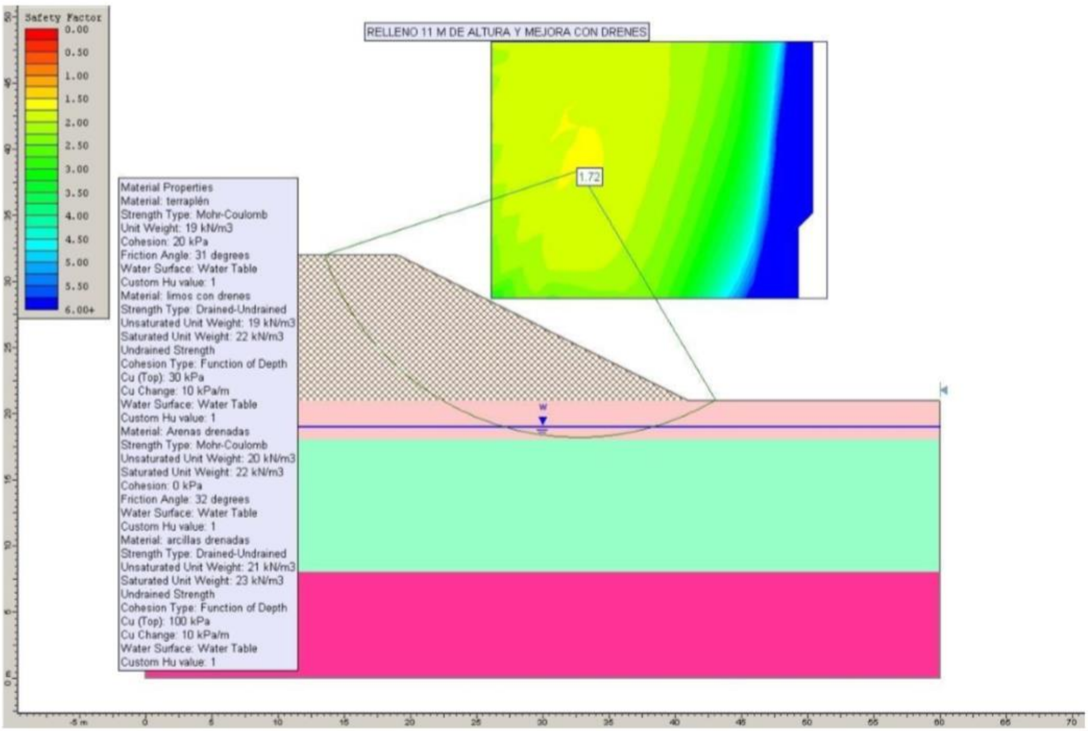


Figure 45 - Embankment design: Slide program

The rest of the situations of lower height of refill is more favorable so it can be concluded that the embankments are stable for the case of rapid loading without drainage of the foundation and using materials of tolerable soil types.

II.9 Calcutation of settlements

II.9.1 Methodology

For the calculation of settlements, the edometric theory for which the division of levels has been used according to its granulometry (argillaceous, sandy and sandy soils) so that in the clays tested with edometers 'has assigned an edometric module value obtained in the test and in the case of the rest of the levels, correlations have been used with the resistance to cutting without drainage in cohesive soils. In the case of the levels of granular type, the edometric module has been correlated with the elasticity module to obtain deformation.

For the total calculation of descents, it has been considered that the levels of sand lime and sand are consolidated immediately when the burden of the embankment is placed so that the settlements will be of a more or less fast and elastic character. In the case of clay a uniform consolidation coefficient of : 2 · 10-3 cm2 / s has been assigned based on the laboratory tests of the current campaign and the data collection of the campaigns carried out in the Baix- Llobregat near the study area and which has a sediment profile very similar to that recorded in the present project.

In the Delta investigations, it has been observed that the intermediate level clays are somewhat preconsolidated, as regards the calculation of settlements, an OCR of 1.3 (overconsolidated) starting from 20 meters and up to 20 meters the OCR of the soil can be considered related at the coefficient 1 (usually consolidated).

Finally, it should be noted that the indefinable level has been considered the section of bass in the lower delta. The division of representative levels with their thicknesses and parameters assigned is summarized below giving rise to the calculations made in the different situations present in the layout, with variable heights of up to 10.5 m in the vicinity of the structure.

				Correlació Nspt	dades assaigs	correlació Nspt Muromachi	correlació	assaig	correlació Agnastopoulos			
Profunditat	H nivell	Nivell	Nspt	Cu (Kp/cm^2)	Cu (Kp/cm^2)	⍰	E (Kp/cm^2)	Ed (Kp/cm^2)	Ed (Kp/cm^2)	⍰ natural	⍰ sumergida	Cv (cm^2/s)

3,00	3,00	Llim	5	0,3			83		33,3	1,9	1,9	∞
5,60	2,60	Sorra	5			28	249		47,5	1,9	0,9	∞
5,70	0,10	Argila	15	1,9			469		187,5	1,9	0,9	$2*10^{-3}$
6,75	1,05	Sorra	15			34	347		127,5	1,9	0,9	∞
7,00	0,25	Argila	15	1,9			469		187,5	1,9	0,9	$2*10^{-3}$
8,25	1,25	Sorra	19			35	386		159,5	1,9	0,9	∞
8,50	0,25	Argila	19	2,4			594		237,5	1,9	0,9	$2*10^{-3}$
10,90	2,40	Sorra	19			35	386		159,5	1,9	0,9	∞
11,50	0,60	Argila	8	1,0			250		100,0	1,9	0,9	$2*10^{-3}$
12,10	0,60	Sorra	8			30	278		71,5	1,9	0,9	∞
13,25	1,15	Argila sorrenca	8	0,5			133		53,3	1,9	0,9	$2*10^{-3}$
14,50	1,25	Sorra	8			30	278		71,5	1,9	0,9	∞
14,60	0,10	Argila	8	1,0			250		100,0	1,9	0,9	$2*10^{-3}$
15,75	1,15	Sorra	8			30	278		71,5	1,9	0,9	∞
15,90	0,15	Argila	8	1,0			250		100,0	1,9	0,9	$2*10^{-3}$
17,00	1,10	Sorra	8			30	278		71,5	1,9	0,9	∞
17,20	0,20	Argila	8	1,0			250		100,0	1,9	0,9	$2*10^{-3}$
17,50	0,30	Sorra	8			30	278		71,5	1,9	0,9	∞
17,70	0,20	Argila	8	1,0			250		100,0	1,9	0,9	$2*10^{-3}$
18,50	0,80	Sorra	8			30	278		71,5	1,9	0,9	∞
23,50	5,00	Argila sorrenca	8	0,5	0,25		133	33,3	53,3	1,95	0,95	$2*10^{-3}$
23,70	0,20	Arcilla	8	1,0			250		100,0	1,9	0,9	$2*10^{-3}$
23,75	0,05	Sorra	8			30	278		71,5	1,9	0,9	∞
32,25	8,50	Argila sorrenca	8	0,5			133	43,47	53,3	1,9	0,9	$2*10^{-3}$
33,75	1,50	Sorra	8			30	278		71,5	1,9	0,9	∞
35,75	2,00	Argila sorrenca	8	0,5			133		53,3	1,9	0,9	$2*10^{-3}$
36,75	1,00	Llim	4	0,3			67		26,7	1,9	0,9	∞
38,45	1,70	Argila llimosa	4	0,5			125		50,0	1,9	0,9	$2*10^{-3}$
38,80	0,35	Llim	4	0,3			67		26,7	1,9	0,9	∞
40,25	1,45	Argila	4	0,5			125		50,0	1,9	0,9	$2*10^{-3}$
46,25	6,00	Argila llimosa	6	0,8			188		75,0	1,9	0,9	$2*10^{-3}$
48,25	2,00	Sorra	8	1,0			250		71,5	1,9	0,9	∞
49,25	1,00	Argila llimosa	8	1,0			250		100,0	1,9	0,9	$2*10^{-3}$
49,75	0,50	Argila	8	1,0			250		100,0	1,9	0,9	$2*10^{-3}$
56,25	6,50	Sorra	48	0,0		40	670		391,5	2,08	1,08	∞
60,00	3,75	Graves sorrenques	47	0,0		44	661		383,5	2,08	1,08	∞

Figure 46 - Geological: soil settlements

II.9.2 Evaluation of the embankments' height

2 meters high

Tram	Gruix	Tipus de terreny	Ed (Kp/cm²)	s consolidació	s inmediat
1	3	llim	33,3		3,063
2	2,6	sorra	47,5		1,863
3	0,1	argila	187,5	0,018	
4	1,05	sorra	127,5		0,281
5	0,25	argila	187,5	0,046	

6	1,25	sorra	159,5		0,268
7	0,25	argila	237,5	0,036	
8	2,4	sorra	159,5		0,516
9	0,6	argila	100	0,198	
10	0,6	sorra	71,5		0,27
11	1,15	argila	53,3	0,67	
12	1,25	sorra	71,5		0,518
13	0,1	argila	100	0,029	
14	1,15	sorra	71,5		0,454
15	0,15	argila	100	0,041	
16	1,1	sorra	71,5		0,415
17	0,2	argila	100	0,053	
18	0,3	sorra	71,5		0,11
19	0,2	argila	100	0,052	
20	0,8	sorra	71,5		0,285
21	5	argila	43,47	2,67	
22	0,2	argila	100	0,043	
23	0,05	sorra	71,5		0,012
24	8,5	argila	53,3	2,413	
25	1,5	sorra	71,5		0,279
26	2	argila	53,3	0,478	
27	1	llim	26,7		0,461
28	1,7	argila	50	0,406	
29	0,35	llim	26,7		0,153
30	1,45	argila	50	0,332	
31	6	argila	75	0,846	
32	2	sorra	71,5		0,274
33	1	argila	100	0,095	
34	0,5	argila	100	0,047	
35	6,5	sorra	391		0,147
		total asentamants	17,842	8,473	9,369

Figure 47 - Embankment 2 m : settlements

3 meters high

Tram	Gruixr	Tipus de terreny	Ed (Kp/cm2)	s consolidació	s inmediat
1	3	llim	33,3		4,402
2	2,6	sorra	47,5		2,679
3	0,1	argila	187,5	0,026	
4	1,05	Sorra	127,5		0,404
5	0,25	argila	187,5	0,066	
6	1,25	sorra	159,5		0,386
7	0,25	argila	237,5	0,052	
8	2,4	sorra	159,5		0,744
9	0,6	argila	100	0,285	
10	0,6	sorra	71,5		0,39
11	1,15	argila	53,3	0,968	
12	1,25	sorra	71,5		0,75
13	0,1	argila	100	0,042	
14	1,15	sorra	71,5		0,658
15	0,15	argila	100	0,06	
16	1,1	sorra	71,5		0,603
17	0,2	argila	100	0,077	
18	0,3	sorra	71,5		0,159
19	0,2	argila	100	0,075	
20	0,8	sorra	71,5		0,415
21	5	argila	43,47	3,892	
22	0,2	argila	100	0,063	
23	0,05	sorra	71,5		0,017
24	8,5	argila	53,3	3,536	
25	1,5	sorra	71,5		0,41
26	2	argila	53,3	0,704	
27	1	llim	26,7		0,679
28	1,7	argila	50	0,598	
29	0,35	llim	26,7		0,225
30	1,45	argila	50	0,489	
31	6	argila	75	1,249	
32	2	sorra	71,5		0,404
33	1	argila	100	0,141	
34	0,5	argila	100	0,069	
35	6,5	sorra	391		0,217
		total asentaments	25,934	12,392	13,542

Figure 48 - Embankment 3 m: settlements

4 meters high

Tram	Sorra	Tipus de terreny	Ed (Kp/cm²)	s consolidació	s inmediat
1	3	llim	33,3		5,657
2	2,6	sorra	47,5		3,443
3	0,1	argila	187,5	0,034	
4	1,05	sorra	127,5		0,52
5	0,25	argila	187,5	0,084	
6	1,25	sorra	159,5		0,496
7	0,25	argila	237,5	0,067	
8	2,4	sorra	159,5		0,959
9	0,6	argila	100	0,368	
10	0,6	sorra	71,5		0,503
11	1,15	argila	53,3	1,25	
12	1,25	sorra	71,5		0,969
13	0,1	argila	100	0,054	
14	1,15	sorra	71,5		0,852
15	0,15	argila	100	0,078	
16	1,1	arena	71,5		0,781
17	0,2	argila	100	0,099	
18	0,3	sorra	71,5		0,207
19	0,2	argila	100	0,098	
20	0,8	sorra	71,5		0,538
21	5	argila	43,47	5,064	
22	0,2	argila	100	0,082	
23	0,05	sorra	71,5		0,023
24	8,5	argila	53,3	4,626	
25	1,5	sorra	71,5		0,538
26	2	argila	53,3	0,924	
27	1	llim	26,7		0,892
28	1,7	argila	50	0,786	
29	0,35	llim	26,7		0,296
30	1,45	argila	50	0,643	
31	6	argila	75	1,645	
32	2	sorra	71,5		0,533
33	1	argila	100	0,185	
34	0,5	argila	100	0,091	
35	6,5	sorra	391		0,286
		total asentaments	33,671	16,178	17,493

Figure 49 - Embankment 4 m: settlements

5 meters high

Tram	Gruix	Tipus de terreny	Ed (Kp/cm²)	s consolidació	s inmediat
1	3	llim	33,3		6,848
2	2,6	sorra	47,5		4,17
3	0,1	argila	187,5	0,041	
4	1,05	sorra	127,5		0,63
5	0,25	argila	187,5	0,102	
6	1,25	sorra	159,5		0,602
7	0,25	argila	237,5	0,081	
8	2,4	sorra	159,5		1,163
9	0,6	argila	100	0,447	
10	0,6	sorra	71,5		0,611
11	1,15	argila	53,3	1,519	
12	1,25	sorra	71,5		1,179
13	0,1	argila	100	0,066	
14	1,15	sorra	71,5		1,038
15	0,15	argila	100	0,095	
16	1,1	sorra	71,5		0,952
17	0,2	argila	100	0,121	
18	0,3	sorra	71,5		0,252
19	0,2	argila	100	0,119	
20	0,8	sorra	71,5		0,657
21	5	argila	43,47	6,198	
22	0,2	argila	100	0,1	
23	0,05	sorra	71,5		0,028
24	8,5	argila	53,3	5,691	
25	1,5	sorra	71,5		0,664
26	2	argila	53,3	1,141	
27	1	llim	26,7		1,102
28	1,7	argila	50	0,972	
29	0,35	llim	26,7		0,367
30	1,45	argila	50	0,796	
31	6	argila	75	2,039	
32	2	sorra	71,5		0,661
33	1	argila	100	0,23	
34	0,5	argila	100	0,114	
35	6,5	sorra	391		0,356
		total asentaments	41,152	19,872	21,28

Figure 50 - Embankmemt 5 m: settlemets

<u>6 meters high</u>

3	0,1	argila	187,5	0,048	
4	1,05	sorra	127,5		0,735
5	0,25	argila	187,5	0,119	
6	1,25	sorra	159,5		0,703
7	0,25	argila	237,5	0,095	
8	2,4	sorra	159,5		1,359
9	0,6	argila	100	0,523	
10	0,6	sorra	71,5		0,714
11	1,15	argila	53,3	1,779	
12	1,25	sorra	71,5		1,382
13	0,1	argila	100	0,077	
14	1,15	sorra	71,5		1,217
15	0,15	argila	100	0,111	
16	1,1	sorra	71,5		1,118
17	0,2	argila	100	0,142	
18	0,3	sorra	71,5		0,296
19	0,2	argila	100	0,14	
20	0,8	sorra	71,5		0,773
21	5	argila	43,47	7,301	
22	0,2	argila	100	0,118	
23	0,05	sorra	71,5		0,033
24	8,5	argila	53,3	6,737	
25	1,5	sorra	71,5		0,788
26	2	argila	53,3	1,356	
27	1	llim	26,7		1,31
28	1,7	argila	50	1,156	
29	0,35	llim	26,7		0,436
30	1,45	argila	50	0,948	
31	6	argila	75	2,431	
32	2	sorra	71,5		0,789
33	1	argila	100	0,275	
34	0,5	argila	100	0,136	
35	6,5	sorra	391		0,425
		total asentaments	48,425	23,492	24,933

Figure 51 - Embankment 6 m: settlements

7 meters high

Tram	Gruix	Tipus de terreny	Ed (Kp/cm²)	s consolidació	s inmediat
1	3	llim	33,3		9,091
2	2,6	sorra	47,5		5,538
3	0,1	argila	187,5	0,054	
4	1,05	sorra	127,5		0,837
5	0,25	argila	187,5	0,136	
6	1,25	sorra	159,5		0,8
7	0,25	argila	237,5	0,108	
8	2,4	sorra	159,5		1,549
9	0,6	argila	100	0,596	
10	0,6	sorra	71,5		0,815
11	1,15	argila	53,3	2,03	
12	1,25	sorra	71,5		1,578
13	0,1	argila	100	0,088	
14	1,15	sorra	71,5		1,391
15	0,15	argila	100	0,127	
16	1,1	sorra	71,5		1,279
17	0,2	argila	100	0,163	
18	0,3	sorra	71,5		0,339
19	0,2	argila	100	0,161	
20	0,8	sorra	71,5		0,885
21	5	argila	43,47	8,38	
22	0,2	argila	100	0,136	
23	0,05	sorra	71,5		0,038
24	8,5	argila	53,3	7,768	
25	1,5	sorra	71,5		0,911
26	2	argila	53,3	1,569	
27	1	llim	26,7		1,517
28	1,7	argila	50	1,339	
29	0,35	llim	26,7		0,506
30	1,45	argila	50	1,099	
31	6	argila	75	2,822	
32	2	sorra	71,5		0,918
33	1	argila	100	0,32	
34	0,5	argila	100	0,158	
35	6,5	sorra	391		0,495
		total asentaments	55,541	27,054	28,487

Figure 52 - Embankments 7 m: settlements

8 meters high

Tram	Gruix	Tipus de terreny	Ed (Kp/cm²)	s consolidació	s inmediat
1	3	llim	33,3		10,161
2	2,6	sorra	47,5		6,191
3	0,1	argila	187,5	0,061	
4	1,05	sorra	127,5		0,936
5	0,25	argila	187,5	0,152	
6	1,25	Sorra	159,5		0,895
7	0,25	argila	237,5	0,121	
8	2,4	sorra	159,5		1,734
9	0,6	argila	100	0,668	
10	0,6	sorra	71,5		0,913
11	1,15	argila	53,3	2,275	
12	1,25	sorra	71,5		1,77
13	0,1	argila	100	0,099	
14	1,15	sorra	71,5		1,561
15	0,15	argila	100	0,143	
16	1,1	sorra	71,5		1,436
17	0,2	argila	100	0,183	
18	0,3	sorra	71,5		0,381
19	0,2	argila	100	0,18	
20	0,8	sorra	71,5		0,995
21	5	argila	43,47	9,438	
22	0,2	argila	100	0,153	
23	0,05	sorra	71,5		0,043
24	8,5	argila	53,3	8,787	
25	1,5	sorra	71,5		1,033
26	2	argila	53,3	1,781	
27	1	llim	26,7		1,723
28	1,7	argila	50	1,522	
29	0,35	llim	26,7		0,575
30	1,45	argila	50	1,25	
31	6	argila	75	3,214	
32	2	sorra	71,5		1,047
33	1	argila	100	0,365	
34	0,5	argila	100	0,18	
35	6,5	Sorra	391		0,565
		total asentaments	62,531	30,572	31,959

Figure 53 - Embankment 8 m: settlements

!0.5 meters high

Tram	Gruix	Tipus de terreny	Ed (Kp/cm²)	s consolidació	s inmediat
1	3	llim	33,3		12,733
2	2,6	sorra	47,5		7,759
3	0,1	argila	187,5	0,076	
4	1,05	sorra	127,5		1,174
5	0,25	argila	187,5	0,19	
6	1,25	sorra	159,5		1,123
7	0,25	argila	237,5	0,151	
8	2,4	sorra	159,5		2,178
9	0,6	argila	100	0,84	
10	0,6	sorra	71,5		1,149
11	1,15	argila	53,3	2,865	
12	1,25	sorra	71,5		2,232
13	0,1	argila	100	0,125	
14	1,15	sorra	71,5		1,972
15	0,15	argila	100	0,18	
16	1,1	sorra	71,5		1,817
17	0,2	argila	100	0,232	
18	0,3	sorra	71,5		0,483
19	0,2	argila	100	0,229	
20	0,8	sorra	71,5		1,261
21	5	argila	43,47	12,013	
22	0,2	argila	100	0,196	
23	0,05	sorra	71,5		0,055
24	8,5	argila	53,3	11,293	
25	1,5	sorra	71,5		1,336
26	2	argila	53,3	2,308	
27	1	llim	26,7		2,237
28	1,7	argila	50	1,978	
29	0,35	llim	26,7		0,748
30	1,45	argila	50	1,628	
31	6	argila	75	4,2	
32	2	sorra	71,5		1,372
33	1	argila	100	0,478	
34	0,5	argila	100	0,236	
35	6,5	Sorra	391		0,744
		total asentamenst	79,591	39,218	40,373

Figure 54 - Embankment 10.5 m: settlements

II.10 Consolidation time

Considering the values considered as representative, the following consolidation times are obtained for argillaceous levels, considering the formulation proposed by Terzaghi:

$$t_v=(T_v x H^2)/c_v$$

Feel the thickness of argillaceous soils divided by 2 when presenting drainage paths on both sides of the level. In this case it has been considered 14 m since the thicknesses of argillaceous soils are approximately 28 m.

The results obtained are reflected in the following consolidation graphs for the different heights analyzed:

<u>2 meters high</u>

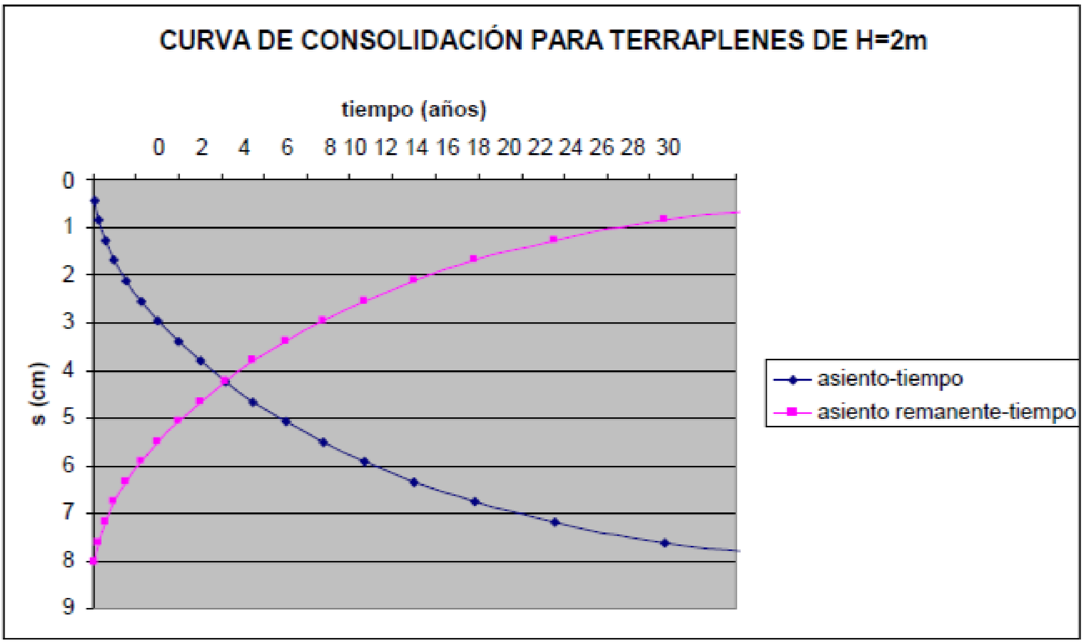


Figure 55 - consolidation curve 2 meter high

	cv cm2/año	H (cm)	s cm consolidació total		
	62208	1400	8,473		
U(%)	Tv	t (años)	s cm conslidació	s remanent	t días s rema.<=10 cm
5	0,0017	0,05356224	0,42365	8,04935	0
10	0,0077	0,24260545	0,8473	7,6257	
15	0,0177	0,55767747	1,27095	7,20205	
20	0,0314	0,98932613	1,6946	6,7784	
25	0,0491	1,5470036	2,11825	6,35475	
30	0,0707	2,22755916	2,5419	5,9311	
35	0,0962	3,0309928	2,96555	5,50745	
40	0,126	3,96990741	3,3892	5,0838	
45	0,159	5,00964506	3,81285	4,66015	
50	0,196	6,17541152	4,2365	4,2365	
55	0,238	7,49871399	4,66015	3,81285	
60	0,286	9,01105967	5,0838	3,3892	
65	0,342	10,775463	5,50745	2,96555	
70	0,403	12,6974023	5,9311	2,5419	
75	0,477	15,0289352	6,35475	2,11825	
80	0,567	17,8645833	6,7784	1,6946	
85	0,684	21,5509259	7,20205	1,27095	
90	0,848	26,718107	7,6257	0,8473	
95	1,129	35,5716307	8,04935	0,42365	

Table 29 - consolidation curve 2 m

The time that has to pass so that there remains a remnant settlement of 10 cm is practically immediate. In this case, and in all those untreated embankments, it should be taken into account that the total settlements generated will be those of elastic type in the sand and the sum of the consolidation with the calculated graph.

<u>2 meters high</u>

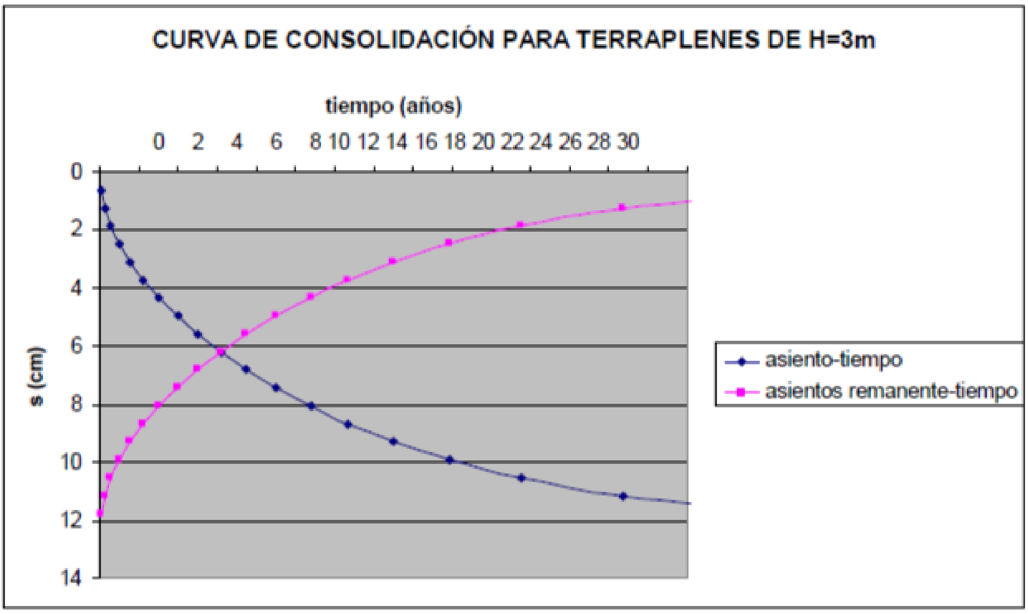


Figure 56 - consolidation curve 3 m

	cv cm2/año	H (cm)	s cm consolidació total		
	62208	1400	12,392		
U(%)	Tv	t (años)	s cm conslidación	s remanente	t días s rema.<=10 cm
5	0,0017	0,05356224	0,6196	11,7724	
10	0,0077	0,24260545	1,2392	11,1528	
15	0,0177	0,55767747	1,8588	10,5332	204
20	0,0314	0,98932613	2,4784	9,9136	
25	0,0491	1,5470036	3,098	9,294	
30	0,0707	2,22755916	3,7176	8,6744	
35	0,0962	3,0309928	4,3372	8,0548	
40	0,126	3,96990741	4,9568	7,4352	
45	0,159	5,00964506	5,5764	6,8156	
50	0,196	6,17541152	6,196	6,196	
55	0,238	7,49871399	6,8156	5,5764	
60	0,286	9,01105967	7,4352	4,9568	
65	0,342	10,775463	8,0548	4,3372	
70	0,403	12,6974023	8,6744	3,7176	
75	0,477	15,0289352	9,294	3,098	
80	0,567	17,8645833	9,9136	2,4784	
85	0,684	21,5509259	10,5332	1,8588	
90	0,848	26,718107	11,1528	1,2392	
95	1,129	35,5716307	11,7724	0,6196	

Table 30 - consolidation curve 3 m

The time that has to pass so that there is a remaining settlement of 15 cm is virtually immediate and because this value reaches 10 cm is 204 days, which is considered compatible with the work.

4 meters high

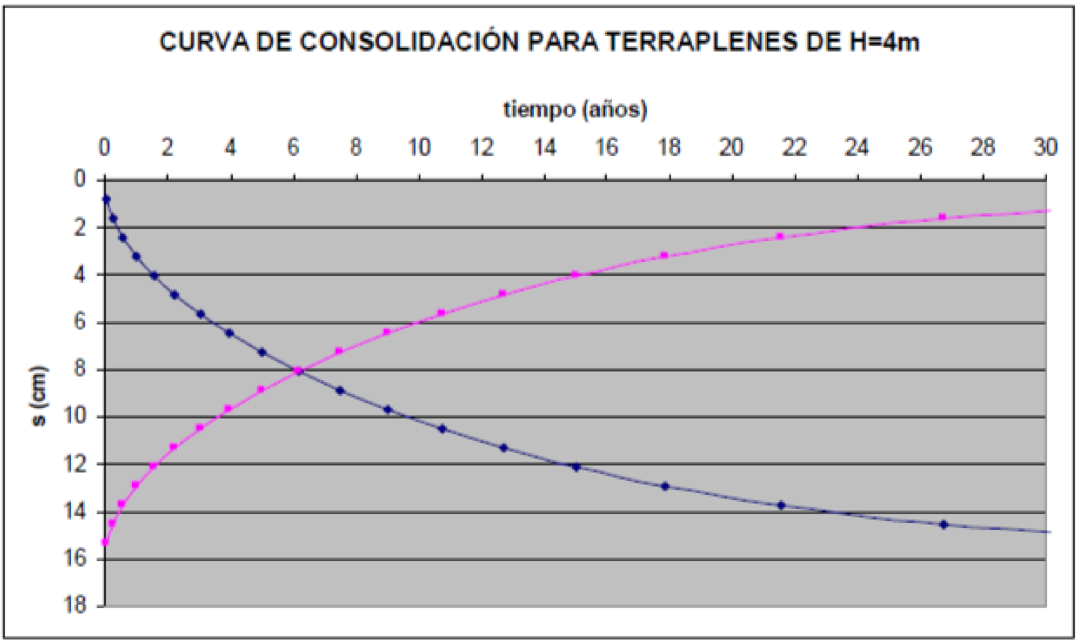


Figure 57 - consolidation curve 4 m

	cv cm2/año	H (cm)	s cm consolidació total		
	62208	1400	16,178		
U(%)	Tv	t (años)	s cm conslidació	s remanent	t días s rema.<=10 cm
5	0,0017	0,05356224	0,8089	15,3691	
10	0,0077	0,24260545	1,6178	14,5602	
15	0,0177	0,55767747	2,4267	13,7513	
20	0,0314	0,98932613	3,2356	12,9424	
25	0,0491	1,5470036	4,0445	12,1335	
30	0,0707	2,22755916	4,8534	11,3246	
35	0,0962	3,0309928	5,6623	10,5157	1106
40	0,126	3,96990741	6,4712	9,7068	
45	0,159	5,00964506	7,2801	8,8979	
50	0,196	6,17541152	8,089	8,089	
55	0,238	7,49871399	8,8979	7,2801	
60	0,286	9,01105967	9,7068	6,4712	
65	0,342	10,775463	10,5157	5,6623	
70	0,403	12,6974023	11,3246	4,8534	
75	0,477	15,0289352	12,1335	4,0445	
80	0,567	17,8645833	12,9424	3,2356	
85	0,684	21,5509259	13,7513	2,4267	
90	0,848	26,718107	14,5602	1,6178	
95	1,129	35,5716307	15,3691	0,8089	

Table 31 - consolidation curve 4 m

The time that must pass so that a remaining settlement of 15 cm is left is of 90 days, that considers compatible with the work. In this case it is recommended to perform a preload of 1.5-2 m in height and waiting time of 3 months to try to reduce the settlements to about 10 cm remaining.

II.10.1 Conclusion

As can be seen from the graphs and consolidation time, it can be established that, for embankments of heights exceeding 4-4.5 m, the consolidation times leave a 10-15 cm of deformation. This is considered asumible for a flexible type structure. However, these settlements are unviable with the deadlines of the work, so they require special treatments for the acceleration of settlements as vertical drains.

II.11 Special treatments

In the case of embankments of heights of less than 3-4 m it is possible to consider that the settlements are admissible for a flexible structure such as the case of an embankment, with a needle of between 1 and 1.5 m with a material of plaster type that improves the conditions of distribution of tensions.

For this reason, a vertical drainage treatment has been proposed to accelerate consolidation settlements.

DADES D'ENTRADA	
Cv (cm2/s)	2,00E-03
gruix compresible H (cm)	2400
Diàmetre dren (dw)	10

ESPAIAT ENTRE DRENS (CM):	150	160	180	200	220	240	260	280	300
diàmetre d'influència (de)	157,5	168	189	210	231	252	273	294	315
n (de/dw)	15,75	16,8	18,9	21	23,1	25,2	27,3	29,4	31,5
n2	248	282	357	441	534	635	745	864	992
F(n)	2,02	2,08	2,20	2,30	2,40	2,48	2,56	2,64	2,70

Cr/Cv	T (días)	Tv	Uv (Terzaghi)									
5	20	0,00060	0,03	0,94	0,91	0,83	0,75	0,67	0,60	0,53	0,47	0,42
5	25	0,00075	0,03	0,97	0,95	0,89	0,82	0,75	0,68	0,61	0,55	0,49
5	30	0,00090	0,03	0,98	0,97	0,93	0,87	0,81	0,74	0,67	0,61	0,55
5	35	0,00105	0,04	0,99	0,98	0,96	0,91	0,85	0,79	0,73	0,67	0,61
5	40	0,00120	0,04	1,00	0,99	0,97	0,94	0,89	0,83	0,77	0,71	0,66
5	45	0,00135	0,04	1,00	1,00	0,98	0,96	0,92	0,87	0,81	0,76	0,70
5	50	0,00150	0,04	1,00	1,00	0,99	0,97	0,94	0,89	0,84	0,79	0,74
5	55	0,00165	0,05	1,00	1,00	0,99	0,98	0,95	0,91	0,87	0,82	0,77
5	60	0,00180	0,05	1,00	1,00	1,00	0,98	0,96	0,93	0,89	0,85	0,80
5	65	0,00195	0,05	1,00	1,00	1,00	0,99	0,97	0,95	0,91	0,87	0,82
5	70	0,00210	0,05	1,00	1,00	1,00	0,99	0,98	0,96	0,92	0,89	0,84
5	75	0,00225	0,05	1,00	1,00	1,00	0,99	0,98	0,96	0,94	0,90	0,86
5	80	0,00240	0,06	1,00	1,00	1,00	1,00	0,99	0,97	0,95	0,92	0,88

5	85	0,00255	0,06	1,00	1,00	1,00	1,00	0,99	0,98	0,96	0,93	0,89
5	90	0,00270	0,06	1,00	1,00	1,00	1,00	0,99	0,98	0,96	0,94	0,91
5	95	0,00285	0,06	1,00	1,00	1,00	1,00	0,99	0,99	0,97	0,95	0,92
5	100	0,00300	0,06	1,00	1,00	1,00	1,00	1,00	0,99	0,97	0,95	0,93
5	105	0,00315	0,06	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,96	0,94
5	110	0,00330	0,06	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,97	0,95
5	115	0,00345	0,07	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,97	0,95
5	120	0,00360	0,07	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,96
5	125	0,00375	0,07	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,96
5	130	0,00390	0,07	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,97
5	135	0,00405	0,07	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,97
5	140	0,00420	0,07	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,97
5	145	0,00435	0,07	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98
5	150	0,00450	0,08	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98
5	180	0,00540	0,08	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99
5	200	0,00600	0,09	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99
5	230	0,00690	0,09	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

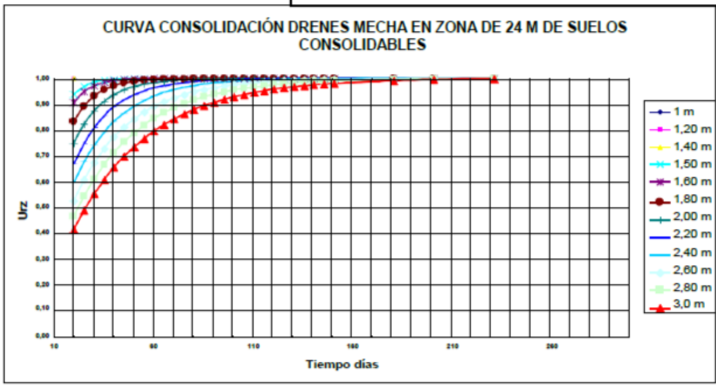


Table 32 - consolidation time with 24m D=10 elements

DADES D'ENTRADA	
Cv (cm2/s)	2,00E-03
Gruix compresible H (cm)	3300
Diàmetre dren (dw)	10

ESPAIAT ENTRE DRENS (CM):	150	160	180	200	220	240	260	280	300
diàmetre d'influència (de)	157,5	168	189	210	231	252	273	294	315
n (de/dw)	15,75	16,8	18,9	21	23,1	25,2	27,3	29,4	31,5
n2	248	282	357	441	534	635	745	864	992

	F(n)			2,02	2,08	2,20	2,30	2,40	2,48	2,56	2,64	2,70
Cr/Cv	T (días)	Tv	Uv (Terzaghi)									
5	20	0,00032	0,02	0,94	0,91	0,83	0,75	0,67	0,59	0,52	0,47	0,41
5	25	0,00040	0,02	0,97	0,95	0,89	0,82	0,75	0,67	0,60	0,54	0,49
5	30	0,00048	0,02	0,98	0,97	0,93	0,87	0,81	0,74	0,67	0,61	0,55
5	35	0,00056	0,03	0,99	0,98	0,96	0,91	0,85	0,79	0,73	0,66	0,60
5	40	0,00063	0,03	1,00	0,99	0,97	0,94	0,89	0,83	0,77	0,71	0,65
5	45	0,00071	0,03	1,00	1,00	0,98	0,95	0,91	0,87	0,81	0,75	0,70
5	50	0,00079	0,03	1,00	1,00	0,99	0,97	0,94	0,89	0,84	0,79	0,73
5	55	0,00087	0,03	1,00	1,00	0,99	0,98	0,95	0,91	0,87	0,82	0,77
5	60	0,00095	0,03	1,00	1,00	1,00	0,98	0,96	0,93	0,89	0,84	0,79
5	65	0,00103	0,04	1,00	1,00	1,00	0,99	0,97	0,94	0,91	0,87	0,82
5	70	0,00111	0,04	1,00	1,00	1,00	0,99	0,98	0,96	0,92	0,88	0,84
5	75	0,00119	0,04	1,00	1,00	1,00	0,99	0,98	0,96	0,94	0,90	0,86
5	80	0,00127	0,04	1,00	1,00	1,00	1,00	0,99	0,97	0,95	0,92	0,88
5	85	0,00135	0,04	1,00	1,00	1,00	1,00	0,99	0,98	0,96	0,93	0,89
5	90	0,00143	0,04	1,00	1,00	1,00	1,00	0,99	0,98	0,96	0,94	0,91
5	95	0,00151	0,04	1,00	1,00	1,00	1,00	0,99	0,99	0,97	0,95	0,92
5	100	0,00159	0,04	1,00	1,00	1,00	1,00	1,00	0,99	0,97	0,95	0,93
5	105	0,00167	0,05	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,96	0,94
5	110	0,00175	0,05	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,97	0,94
5	115	0,00182	0,05	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,97	0,95
5	120	0,00190	0,05	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,96
5	125	0,00198	0,05	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,96
5	130	0,00206	0,05	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,97
5	135	0,00214	0,05	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,97
5	140	0,00222	0,05	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,97
5	145	0,00230	0,05	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98

Table 33 - consolidation time 33m d=10 element

DADES D'ENTRADA	
Cv (cm2/s)	2,00E-03
gruix compresible H (cm)	4000
diàmetre dren (dw)	10

ESPAIAT ENTRE DRENS (CM):	150	160	180	200	220	240	260	280	300
diàmetre d'influència (de)	157,5	168	189	210	231	252	273	294	315
n (de/dw)	15,75	16,8	18,9	21	23,1	25,2	27,3	29,4	31,5
n2	248	282	357	441	534	635	745	864	992
F(n)	2,02	2,08	2,20	2,30	2,40	2,48	2,56	2,64	2,70

Cr/Cv	T (días)	Tv	Uv (Terzaghi)									
5	20	0,00022	0,02	0,94	0,91	0,83	0,75	0,67	0,59	0,52	0,46	0,41
5	25	0,00027	0,02	0,97	0,95	0,89	0,82	0,75	0,67	0,60	0,54	0,48
5	30	0,00032	0,02	0,98	0,97	0,93	0,87	0,81	0,74	0,67	0,61	0,55
5	35	0,00038	0,02	0,99	0,98	0,96	0,91	0,85	0,79	0,72	0,66	0,60
5	40	0,00043	0,02	1,00	0,99	0,97	0,94	0,89	0,83	0,77	0,71	0,65
5	45	0,00049	0,02	1,00	1,00	0,98	0,95	0,91	0,86	0,81	0,75	0,69
5	50	0,00054	0,03	1,00	1,00	0,99	0,97	0,93	0,89	0,84	0,79	0,73
5	55	0,00059	0,03	1,00	1,00	0,99	0,98	0,95	0,91	0,87	0,82	0,76
5	60	0,00065	0,03	1,00	1,00	1,00	0,98	0,96	0,93	0,89	0,84	0,79
5	65	0,00070	0,03	1,00	1,00	1,00	0,99	0,97	0,94	0,91	0,87	0,82
5	70	0,00076	0,03	1,00	1,00	1,00	0,99	0,98	0,95	0,92	0,88	0,84
5	75	0,00081	0,03	1,00	1,00	1,00	0,99	0,98	0,96	0,94	0,90	0,86
5	80	0,00086	0,03	1,00	1,00	1,00	1,00	0,99	0,97	0,95	0,91	0,88
5	85	0,00092	0,03	1,00	1,00	1,00	1,00	0,99	0,98	0,96	0,93	0,89
5	90	0,00097	0,04	1,00	1,00	1,00	1,00	0,99	0,98	0,96	0,94	0,91
5	95	0,00103	0,04	1,00	1,00	1,00	1,00	0,99	0,99	0,97	0,95	0,92
5	100	0,00108	0,04	1,00	1,00	1,00	1,00	1,00	0,99	0,97	0,95	0,93
5	105	0,00113	0,04	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,96	0,94
5	110	0,00119	0,04	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,97	0,94
5	115	0,00124	0,04	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,97	0,95
5	120	0,00130	0,04	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,97	0,96
5	125	0,00135	0,04	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,96
5	130	0,00140	0,04	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,97
5	135	0,00146	0,04	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98	0,97
5	140	0,00151	0,04	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,97
5	145	0,00157	0,04	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,98
5	150	0,00162	0,05	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,98
5	180	0,00194	0,05	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99
5	200	0,00216	0,05	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99
5	230	0,00248	0,06	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

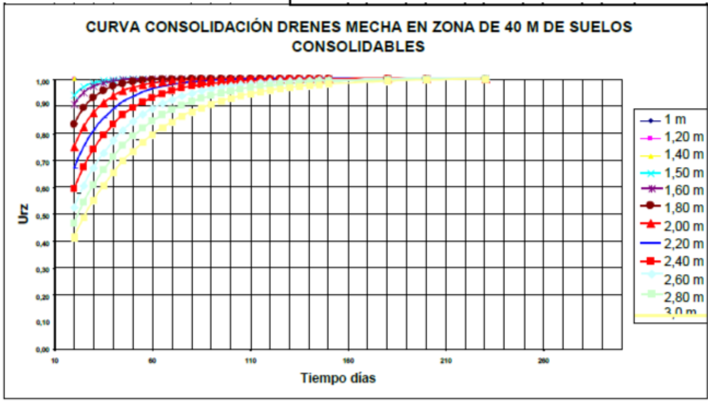


Table 34 - consolidation time 40m d=10

II.12 Summaries and conclusions

Fences of heights less than 3 m

Guidelines of 1-1.5 m will be carried out in order to regularize the support and guarantee an adequate distribution of tensions transmitted to the foundation.

When the settlements become stabilized, the recreation of the embankment can be made to compensate for the descents generated and to execute the layers of firmness. The remaining settlements will be inferior to 8 cm acceptable for the work.

Embankments heights between 3 and 4.5 m

The time to have a remaining settlement of 15 cm is 90 days, so that to reduce the postcostructural settlements, a preload of 1.5-2 m should be carried out so that keeping this material in the order of 3 months the remnant of final settlements will be less than 10 cm.

Embankment height between 4.5 and 7 m

They require a treatment with vertical geogridges, with a mesh of triangular distribution of 3 m of side and length of 23 m. In this situation the remaining settlements are less than 10 cm.

Embankment height between 7 and 10.5 m

They require a treatment with vertical geogridges, with a mesh of triangular distribution of 3 m of side and length of 30 m. In this situation the remaining settlements are less than 10 cm.

The construction will be carried out in stages to allow time for the dissipation of interstitial pressures and to avoid breakage of the foundation especially in those cases where the heights exceed 7 m.

In the case of the nearby embankments or in the strut of the structure, it will proceed to the execution of drains in triangular mesh of 2.4 m of side but of 40 m in length to leave a remnant of settlements less than 5 cm so that it can be compatible with the settlements of the piloned stirrup.

The execution of the embankment will be carried out sufficiently in advance to remove the height of earth in the zone of implantation of the stirrup and to avoid so that with the consolidation negative friction occurs and thrusts in the batteries that are inadmissible or they pose a very important increase in the length and armor of the bollards.

In this case, the mesh proposed is a bit smaller so that the consolidation is obtained at 95 days in order not to extend the deadlines. If the necessary time should be lower then the densification of the trap mesh will be done with a 2 m spacing for a period of 2 months.

Consolidation times in all cases have to be counted since the embankment begins to run, although settlement plates must be made to evaluate the rates of descents and the real consolidation curve to establish the viability of the calculations made.

The zone of influence of settlements on the stirrup and, therefore, will mark the mesh of treatment, will be established based on the angular distortions that allow the structure that will be of the order of 30 m.

On all embankments, a thickness of materials of equal thickness must be counted on the total settlements calculated for each height. In the case of elastic seats the recreated will be progressive whereas in the case of the consolidation the contribution of material will be in the final stages of the work once the final height has arrived.

The layer of the vegetal land will be removed previously to the execution of the re-completion. The vegetal land and land of work of thickness approximated of 0.9 -1 m. It will be stacked properly to be used in the revegetation or failing, this will be re-compacted at the bottom of the excavation once the vegetation itself (whose thicknesses are considered 20 to 30 cm below) are eliminated. Alluvial soils of argillaceous-lime nature, and sandy alluvial terms are available on the land, so the size of the settlements will be variable.

Depending on the height of the refurbishments and settlements and consolidation times calculated, the following treatments of the underlying terrain are planned:

			Tractament amb drens verticals			
H reblert	**Saneig**	**Precàrrega**	**Malla**	**Costat**	**Longitud**	**asent postconstructiu**
0-2 m	1m	no	no	no	no	<10 cm
2-3 m	1,5 m	no	no	no	no	<10 cm
3-4,5 m	0,3 m	1,5-2 m	no	no	no	<10 cm
4,5-7 m	0,3 m	no	triangular	3 m	23 m	<10 cm
7-10,5 m	0,3 m	no	triangular	3 m	30 m	<10 cm
7-10,5 m estribos	0,3 m	no	triangular	2 m	40 m	<5 cm

Table 35 - Results with drainage elements

II.12.1 Exploiting the material's characteristics

In order to classify the present materials, we proceed to consider the results obtained from the laboratory trials carried out with the five samples of land extracted from the coves carried out, which are summarized in the table that is attached to the next page.

According to these results, it is determined that practically all the materials present are classified as tolerable soils according to the "Circular Order 326/00".
In this way considering this classification of soils it is obtained that the totality of the present materials can be considered as apt to constitute a good foundation base of embankment, once realized the reconstitution of the surface and the elimination of the layer of vegetal earth.

The fact that none of the samples tested can not be classified as suitable soil mainly responds that in all cases the percentage of material that passes through the 0.080 UNE sieve is greater than 35%, as well as the fact that the content in soluble salts, including plaster, are more than 0.2%.

In any case, due to the fact that the project covered by this study does not contemplate carrying out detachments, in order to obtain any type of soil, loan materials should be used.

II.12.2 Characteristic of the embankments

In order to determine the category of the esplanade necessary for the sizing of the firm, it should be considered that, on the embankments, this category of the esplanade will depend directly on the characteristics of the material used to execute the coronation of the same.

It should be noted that, according to the instructions given by "Circular Order 326/00", for the coronation of embankments, materials classified as suitable or selected must be used.

In any case, it should be noted that, considering the results obtained from laboratory tests carried out with samples extracted from the coves, almost all of the present materials are classified, according to the aforementioned "Circular Order 326/00", as tolerable soils.

According to this classification of the soils present as tolerable, and considering the "Instruction of Roads Norm 6.1 IC Sections of Firm", it is determined that the use of the present materials would not allow the direct obtaining of any category of clear esplanade determined.

However, in any case, an esplanade of superior support capacity can be obtained by means of treatments based on considering the contribution of different powers of other soils of better quality.

The powers and the quality of the land to be contributed must comply with the requirements set forth in article 5.1 of the aforementioned "Norm Instruction 6.1 IC Sections of Firm" Consequently, and as an example, mention should be made of the fact that on embankments, for which coronation is used, soils classified as suitable, in order to obtain a category of E3 esplanade, only 30 cm thick soil stabilized in situ.

In the same way, if embankments are considered to be used for coronation, soils classified as selected, to obtain a category of E3 esplanade only have to have a thickness of 30 cm of soil stabilized in situ type 3.

ANNEX 3
HYDROLOGY AND DRAINAGE

As written before the calculation of the maximum flow rates for different periods of return of the basin is carried out thank to a previous study conducted by another student of the Universitat Politecnica de Catalunya, in which it was developed a flow study with a HEC-RAS model for the same river just a pair of kilometers beneath.

So, the author has assumed that using these results of the flow rates the problem will be developed on the security side. Then checking the impact of the bridge on the river, it is concluded that the bridge does not mean any variation in the balance of the river and that it does not alter the regime at any time.

The results about this study will be attached below translated in English.

III.1 Introduction

In the present annex, the calculation of the maximum flow rates for different periods of return of the basin intercepted by the trace is carried out and the results of the HEC-RAS model are shown, performed to check the impact of the bridge piles on it laugh.

The process to follow has to begin to delimit the intercepted basin and the determination of the physical characteristics of the same in order to choose the appropriate method of calculation of flow rates.

Hydrometeorological methods of rain-run transformation allow us to study the hydrological behavior of a single basin as a response to the action of precipitation, taking into account the characteristics of the basin itself (humidity, vegetation, presence of snow, etc.).). Within hydrometeorological methods, aggregate models consider that the rain-run transformation is carried out in the entire basin in a unitary manner

The simplified methods of the aggregate models calculate the flow rate of the hydrograph, that is, the maximum flow rate of surface spill due to a precipitation of constant intensity, both in space and time, throughout the basin. The simplified method for the only wider single basin is the Rational Method, the limitations of application, according to the Catalan Water Agency are:

- The surface of the basin must not exceed 1,000 km2.

- The basin must be predominantly rural.

- The concentration time Tc must be between 0.25 and 24 hours.

In the present Project, the Rational Method will be used whenever possible. Otherwise, it will be necessary to resort to other methodologies, such as the Unitary Hydrograph method. The flow calculations will be made for the return periods of 2, 10, 25, 50, 100 and 500 years, in order to have all the possible data when it comes to dimensioning any drainage work. Finally, a study is carried out using the HEC-RAS model with the calves calculated for a return period of 100 and 500 years. The results released by the model show that there is no affectation of the catwalk on the river and that it is not necessary to perform the calculation of the road of intense drainage.

III.2 Pluviometric study

This section will study rainfall from the point of view of daily maximum rainfall, in order to use them in the application to calculate rain intensities and the calculation of flow rates. The selection of rainfall stations is carried out, first of all, taking into account their location with regard to the basin. It is convenient to choose stations in the area of river basin boundaries. For the selection of useful stations for the purpose of obtaining the Pd (Maximum Daily Precipitation) by statistical treatment, the following criteria have been considered:

- The amount of data: number of years with data, number of data, ...
- The quality of the data: type of station, coherent aspect of the data, number of incomplete years, number of representative years.

These selection criteria for seasons are simplified at:

- Consider representing those years in which readings of 12 months are available.
- Consider those stations with fifteen or more representative years to be acceptable.

Below is a table with the selected station for the rainfall study:

Codi	Estació	Longitud	Latitud	Altitud	Anys totals
F007760	Torroella de Montgrí (UE)	3,15719	42,02306	4	17

Table 36 - Project's location coordinates

It must be said that in the surroundings there are other stations, but even so, this is the closest to the location of the catwalk. Next, the following table shows the maximum daily precipitation of the years in which there are records of the station considered in this rainfall study.

Sèries d'anys	Precipitació
1998	41,5
1999	48,5
2000	120,0
2001	68,5
2002	77,0
2003	137,6
2004	59,7
2005	80,5
2006	38,0
2007	65,0
2008	73,0
2009	63,5
2010	87,5
2011	43,5
2012	73,5
2013	65,5
2014	94,0
2015	41,0

Table 37 - Pluviometric datas

III.2.1 Gumbel and S-QRT-ETMAX methos

Based on the previously described rainfall data and once the maximum rainfall series have been defined, rainfall intensities have been adjusted to maximize precipitation by two different methods: Gumbel and SQRT-ET max. These distributions use local data, are bi-parameter and use the same adjustment method.

The adjustment of maximum distributions of Gumbel is determined by the frequency defined by the Hazen formula, with the following formula:

$$f_{(i)} = \frac{i - 0.5}{N}$$

- "i" is the order number
- "N" is the total number of terms in the series

The distribution function of Gumbel is:

$$F_{(x)} = e^{-e^{\frac{-1}{\alpha}(x-\mu)}}$$

Where 1 / α and μ are the parameters of the function.

Meanwhile the SQRT-ETMAX has the following expression:

$$F_{(x)} = e^{-k(1+\sqrt{\alpha x})e^{-\sqrt{\alpha x}}}$$

Where α is the scale parameter and *k* is the frequency parameter. These parameters define the law and must be adjusted to existential data.

This law assumes a value of the coefficient of bias superior to the resulting one of Gumbel and that is function of the value of the coefficient of variation. Estimated quantifiers are similar to those obtained by Gumbel for low and medium return periods, reaching higher values for high return periods. The summary, of the values that are obtained after the application of these two distributions, is the following result for the different periods of return:

Període de retorn	SQRT	Gumbel
2	67	69
10	110	106
25	135	125
50	154	138
100	176	152
500	229	184

Table 38 - Period of no return

III.2.2 Checking the Isolin method

To compare the results obtained, they compare with the values given in the publication "Maximum daily rains in Peninsular Spain", published by the General Roads Department, together with the developed computer application (MAXPLU) that allows to obtain the maximum precipitations in a certain place in peninsular Spain just by knowing its geographic coordinates or UTM depending on different periods of return. The model is based on a division of peninsular Spain in 26 geographic regions with common meteorological features. The regional estimation of the parameters is carried out through a distribution function SQRT-ET max. The maximum precipitations obtained, following the values of the publication of the Ministry of Public Works "isolins of foresee maximum precipitations in a day", are:

Període de retorn	Valor
2	74
10	130
25	164
50	191
100	220
500	294

Table 39 -Pluviometric values: Period of no return with Isolin method

III.2.3 Project precipitations

Comparing the maximum precipitations obtained by the Gumbel law, the SQRT-ETMAX law and the MAXPLU application, it is chosen to adopt as the most unfavorable project precipitation for each return period. For all periods of return it is observed that the most unfavorable is the precipitation provided by the MAXPLU application.

Therefore, as the starting point for the development of the hydrological study, the following precipitation will be used:

Precipitació diària màxima (mm) - Valors de projecte						
	Període de retorn					
Estació	2	10	25	50	100	500
Torroella de Montgrí	74	130	164	191	220	294

Table 40 - Pluviometric study: daily precipitation

III.2.4 Delimitation and physical characteristic of the site

In the present section, the basin intercepted by the structure is defined and characterized geometrically. On the cartography available, the difference between the head of the basin and the point of incidence in the trace is measured. Next, you get the average slope as a quotient between this difference in level and the length of the spillage.

Below is the geometric characterization, defining the following variables:

- Surface area (km2).
- Length (km).
- Slope (m)
- Pending (%).
- Concentration time (Tc) in hours.

For the calculation of concentration time, which intervenes in the dimensioning of drainage works, the following expression has been used:

-

$$T_C = 0,3 \cdot \left(\frac{L}{J^{\frac{1}{4}}}\right)^{0,76}$$

- Tc = concentration time of the basin
- L = length of the basin's main channel in km
- J = pending m / m

The formula of the concentration time, indicated above, is applied especially in rural basins or with a proportion of waterproofed surface of less than 0.04 the total area. The following table summarizes the physical characteristics of the basin and its concentration time.

Característiques físiques de la conca						
A (km^2)	L (km)	Cotai	Cotaaf	Desnivell	J	Tc (h)
3,715	2,87	124,00	56,64	67,36	0,0235	1,364

Table 41 - Pluviometric study: Physic characteristics

III.2.5 Evaluating the maximum capacity

For the calculation of flow rates, the basins will be differentiated according to their concentration time, since according to the value of this parameter a different methodology will be followed.

- Flows in basins with Tc> 24 h: There are no basins in the section covered by this Project with Tc> 24 h.

- Flues in basins with Tc <24 h

III.2.5.1 Calculation procedure

The Catalan Water Agency allows the use of the Rational Method provided that the following limitations are met:

- The surface of the basin must not exceed 1,000 km2.
- The basin must be predominantly rural
- The concentration time Tc must be between 0.25 and 24 h

The rational method calculates the maximum flow of surface runoff Q of a rainfall intensity that falls on a basin with a surface A, which begins instantaneously and is constant for a minimum time equal to the concentration time of the Tc basin. The classical formula of the rational method is:

$$Q = \frac{C \cdot I \cdot A}{3,6}$$

- Q = tip discharge (m3 / s)
- C = runoff coefficient (non-dimensional)
- I = intensity of precipitation, supposed constant (mm / h)
- A = surface of the basin (km2)

The constant rain intensity hypothesis is not real and in practice there are variations in its temporal distribution that increase the tip flow rates. Therefore, it is necessary to apply to the previous formula a coefficient of majoration K of the tip cabal, which serves to refer to the determined tip heads, considering the variation of the rain, to the homologous volumes calculated with constant net rain. This coefficient K is called a uniformity coefficient.

This coefficient depends on several factors, such as the torrential rainfall or the physical characteristics of the basin, but for its calculation it is only dependent on the geometry of the basin, expressed through its concentration time Tc. From the analysis of many rains in numerous basins, Temez derived the following formula for calculating the K (dimensionless) uniformity coefficient:

$$K = 1 + \frac{T_c^{1,25}}{T_c^{1,25} + 14}$$

With the application of this uniformity coefficient, you get the formula of the Modified Rational Method, which contemplates the temporary cast of the flood:

$$Q = \frac{C \cdot I \cdot A}{3,6} \cdot K$$

- Q = tip discharge (m3 / s)
- C = runoff coefficient (non-dimensional)
- I = intensity of precipitation, supposed constant (mm / h)
- A = surface of the basin (km2)
- K = uniformity coefficient

III.2.5.2 Precipitation intensity

In order to obtain precipitation intensity, the proposed method is part of a hypothesis that simplifies the phenomenon of precipitation, and that in small sized basins it is common to admit:

- Simultaneity of rainy episodes of the same period of return in terms of the total amount of precipitated water in all points in the basin.
- The same percentage distribution of water precipitated over time in the different points in the basin.

The expressions for their calculation are:

$$\frac{I}{I_d} = \left(\frac{I_1}{I_d}\right)^{\frac{28^{0.1} - D^{0.1}}{28^{0.1} - 1}}$$

Where

- I = intensity of precipitation for an effective duration of rain D hours corresponding to the period of return considered, in mm / h.

- I1 = hourly intensity for the period of return considered, which is the precipitation intensity for an effective duration of one hour rain, expressed in mm / h.

- Id = average daily intensity for the period of return considered, which is the precipitation intensity for an effective rainfall of one day, expressed in mm / h.

- D = Effective duration of rain for which the intensity I is calculated, expressed in hours.

The quotient I1 / Id, independent of the period of return is a regional coefficient, characteristic of the study area. The Catalan Water Agency states that in Catalonia it can be considered an average value of I1 / Id equal to 11. Therefore, the intensity of Id precipitation for a duration D of rain that corresponds to a period of return Tc the precipitation is P'd can be calculated as:

$$I_D = \frac{P'_d}{24}(11)^{\frac{28^{0.1}-D^{0.1}}{28^{0.1}-1}}$$

The precipitation intensity I to be used in the application of the Modified Rational Method must be calculated considering an effective D-time of rain equal to the concentration time Tc. The value P'd is a corrected value of the daily precipitation Pd obtained by the statistical treatment of the series of historical rains obtained from the registries of the meteorological stations near the basin.

This necessary correction is motivated because the values registered by the stations are obtained in specific points (the own station), instead of extensive areas as considered in the calculations. For this, a KA coefficient, daily precipitation lesser, called coefficient of simultaneity, is defined, which is obtained by the following expression:

$K_A = 1$ Si $A < 1$ km²
$K_A = 1 - \log A/15$ Si 1 km² $< A <$ 3.000 km²

With this coefficient, it is taken into account the fact that these stations are sometimes in the center of the waterfalls, other times in the outer limits and others in intermediate positions. Therefore, the value $P'd$ is obtained as from:

The values of the average precipitation intensities that have been obtained for the different periods of return are those that appear later in the summaries of the calculation of volumes.

$$P'_d = P_d \cdot K_A$$

Next, it is necessary to determine that the value of Pd obtained is assigned to the basin. The procedure followed is the so-called Polygons of Thiessen. This method basically involves joining the stations found near the basin by means of straight segments. Next, the mediators of these segments are traced, which is used to determine the percentage of precipitation to be assigned to the basin according to the different stations.

T	P_d mm	K_A	P'_d
2	74,0	0,9620	71,19
10	130,0	0,9620	125,06
25	164,0	0,9620	157,77
50	191,0	0,9620	183,74
100	220,0	0,9620	211,64
500	294,0	0,9620	282,83

Table 42 - Pluviometric study: precipitation intensity

III.2.6 Coefficient of escape

Surface runoff is the water that comes from the rain that circulates around the surface and is concentrated in the canals. It represents, therefore, the rest of rain that remains to the

surface after discounting the evaporation and evapotranspiration phenomena, storage and infiltration in the lower layers. The runoff coefficient defines the proportion of the surface component of the precipitation of intensity I, and depends on the quotient between the daily precipitation Pd, corresponding to the return period, and Po poisoning threshold, from which it starts this one**.** In the Peninsula, it is used to calculate the spill coefficient with the formula deduced by Temez from the U.S. method. Soil Conservation Service (USA), which is also accepted by the ACA.
The formula is as follows:

$$C = \frac{(P'_d - P'_0) \cdot (P' + 23 \cdot P'_d)}{(P'_d + 11 \cdot P'_0)^2}$$

- C = runoff coefficient (non-dimensional)
- P '= daily precipitation, collected by the simultaneity factor, in mm
- P '= slip threshold, corrected by regional factor r, in m

The Po runoff threshold is the parameter that allows calculating rainfall from a given precipitation, taking into account the interception of vegetation, storage in small depressions of the surface of the soil and infiltration. The Catalan Water Agency recommends obtaining the runoff threshold by the SCS method, based on the so-called curve name (NC). Through this number a Po corresstand threshold corresponds. This number can vary between 0 and 100 and it is established that the number of curve NC = 100 corresponds to a completely waterproof surface, that is, a Po = 0. The SCS tabulates the NC according to the use of the ground, the slope, the hydrological characteristics and the group of soil. From the analysis of the results obtained in numerous basins it has been concluded that it is advisable to increase the po dump threshold with a regional coefficient r, which reflects the regional variation of normal moisture in the soil at the beginning of rains.

From the analysis of the results obtained with the application of this coefficient, the Catalan Water Agency considers that this value is excessive and recommends adopting a regional factor r = 1.3. Therefore, the threshold of spill to be used in the calculation of clean rain is the value P 'calculated as:

$$P'_0 = 1{,}3 \times P'_0$$

At this point, to get Po only the basins in the following aspects:

- Soil group

- Use of the soil
- Pending
- Hydrological characteristics

III.2.7 Soil group

Catalana de l'Aigua recommends using geological cartography at the 1: 250,000 scale of the Cartographic Institute of Catalonia (ICC) in which the soils classified according to different codes appear. These codes have a direct correspondence with the classification of soils that SCS makes. The SCS considers 4 types of soil:

- Group A. Floors in which the water infiltrates rapidly, although they are very humid. They are formed by low-power granular soils basically sandy sands.

- Group B. Soils that when they are very humid have a moderate infiltration capacity. They are formed by layers of soils of moderate to large powers, with franco-sandy, frank, franco-argyl-sandy or franco-llimoses lithographies. They are usually well or moderately well drained.

- Group C. Floors in which the water slowly infiltrates when they are very humid. They are formed by soils of little or medium power with franco-argilosas, franco-argilo-llimoses, limosas or argilloarenas lithographies. They are imperfectly drained soils.

- Group D. Soils with a very slow infiltration when they are wet. They have surface or surface clayey strata. They are poorly or very poorly drained. In this group, the floors with permanent levels near the surface and soils of very little power are included.

For the determination of the run-off threshold it is necessary to classify the land for the slope they have, for the use that is given to the land, for its hydrological conditions and for the type of soil. To get to this classification, it has been used as basic information:

- Geological map of Catalonia, scale 1: 250,000 published by the Cartographic Institute of Catalonia (Generalitat de Catalunya).

- Map of uses of the Land of Catalonia, scale 1: 250,000 published by the Cartographic Institute of Catalonia.

III.2.8 Use of the soil

The ICC has published a land use map in Catalonia at 1: 250,000 scale that represents the state of land use. The correlation of land uses between the ICC map and the SCS method is shown below:

Correlación de códigos utilizados en la cartografía de usos del suelo editada por ICC

Categoría	Usos del suelo ICC	Usos del suelo del método del SCS
1	Fuera de Cataluña	-
2	Agua continental	Zona impermeable
3	Agua marina	Zona impermeable
4	Acumulación de nieve	Zona impermeable
5	Infraestructuras viarias	Zona impermeable
6	Urbanizaciones	Zona impermeable
7	Núcleos urbanos	Zona impermeable
8	Zonas industriales y comerciales	Zona impermeable
9	Cultivos de secano	Cereales de invierno
10	Cultivos de regadío	Rotación de cultivos densos
11	Frutales de secano	Plantaciones regulares de aprovechamiento forestal pobre
12	Frutales de regadío	Plantaciones regulares de aprovechamiento forestal media
13	Viñedos	Plantaciones regulares de aprovechamiento forestal pobre
14	Prados supraforestal	Praderas pobre
15	Arbustos y prados	Masa forestal media
16	Bosque de esclerófilos	Masa forestal espesa
17	Bosque de caducifolios	Masa forestal espesa
18	Bosque de coníferas	Masa forestal espesa
19	Vegetación de zonas húmedas	Roca permeable
20	Suelo con vegetación escasa o nula	Barbecho
21	Zonas quemadas	Barbecho
22	Zonas de tierra y playa	Barbecho

Table 43 - Pluviometric study: correlation codes by ICC

III.2.9 Slope inclination

In the SCS method, soils are classified into two slopes, greater than 3% and less than 3%. Consulting the available topographic maps determines that the basin under study has a slope smaller than 3% in the different uses of the soil**.**

III.2.10 Flow obtained

The calculation of flow rates for periods of return of 2, 10, 25, 50, 100 and 500 years is summarized in the following table. In it all the coefficients necessary for the calculation of the reference flow rates appear according to the Modified Rational Method.

$$Q = \frac{C \cdot I \cdot A}{3,6} \cdot K$$

- Q = tip discharge (m3 / s)
- C = runoff coefficient (non-dimensional)
- I = intensity of precipitation, supposed constant (mm / h)
- A = surface of the basin (km2)
- K = uniformity coefficient

Below are shoed the results:

T	P'_d(mm)	I_t/I_d	I (mm/h)	P'_0	C	K	Cabal (m^3/s)
5	71,19	11	26,9	28,6	0,208	1,1	6,346
10	125,06	11	47,3	28,6	0,390	1,1	20,887
25	157,77	11	59,7	28,6	0,472	1,1	31,849
50	183,74	11	69,6	28,6	0,525	1,1	41,306
100	211,64	11	80,1	28,6	0,574	1,1	52,011
500	282,83	11	107,1	28,6	0,670	1,1	81,044

Table 44 - Pluviometric study: Flow results

III.2.11 Drainage

The purpose of this section is to define and justify hydraulically the necessary checks and works to allow the drainage of run-off water. The terrain of the project belongs to the river basin of the River Ter. The runoff on the platform is secured by the 2% water slope and highly waterproof.

III.3 DESIGN CRITERIA AND INFORMATION USED

For the design of the Transverse Drainage the following criteria are established:

- The solutions to be projected must respect the natural flow of the avenue, avoiding the contribution of flows to adjacent basins without altering the existing conditions of conditions. In very diffuse basins to minimize the effects that would cause the concentration of volumes at one point, they are arranged in the same O.D.T. in different points.

- The basins with a flow of contribution greater than 50 m3 / s for the period of return of 500 years are saved with the execution of bridges and / or viaducts. Likewise, in those points where the height of the land is advised and following the recommendations of the Declaration of Environmental Impact, viaducts will be carried out regardless of the volume provided.

- With a view to approving the projected projects on the existing channels by the basin organism (in this case, the Catalan Water Agency ACA), they will be carried out following the criteria set out in the Publication "Technical Recommendations for the design of infrastructures that interfere with the fluvial space" of the ACA.

The design criteria to follow in the transverse drainage works or viaducts necessary to guarantee the transverse drainage of the intercepted basins, are the following:

- The volume to consider in the dimensioning of the transverse drainage works will be the one corresponding to the period of return of 500 years. With the flow corresponding to the period of return of 500 years will be verified the damages by flood and possible affections to third parties.

- In basins with a Q500 discharge ≥ 200 m3 / s, or areas with a risk of catastrophic damage, the design of the work must be carried out by means of the mathematical model of a gradually varied HEC-RAS system.

The channel will be analyzed without the drainage work and with the implantation of the work, to be able to delimit the elevation that it causes. For newly built construction, the over-elevation at the entrance to the 500-year avenue must be less than 0.30 m in relation to the natural situation.

On the other hand, the minimum shelter between the maximum level of the water lamina inside the drainage work and the key of the work for Q500 will be greater than 1.0 m. If the risk of obstruction was high (high density case of bush vegetation or trees) a minimum shelf of 1.50 m will be left in a 12.0 m free light. In addition, it will fulfill the non-occupation of Via Intense Drain. is called Via d'Intens Desguàs (VID), at the width of the channel such that the 100-year avenue return period produces an overflow of water sheet less than 0.30 m with respect to the elevation That this would have no drainage work. For bridges and viaducts these limitations are equivalent to the non-occupation of the VID for the bridge piles.

- In basins with a flow rate of 200 m3 / s> Q500 ≥ 50 m3 / s and areas without risk of catastrophic damage, the design of the work must be carried out using the HEC-RAS gradually varied mathematical model. In this case, it is assumed that the geometric definition of the model is a simplification.

The limits of elevation and protection regarding the work key mentioned in the previous paragraph are applicable.

- In basins with a flow rate of 50 m3 / s> Q500 ≥ 7.5 m3 / s and areas without risk of catastrophic damage, in addition to modeling using HAC-RAS, you can use other simplified methodologies.

For this range of design flows and a zone without risk of catastrophic damage, the ACA considers the methodology proposed in Instruction 5.2.-IC valid for estimating the elevation at the entrance of the work of passage. The over-elevation for the avenue associated with 500 years of return period must be less than 0.30 m above the current level, as a general rule. In the case of passage works, the minimum free shelf between the maximum level of the water sheet inside the workpiece and the key thereof, for Q500, will be greater than 0.5 m and will be checked That the power line does not touch the key to the work.

- In basins with a Q500 discharge ≤ 7.5 m3 / s and areas without risk of catastrophic damage, a hydraulic analysis of the initial conditions of the natural channel will not be necessary. The minimum dimensions required in the drainage works have drainage capacity for these smaller shafts. However, it must be checked that the elevation of the water that occurs at the entrance does not affect third parties.

- The minimum dimensions of drainage works must meet the following conditions

All drainage works must be visited. The interior dimensions will not be less than Ø 2,0 m in the circular sections and 2x2 m2 in the rectangular ones. When Q500 ≤ 3 m3 / s, inferior diameters are admitted, provided that sections that guarantee the drainage and the absence of landing risk are projected. In these cases, the dimensions must be adjusted, at least, to what marks the 5.2.- IC according to the length of the work. In case the internal volume is greater than or equal to 250 m3, the access and exit of the machinery for its maintenance will be facilitated.

III.4 HEC-RAS STUDY

The hydraulic calculation allows to estimate the behavior of a river course in the area of the infrastructure to be analyzed, to verify and ensure the drainage capacity of the latter for the design flow, to design the work with a shelf and a width free to ensure this drain, even in the case of drags, and to limit the influence of the work both upstream and downstream, also checking the impact of the bridges on the bridge over the river. The process to follow has to begin to delimit the intercepted basin and the determination of the physical characteristics of the own one with the aim of choosing the appropriate method of calculation of volumes.

A study will be carried out using the HEC-RAS model with the flow rates of return periods 100 and 500 years. The results provided by the model will demonstrate that there is no involvement of the catwalk on the river in case of flood. To carry out this study, it has been necessary to consult the data provided by the Catalan Water Agency (ACA), by means of maps indicating the level of the water surface caused by the flow relative to periods of return of 100 and 500 years.

III.4.1 Technical recommendations

Following the 'Technical recommendations for the design of infrastructures that interfere with the fluvial space' of the Catalan Water Agency, it is demanded so much to the new construction infrastructures as the existing ones, to allow the drainage of the flow of Design, which is equivalent to the 500-year return period.

In addition, in basins where the Q500 discharge ≥ 200 m3 / s or areas with a risk of catastrophic damage, the design of the work must be carried out using the HEC-RAS gradually varied mathematical model. The flow and the river will be analyzed without the work and with the implementation of it, in order to reduce the overbearing caused by it. For newly built construction, the elevation at the entrance to the 500-year avenue should be less than 0.3 m in relation to the natural situation. On the other hand, the minimum shelter between the maximum level of the water sheet inside the drainage openings and the key of the work for Q500 will be more than 1 m. If the risk of obstruction was high (case of high density of bush vegetation or trees) a minimum shelf of 1.5 m will be left in a free light 12.0 m. In addition, the non-occupation of the road of intensive drainage (VID) will be fulfilled, at the width of the channel such that the 100-year avenue of return period produces an overflow of the water sheet below 0.30 m with respect to the level that this would have without the work of drainage. For bridges and viaducts these limitations are equivalent to the non-occupation of the VID for the bridges of the bridge.

To meet all these criteria, the following documentation has been used:

- Instruction 5.2.-IC. "Superficial Drenaje" de la Dirección General de Carreteras del Ministerio de Fomento. For the calculation of the transverse drainage works, the publication of the Directorate General for Highways of Transversal Drainage of Roads has been taken into account. Little works of passage. Hydraulic sizing.

- Publication "Technical Recommendations for the design of infrastructures that interfere with the river space" carried out by the Catalan Water Agency.

- Annex Cartography and Topography.

III.4.2 Data used in the calculation

In order to estimate the behavior of a river course for a specific flow, numerical simulation models are used, such as the HEC RAS model or the MIKE 11 model, in which case the first one will be used. The basic calculation procedure is based on the solution of the one-dimensional energy equation and evaluates the loss of energy due to friction with the Manning equation. The adopted resolution method is known in the name of the Standard Step Method.

III.4.3 Topography and geometry of the sections

It will be necessary to specify the geometry of the different sections of the river, so upstream as below the gateway, which is obtained from the database of the Cartographic Institute of Catalonia, which will use the topographic base 1: 500.

III.4.3.1 Flows

Once the geometry is defined, 3 profiles will be analyzed, each produced by different volumes of interest. Thus, these shadows will be those produced by avenues of 100 and 500 years apart from the middle flow of the river. The data of these avenues, which are extracted from the Catalan Water Agency, are the following:

Avinguda	Cabal (m^3/s)
Mitjà	27
T=100	1962
T=500	3059

Table 45 - Pluviometric study: Definitive flows

III.4.3.2 Energy loss coefficients

The HEC-RAS program uses several types of coefficients to calculate energy losses:

- Manning coefficient "n" for friction losses.
- Coefficient of contraction and expansion to evaluate losses in transitions.

Generally, several coefficients of roughness "n" values are used to describe the central channel and the flood margins. The contraction and expansion of the flow due to changes in the cross section is a common cause of losses in a section. When this happens, the losses are calculated by specifying the values of contraction and expansion coefficients. In this case, the changes in the section are small and therefore, the following values have been adopted:

- Coefficient of contraction: 0.1
- Expansion coefficient: 0.3

III.5 HEC-RAS MODEL

The HEC-RAS program was developed at the Hydrologic Engineering Center by Bill S. Eichert. The purpose of the HEC-RAS is the calculation of the profile of the water lamina in natural or artificial channels by flow gradually varied in stationary regime. The model can calculate profiles in slow or fast regime and allows to consider the effects that various obstructions such as bridges, sewers, spillways or other structures which can be produced in the flow. It should be mentioned that the cases studied are always in slow regime. The basic calculation procedure is based on the solution of the one-dimensional energy equation and evaluates the loss of energy due to friction with the Manning equation. The adopted resolution method is known by the name of the Standard Step Method.

The main hypotheses assumed in the HEC-RAS model are the following:

- Stationary flow, so there is no change in draft or speed over time.
- Flow gradually varied. This leads to a hydrostatic distribution of pressures.
- One-dimensional flow, the only component of the speed is in the flow direction.
- The slopes must be small, less than 1/10. The vertical draft is representative of the pressure height.
- The contours are rigid, without admitting erosion or sedimentation in the channel.

The fundamental hypothesis realized by the HEC-RAS is that the loss of height by friction in a section is the same that would have a uniform flow that had the same speed and hydraulic radius that those corresponding to this section. This hypothesis allows to apply the formula of Manning of uniform flow to evaluate the slope of friction in a cross section of the channel.

The evaluation of the average friction slope in the section, based on the values existing in the two sections that limit it, admits several options: arithmetic, geometric, harmonic, etc. The method of resolution uses successive approximations to determine the elevation of the water sheet in the following section with the Q flow data and the elevation in the previous section.

The calculation of the profile begins in a cross section with a certain initial condition and continues upstream in the case of slow regime. The HEC-RAS model does not allow to directly locate the position of a regime change, from slow to fast or vice versa. When in the step-by-step calculation there is a change in scheme, the model once again starts calculations with the critical regime. Therefore, the calculated profile will always be above the critical depth in the case of slow regime and below in case of rapid regime. In cases where there is a regime change, it is necessary to calculate the profile twice alternatively assuming a slow and fast regime and study both results to obtain the final one. However, in the section where coexistence of two regimes can coexist, it does not allow the hydraulic spring to be located by not calculating the corresponding conjugates and it is not possible to deduce the regime that is actually existing in conflicting sections.

III.5.1 Conclusions

As can be seen in the calculations and plans that are attached in the appendix of this annex, the construction of the projected structure on the River Ter channel does not cause alterations to the current situation, fulfilling all the conditions imposed by the ACA. The results obtained from the HEC-RAS program are as follows:

- Medium: Obviously the flow that circulates in normal situations does not generate flooding nor is it of much relevance to see the behavior of the river in the case of avenue but nevertheless it is possible to do the comparison of the different situations of avenue and the normal behavior of the river , thus seeing the variations and increments of quota of the water-free sheet. First of all, introducing the topography of the area and the same river into the HEC-RAS program, and knowing the value of the medium flow, the river can be modeled.

Therefore, the results obtained are the following:

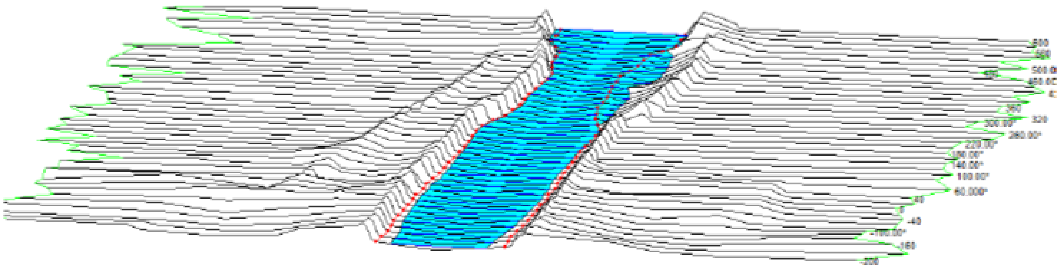


Figure 58 - HEC-RAS model: river's morphology

It can easily be appreciated that the space occupied by the middle flow corresponds to part of the main channel, although it does not end up completely filling it.

100 years return period

For this period of return, the flooded area became, logically, greater than the previous one, causing the flood of the area closest to the urban center of Torroella de Montgrí, without affecting it, and extending beyond the crop plain. With regard to the solution obtained from the HEC-RAS model, obviously the water will occupy the floodplain, filling the main riverbed completely, which will consequently cause water to flood nearby areas as shown in the photograph of the floodable area attached below:

Figure 59 - HEC-RAS model: flooded area for T=1oo years

500 years return period

In this case, the flood that may occur may have consequences to be taken into account, since the level of water gets to flood part of the urban area of L'Estartit, where it could cause significant damage, however, does not reach affect the nucleus of Torroella. The results obtained with the HEC-RAS show, logically, the flood of the circumcised zone in the river, as shown below:

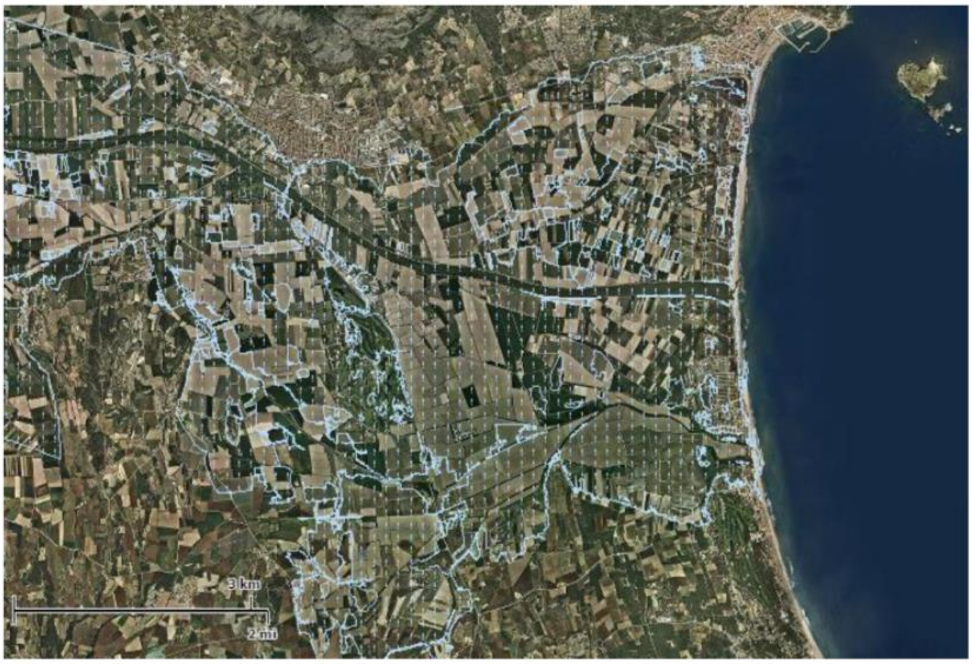


Figure 60 - HEC-RAS model: flooded area for T=500 years

Since in the three different periods of return, the water exceeds the main channel causing the flood of the surrounding area, only shows the case of a period of return of 500 years, which is what causes greater flood.

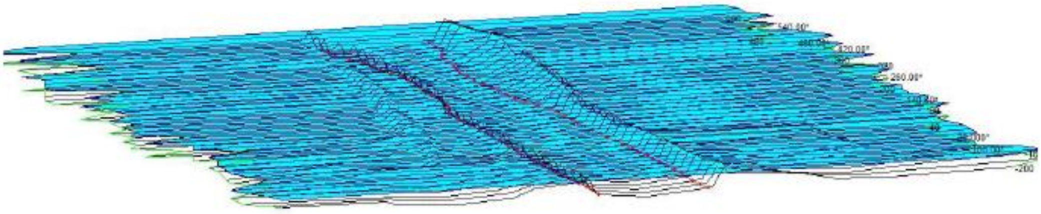


Figure 61 - HEC-RAS model: Flood for T=500 years

Therefore, it is possible to be seen how indeed the water exceeds the main channel flooding the zone next to the river.

Once the maximum level of the water sheet has been studied, which becomes 5.8 m in the section where the gateway is to be located, the height to which the bridge must be located will be determined, which will be finally 6.80 m. This height of the structure contemplates the minimum shelf of 1.0 m that should be applied in this case.
All these considerations and recommendations dictated by the ACA are very useful in many cases, but in this case, contextualizing the situation of the footbridge, it can be considered unnecessary to provide a minimum protection, Water reaches the height of the speck, when it surpasses it, it will occupy the entire nearest surface, extending as it has been seen to almost Estartit. Well, the level of water will never exceed the level of the type, because after the type, water will fall to the level of the fields, extending to the entire rural-agricultural area that surrounds the river and which is finds a lower share than the speck.
The dimensions of the area that surrounds the river are so considerable that in the most unfavorable cases, as in the period of return of 500 years, the water will remain at a maximum level corresponding to the level of the type. Therefore, the height of the catwalk has been place above 5.3 m, which is the level of the type, but without strictly applying the minimum protection dictated by the ACA.

Finally, this study can be concluded, stating that, in fact, the location of the catwalk in this river stretch does not cause alterations to the river, neither in normal conditions nor in extreme conditions or flood.

ANNEX 4
ENVIRONMENTAL IMPACT

IV.1 INTRODUCTION

The object of this annex is the environmental analysis of the project to build a footbridge over the River Ter. Preventive and corrective measures are defined in order to avoid alterations in the receiving environments and integrate the infrastructure in their environment. The environmental monitoring program is implemented in order to guarantee the implementation and the effectiveness of measures.

Many of the necessary data, for the correct fulfillment of the “DIA”, have not been possible to be obtained, since acoustic studies, studies of flora and fauna as well as field studies, are out of reach of the author's possibilities.

In this way, the preventive and corrective measures, as well as the environmental monitoring program, have been defined in a particular way in the project area, although generically.

IV.2 General aspects

The present project incorporates the recommendations and the preventive and corrective measures included in the Environmental Impact Study, referred specifically to the following aspects:

- **Acoustic impact**:
  study of sound levels and, if applicable, installation of acoustic displays and minimize discomfort in the population and fauna. (This part goes out of the scope of the project).

- **Impact on vegetation:**
  occupation surfaces, revegetation measures, criteria for selection and distribution of species, embankment and disassembling slopes, periodic irrigation, maintenance of machinery, prevention of discharges and maintenance.

- **Impact on the landscape**
  generic measures of design of the structures, measures of landscape integration of all the elements that make up the work.

- **Impact on the historical cultural heritage:**
  archaeological action plan. (This part goes out of the scope of the project)

- **Impact on the socio-economic environment:**
  employment of local workforce and adequate valuation of the property to be expropriated (this part is outside the scope of the project).

- **Impact on the soil:**
  avoiding the attachment to the most fertile soil, sloping design to reduce erosion, control of the surface of employment, collection, stacking and conservation of land with agrological value, spread of vegetal earth on the zones without ground, revegetation of slopes, prevention of the contamination of the floors, conditioning of compact floors and maintenance of the structures.

- **Impact on hydrology:**
  control of the recharge of aquifers, design of structures and defense works so that avoid the attachment to the banks of the beds, adequate sizing of longitudinal and transverse drains, control of the drag of sediments in the channels, prevention of possible discharges and maintenance of drainage and planting works.

IV.3 PROTECTION AND CONSERVATION OF SOILS AND VEGETATION

IV.3.1 Protection of vegetation

Before the works begin, the limits of the employment range of the explanation of the road and the paths of access to the work site land will be delimited with barriers. These barriers will be made up of metal supports of 30 mm and one meter high, with the top 20 cm covered by a red paint and leaving a minimum height of 50 cm between the ground level and the lower limit of the closing mesh. These supports, placed every 8 meters, will join each other by means of a signposting tape, tied under the painted area of the metallic angle.

The areas of auxiliary facilities and access roads will be signposted, so that the movement of personnel and machinery is restricted to the bounded area, in order to do not affect the land annexed to the work.

In addition, during the construction phase, the tree trunks of the trees that face the works in the areas with arboreal vegetation will be carried out, to prevent accidental damage caused by the movement of land or traffic of machinery.

IV.3.2 Recovery of the upper layer of vegetable land

The thickness of plant ground varies from 0.30 m in floors occupied by terraces, up to 0.60 m where the substrate is formed by sands.

The reuse of the vegetal land in the work carries the following positive impacts:

- avoid the export of the same to landfill, to increase the stability of the slopes and to favor the re-vegetation, since the own vegetal earth carries seeds of the natural vegetation of the area;
- the removal of the layer of vegetal earth will be made to coincide as far as possible with the clearing tasks, so that the vegetal land incorporates seeds and rests of the existing vegetation in the land and thus facilitate the later process of colonization of the vegetation

In the excavation tasks, the following criteria will be taken into account:

- If the layer has a minimum thickness of 30 cm, all of it will be excavated, as it constitutes the highest quality layer for the future vegetation settlement.

- If its depth is less than 30 cm, is necessary to reach the minimum depth specified.

- The land will be protected from rain when it occurs, in order to conserve to the maximum the germinal potential of the seeds contained. If its reuse is programmed in the long term, proper conservation tasks will be carried out with resembling seeds, irrigation and enrichment with organic fertilizers (compost).

The extension of vegetal land in the ways of connection and service will be carried out during the last two months of the work, as well as the recovery and contribution of vegetal land in the terrains of the auxiliary facilities area and temporary stacking area, which will be left for the last month of construction.

IV.4 MEASURES OF DEFENSE AGAINST EROSION, ENVIRONMENTAL RECOVERY AND LANDSCAPE INTEGRATION

IV.4.1 General objectives and criteria

With the introduction of a plant cover and other projected actions that complement the application of other corrective measures, it is pursued as a fundamental objective to integrate the structure in its closest environment and recover the adjacent areas altered by the construction of the road.

Consequently, like particular objectives are mentioned the following:

- Stabilization of the slopes through the establishment of a vegetation cover that stops superficial erosion and also facilitates the landscape integration of the foot-cyclelane bridge in its surroundings.
- Defense of structures and works.

In addition to sowing and planting, other complementary actions are projected as the recovery of the upper layer of vegetal soil that must be altered by the works for later use in the processes of restoration of soil and vegetation.

The type of vegetal restoration that is projected is consistent with the ecological and landscape characteristics of the environment through which the route runs, designing sowing and planting with native species, well adapted to the conditions of the environment, so that the success is guaranteed of the treatment while reducing maintenance costs.

IV.4.2 Description of catering treatments

The proposed actions are of various types and, basically, the following techniques will be used:

IV.4.2.1 Preparation of land and contribution of vegetable land

The land from the trace will be reused in all areas that will be revegetated, such as the slopes of the platform, segregated plot area, margins of service roads and replacement, areas of influence of the bridge, and to recover the affected areas by the work facilities, zone of temporary stacking, providing a layer of thickness of 30 cm of vegetal earth in all the surfaces, except in the installations. Plant ground pools will be provided with 50 cm and in the temporary stacking area that will be provided 65 cm.

The vegetable land also contains a large quantity of vegetable seeds that are best adapted to the conditions of the area, especially annual, so that it ensures a fast and efficient coating of surfaces.

IV.4.2.2 Planting of trees

This type of plantation takes place in flat areas as a base of embankment slopes and areas of influence of the structure. It consists of the creation of a bush of trees and shrubs that acts as a visual screen visually hiding or fragmenting the slopes and structures.

The plantations will be carried out forming woods, in some cases, or alignments in others, with 2 m of separation between the trees and 1 m of separation between shrubs, alternating the plants of different port.
Once the replanting is done, excavation of the holes will be carried out and this excavation should be carried out as early as possible on the plantation to favor the weathering of the earth.
Once the plant is placed in the hole, the envelope that protects the ground bread will be separated so that it is not destroyed. The filling of the hole must be done with vegetable soil, avoiding that there is air between the earth.

Mixed with organic soil to increase the chances of success of plantations. Likewise, it will add 0.050 kg of simple mineral fertilizer.
The ideal time in which the plantations are due is in autumn and winter, during the period of vegetative rest. After finishing the plantation, it is necessary to water abundantly on the plant, so that the water reaches the ground bread where the roots lie.

IV.4.2.3 Planting shrubs

The shrubs will be used along the route of generalized form on embankment slopes.
The plantation will be carried out forming groups, with an average density of 1 ud / 2 m^2.

The planting process is similar to that described for tree species, requiring immediately after planting irrigation to facilitate good bonding of the soil with the roots of 15 l / A.
The filling of the hole must be made with plant ground (0.25 m^3) and will be carried out by organic materials, avoiding that there is air between the earth. A manure-type organic (0.6 kg) will be mixed with vegetable soil to increase the chances of successful planting.

The planting season should be during the period of vegetative rest, as indicated in the other plantations, so winter and autum.

IV.4.2.4 Maintenance of the implanted vegetation and restored areas

Maintenance tasks will cover the two years after the planting time.
During the following winter, the corresponding faults will be reconsidered, 20% for shrubs and 5% for those of arboreal parts.

The revision of the hydrosemitrations during the initial maintenance phase will be carried out, in areas where the rootness of the herbaceous deck has been more insufficient, it does not reach 90% coverage, which is considered more necessary than the irrigation practice .
The surfaces sown, at least once during the maintenance period to avoid accumulations of dead vegetation.

The number of irrigations will be 5 in the months of lower precipitation (between July and August) and the recommended doses will be 20 l / Ut / time for the leafy and 6 l / Ut / time for bushes.

Other treatments, maintenance pads, will be at the discretion of the Faculty and the Contractor.

IV.5 PROTECTION OF HYDROGOLOGICAL AND HYDROGEOLOGICAL SYSTEMS

IV.5.1 Protection of river systems

As a general criterion, for the location of the auxiliary works and facilities, it has been taken into account to avoid any direct or indirect affection in the natural drainage channels. The sizing of the structures and project works projected for cross the river, as well as the measures established to avoid contamination processes and prevent the possible barrier effect, will be defined in coordination with the Catalan Water Agency of the Generalitat de Catalunya, following the instructions set out in the Technical Guide - " Recomanacions tècniques per al disseny d'infraestructures que interfereixen amb l'espai fluvial" provided by the said organization and maintaining the opportune contacts (written, field visits, etc.)

IV.5.2 Treatment of waste water from machinery facilities

During the work, runoff waters from the auxiliary installation that present large amounts of suspended solids, will be treated before their discharge into the watercourses or on the terrain.

It is unlikely that these waters present harmful chemicals in suspension or dilution, so that only a decantation treatment will be necessary.

The runoff water in the auxiliary work facility area (aggregate treatment plant, machinery park, etc.) will reach, through the drainage basins, to the decanting pool, where it is located. They will be accumulate before their discharge into the river or the ground.

Its construction will be based on the realization of an excavation with the required dimensions, covering its base and its slopes with a waterproof sheet consisting of a double layer of geotextile with another intermediate of bentonite, which prevents retained waters filter into the natural terrain.

This material presents the advantage, in contrast to other conventional materials, of recovering. In its placement it will be necessary to foresee a shelf of 0.5 m wide throughout the perimeter of the raft at ground level.

The rafts will be subjected to periodic cleaning and emptying of the solids deposited in the bottom, to ensure its correct operation. The deposits withdrawn, of inorganic and inert nature, will be deposited in the area of collected inert materials.

However, more frequent cleaning of the surface lamina must be carried out to remove possible accumulations of oils. For this, a weekly monitoring of the state of the water in autumn and spring will need to be carried out, as well as after intense rainy episodes.

During the works, an analytical (monthly) monitoring of the waters from these decanting pools will be carried out, that their results, if the values established by current legislation in terms of discharge are exceeded, will determine the need for these water to be treated by a coagulation and flocculation system before its discharge.

Periodically, the water from the storage pool will be collected, by means of a tanker truck and reused in the process of concrete or for irrigation of the installations. The decanted waters that are not reused will be discharged directly to the immediate channels or to the ground, provided that their quality meets the quantitative and qualitative limits.

IV.5.3 Barriers to sediment retention in areas of possible drags in public lands

The elimination of vegetation and land movements during the works increase the erosion risks in a remarkable way. In addition, the soils dragged by the water will tend to deposit in the network of natural drainage and can produce his landing. This process can be very pronounced in case of intense rainy episodes during the execution of the works.
To prevent the entry of suspended solids into the riverbed, at the stage of land movement and during the construction of the viaduct, systems will be installed that will serve as provisional barriers to sediment retention.

The contractor will define the most appropriate solution among the ones indicated below.

Barriers of sediments with straw bales
The cereal straw bales allow the circulation of the waters, retaining much of the land that has been dragged. For them to be effective, they must support ground plan so that water can not flow under them. For this reason, each bullet must be fixed to the floor conveniently by means of wooden stakes of approximately 1.10 m in height and must be buried at a depth of 10 cm to withstand the push of the water. The number of bullets to be placed will be the function of the width of the area of circulation of the waters, having to avoid that the water surrounds them and circulate around the sides of the bales.

Barrier of filter sheets
The filter barrier is constructed with wood poles (height not exceeding 90 cm), metal and geotextile. These are temporary structures with a shelf life of approximately 6 months and a flow limit of water of 30 l / s. It is estimated that for about 1,000 m^2 of surface area it is necessary to have about 30 m of barrier.

The maximum length of the slope must not exceed 30 m and the slope of the slope must be less than 2H: 1V.

Barrier of earth bags
In the strip affected by the construction of the planned bridge, parapets, consisting of sacks of earth, with a height equivalent to two sacks, that will be fixed to the ground with wooden stakes or metal feet, trace excavation material will be used.

After each waterfall an inspection and repair of damages must be carried out, as well as the cleaning of the sediments when they reach a height equivalent to half the barrier.

IV.5.4 Provisional steps for heavy machinery on public channels

It will not be necessary to open new access roads to the works, but if for the construction of the gateway it was necessary, provisional steps will be installed for the machinery, so that the course of water and avoid turbidity of the waters, these will be demolished after the completion of the works, having to obtain authorization from the Catalan Water Agency.

IV.5.5 Waste Management

The residual products from the works (discharges of oils, fuels, cement and other suspended solids) will be managed in accordance with current state and autonomous regulations. The oils, fuels, cements and other solids from the areas of work facilities, will not be in any case discharges to the water courses.

The areas where deposits of storage of lubricants and fuels, refills and oil changes are located, will be built in a special way, with protection for possible leaks, through the provision of retainers. These systems of reception of possible leaks will have in addition to the equipment of pumping necessary for his collection and storage.

Used oils and greases from machinery maintenance operations will be available in appropriate and labeled drums, according to article 11 of the Order of February 28, 1989, on used oil management and will be arranged, with a company authorized waste management, the correct management of collection, transportation, and treatment of waste (used oils, fats, cans, etc.).

The soils contaminated by accidental or uncontrolled discharges of fuels or lubricants will be quickly removed and stored on pavements waterproofed and managed by a waste management company duly authorized by the competent bodies.
For the management of solid waste generated during the works, the installation of clean points is planned, distributed in the auxiliary installation. These clean points or fixed areas of temporary storage, consist of a set of containers, some with compaction capacity, distinguishable according to the type of waste.

The development of the work will advise the expansion of containers or the removal of some of them. There will be a daily and selective collection service. The determination of the most convenient collection time will depend on the particular conditions of the work of the moment of operation.

Once the functionality of the auxiliary installations has been completed, the total dismantling and cleaning and destruction of the affected area will be carried out, with the transfer of waste to a controlled landfill and / or adequate management of waste and contaminated soils, depending on establish current legislation.

IV.5.6 Area of influence of the bridge

Throughout the surface affected by the work, equivalent to the shadow of the structure, there will be a previous decomposition of the ground, by plow or subsoil. Later a layer of 30 cm of vegetal soil will be provided and a planting will be carried out at full wind, since the capacity of recovery of the affected species is sufficient so that, in a short time, colonize the affected areas for the construction works.

IV.5.7 Manual of good environmental practices

Prior to the commencement of the works, the contract will deliver to the Administration a manual of good environmental practices. This will include all the measures taken by the Works Directorate and the Technical Manager of the Environment to avoid impacts from the management of the works.

Among other determinations will include:

- waste and rubbish control practices. The references to control of used oils, remains of tar, tin, packaging of construction materials, both plastic and wood, will be explicitly mentioned.

- prohibited actions, explicitly mentioning the production of bonfires, dumping of used oils, cleaning waters of concrete mixers, and rubbish.

- Driving practices, maximum speeds and compulsory circulation for the paths stipulated in the works plan.

- Practices aimed at avoiding damages overflowing with vegetation or fauna.

- The accomplishment of an Environmental Newspaper of the Work in which they must write down the environmental operations carried out and the personnel responsible for each one of these operations and their follow-up.

The responsibility of the Diario corresponds to the technical manager of the Environment.
This manual must be approved by the Environmental Director of the work and widely disseminated among all the staff.

ANNEX 5
MODEL RESULTS

In this annex the results of the most critical elements of the structure are gathered, with the aim to show how the results were treated.
First, in order to find out which elemets were the most urged, the software interface has been exploited which permits to see with different colors the megnitude of the stresses related to each element as shown below.

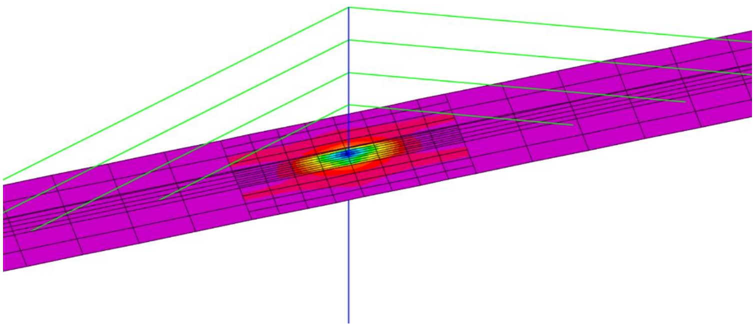


Figure 62 - Results: stresses on the deck around the pylons

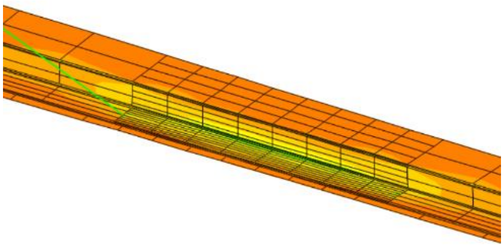


Figure 63 - Results: stresses below the deck

V.1 Shell elemets

TABLE: Element Stresses - Area Shells

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
10	6	ULS1	3.11	-84.08	20.53	7.71	-88.67	12.61	92.76	4.98	-84.69	32.09	15.28	-95.00	17.80	103.49
10	12	ULS1	6.21	-69.21	-43.80	26.30	-89.30	-24.63	104.94	10.36	-71.30	-33.30	22.21	-83.16	-19.60	96.21
10	13	ULS1	4.93	-68.80	-36.16	19.70	-83.58	-22.22	94.97	-10.48	-78.35	-42.31	9.82	-98.65	-25.63	103.91
10	389	ULS1	-1.90	-84.79	28.16	6.77	-93.45	17.10	97.01	-12.13	-90.62	23.09	-5.85	-96.91	15.23	94.12
10	6	ULS2	4.57	-118.84	5.23	4.79	-119.07	2.42	121.53	6.56	-121.15	18.75	9.25	-123.85	8.18	128.72
10	12	ULS2	3.05	-115.20	-19.63	6.22	-118.37	-9.18	121.60	9.94	-118.60	-7.42	10.37	-119.03	-3.29	124.54
10	13	ULS2	4.99	-115.41	-12.12	6.20	-116.62	-5.69	119.84	-10.59	-123.97	-19.42	-7.36	-127.20	-9.46	123.69
10	389	ULS2	2.18	-120.32	12.74	3.49	-121.63	5.87	123.42	-9.64	-125.25	6.74	-9.25	-125.64	3.33	121.28
10	6	ULS3	2.26	-36.14	5.39	3.00	-36.88	7.84	38.47	1.78	-37.17	11.50	4.92	-40.31	15.28	42.99
10	12	ULS3	2.80	-32.32	-15.20	8.46	-37.98	-20.44	42.84	3.28	-34.19	-9.68	5.63	-36.54	-13.66	39.66
10	13	ULS3	3.67	-31.62	-11.00	6.81	-34.77	-15.97	38.62	-6.68	-37.62	-14.17	-1.17	-43.13	-21.25	42.56
10	389	ULS3	1.03	-36.07	9.59	3.36	-38.40	13.67	40.19	-6.08	-39.97	7.00	-4.69	-41.36	11.23	39.23
10	6	ULS4	3.41	-93.95	4.83	3.65	-94.19	2.83	96.06	4.46	-96.31	14.96	6.63	-98.48	8.27	101.96
10	12	ULS4	2.84	-90.22	-16.02	5.52	-92.91	-9.50	95.79	6.95	-93.59	-6.87	7.42	-94.05	-3.89	97.98
10	13	ULS4	4.58	-90.77	-10.64	5.75	-91.94	-6.29	94.95	-7.80	-96.95	-16.13	-4.97	-99.78	-9.95	97.39
10	389	ULS4	2.00	-95.41	10.21	3.06	-96.47	5.92	98.04	-7.16	-98.75	5.70	-6.81	-99.10	3.55	95.88
10	6	ULS5	1.98	-60.57	20.10	7.89	-66.48	16.36	70.75	2.99	-61.22	28.47	13.80	-72.02	20.78	79.82
10	12	ULS5	6.00	-45.64	-40.39	28.12	-67.76	-28.71	85.37	7.52	-47.68	-32.79	22.77	-62.94	-24.96	76.90
10	13	ULS5	4.52	-45.55	-34.77	22.33	-63.35	-27.12	76.98	-7.81	-52.82	-39.18	14.87	-75.50	-30.06	83.93
10	389	ULS5	-2.09	-61.27	25.73	7.53	-70.89	20.50	74.94	-9.74	-65.57	22.08	-2.07	-73.24	19.17	72.23
10	6	ULS6	4.08	-139.22	8.66	4.60	-139.75	3.45	142.10	6.57	-142.35	22.09	9.78	-145.56	8.26	150.69
10	12	ULS6	3.78	-132.39	-23.74	7.80	-136.41	-9.61	140.47	10.59	-136.79	-11.59	11.49	-137.69	-4.47	143.79
10	13	ULS6	5.43	-133.93	-17.18	7.51	-136.02	-6.93	139.93	-8.85	-140.58	-24.55	-4.43	-145.01	-10.22	142.85
10	389	ULS6	1.77	-141.93	15.21	3.36	-143.52	5.98	145.23	-8.91	-144.99	9.14	-8.30	-145.60	3.83	141.63
10	6	ULS7	4.57	-148.90	8.86	5.08	-149.41	3.29	152.01	7.39	-152.03	23.62	10.81	-155.45	8.25	161.13
10	12	ULS7	3.88	-142.09	-25.14	8.09	-146.29	-9.50	150.50	11.77	-146.51	-11.80	12.64	-147.39	-4.24	154.10
10	13	ULS7	5.60	-143.50	-17.75	7.69	-145.58	-6.70	149.58	-9.97	-151.10	-25.84	-5.39	-155.68	-10.06	153.06
10	389	ULS7	1.86	-151.61	16.24	3.56	-153.31	5.98	155.12	-9.92	-155.32	9.58	-9.29	-155.95	3.75	151.52
10	6	ULS10	4.50	-27.13	6.06	5.62	-28.25	10.49	31.44	2.58	-29.02	11.43	6.28	-32.72	17.94	36.27
10	12	ULS10	3.41	-26.45	-2.13	3.56	-26.60	-4.07	28.55	3.97	-28.72	2.54	4.16	-28.91	4.42	31.20
10	13	ULS10	3.83	-26.00	0.82	3.85	-26.02	1.58	28.15	-8.09	-32.66	-2.80	-7.78	-32.97	-6.42	29.85
10	389	ULS10	2.58	-27.34	9.02	5.09	-29.85	15.54	32.70	-7.15	-32.30	6.09	-5.75	-33.70	12.92	31.23
10	6	ULS11	4.38	-37.75	12.36	7.74	-41.11	15.21	45.48	3.11	-39.48	18.72	10.17	-46.53	20.66	52.36
10	12	ULS11	4.78	-32.31	-12.95	8.86	-36.39	-17.47	41.53	5.80	-34.65	-7.37	7.10	-35.95	-10.01	39.97
10	13	ULS11	4.19	-32.12	-9.37	6.47	-34.40	-13.66	38.05	-8.59	-39.33	-13.53	-3.48	-44.44	-20.68	42.81
10	389	ULS11	1.25	-38.29	15.94	6.88	-43.92	19.44	47.73	-8.73	-43.43	12.55	-4.66	-47.49	17.94	45.34

Figure 64 - Results: element 10

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
11	11	ULS1	-24.30	-117.93	77.50	19.43	-161.66	29.43	172.19	19.11	-93.82	77.53	58.56	-133.27	26.97	170.28
11	380	ULS1	-30.92	-115.04	-53.57	-4.87	-141.09	-25.93	138.71	29.29	-84.84	-56.33	52.41	-107.96	-22.31	141.63
11	14	ULS1	-9.79	-105.08	-75.03	31.44	-146.32	-28.79	164.31	3.53	-96.19	-69.87	39.51	-132.17	-27.24	155.73
11	12	ULS1	-7.73	-109.36	56.04	17.11	-134.19	23.90	143.51	-2.09	-103.77	63.99	28.80	-134.66	25.77	151.14
11	11	ULS2	-38.54	-157.18	30.17	-31.30	-164.41	13.48	151.21	20.63	-126.91	29.45	26.30	-132.57	10.88	147.48
11	380	ULS2	-57.67	-188.16	11.95	-56.59	-189.24	5.19	168.24	23.54	-150.04	7.34	23.85	-150.35	2.42	163.58
11	14	ULS2	-10.04	-169.32	-2.57	-10.00	-169.36	-0.92	164.59	6.68	-159.64	2.02	6.70	-159.67	0.70	163.12
11	12	ULS2	3.17	-140.17	15.65	4.86	-141.86	6.16	144.35	9.70	-134.69	24.13	13.63	-138.61	9.24	145.90
11	11	ULS3	-13.98	-54.38	25.15	-1.92	-66.44	25.61	65.50	10.44	-41.54	25.49	20.86	-51.96	22.22	64.95
11	380	ULS3	-18.60	-54.91	-15.45	-12.92	-60.59	-20.20	55.27	15.79	-38.59	-16.88	20.60	-43.40	-15.92	56.59
11	14	ULS3	-3.35	-48.49	-22.86	6.20	-58.04	-22.68	61.38	1.54	-44.71	-20.66	9.42	-52.59	-20.89	57.88
11	12	ULS3	-1.59	-48.84	17.74	4.33	-54.76	18.45	57.05	-0.95	-46.78	21.72	7.70	-55.44	21.73	59.66
11	11	ULS4	-27.81	-119.92	24.35	-21.77	-125.96	13.93	116.61	14.27	-98.51	23.58	19.01	-103.24	11.35	113.94
11	380	ULS4	-42.47	-145.37	9.77	-41.55	-146.29	5.38	130.57	15.37	-118.27	6.20	15.66	-118.56	2.65	127.11
11	14	ULS4	-6.96	-131.36	-1.99	-6.92	-131.39	-0.92	128.07	4.42	-124.91	1.57	4.44	-124.93	0.70	127.21
11	12	ULS4	3.49	-107.21	12.58	4.90	-108.63	6.40	111.16	7.54	-103.85	18.95	10.67	-106.99	9.40	112.70
11	11	ULS5	-14.04	-82.66	71.88	31.30	-128.00	32.24	146.19	13.05	-66.99	71.88	55.29	-109.24	30.45	145.02
11	380	ULS5	-16.38	-74.48	-55.65	17.34	-108.20	-31.22	117.83	21.50	-54.78	-57.41	52.28	-85.56	-28.20	120.53
11	14	ULS5	-6.88	-69.14	-74.49	42.72	-118.74	-33.66	144.90	1.41	-63.30	-70.27	46.41	-108.31	-32.64	137.52
11	12	ULS5	-7.46	-78.21	53.04	20.93	-106.59	28.15	118.45	-4.14	-74.62	59.01	29.36	-108.11	29.58	125.40
11	11	ULS6	-36.96	-171.34	37.12	-27.39	-180.91	14.46	168.89	17.52	-143.48	35.52	25.01	-150.97	11.90	164.90
11	380	ULS6	-57.63	-210.88	15.08	-56.16	-212.35	5.57	190.58	16.66	-175.72	10.00	17.18	-176.24	2.97	185.42
11	14	ULS6	-10.34	-192.15	-2.82	-10.29	-192.20	-0.89	187.26	6.28	-183.37	2.22	6.30	-183.40	0.67	186.63
11	12	ULS6	5.21	-154.20	19.22	7.50	-156.48	6.78	160.36	12.26	-149.55	27.73	16.88	-154.17	9.46	163.27
11	11	ULS7	-41.26	-185.91	39.50	-31.18	-196.00	14.32	182.42	20.06	-154.54	37.92	27.94	-162.41	11.74	178.03
11	380	ULS7	-63.73	-227.67	15.95	-62.19	-229.21	5.51	205.30	19.92	-188.13	10.45	20.44	-188.66	2.87	199.66
11	14	ULS7	-11.53	-207.01	-3.04	-11.49	-207.06	-0.89	201.56	7.15	-196.97	2.37	7.18	-196.99	0.67	200.68
11	12	ULS7	5.12	-167.04	20.51	7.53	-169.46	6.70	173.34	13.11	-161.57	29.83	18.06	-166.53	9.43	176.25
11	11	ULS10	-23.33	-48.25	20.85	-11.50	-60.08	29.57	55.23	8.77	-33.01	20.76	17.34	-41.57	22.41	52.43
11	380	ULS10	-33.26	-62.11	6.92	-31.68	-63.68	12.81	55.15	11.64	-42.70	4.24	11.97	-43.03	4.43	50.10
11	14	ULS10	-0.92	-50.70	2.15	-0.83	-50.80	2.47	50.39	1.56	-47.43	1.96	1.63	-47.51	2.28	48.34
11	12	ULS10	4.81	-38.11	16.08	10.17	-43.47	18.42	49.35	2.89	-36.47	18.48	10.21	-43.79	21.60	49.68
11	11	ULS11	-23.40	-60.58	40.90	2.93	-86.92	32.78	88.42	9.92	-44.08	40.66	31.73	-65.89	28.21	86.25
11	380	ULS11	-32.37	-70.73	-10.30	-29.79	-73.32	-14.12	63.87	14.13	-49.82	-13.13	16.71	-52.41	-11.16	62.47
11	14	ULS11	-2.45	-59.77	-19.98	3.82	-66.05	-17.44	68.04	1.52	-55.59	-19.30	7.43	-61.51	-17.03	65.53
11	12	ULS11	2.30	-50.89	31.22	16.71	-65.31	24.79	75.07	1.54	-48.58	34.49	19.11	-66.15	27.00	77.49

Figure 65 - Results: element 11

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
12	12	ULS1	3.26	-70.11	-45.88	25.32	-92.17	-25.68	107.10	8.25	-71.93	-38.21	23.54	-87.22	-21.81	101.07
12	14	ULS1	3.09	-64.79	26.20	12.02	-73.73	18.84	80.41	11.50	-67.01	31.61	22.64	-78.16	19.42	91.60
12	391	ULS1	9.55	-62.04	32.82	22.32	-74.81	21.26	88.11	-18.87	-76.93	27.24	-8.09	-87.71	21.59	83.96
12	13	ULS1	5.77	-68.54	-39.26	22.67	-85.44	-23.29	98.75	-18.16	-80.66	-42.58	3.41	-102.23	-26.86	103.97
12	12	ULS2	10.51	-112.96	-21.19	14.05	-116.50	-9.47	124.12	15.88	-116.82	-13.49	17.24	-118.18	-5.75	127.67
12	14	ULS2	11.61	-99.88	-2.98	11.69	-99.96	-1.53	106.29	22.72	-103.42	2.33	22.77	-103.46	1.06	116.53
12	391	ULS2	8.17	-101.74	2.45	8.23	-101.79	1.28	106.15	-18.72	-115.02	-2.75	-18.64	-115.10	-1.63	107.01
12	13	ULS2	2.78	-116.07	-15.77	4.84	-118.13	-7.43	120.62	-21.27	-127.17	-18.57	-18.11	-130.33	-9.66	122.29
12	12	ULS3	2.95	-32.27	-15.76	8.97	-38.29	-20.91	43.48	3.25	-34.20	-12.09	6.82	-37.76	-16.43	41.59
12	14	ULS3	2.29	-31.13	7.36	3.84	-32.67	11.88	34.75	4.59	-33.11	9.84	7.00	-35.53	13.79	39.50
12	391	ULS3	5.28	-29.79	10.33	8.10	-32.61	15.25	37.32	-11.69	-38.43	7.82	-9.57	-40.55	15.17	36.71
12	13	ULS3	3.84	-31.57	-12.79	7.97	-35.70	-17.93	40.29	-10.91	-38.89	-14.11	-5.03	-44.77	-22.63	42.48
12	12	ULS4	8.50	-88.53	-17.17	11.45	-91.47	-9.74	97.70	11.63	-92.18	-11.33	12.85	-93.41	-6.16	100.45
12	14	ULS4	9.89	-77.21	-2.28	9.95	-77.27	-1.50	82.69	17.08	-80.71	1.77	17.12	-80.74	1.04	90.52
12	391	ULS4	7.40	-79.04	1.76	7.43	-79.08	1.16	83.05	-13.48	-88.79	-2.20	-13.41	-88.85	-1.68	82.96
12	13	ULS4	2.83	-91.29	-13.13	4.63	-93.09	-7.80	95.49	-15.75	-99.33	-15.30	-13.04	-102.05	-10.06	96.19
12	12	ULS5	1.31	-47.05	-42.08	25.67	-71.41	-30.06	87.12	4.23	-48.66	-36.16	22.58	-67.01	-26.91	80.70
12	14	ULS5	1.41	-43.43	26.82	13.94	-55.97	25.05	64.09	6.14	-45.61	31.06	20.69	-60.16	25.10	72.74
12	391	ULS5	8.81	-40.65	32.14	24.63	-56.47	26.21	72.02	-13.91	-52.19	27.72	0.64	-66.73	27.69	67.06
12	13	ULS5	5.81	-45.15	-36.77	25.06	-64.40	-27.64	79.94	-12.91	-54.36	-39.49	10.97	-78.23	-31.16	84.25
12	12	ULS6	11.72	-130.01	-25.59	16.20	-134.48	-9.93	143.27	17.46	-134.73	-17.68	19.48	-136.75	-6.54	147.46
12	14	ULS6	14.69	-111.21	-3.13	14.77	-111.29	-1.42	119.36	25.81	-115.79	2.45	25.85	-115.83	0.99	130.68
12	391	ULS6	9.81	-114.75	2.27	9.85	-114.79	1.05	120.02	-15.25	-126.03	-3.19	-15.16	-126.12	-1.65	119.27
12	13	ULS6	2.73	-134.74	-20.19	5.63	-137.65	-8.18	140.55	-19.50	-143.78	-23.31	-15.27	-148.00	-10.28	140.99
12	12	ULS7	12.55	-139.48	-27.15	17.26	-144.19	-9.83	153.54	19.12	-144.31	-18.53	21.19	-146.38	-6.39	158.05
12	14	ULS7	15.41	-119.97	-3.36	15.50	-120.05	-1.42	128.50	28.03	-124.57	2.69	28.08	-124.62	1.01	140.78
12	391	ULS7	10.11	-123.53	2.57	10.16	-123.58	1.10	128.96	-17.30	-136.20	-3.37	-17.20	-136.30	-1.62	128.56
12	13	ULS7	2.72	-144.37	-21.22	5.72	-147.37	-8.05	150.31	-21.68	-154.61	-24.58	-17.28	-159.01	-10.15	151.12
12	12	ULS10	8.50	-24.92	-2.66	8.71	-25.13	-4.52	30.43	5.64	-28.22	-1.10	5.68	-28.25	-1.86	31.48
12	14	ULS10	8.66	-19.69	4.40	9.33	-20.36	8.61	26.29	8.79	-22.40	5.04	9.58	-23.19	8.95	29.19
12	391	ULS10	4.01	-20.80	5.83	5.31	-22.10	12.58	25.18	-11.06	-28.64	4.38	-10.03	-29.67	13.25	26.14
12	13	ULS10	2.01	-26.55	-1.23	2.06	-26.60	-2.46	27.69	-12.37	-33.94	-1.75	-12.22	-34.08	-4.62	29.90
12	12	ULS11	7.80	-31.41	-13.97	12.27	-35.87	-17.73	43.33	6.08	-34.56	-11.42	9.07	-37.55	-14.67	42.82
12	14	ULS11	8.29	-25.11	12.73	12.59	-29.41	18.66	37.33	9.49	-27.89	14.13	14.23	-32.63	18.55	41.61
12	391	ULS11	5.53	-25.59	15.18	11.70	-31.77	22.14	38.96	-12.04	-34.69	12.90	-6.20	-40.54	24.36	37.82
12	13	ULS11	2.85	-32.52	-11.52	6.27	-35.94	-16.54	39.46	-13.25	-40.73	-12.65	-8.32	-45.67	-21.32	42.13

Figure 66 - Results: Element 12

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
13	389	ULS1	4.67	-62.16	-10.85	6.38	-63.88	-8.99	67.29	-3.63	-63.04	-16.80	0.79	-67.46	-14.75	67.86
13	13	ULS1	9.03	-55.86	30.78	21.31	-68.14	21.75	80.93	-4.46	-57.54	25.65	5.90	-67.91	22.01	71.04
13	15	ULS1	2.95	-56.50	24.38	11.67	-65.22	19.68	71.77	2.18	-56.74	25.04	11.38	-65.94	20.18	72.31
13	10	ULS1	0.42	-62.24	-17.25	4.85	-66.68	-14.42	69.23	1.18	-62.78	-17.41	5.61	-67.22	-14.28	70.19
13	389	ULS2	7.76	-101.31	-0.84	7.77	-101.32	-0.44	105.42	-2.97	-103.43	-7.94	-2.35	-104.05	-4.49	102.90
13	13	ULS2	9.85	-99.62	21.52	13.94	-103.70	10.73	111.32	-4.04	-101.71	15.48	-1.65	-104.11	8.79	103.29
13	15	ULS2	-0.45	-100.41	14.19	1.52	-102.39	7.93	103.16	1.00	-102.50	15.46	3.26	-104.76	8.32	106.43
13	10	ULS2	-0.64	-101.55	-8.17	0.02	-102.21	-4.60	102.22	0.15	-104.77	-7.95	0.75	-105.37	-4.31	105.75
13	389	ULS3	3.50	-27.50	-1.33	3.56	-27.55	-2.46	29.50	-2.60	-28.69	-4.41	-1.88	-29.42	-9.34	28.53
13	13	ULS3	6.20	-23.51	12.43	10.71	-28.02	19.97	34.64	-3.07	-25.28	9.83	0.65	-29.01	20.76	29.34
13	15	ULS3	2.45	-24.08	9.18	5.32	-26.95	17.34	29.97	0.65	-24.71	9.36	3.73	-27.79	18.22	29.83
13	10	ULS3	0.78	-27.78	-4.58	1.49	-28.49	-8.90	29.27	0.10	-28.42	-4.88	0.91	-29.23	-9.45	29.70
13	389	ULS4	5.97	-81.89	-2.36	6.03	-81.95	-1.54	85.13	-2.71	-84.23	-7.70	-1.99	-84.95	-5.35	83.97
13	13	ULS4	7.38	-81.74	16.13	10.21	-84.57	9.95	90.11	-4.06	-84.18	11.60	-2.42	-85.82	8.07	84.64
13	15	ULS4	-0.21	-82.15	10.76	1.18	-83.54	7.36	84.14	-0.10	-84.86	11.73	1.49	-86.45	7.74	87.20
13	10	ULS4	-0.24	-81.90	-7.73	0.48	-82.63	-5.36	82.87	-0.13	-85.30	-7.57	0.54	-85.97	-5.04	86.24
13	389	ULS5	2.94	-43.86	-12.29	5.97	-46.89	-13.85	50.14	-3.36	-44.93	-16.57	2.44	-50.73	-19.28	51.99
13	13	ULS5	6.68	-39.01	25.62	18.16	-50.49	24.14	61.61	-4.46	-41.00	21.92	5.81	-51.27	25.10	54.41
13	15	ULS5	3.18	-39.27	21.08	11.87	-47.96	22.40	54.86	1.15	-40.11	21.44	10.27	-49.23	23.05	55.09
13	10	ULS5	0.77	-43.72	-16.83	6.42	-49.37	-18.55	52.88	0.92	-44.43	-17.05	6.61	-50.13	-18.47	53.74
13	389	ULS6	7.44	-122.63	-6.20	7.73	-122.92	-2.72	126.96	-3.00	-125.70	-13.36	-1.57	-127.14	-6.14	126.36
13	13	ULS6	8.28	-124.82	22.33	11.92	-128.46	9.27	134.82	-5.12	-127.76	16.20	-3.02	-129.86	7.40	128.38
13	15	ULS6	-1.78	-125.02	15.19	0.07	-126.87	6.92	126.90	-0.47	-129.17	16.73	1.67	-131.31	7.29	132.15
13	10	ULS6	-0.92	-122.34	-13.33	0.53	-123.79	-6.19	124.05	-0.05	-127.60	-12.83	1.23	-128.88	-5.69	129.49
13	389	ULS7	8.17	-130.13	-5.60	8.40	-130.36	-2.32	134.75	-3.13	-133.14	-13.47	-1.75	-134.52	-5.85	133.65
13	13	ULS7	9.26	-131.74	24.49	13.39	-135.87	9.58	143.04	-5.14	-134.56	17.76	-2.74	-136.95	7.68	135.60
13	15	ULS7	-1.87	-132.11	16.59	0.21	-134.18	7.15	134.29	-0.04	-136.01	18.26	2.37	-138.42	7.52	139.61
13	10	ULS7	-1.06	-129.95	-13.50	0.34	-131.35	-5.92	131.52	0.05	-135.14	-12.98	1.29	-136.37	-5.43	137.02
13	389	ULS10	4.84	-19.98	4.84	5.75	-20.90	10.65	24.29	-4.03	-21.75	1.29	-3.94	-21.85	4.16	20.17
13	13	ULS10	6.29	-17.62	16.95	15.08	-26.41	27.41	36.37	-4.06	-19.39	14.04	4.27	-27.72	30.68	30.08
13	15	ULS10	2.12	-18.42	14.13	9.32	-25.61	27.00	31.33	1.03	-18.32	14.51	8.80	-26.08	28.15	31.42
13	10	ULS10	1.17	-20.64	2.02	1.36	-20.83	5.24	21.54	0.57	-20.82	1.77	0.71	-20.96	4.69	21.33
13	389	ULS11	4.61	-27.12	0.15	4.61	-27.12	0.28	29.69	-4.35	-28.83	-3.92	-3.74	-29.44	-8.87	27.76
13	13	ULS11	6.51	-24.37	22.63	18.46	-36.32	27.85	48.28	-4.65	-26.24	19.24	6.62	-37.50	30.35	41.21
13	15	ULS11	2.43	-25.04	19.24	12.34	-34.94	27.24	42.48	1.26	-25.02	19.70	11.80	-35.56	28.15	42.70
13	10	ULS11	1.16	-27.60	-3.23	1.52	-27.96	-6.34	28.75	0.92	-27.80	-3.45	1.33	-28.21	-6.76	28.90

Figure 67 - Results: element 13

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
14	10	ULS1	5.07	-47.50	-16.28	9.70	-52.13	-15.88	57.59	7.22	-41.89	-15.72	11.82	-46.49	-16.32	53.39
14	15	ULS1	3.45	-54.06	-22.41	11.15	-61.76	-18.96	68.02	4.96	-48.26	-22.52	13.21	-56.51	-20.12	64.15
14	16	ULS1	-5.81	-54.14	-9.36	-4.06	-55.89	-10.58	53.97	-16.26	-57.32	-6.30	-15.31	-58.26	-8.52	52.32
14	307	ULS1	-4.78	-47.73	-3.23	-4.54	-47.97	-4.27	45.87	-13.40	-50.80	0.50	-13.40	-50.81	0.77	45.61
14	10	ULS2	-0.23	-100.58	-22.13	4.44	-105.24	-11.90	107.53	4.33	-90.46	-20.98	8.77	-94.90	-11.94	99.57
14	15	ULS2	-2.99	-108.48	-6.04	-2.64	-108.82	-3.27	107.52	2.55	-97.70	-5.77	2.88	-98.03	-3.29	99.51
14	16	ULS2	-1.70	-103.05	11.79	-0.34	-104.40	6.55	104.23	-12.67	-107.31	15.05	-10.34	-109.65	8.82	104.86
14	307	ULS2	0.38	-95.33	-4.30	0.57	-95.52	-2.56	95.81	-10.21	-99.89	-0.16	-10.21	-99.89	-0.10	95.20
14	10	ULS3	3.34	-19.54	-11.78	8.32	-24.52	-22.92	29.57	3.42	-17.06	-11.66	8.70	-22.35	-24.36	27.74
14	15	ULS3	1.86	-25.76	-6.83	3.45	-27.35	-13.15	29.23	1.18	-23.24	-7.09	3.09	-25.15	-15.08	26.83
14	16	ULS3	-2.59	-25.65	-0.89	-2.56	-25.68	-2.20	24.50	-10.07	-28.06	1.06	-10.01	-28.12	3.36	24.69
14	307	ULS3	-1.47	-19.52	-5.84	0.26	-21.24	-16.46	21.37	-7.48	-21.79	-3.51	-6.66	-22.61	-13.07	20.12
14	10	ULS4	-1.37	-85.95	-15.70	1.45	-88.77	-10.18	89.50	2.10	-77.58	-14.80	4.76	-80.24	-10.19	82.73
14	15	ULS4	-2.52	-89.57	-4.78	-2.26	-89.83	-3.14	88.72	1.19	-80.84	-4.59	1.45	-81.10	-3.19	81.83
14	16	ULS4	1.03	-84.31	9.77	2.13	-85.41	6.45	86.50	-8.53	-87.96	12.29	-6.68	-89.82	8.60	86.67
14	307	ULS4	1.68	-80.82	-1.15	1.70	-80.83	-0.80	81.70	-7.12	-84.56	2.08	-7.06	-84.62	1.54	81.32
14	10	ULS5	3.98	-33.71	-10.25	6.59	-36.31	-14.27	40.01	5.13	-29.74	-9.94	7.76	-32.38	-14.85	36.87
14	15	ULS5	3.89	-36.22	-21.22	13.03	-45.36	-23.31	53.09	3.67	-32.35	-21.42	13.65	-42.33	-24.97	50.55
14	16	ULS5	-3.24	-36.46	-11.26	0.22	-39.92	-17.07	40.03	-12.34	-39.05	-8.89	-9.65	-41.74	-16.83	37.85
14	307	ULS5	-3.57	-34.05	-0.29	-3.57	-34.05	-0.55	32.42	-10.47	-36.34	2.58	-10.21	-36.59	5.64	32.70
14	10	ULS6	-4.34	-134.13	-17.79	-1.94	-136.52	-7.67	135.56	1.69	-121.42	-16.33	3.82	-123.55	-7.43	125.50
14	15	ULS6	-4.86	-134.91	-7.52	-4.42	-135.34	-3.30	133.19	1.89	-121.68	-7.01	2.29	-122.08	-3.23	123.24
14	16	ULS6	3.29	-126.31	13.88	4.76	-127.78	6.05	130.23	-8.11	-130.84	16.90	-5.83	-133.12	7.70	130.31
14	307	ULS6	3.20	-125.69	3.61	3.30	-125.79	1.60	127.47	-7.71	-130.41	7.57	-7.24	-130.88	3.52	127.41
14	10	ULS7	-3.88	-139.79	-20.25	-0.93	-142.74	-8.30	142.28	2.54	-126.41	-18.68	5.19	-129.07	-8.08	131.74
14	15	ULS7	-5.04	-142.24	-8.01	-4.57	-142.71	-3.33	140.48	2.42	-128.23	-7.45	2.84	-128.65	-3.26	130.09
14	16	ULS7	2.24	-133.58	14.66	3.81	-135.15	6.09	137.09	-9.74	-138.35	17.96	-7.27	-140.82	7.80	137.32
14	307	ULS7	2.71	-131.31	2.43	2.76	-131.35	1.04	132.75	-8.93	-136.36	6.74	-8.57	-136.72	3.02	132.64
14	10	ULS10	2.82	-15.73	-4.91	4.04	-16.95	-13.94	19.29	2.45	-13.93	-4.65	3.68	-15.16	-14.80	17.30
14	15	ULS10	0.45	-23.38	2.35	0.68	-23.61	5.57	23.95	0.28	-21.45	2.18	0.49	-21.66	5.68	21.92
14	16	ULS10	-2.26	-22.97	5.95	-0.68	-24.56	14.94	24.23	-9.68	-25.66	6.59	-7.31	-28.02	19.76	25.18
14	307	ULS10	-0.36	-15.43	-1.31	-0.25	-15.54	-4.91	15.42	-7.03	-18.03	-0.25	-7.03	-18.04	-1.29	15.75
14	10	ULS11	3.10	-21.89	-4.29	3.82	-22.61	-9.48	24.74	3.20	-19.44	-3.96	3.87	-20.12	-9.64	22.30
14	15	ULS11	1.32	-27.98	-3.83	1.81	-28.47	-7.33	29.42	1.35	-25.46	-3.97	1.93	-26.03	-8.24	27.05
14	16	ULS11	-2.56	-27.72	1.51	-2.47	-27.81	3.43	26.66	-10.67	-30.48	2.34	-10.40	-30.76	6.65	27.10
14	307	ULS11	-1.27	-21.75	1.05	-1.22	-21.80	2.93	21.22	-8.33	-24.36	2.35	-7.99	-24.70	8.16	21.83

Figure 68 - Results: element 14

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
1417	1124	ULS1	-4.21	61.18	9.98	62.67	-5.70	81.51	65.71	-6.93	57.44	10.03	58.97	-8.46	81.35	63.62
1417	1315	ULS1	0.90	73.57	-4.08	73.80	0.67	-86.80	73.47	-4.91	68.81	-4.14	69.04	-5.14	-86.79	71.75
1417	1316	ULS1	10.42	76.23	-5.17	76.64	10.02	-85.53	72.15	3.17	71.43	-5.56	71.89	2.72	-85.37	70.56
1417	1317	ULS1	5.36	63.91	8.89	65.23	4.04	81.56	63.30	1.10	60.00	8.61	61.23	-0.13	81.85	61.30
1417	1124	ULS2	-4.69	16.67	2.34	16.92	-4.94	83.83	19.86	-0.87	16.05	2.39	16.38	-1.20	82.12	17.01
1417	1315	ULS2	-2.56	17.94	0.62	17.96	-2.58	88.26	19.38	-2.61	16.06	0.58	16.07	-2.63	88.22	17.54
1417	1316	ULS2	5.07	21.11	0.13	21.11	5.07	89.54	19.09	2.96	16.85	-0.75	16.89	2.92	-86.93	15.63
1417	1317	ULS2	2.79	19.79	1.84	19.99	2.59	83.88	18.83	4.86	16.88	1.06	16.98	4.77	85.01	15.17
1417	1124	ULS3	-3.79	40.21	6.00	41.01	-4.59	82.37	43.49	-1.68	39.33	6.06	40.21	-2.55	81.77	41.55
1417	1315	ULS3	-0.64	44.90	-2.26	45.02	-0.75	-87.16	45.40	-2.37	42.83	-2.31	42.95	-2.48	-87.08	44.24
1417	1316	ULS3	5.01	46.44	-2.80	46.63	4.82	-86.15	44.42	1.99	44.29	-3.16	44.52	1.75	-85.76	43.67
1417	1317	ULS3	1.96	41.79	5.46	42.53	1.22	82.33	41.93	2.59	40.75	5.22	41.45	1.89	82.36	40.54
1417	1124	ULS4	-3.43	-14.96	-1.23	-3.30	-15.09	-5.99	13.74	0.34	-14.55	-1.20	0.44	-14.65	-4.58	14.87
1417	1315	ULS4	-1.52	-14.34	1.86	-1.26	-14.61	8.08	14.02	-1.57	-15.18	1.84	-1.33	-15.42	7.55	14.81
1417	1316	ULS4	3.14	-11.93	1.68	3.32	-12.12	6.28	14.08	1.56	-15.25	0.90	1.60	-15.30	3.06	16.16
1417	1317	ULS4	1.02	-12.61	-1.40	1.17	-12.76	-5.82	13.38	3.68	-14.57	-2.14	3.92	-14.82	-6.59	17.12
1417	1124	ULS5	-2.96	31.21	6.61	32.44	-4.20	79.42	34.73	-5.84	28.40	6.64	29.65	-7.08	79.41	33.75
1417	1315	ULS5	1.92	42.96	-2.91	43.17	1.72	-85.97	42.34	-3.96	39.17	-2.95	39.38	-4.16	-86.10	41.61
1417	1316	ULS5	8.62	44.90	-3.71	45.27	8.25	-84.23	41.77	1.80	40.98	-4.00	41.38	1.40	-84.23	40.70
1417	1317	ULS5	3.74	33.19	5.82	34.30	2.63	79.23	33.06	-0.07	30.16	5.59	31.16	-1.07	79.86	31.70
1417	1124	ULS6	-2.95	-54.61	-5.90	-2.28	-55.27	-6.44	54.17	0.52	-53.88	-5.91	1.15	-54.52	-6.13	55.10
1417	1315	ULS6	-1.37	-54.69	4.43	-1.00	-55.06	4.72	54.56	-1.48	-55.18	4.43	-1.11	-55.55	4.69	55.00
1417	1316	ULS6	2.90	-51.60	4.43	3.26	-51.95	4.61	53.66	1.21	-56.19	3.38	1.41	-56.39	3.36	57.10
1417	1317	ULS6	0.88	-51.64	-5.91	1.54	-52.30	-6.34	53.08	3.64	-54.77	-6.96	4.46	-55.58	-6.71	57.94
1417	1124	ULS7	-3.49	-42.20	-4.51	-2.98	-42.72	-6.56	41.31	0.10	-41.85	-4.51	0.57	-42.33	-6.06	42.62
1417	1315	ULS7	-1.81	-42.02	3.95	-1.43	-42.40	5.56	41.70	-1.84	-42.90	3.94	-1.47	-43.27	5.44	42.56
1417	1316	ULS7	3.62	-38.62	3.82	3.96	-38.97	5.12	41.09	1.79	-43.57	2.73	1.96	-43.73	3.43	44.74
1417	1317	ULS7	1.52	-38.93	-4.64	2.05	-39.45	-6.47	40.52	4.15	-42.40	-5.72	4.84	-43.09	-6.90	45.70
1417	1124	ULS10	-23.04	56.45	6.94	57.05	-23.64	85.05	71.86	17.81	66.57	7.15	67.59	16.78	81.83	60.96
1417	1315	ULS10	-15.03	62.46	-2.48	62.54	-15.11	-88.17	71.30	12.15	68.40	-2.63	68.52	12.02	-87.33	63.37
1417	1316	ULS10	-7.56	64.30	-2.91	64.42	-7.68	-87.69	68.58	15.09	69.68	-3.87	69.96	14.82	-85.97	63.85
1417	1317	ULS10	-15.11	58.40	6.50	58.97	-15.69	84.98	68.18	20.29	67.74	5.91	68.47	19.57	83.00	61.08
1417	1124	ULS11	-22.69	52.77	7.22	53.46	-23.38	84.59	68.22	16.02	62.05	7.42	63.22	14.85	81.07	57.25
1417	1315	ULS11	-13.93	61.81	-2.76	61.91	-14.03	-87.92	69.99	11.45	67.01	-2.91	67.16	11.30	-87.01	62.28
1417	1316	ULS11	-6.00	63.82	-3.30	63.98	-6.15	-87.30	67.27	15.01	68.44	-4.24	68.77	14.68	-85.49	62.74
1417	1317	ULS11	-14.34	54.90	6.67	55.53	-14.97	84.54	64.34	19.16	63.37	6.09	64.20	18.33	82.30	57.27

Figure 69 - Results: element 1417

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
1418	1317	ULS1	3.44	57.46	-12.56	60.24	0.66	-77.53	59.91	-0.99	53.07	-12.90	55.99	-3.91	-77.25	58.04
1418	1316	ULS1	5.84	61.00	0.00	61.00	5.84	-90.00	58.30	-1.43	56.07	-0.27	56.08	-1.43	-89.74	56.80
1418	1318	ULS1	-0.93	58.28	-3.07	58.44	-1.09	-87.04	58.99	-6.79	55.16	-1.30	55.18	-6.82	-88.80	58.89
1418	1093	ULS1	-3.41	54.67	-15.63	58.61	-7.35	-75.85	62.60	-6.27	52.22	-13.93	55.37	-9.42	-77.27	60.63
1418	1317	ULS2	0.50	12.17	-3.09	12.94	-0.27	-76.04	13.07	2.86	10.23	-3.94	11.94	1.15	-66.54	11.41
1418	1316	ULS2	1.47	9.09	-3.29	10.31	0.24	-69.58	10.19	-0.14	6.52	-4.08	8.46	-2.08	-64.62	9.66
1418	1318	ULS2	-4.50	5.55	-7.11	9.23	-8.19	-62.62	15.09	-4.10	7.08	-3.61	8.15	-5.17	-73.58	11.62
1418	1093	ULS2	-5.53	8.61	-6.91	11.43	-8.34	-67.82	17.19	-1.04	10.81	-3.47	11.75	-1.98	-74.82	12.86
1418	1317	ULS3	0.91	38.30	-7.46	39.74	-0.52	-79.13	40.00	1.43	36.90	-7.78	38.53	-0.21	-78.16	38.63
1418	1316	ULS3	2.34	37.53	0.15	37.53	2.33	89.76	36.42	-0.72	35.27	-0.09	35.27	-0.72	-89.86	35.63
1418	1318	ULS3	-1.75	35.96	-1.71	36.03	-1.82	-87.42	36.98	-3.50	34.79	-0.43	34.79	-3.50	-89.35	36.67
1418	1093	ULS3	-3.29	36.68	-9.31	38.74	-5.36	-77.51	41.68	-1.23	36.47	-8.13	38.14	-2.91	-78.34	39.68
1418	1317	ULS4	-0.77	-18.56	1.29	-0.67	-18.66	4.12	18.33	2.27	-19.26	0.53	2.28	-19.27	1.41	20.51
1418	1316	ULS4	1.02	-19.01	-3.40	1.58	-19.57	-9.37	20.40	0.01	-20.41	-4.12	0.81	-21.21	-10.98	21.62
1418	1318	ULS4	-2.93	-21.81	-6.35	-0.99	-23.75	-16.97	23.27	-2.34	-19.49	-3.23	-1.75	-20.08	-10.31	19.27
1418	1093	ULS4	-4.72	-21.37	-1.67	-4.55	-21.54	-5.66	19.66	-0.07	-18.34	1.42	0.04	-18.45	4.41	18.47
1418	1317	ULS5	2.29	28.33	-8.41	30.81	-0.19	-73.57	30.91	-1.60	25.09	-8.66	27.66	-4.16	-73.50	29.96
1418	1316	ULS5	5.45	34.35	-0.10	34.35	5.45	-89.80	31.98	-1.32	30.51	-0.30	30.51	-1.33	-89.46	31.20
1418	1318	ULS5	0.58	32.33	-2.36	32.50	0.41	-85.78	32.30	-5.15	29.93	-0.93	29.96	-5.17	-88.48	32.85
1418	1093	ULS5	-2.61	26.24	-10.67	29.76	-6.13	-71.76	33.25	-5.39	24.57	-9.30	27.22	-8.04	-74.09	32.00
1418	1317	ULS6	-1.51	-59.61	6.89	-0.71	-60.42	6.67	60.07	1.97	-60.34	5.86	2.52	-60.88	5.33	62.18
1418	1316	ULS6	1.02	-57.86	-5.83	1.59	-58.44	-5.60	59.25	0.32	-59.13	-6.86	1.10	-59.92	-6.50	60.47
1418	1318	ULS6	-3.04	-61.61	-9.63	-1.50	-63.15	-9.10	62.42	-2.01	-57.31	-5.23	-1.52	-57.80	-5.36	57.05
1418	1093	ULS6	-5.47	-63.33	3.09	-5.31	-63.49	3.05	61.01	-0.46	-58.54	7.49	0.49	-59.49	7.23	59.74
1418	1317	ULS7	-1.07	-47.56	5.18	-0.50	-48.13	6.28	47.88	2.25	-48.74	4.11	2.58	-49.07	4.58	50.41
1418	1316	ULS7	1.16	-46.83	-5.79	1.85	-47.52	-6.79	48.47	0.30	-48.53	-6.85	1.24	-49.48	-7.84	50.11
1418	1318	ULS7	-3.68	-50.85	-9.93	-1.67	-52.86	-11.41	52.04	-2.67	-46.85	-5.38	-2.03	-47.50	-6.85	46.52
1418	1093	ULS7	-5.82	-51.56	1.04	-5.80	-51.58	1.31	48.94	-0.81	-47.08	5.58	-0.14	-47.74	6.78	47.67
1418	1317	ULS10	-15.69	56.06	-8.80	57.13	-16.75	-83.11	67.09	19.09	64.17	-9.35	66.03	17.23	-78.73	59.32
1418	1316	ULS10	-10.62	54.50	0.36	54.51	-10.63	89.68	60.52	12.03	59.07	-0.61	59.08	12.02	-89.26	54.08
1418	1318	ULS10	-11.55	53.79	-1.42	53.82	-11.58	-88.75	60.45	6.04	57.71	-1.39	57.75	6.00	-88.46	54.99
1418	1093	ULS10	-15.98	55.57	-10.59	57.11	-17.51	-81.76	67.59	12.46	62.58	-10.13	64.55	10.49	-78.99	60.00
1418	1317	ULS11	-15.09	51.96	-9.24	53.21	-16.34	-82.30	62.99	17.80	59.27	-9.76	61.45	15.62	-77.40	55.32
1418	1316	ULS11	-9.28	53.30	0.25	53.30	-9.28	89.77	58.49	11.76	57.18	-0.70	57.19	11.75	-89.12	52.31
1418	1318	ULS11	-10.56	52.38	-1.71	52.43	-10.61	-88.45	58.46	5.32	55.78	-1.60	55.83	5.27	-88.18	53.39
1418	1093	ULS11	-15.69	51.27	-11.20	53.09	-17.51	-80.75	63.68	10.67	57.64	-10.66	59.95	8.37	-77.79	56.23

Figure 70 - Results: elements 1418

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
1419	1315	ULS1	-4.05	72.10	-4.11	72.32	-4.27	-86.92	74.55	-10.19	67.22	-4.11	67.43	-10.41	-86.97	73.20
1419	1125	ULS1	-0.02	82.43	3.42	82.57	-0.17	87.63	82.65	-8.24	76.81	3.40	76.95	-8.37	87.71	81.46
1419	1319	ULS1	12.72	85.98	3.02	86.11	12.60	87.64	80.55	4.68	80.96	2.55	81.04	4.60	88.09	78.85
1419	1316	ULS1	8.90	75.76	-4.50	76.07	8.60	-86.16	72.15	2.53	71.25	-4.96	71.61	2.17	-85.89	70.55
1419	1315	ULS2	-2.78	17.88	0.62	17.90	-2.80	88.28	19.45	-3.52	15.78	0.58	15.80	-3.54	88.27	17.83
1419	1125	ULS2	-1.11	18.40	-0.23	18.40	-1.11	-89.33	18.98	-5.21	15.19	-0.17	15.19	-5.22	-89.52	18.36
1419	1319	ULS2	5.84	21.37	-0.03	21.37	5.84	-89.91	19.13	2.99	16.76	-0.84	16.81	2.94	-86.53	15.56
1419	1316	ULS2	4.67	20.99	0.82	21.03	4.63	87.12	19.14	4.18	17.21	-0.08	17.21	4.18	-89.64	15.55
1419	1315	ULS3	-2.57	44.33	-2.29	44.44	-2.68	-87.21	45.84	-4.62	42.15	-2.29	42.26	-4.73	-87.21	44.81
1419	1125	ULS3	-0.36	47.57	1.57	47.63	-0.41	88.13	47.83	-5.15	44.51	1.57	44.56	-5.20	88.19	47.37
1419	1319	ULS3	6.82	49.55	1.45	49.60	6.77	88.06	46.59	2.30	46.92	1.05	46.94	2.27	88.66	45.85
1419	1316	ULS3	4.77	46.37	-2.41	46.51	4.64	-86.70	44.37	2.66	44.49	-2.82	44.68	2.47	-86.17	43.50
1419	1315	ULS4	-1.20	-14.25	1.87	-0.94	-14.51	7.99	14.06	-1.69	-15.22	1.83	-1.45	-15.46	7.56	14.79
1419	1125	ULS4	0.51	-13.53	-0.85	0.56	-13.58	-3.47	13.87	-3.29	-15.58	-0.80	-3.24	-15.63	-3.69	14.29
1419	1319	ULS4	3.49	-11.62	-0.54	3.51	-11.64	-2.03	13.73	0.83	-15.36	-1.22	0.93	-15.45	-4.29	15.93
1419	1316	ULS4	2.22	-12.21	2.18	2.54	-12.53	8.42	13.98	2.00	-15.12	1.40	2.11	-15.24	4.65	16.39
1419	1315	ULS5	-2.51	41.64	-2.93	41.83	-2.71	-86.23	43.25	-8.50	37.80	-2.93	37.99	-8.68	-86.39	42.99
1419	1125	ULS5	1.53	52.14	2.83	52.30	1.37	86.81	51.63	-6.44	47.62	2.81	47.76	-6.59	87.03	51.38
1419	1319	ULS5	10.51	54.70	2.54	54.84	10.37	86.72	50.46	2.62	50.48	2.19	50.58	2.52	87.39	49.37
1419	1316	ULS5	6.61	44.29	-3.22	44.56	6.34	-85.16	41.75	0.43	40.57	-3.56	40.89	0.12	-84.98	40.83
1419	1315	ULS6	-0.26	-54.36	4.47	0.10	-54.73	4.69	54.78	-0.82	-54.98	4.40	-0.46	-55.34	4.61	55.11
1419	1125	ULS6	1.63	-53.25	-2.12	1.71	-53.33	-2.20	54.21	-2.39	-55.03	-2.03	-2.32	-55.11	-2.20	53.99
1419	1319	ULS6	2.30	-51.23	-1.55	2.34	-51.28	-1.66	52.49	-0.06	-56.15	-2.41	0.04	-56.25	-2.45	56.27
1419	1316	ULS6	1.01	-52.16	5.03	1.48	-52.64	5.36	53.39	0.90	-56.28	4.02	1.18	-56.56	4.00	57.16
1419	1315	ULS7	-0.92	-41.75	3.98	-0.54	-42.13	5.52	41.87	-1.49	-42.79	3.91	-1.13	-43.16	5.37	42.61
1419	1125	ULS7	0.98	-40.70	-1.87	1.06	-40.79	-2.56	41.33	-3.12	-42.92	-1.78	-3.04	-43.00	-2.56	41.57
1419	1319	ULS7	3.20	-38.27	-1.35	3.24	-38.31	-1.87	40.03	0.80	-43.52	-2.26	0.92	-43.63	-2.91	44.09
1419	1316	ULS7	1.93	-39.13	4.50	2.42	-39.62	6.18	40.88	1.79	-43.57	3.43	2.05	-43.83	4.31	44.88
1419	1315	ULS10	-17.26	61.79	-2.63	61.87	-17.34	-88.10	72.13	10.09	67.79	-2.48	67.89	9.98	-87.55	63.49
1419	1125	ULS10	-10.46	65.93	1.22	65.95	-10.48	89.09	71.76	4.63	68.10	1.12	68.12	4.61	88.99	65.94
1419	1319	ULS10	-0.93	68.43	1.49	68.46	-0.96	88.77	68.94	11.06	70.39	-0.02	70.39	11.06	-89.98	65.56
1419	1316	ULS10	-7.48	64.33	-2.35	64.41	-7.55	-88.13	68.50	16.27	70.03	-3.61	70.27	16.03	-86.18	63.79
1419	1315	ULS11	-17.24	60.81	-2.91	60.92	-17.35	-87.87	71.20	8.41	66.10	-2.76	66.23	8.28	-87.27	62.50
1419	1125	ULS11	-9.66	68.06	1.76	68.10	-9.70	88.70	73.43	4.06	69.60	1.65	69.64	4.01	88.56	67.72
1419	1319	ULS11	0.67	70.81	1.96	70.87	0.62	88.40	70.56	11.21	72.09	0.48	72.10	11.21	89.55	67.20
1419	1316	ULS11	-6.67	63.62	-2.71	63.73	-6.77	-87.80	67.37	15.33	68.53	-3.94	68.82	15.04	-85.79	62.67

Figure 71 - Results: element 1419

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
1420	1316	ULS1	4.34	60.54	0.69	60.55	4.33	89.29	58.50	-2.10	55.88	0.31	55.88	-2.10	89.70	56.96
1420	1319	ULS1	8.22	71.01	-2.56	71.12	8.12	-87.67	67.43	0.28	66.25	-3.05	66.39	0.14	-87.36	66.32
1420	1092	ULS1	2.34	68.63	-5.16	69.03	1.94	-85.58	68.08	-6.91	64.72	-3.36	64.88	-7.07	-87.32	68.68
1420	1318	ULS1	-1.78	58.03	-1.90	58.09	-1.85	-88.18	59.03	-9.04	54.47	0.00	54.47	-9.04	90.00	59.51
1420	1316	ULS2	1.06	8.97	-2.65	9.77	0.26	-73.10	9.64	1.09	6.89	-3.37	8.43	-0.46	-65.39	8.67
1420	1319	ULS2	2.03	8.67	2.08	9.26	1.44	73.98	8.64	-0.10	6.48	1.06	6.65	-0.27	81.07	6.78
1420	1092	ULS2	0.96	6.59	-1.84	7.13	0.41	-73.44	6.94	-4.94	6.79	1.32	6.93	-5.09	83.65	10.45
1420	1318	ULS2	-0.69	6.69	-6.56	10.52	-4.53	-59.69	13.38	-3.08	7.39	-3.10	8.24	-3.93	-74.66	10.76
1420	1316	ULS3	2.10	37.46	0.58	37.47	2.09	89.06	36.47	-0.05	35.47	0.22	35.47	-0.05	89.65	35.50
1420	1319	ULS3	4.30	41.16	-0.96	41.19	4.28	-88.51	39.23	-0.16	38.72	-1.39	38.77	-0.21	-87.96	38.88
1420	1092	ULS3	1.04	39.85	-2.67	40.03	0.85	-86.09	39.61	-4.39	37.79	-1.34	37.83	-4.43	-88.18	40.23
1420	1318	ULS3	-1.37	36.07	-1.13	36.10	-1.41	-88.27	36.83	-4.06	34.61	0.26	34.62	-4.06	89.61	36.82
1420	1316	ULS4	0.10	-19.28	-2.95	0.54	-19.72	-8.47	20.00	0.45	-20.28	-3.56	1.04	-20.87	-9.47	21.41
1420	1319	ULS4	0.98	-19.97	2.41	1.26	-20.24	6.47	20.90	-0.91	-21.17	1.53	-0.80	-21.29	4.30	20.90
1420	1092	ULS4	1.81	-21.35	-0.86	1.85	-21.38	-2.13	22.36	-3.49	-20.32	1.89	-3.28	-20.53	6.34	19.10
1420	1318	ULS4	0.32	-20.84	-6.22	2.01	-22.53	-15.23	23.60	-1.52	-19.25	-3.20	-0.97	-19.81	-9.91	19.34
1420	1316	ULS5	3.46	33.75	0.40	33.75	3.46	89.24	32.16	-2.73	30.10	0.13	30.10	-2.73	89.78	31.55
1420	1319	ULS5	7.25	43.85	-2.25	43.98	7.11	-86.50	40.89	-0.51	40.01	-2.60	40.17	-0.68	-86.34	40.52
1420	1092	ULS5	3.17	42.12	-4.24	42.58	2.71	-83.87	41.29	-5.57	38.99	-2.82	39.17	-5.75	-86.40	42.33
1420	1318	ULS5	-0.80	31.92	-1.58	32.00	-0.88	-87.24	32.44	-7.60	29.19	-0.09	29.19	-7.60	-89.87	33.64
1420	1316	ULS6	-0.87	-58.43	-5.36	-0.38	-58.93	-5.27	58.74	0.02	-59.22	-6.10	0.64	-59.84	-5.82	60.17
1420	1319	ULS6	-0.40	-60.22	4.29	-0.09	-60.53	4.08	60.48	-1.52	-60.99	3.14	-1.35	-61.15	3.01	60.49
1420	1092	ULS6	2.95	-61.75	-0.09	2.95	-61.75	-0.08	63.28	-3.22	-58.97	3.63	-2.98	-59.20	3.71	57.77
1420	1318	ULS6	1.62	-60.21	-9.74	3.11	-61.71	-8.74	63.32	-0.82	-56.95	-5.60	-0.27	-57.51	-5.64	57.37
1420	1316	ULS7	-0.53	-47.33	-5.24	0.05	-47.91	-6.31	47.94	0.30	-48.53	-6.02	1.03	-49.27	-6.93	49.79
1420	1319	ULS7	-0.01	-48.96	4.16	0.34	-49.31	4.82	49.48	-1.18	-50.11	2.95	-1.00	-50.28	3.44	49.79
1420	1092	ULS7	2.60	-50.77	-0.48	2.60	-50.77	-0.51	52.12	-3.76	-48.29	3.41	-3.50	-48.55	4.35	46.90
1420	1318	ULS7	1.19	-49.39	-9.87	3.05	-51.25	-10.66	52.84	-1.40	-46.47	-5.57	-0.72	-47.14	-6.94	46.79
1420	1316	ULS10	-10.26	54.62	0.88	54.63	-10.27	89.22	60.43	12.93	59.33	-0.32	59.33	12.93	-89.61	54.04
1420	1319	ULS10	-3.92	58.87	-0.41	58.87	-3.93	-89.62	60.93	8.19	60.41	-1.95	60.48	8.12	-87.86	56.85
1420	1092	ULS10	-5.82	57.80	-1.88	57.86	-5.87	-88.31	61.01	2.53	59.20	-1.96	59.27	2.46	-88.02	58.08
1420	1318	ULS10	-11.37	53.83	-0.59	53.84	-11.38	-89.49	60.34	6.49	57.85	-0.33	57.85	6.48	-89.64	54.90
1420	1316	ULS11	-9.67	53.19	0.81	53.20	-9.68	89.27	58.64	11.79	57.18	-0.35	57.18	11.79	-89.55	52.29
1420	1319	ULS11	-2.65	60.17	-0.97	60.19	-2.67	-89.12	61.56	8.05	61.11	-2.48	61.22	7.93	-87.34	57.67
1420	1092	ULS11	-4.91	58.93	-2.56	59.03	-5.01	-87.71	61.69	2.01	59.86	-2.59	59.98	1.89	-87.44	59.06
1420	1318	ULS11	-11.13	52.20	-0.78	52.21	-11.14	-89.29	58.58	4.96	55.67	-0.47	55.68	4.95	-89.47	53.37

Figure 72 - Results: element 1420

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
1421	1093	ULS1	-5.10	49.29	5.59	49.86	-5.67	84.19	52.92	-8.33	45.09	7.31	46.07	-9.31	82.34	51.36
1421	1318	ULS1	2.48	69.36	-14.11	72.21	-0.38	-78.56	72.40	-4.47	63.16	-12.36	65.34	-6.66	-79.96	68.91
1421	1320	ULS1	13.90	71.91	-6.68	72.67	13.14	-83.51	67.07	8.77	68.01	-11.57	70.19	6.60	-79.34	67.13
1421	1321	ULS1	7.16	52.11	13.02	55.61	3.66	74.96	53.87	4.07	49.66	8.11	51.06	2.67	80.21	49.78
1421	1093	ULS2	-5.28	9.20	-3.13	9.85	-5.93	-78.31	13.81	-2.28	6.90	0.36	6.91	-2.30	87.77	8.30
1421	1318	ULS2	-2.12	13.70	-9.75	18.35	-6.77	-64.53	22.51	-3.65	8.38	-6.24	11.03	-6.30	-66.98	15.19
1421	1320	ULS2	11.20	18.37	-0.47	18.40	11.17	-86.28	16.06	11.42	12.23	-9.82	21.66	2.00	-46.18	20.73
1421	1321	ULS2	9.84	14.40	6.15	18.68	5.56	55.16	16.62	10.99	10.22	-3.23	13.85	7.36	-41.62	12.01
1421	1093	ULS3	-4.34	33.23	3.78	33.60	-4.72	84.31	36.19	-2.49	32.23	5.03	32.94	-3.21	81.92	34.66
1421	1318	ULS3	0.33	42.84	-8.09	44.32	-1.16	-79.58	44.91	-1.93	40.03	-6.85	41.12	-3.02	-80.96	42.71
1421	1320	ULS3	6.77	44.30	-3.66	44.65	6.42	-84.49	41.81	5.40	42.70	-6.80	43.91	4.20	-79.98	41.97
1421	1321	ULS3	2.80	34.90	8.22	36.88	0.82	76.45	36.48	4.15	34.69	5.08	35.51	3.33	80.81	33.97
1421	1093	ULS4	-3.70	-18.18	-5.70	-1.73	-20.15	-19.11	19.35	-0.45	-19.42	-2.57	-0.11	-19.76	-7.58	19.71
1421	1318	ULS4	-1.67	-17.42	-5.51	0.06	-19.16	-17.48	19.19	-2.88	-21.49	-2.37	-2.58	-21.79	-7.14	20.62
1421	1320	ULS4	8.31	-13.41	1.68	8.44	-13.54	4.40	19.21	8.12	-19.20	-6.72	9.69	-20.77	-13.10	26.95
1421	1321	ULS4	7.84	-13.71	1.49	7.94	-13.82	3.93	19.07	8.99	-17.59	-6.93	10.68	-19.29	-13.76	26.31
1421	1093	ULS5	-3.57	23.33	3.17	23.70	-3.94	83.38	25.89	-6.63	20.12	4.55	20.87	-7.39	80.61	25.38
1421	1318	ULS5	2.93	39.86	-10.09	42.43	0.36	-75.68	42.25	-3.77	34.82	-8.69	36.69	-5.64	-77.88	39.81
1421	1320	ULS5	11.18	41.78	-4.65	42.47	10.49	-81.54	38.32	5.64	38.20	-8.63	40.35	3.49	-76.03	38.72
1421	1321	ULS5	5.29	25.46	8.60	28.63	2.12	69.77	27.63	2.16	23.28	4.61	24.24	1.20	78.22	23.66
1421	1093	ULS6	-3.05	-55.53	-12.22	-0.35	-58.24	-12.49	58.07	-0.25	-57.55	-7.80	0.80	-58.60	-7.62	59.00
1421	1318	ULS6	-2.26	-58.74	-4.31	-1.93	-59.06	-4.34	58.12	-4.02	-64.27	0.13	-4.02	-64.27	0.12	62.35
1421	1320	ULS6	10.57	-52.91	4.97	10.95	-53.29	4.45	59.53	9.97	-62.05	-7.16	10.68	-62.76	-5.63	68.72
1421	1321	ULS6	11.89	-49.08	-2.94	12.03	-49.22	-2.75	56.21	11.63	-55.96	-15.10	14.85	-59.18	-12.04	67.83
1421	1093	ULS7	-3.71	-44.79	-11.22	-0.84	-47.65	-14.32	47.24	-0.93	-47.20	-6.66	0.01	-48.14	-8.03	48.15
1421	1318	ULS7	-2.46	-46.52	-5.98	-1.67	-47.32	-7.59	46.51	-4.29	-52.53	-1.39	-4.25	-52.57	-1.65	50.58
1421	1320	ULS7	11.68	-40.43	4.13	12.01	-40.76	4.51	47.90	11.27	-49.71	-8.38	12.40	-50.84	-7.68	58.04
1421	1321	ULS7	12.65	-38.05	-1.11	12.67	-38.07	-1.26	45.75	12.42	-45.03	-13.65	15.50	-48.11	-12.71	57.45
1421	1093	ULS10	-16.97	51.53	4.67	51.85	-17.29	86.11	62.32	10.80	57.76	5.40	58.37	10.19	83.52	54.01
1421	1318	ULS10	-9.59	61.06	-8.18	62.00	-10.52	-83.48	67.87	8.08	63.76	-8.30	64.97	6.87	-81.70	61.83
1421	1320	ULS10	1.41	63.33	-3.03	63.47	1.26	-87.21	62.85	9.42	65.20	-7.25	66.13	8.49	-82.72	62.32
1421	1321	ULS10	-4.23	54.28	9.83	55.89	-5.84	80.72	59.02	10.40	58.71	6.45	59.56	9.56	82.53	55.40
1421	1093	ULS11	-16.65	47.44	4.42	47.75	-16.95	86.07	58.11	9.01	52.71	5.21	53.33	8.40	83.29	49.66
1421	1318	ULS11	-8.47	59.96	-9.06	61.14	-9.65	-82.59	66.49	7.28	61.70	-9.11	63.18	5.80	-80.75	60.49
1421	1320	ULS11	3.32	62.42	-3.47	62.62	3.12	-86.66	61.13	9.54	63.45	-8.05	64.62	8.37	-81.69	60.87
1421	1321	ULS11	-3.15	50.39	10.02	52.21	-4.96	79.74	54.86	9.56	53.98	6.27	54.84	8.69	82.12	51.06

Figure 73 - Results: element 1421

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
1422	1321	ULS1	-5.72	6.85	-0.89	6.91	-5.79	-85.97	11.01	-10.58	3.16	-5.63	5.17	-12.59	-70.33	15.83
1422	1320	ULS1	-4.19	13.94	-9.02	17.66	-7.91	-67.57	22.68	-7.50	11.45	-14.09	18.96	-15.00	-61.96	29.47
1422	1322	ULS1	5.88	14.66	10.87	21.99	-1.45	56.00	22.75	0.19	16.06	11.95	22.47	-6.22	61.80	26.14
1422	998	ULS1	5.18	7.88	19.00	25.58	-12.51	47.03	33.62	-3.73	7.45	20.41	23.02	-19.30	52.67	36.69
1422	1321	ULS2	-3.12	-30.01	-9.89	0.12	-33.26	-18.17	33.32	-0.66	-27.40	-19.27	9.42	-37.49	-27.63	42.98
1422	1320	ULS2	-2.85	-27.25	7.09	-0.94	-29.16	15.09	28.70	1.43	-22.27	-2.30	1.66	-22.49	-5.50	23.36
1422	1322	ULS2	-21.50	-32.25	27.50	1.14	-54.89	39.47	55.47	-16.76	-28.33	32.42	10.39	-55.48	39.94	61.34
1422	998	ULS2	-20.74	-34.66	10.52	-15.09	-40.31	28.25	35.27	-19.89	-33.81	15.45	-9.91	-43.80	32.88	39.78
1422	1321	ULS3	-4.37	10.02	0.09	10.02	-4.37	89.63	12.78	-3.88	8.91	-2.93	9.54	-4.52	-77.71	12.44
1422	1320	ULS3	-3.59	10.75	-4.94	12.29	-5.12	-72.72	15.50	-4.18	9.81	-8.21	13.60	-7.97	-65.21	18.89
1422	1322	ULS3	2.80	11.24	5.55	13.99	0.05	63.61	13.97	0.26	12.57	6.26	15.19	-2.36	67.27	16.50
1422	998	ULS3	2.73	10.74	10.59	18.06	-4.58	55.36	20.73	-0.16	11.43	11.54	18.55	-7.28	58.33	23.07
1422	1321	ULS4	-1.47	-45.80	-10.09	0.71	-47.99	-12.24	48.35	1.32	-42.10	-18.57	8.18	-48.96	-20.27	53.52
1422	1320	ULS4	-0.15	-40.58	10.08	2.22	-42.96	13.25	44.11	3.73	-34.88	1.71	3.81	-34.96	2.53	37.01
1422	1322	ULS4	-22.61	-46.04	25.97	-5.83	-62.82	32.86	60.11	-17.21	-42.44	30.77	3.43	-63.08	33.85	64.86
1422	998	ULS4	-23.21	-51.01	5.80	-22.05	-52.17	11.33	45.36	-20.34	-49.92	10.48	-17.00	-53.25	17.66	47.11
1422	1321	ULS5	-4.15	-8.16	-1.08	-3.87	-8.44	-14.18	7.31	-8.72	-10.82	-4.98	-4.68	-14.86	-39.04	13.16
1422	1320	ULS5	-1.63	1.26	-6.19	6.18	-6.54	-51.55	11.02	-5.33	-0.55	-10.29	7.63	-13.51	-51.55	18.54
1422	1322	ULS5	4.82	1.53	9.44	12.76	-6.41	40.06	16.90	-0.24	2.65	10.40	11.70	-9.30	48.94	18.23
1422	998	ULS5	2.84	-7.67	14.55	13.05	-17.88	35.08	26.90	-4.16	-7.86	15.72	9.82	-21.83	41.65	28.06
1422	1321	ULS6	0.54	-88.35	-17.21	3.75	-91.57	-10.59	93.50	3.43	-81.87	-29.58	12.68	-91.13	-17.37	98.09
1422	1320	ULS6	2.72	-77.64	19.77	7.32	-82.24	13.10	86.13	8.69	-67.74	7.77	9.48	-68.53	5.75	73.72
1422	1322	ULS6	-38.98	-87.12	40.68	-15.78	-110.32	29.69	103.33	-29.00	-82.08	48.27	-0.46	-110.63	30.60	110.40
1422	998	ULS6	-40.50	-97.58	3.70	-40.26	-97.82	3.69	85.15	-34.93	-96.46	10.92	-33.05	-98.34	9.77	86.68
1422	1321	ULS7	-0.12	-82.11	-17.13	3.31	-85.55	-11.34	87.25	2.67	-76.06	-29.85	12.71	-86.09	-18.59	93.10
1422	1320	ULS7	1.65	-72.36	18.60	6.07	-76.78	13.34	79.98	7.81	-62.75	6.20	8.35	-63.29	4.99	67.85
1422	1322	ULS7	-38.54	-81.66	41.26	-13.54	-106.65	31.20	100.56	-28.82	-76.50	48.90	1.74	-107.06	32.00	107.94
1422	998	ULS7	-39.52	-91.11	5.53	-38.94	-91.70	6.05	79.71	-34.75	-90.10	12.84	-31.92	-92.94	12.45	81.79
1422	1321	ULS10	-9.53	35.36	2.05	35.45	-9.62	87.39	41.11	3.39	36.61	-1.25	36.65	3.34	-87.84	35.10
1422	1320	ULS10	-9.12	29.51	-3.24	29.78	-9.39	-85.24	35.42	-0.80	29.85	-7.56	31.61	-2.57	-76.88	32.97
1422	1322	ULS10	4.04	31.82	2.98	32.13	3.73	83.95	30.44	0.57	31.90	2.71	32.13	0.34	85.09	31.96
1422	998	ULS10	5.19	38.19	8.28	40.15	3.23	76.68	38.64	3.21	38.13	9.02	40.32	1.02	76.35	39.83
1422	1321	ULS11	-9.44	27.65	1.55	27.71	-9.50	87.61	33.49	1.30	28.23	-2.14	28.40	1.13	-85.49	27.85
1422	1320	ULS11	-8.29	25.51	-3.80	25.93	-8.71	-83.67	31.21	-1.31	25.48	-8.47	27.93	-3.77	-73.84	29.99
1422	1322	ULS11	4.91	27.73	4.66	28.64	4.00	78.90	26.87	0.36	27.72	4.50	28.44	-0.36	80.89	28.62
1422	998	ULS11	5.24	30.39	10.00	33.88	1.75	70.75	33.04	1.50	29.95	10.84	33.61	-2.16	71.35	34.74

Figure 74 - Results: element 1422

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
1423	1318	ULS1	1.44	69.06	-12.84	71.41	-0.91	-79.60	71.87	-6.54	62.53	-11.16	64.29	-8.30	-81.05	68.81
1423	1092	ULS1	4.06	74.08	-10.34	75.57	2.56	-81.78	74.32	-6.65	65.86	-8.32	66.81	-7.59	-83.54	70.91
1423	1323	ULS1	4.31	73.24	-3.39	73.40	4.15	-87.19	71.42	-0.03	68.77	-7.87	69.66	-0.91	-83.56	70.12
1423	1320	ULS1	2.68	68.54	-5.89	69.06	2.16	-84.93	68.00	-0.90	65.11	-10.70	66.80	-2.59	-81.02	68.14
1423	1318	ULS2	1.83	14.89	-8.97	19.45	-2.73	-63.03	20.95	-2.77	8.65	-5.97	11.20	-5.32	-66.86	14.60
1423	1092	ULS2	2.57	12.17	-13.05	21.28	-6.54	-55.10	25.19	-5.94	3.24	-9.35	9.07	-11.77	-58.07	18.09
1423	1323	ULS2	2.09	12.72	-2.46	13.26	1.55	-77.57	12.56	5.49	5.97	-10.60	16.34	-4.88	-45.66	19.24
1423	1320	ULS2	3.63	16.10	1.63	16.31	3.42	82.69	14.90	6.39	10.72	-7.22	16.10	1.02	-53.35	15.61
1423	1318	ULS3	0.68	42.94	-7.47	44.22	-0.60	-80.27	44.53	-2.48	39.87	-6.20	40.76	-3.37	-81.84	42.54
1423	1092	ULS3	1.96	42.89	-6.23	43.82	1.03	-81.53	43.31	-4.23	38.32	-4.76	38.85	-4.76	-83.70	41.43
1423	1323	ULS3	1.77	42.35	-1.78	42.43	1.69	-87.49	41.61	-0.33	39.97	-4.75	40.52	-0.88	-83.37	40.97
1423	1320	ULS3	1.26	42.64	-3.01	42.86	1.05	-85.86	42.35	0.65	41.28	-6.19	42.20	-0.27	-81.52	42.34
1423	1318	ULS4	1.70	-16.41	-5.16	3.07	-17.78	-14.84	19.49	-2.19	-21.28	-2.55	-1.86	-21.62	-7.47	20.75
1423	1092	ULS4	3.12	-16.81	-9.80	7.13	-20.82	-22.26	25.15	-4.59	-24.17	-6.56	-2.60	-26.17	-16.91	24.97
1423	1323	ULS4	2.35	-16.01	-0.80	2.38	-16.04	-2.49	17.36	4.95	-22.34	-8.07	7.16	-24.55	-15.29	28.80
1423	1320	ULS4	2.94	-15.03	3.84	3.72	-15.81	11.58	17.97	5.35	-20.04	-4.05	5.98	-20.67	-8.86	24.22
1423	1318	ULS5	1.35	39.39	-9.24	41.51	-0.77	-77.05	41.90	-6.03	34.14	-7.92	35.65	-7.53	-79.24	39.95
1423	1092	ULS5	4.60	46.60	-7.26	47.82	3.38	-80.46	46.22	-5.40	39.86	-5.68	40.56	-6.10	-82.96	43.93
1423	1323	ULS5	4.56	45.99	-1.81	46.07	4.48	-87.50	44.00	-0.54	41.91	-5.46	42.60	-1.23	-82.79	43.23
1423	1320	ULS5	2.04	39.03	-3.79	39.41	1.66	-84.21	38.61	-1.90	35.94	-7.70	37.45	-3.41	-78.93	39.27
1423	1318	ULS6	2.57	-57.29	-4.09	2.85	-57.57	-3.89	59.04	-3.00	-63.96	-0.57	-3.00	-63.97	-0.53	62.52
1423	1092	ULS6	4.65	-55.81	-12.44	7.11	-58.27	-11.18	62.13	-5.15	-65.64	-7.99	-4.11	-66.68	-7.40	64.73
1423	1323	ULS6	3.54	-54.14	-0.14	3.54	-54.14	-0.14	55.99	8.41	-63.58	-10.45	9.90	-65.07	-8.10	70.54
1423	1320	ULS6	4.26	-54.80	8.21	5.38	-55.92	7.77	58.79	7.74	-62.72	-3.03	7.87	-62.85	-2.46	67.13
1423	1318	ULS7	2.59	-45.01	-5.58	3.24	-45.65	-6.60	47.35	-3.20	-52.20	-1.91	-3.13	-52.27	-2.23	50.78
1423	1092	ULS7	4.42	-44.43	-13.70	8.00	-48.01	-14.65	52.47	-5.65	-54.87	-9.08	-4.03	-56.49	-10.13	54.59
1423	1323	ULS7	3.43	-42.85	-0.79	3.44	-42.87	-0.97	44.69	8.62	-52.46	-11.45	10.70	-54.53	-10.28	60.59
1423	1320	ULS7	4.52	-42.58	7.34	5.64	-43.70	8.66	46.77	8.16	-50.64	-4.27	8.47	-50.95	-4.14	55.67
1423	1318	ULS10	-8.92	61.26	-7.48	62.05	-9.71	-83.98	67.43	8.03	63.75	-7.09	64.64	7.14	-82.86	61.38
1423	1092	ULS10	-5.77	58.72	-6.10	59.29	-6.34	-84.64	62.70	2.38	57.94	-6.21	58.63	1.69	-83.70	57.80
1423	1323	ULS10	-1.69	58.94	-1.67	58.99	-1.74	-88.42	59.88	1.67	58.73	-6.89	59.55	0.85	-83.21	59.13
1423	1320	ULS10	-3.23	61.94	-3.05	62.08	-3.37	-87.32	63.83	5.72	64.09	-7.78	65.11	4.70	-82.54	62.89
1423	1318	ULS11	-8.63	59.91	-8.26	60.89	-9.61	-83.22	66.22	6.50	61.46	-7.85	62.56	5.40	-82.03	60.04
1423	1092	ULS11	-4.64	60.47	-6.56	61.12	-5.29	-84.30	63.94	1.87	58.75	-6.62	59.51	1.11	-83.45	58.97
1423	1323	ULS11	-0.50	60.66	-1.70	60.71	-0.54	-88.41	60.98	1.59	59.72	-7.21	60.60	0.71	-83.04	60.25
1423	1320	ULS11	-2.89	60.56	-3.40	60.74	-3.07	-86.94	62.34	4.63	61.97	-8.44	63.19	3.41	-81.80	61.55

Figure 75 - Result: element 1423

Area	Joint	Combination	S11Top	S22Top	S12Top	SMaxTop	SMinTop	SAngleTop	SVMTop	S11Bot	S22Bot	S12Bot	SMaxBot	SMinBot	SAngleBot	SVMBot
Text	Text	Text	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	Degrees	N/mm2
1424	1320	ULS1	-13.86	11.05	-8.39	13.62	-16.42	-73.02	26.05	-18.72	8.07	-13.06	13.38	-24.03	-67.86	32.83
1424	1323	ULS1	-4.72	45.46	64.39	89.47	-48.73	55.65	121.41	-6.77	43.95	59.73	83.47	-46.30	56.50	113.91
1424	997	ULS1	14.18	48.73	47.97	82.44	-19.53	54.90	93.74	14.57	52.75	48.65	85.92	-18.61	55.71	96.58
1424	1322	ULS1	5.83	14.63	-24.81	35.42	-14.97	-50.03	44.82	1.83	16.57	-24.13	34.43	-16.03	-53.49	44.66
1424	1320	ULS2	-9.62	-29.27	9.03	-6.10	-32.79	21.30	30.21	-4.39	-24.03	0.45	-4.38	-24.04	1.33	22.17
1424	1323	ULS2	-5.90	-12.71	48.04	38.85	-57.46	42.97	83.93	2.59	-4.89	39.55	38.58	-40.88	42.30	68.82
1424	997	ULS2	-16.71	-15.42	23.35	7.29	-39.42	45.79	43.52	-6.37	-8.11	27.55	20.32	-34.81	44.10	48.29
1424	1322	ULS2	-19.58	-31.68	-15.66	-8.85	-42.42	-34.44	38.76	-14.21	-27.55	-11.55	-7.54	-34.22	-29.99	31.14
1424	1320	ULS3	-8.44	9.30	-4.41	10.34	-9.48	-76.78	17.17	-9.58	8.18	-7.49	10.92	-12.31	-69.93	20.13
1424	1323	ULS3	-3.14	26.98	36.84	51.71	-27.88	56.12	69.95	-4.12	26.34	33.75	48.13	-25.92	57.15	65.09
1424	997	ULS3	8.05	28.86	27.77	48.11	-11.20	55.27	54.58	8.48	31.59	28.26	50.57	-10.50	56.12	56.55
1424	1322	ULS3	3.43	11.42	-13.48	21.48	-6.64	-53.26	25.46	2.35	13.21	-12.97	21.84	-6.28	-56.35	25.57
1424	1320	ULS4	-4.84	-41.98	12.15	-1.22	-45.60	16.60	45.01	0.27	-35.93	4.48	0.81	-36.47	6.95	36.89
1424	1323	ULS4	-3.33	-33.89	28.98	14.15	-51.37	31.10	59.72	4.28	-25.60	21.42	15.46	-36.78	27.56	46.48
1424	997	ULS4	-20.70	-37.88	7.14	-18.12	-40.46	19.88	35.10	-11.68	-31.61	11.36	-6.54	-36.76	24.37	33.96
1424	1322	ULS4	-21.67	-45.77	-9.69	-18.26	-49.18	-19.40	43.06	-16.24	-42.15	-5.59	-15.09	-43.30	-11.67	38.07
1424	1320	ULS5	-9.32	-1.04	-5.44	1.66	-12.02	-63.64	12.93	-14.31	-3.25	-9.25	1.99	-19.56	-60.44	20.63
1424	1323	ULS5	-2.29	25.36	46.37	59.92	-36.85	53.30	84.60	-5.17	24.29	42.60	54.63	-35.51	54.54	78.65
1424	997	ULS5	10.38	27.41	32.64	52.63	-14.84	52.31	61.40	9.54	30.45	33.33	54.93	-14.94	53.71	63.72
1424	1322	ULS5	3.84	1.23	-19.18	21.76	-16.69	-43.05	33.39	-0.10	2.70	-18.51	19.86	-17.27	-47.16	32.18
1424	1320	ULS6	-2.65	-79.24	22.92	3.69	-85.58	15.45	87.48	5.53	-68.71	11.99	7.41	-70.59	8.95	74.58
1424	1323	ULS6	-3.18	-75.13	26.28	5.39	-83.70	18.07	86.52	9.61	-61.00	15.56	12.88	-64.27	11.89	71.59
1424	997	ULS6	-39.24	-82.99	-5.37	-38.59	-83.64	-6.90	72.51	-24.87	-74.29	1.39	-24.83	-74.33	1.61	65.54
1424	1322	ULS6	-38.30	-86.93	-8.72	-36.78	-88.44	-9.87	76.95	-29.36	-82.18	-2.19	-29.27	-82.27	-2.37	72.23
1424	1320	ULS7	-4.53	-74.21	21.71	1.68	-80.42	15.96	81.27	3.71	-63.99	10.41	5.28	-65.56	8.55	68.35
1424	1323	ULS7	-4.19	-66.79	33.70	10.50	-81.49	23.56	87.22	8.95	-52.85	22.62	16.34	-60.24	18.10	69.86
1424	997	ULS7	-37.67	-74.15	0.96	-37.64	-74.18	1.50	64.24	-22.79	-65.05	7.71	-21.43	-66.41	10.02	58.71
1424	1322	ULS7	-37.47	-81.35	-11.04	-34.85	-83.97	-13.36	73.07	-28.56	-76.41	-4.50	-28.14	-76.83	-5.32	67.33
1424	1320	ULS10	-12.91	28.38	-3.31	28.64	-13.17	-85.45	37.03	-5.36	28.47	-8.05	30.29	-7.17	-77.28	34.44
1424	1323	ULS10	-6.66	43.66	36.23	62.61	-25.61	62.39	78.60	-2.57	43.29	30.99	58.92	-18.19	63.25	69.81
1424	997	ULS10	10.24	47.01	31.06	64.72	-7.47	60.31	68.76	9.91	48.76	30.73	65.68	-7.02	61.15	69.46
1424	1322	ULS10	5.52	32.25	-8.47	34.70	3.06	-73.82	33.28	5.60	33.42	-8.31	35.71	3.30	-74.57	34.18
1424	1320	ULS11	-13.32	24.02	-3.77	24.39	-13.69	-84.30	33.41	-7.42	23.63	-8.82	25.96	-9.75	-75.19	31.97
1424	1323	ULS11	-6.31	43.08	40.42	65.76	-28.98	60.71	84.08	-3.03	42.53	34.89	61.42	-21.92	61.57	74.83
1424	997	ULS11	11.26	46.51	33.24	66.51	-8.74	58.97	71.29	10.39	48.40	32.99	67.47	-8.68	59.97	72.20
1424	1322	ULS11	5.71	27.95	-10.95	32.44	1.22	-67.73	31.84	4.56	28.99	-10.72	33.03	0.52	-69.37	32.77

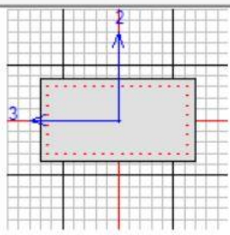
Figure 76 - Results: element 1424

V.2 Pylon

Concrete Design Data Eurocode 2-2004

File

Units KN, m, C



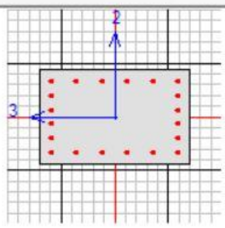

```
Eurocode 2-2004 COLUMN SECTION DESIGN  Type: DC HIGH MRF  Units: KN, m, C  (Summary)

L=10.700
Element      : 32              B=1.500         D=0.800          dc=0.068
Section ID   : PylonBase       E=35000000      fck,cyl=40000.   Lt.Wt. Fac.=1.000
Combo ID     : DCON5           fyk=413685.473  fywk=413685.47
Station Loc  : 10.700          RLLF=1.000      SOM: Nominal Curvature
Combo Eq.    : Eq. 6.10

Gamma(Concrete): 1.500         AlphaCC=1.000   AlphaCT=1.000
Gamma(Steel)   : 1.150         AlphaLCC=0.850  AlphaLCT=0.850


AXIAL FORCE & BIAXIAL MOMENT CHECK FOR NEd, MEd2, MEd3
            Capacity     Design     Design     Design    Minimum    Minimum
               Ratio        NEd       MEd2       MEd3         M2         M3
               0.956   6012.400  -1958.725   3563.487    300.620    160.331

AXIAL FORCE & BIAXIAL MOMENT FACTORS
                           M0Ed       Madd    Minimum       Beta          L
                         Moment     Moment        Ecc     Factor     Length
   Major Bending(M3)   3563.487      0.000      0.027      1.000     10.700
   Minor Bending(M2)  -1958.725      0.000      0.050      1.000     10.700

SHEAR DESIGN FOR V2,V3
                          Rebar      Shear      Shear      Shear Tan(Theta)
                          Asw/s        VEd       VRdc       VRds      Ratio
   Major Shear(V2)        0.000    235.403   1489.253      0.000      0.000
   Minor Shear(V3)        0.000    309.757   1477.243      0.000      0.000
```

Figure 77 - Results: Bottom part of the pylons

Concrete Design Data Eurocode 2-2004

File

Units KN, m, C



Eurocode 2-2004 COLUMN SECTION DESIGN Type: DC HIGH MRF Units: KN, m, C (Summary)

L=3.200			
Element : 12	B=0.800	D=0.500	dc=0.060
Section ID : Pylon	E=35000000	fck,cyl=40000.	Lt.Wt. Fac.=1.000
Combo ID : DCON5	fyk=413685.473	fywk=413685.47	
Station Loc : 3.200	RLLF=1.000	SOM: Nominal Curvature	
Combo Eq. : Eq. 6.10			

Gamma(Concrete): 1.500	AlphaCC=1.000	AlphaCT=1.000
Gamma(Steel) : 1.150	AlphaLCC=0.850	AlphaLCT=0.850

AXIAL FORCE & BIAXIAL MOMENT CHECK FOR NEd, MEd2, MEd3

Capacity Ratio	Design NEd	Design MEd2	Design MEd3	Minimum M2	Minimum M3
0.651	4884.518	912.229	189.031	130.254	97.690

AXIAL FORCE & BIAXIAL MOMENT FACTORS

	M0Ed Moment	Madd Moment	Minimum Ecc	Beta Factor	L Length
Major Bending(M3)	189.031	0.000	0.020	1.000	3.200
Minor Bending(M2)	912.229	0.000	0.027	1.000	3.200

SHEAR DESIGN FOR V2,V3

	Rebar Asw/s	Shear VEd	Shear VRdc	Shear VRds	Tan(Theta) Ratio
Major Shear(V2)	0.000	13.271	544.553	0.000	0.000
Minor Shear(V3)	0.000	197.866	542.784	0.000	0.000

Figure 78 - Above part of the pylon

V.3 Natural frequencies

TABLE: Modal Periods And Frequencies				
OutputCase	StepType	StepNum	Period	Frequency
Text		Unitless	Sec	Hz
MODAL	Mode	1	0.70	1.43
		2	0.77	1.30
		3	0.70	1.43
		4	0.70	1.43
		5	0.70	1.43
		6	0.70	1.43
		7	0.70	1.43
		8	0.70	1.43
		9	0.70	1.43
		10	0.70	1.43
		11	0.70	1.43
		12	0.70	1.43

Table 46 - Results: Natural frequencies

V.4 Preliminary design – Load combinations

Load condition 1

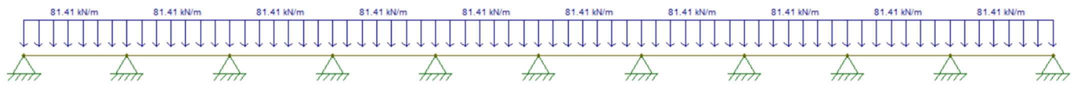


Figure 79 - Preliminary design - load condition 1

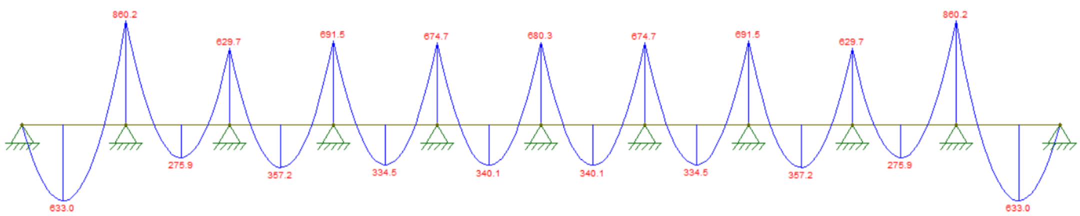


Figure 80 - Preliminary design - Moment 1

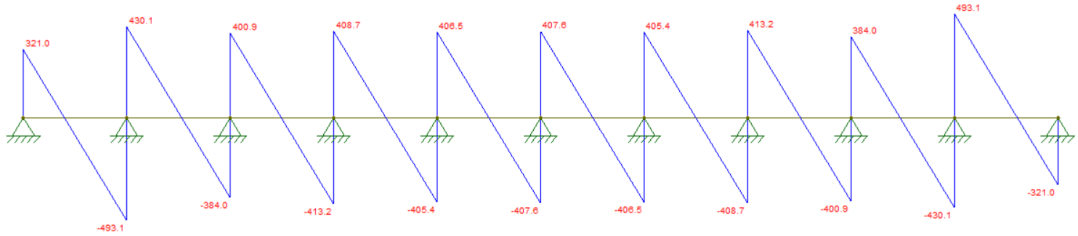


Figure 81 - Preliminary design - Shear 1

Load condition 2

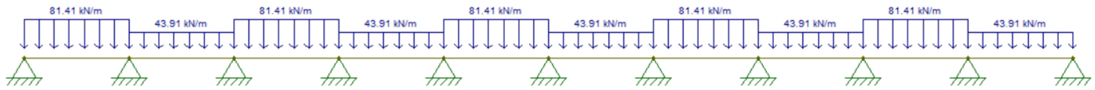


Figure 82 - Preliminary design - Load condition 2

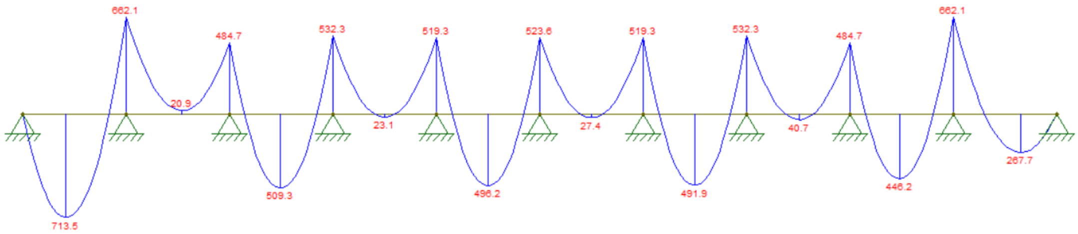


Figure 83 - Preliminary design - Moment 2

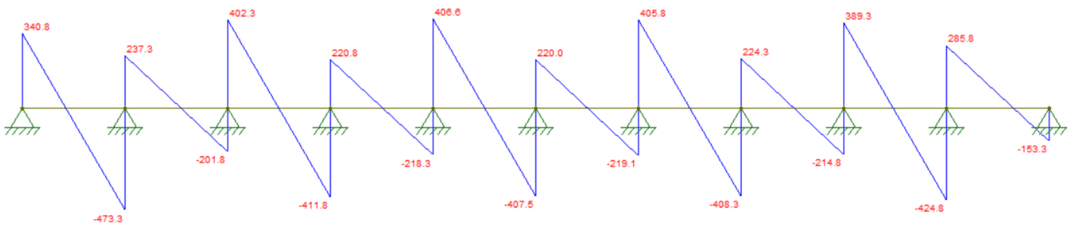


Figure 84 - Preliminary design - Shear 2

Load condition 3

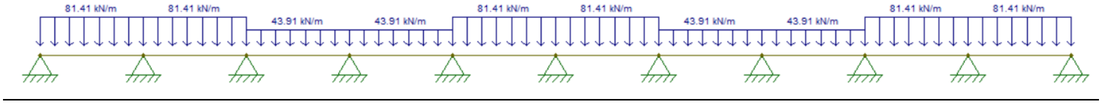


Figure 85 - Preliminary design - Load condition 3

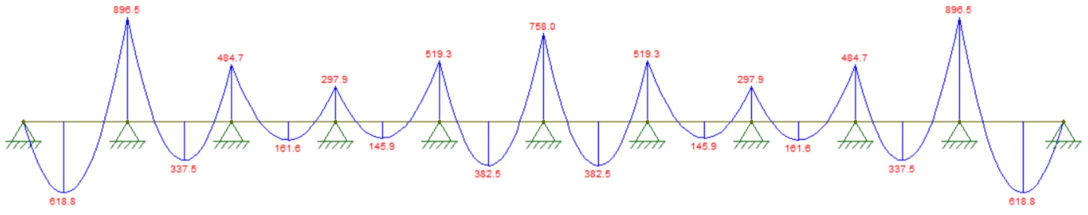


Figure 86 - Preliminary design - Moment 3

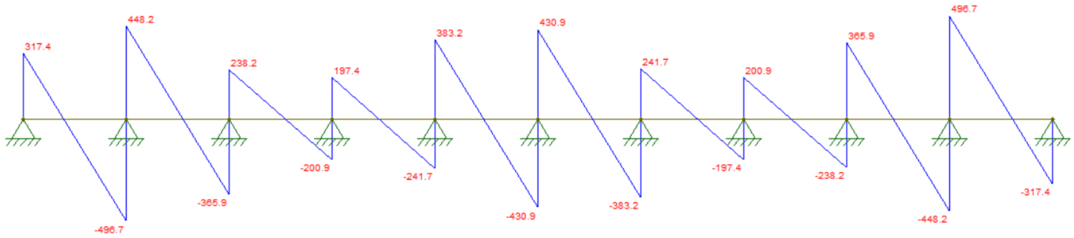


Figure 87 - Preliminary design - shear 3

Load condition 4

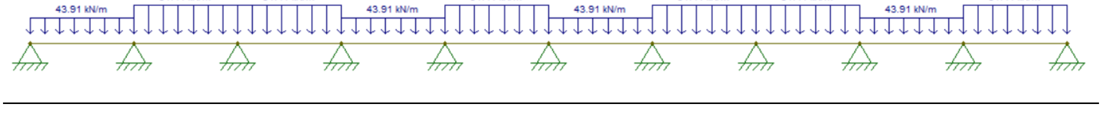


Figure 88 - Preliminary design - Load condition 4

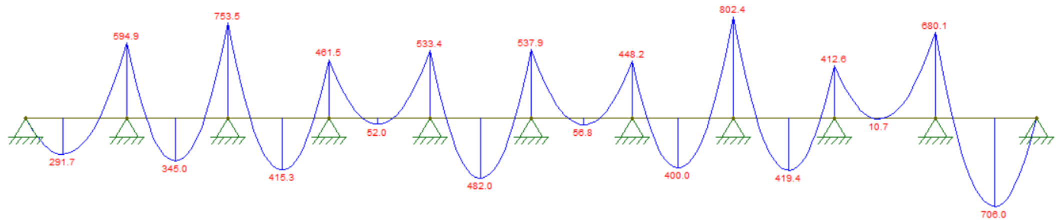


Figure 89 - Preliminary design - Moment 4

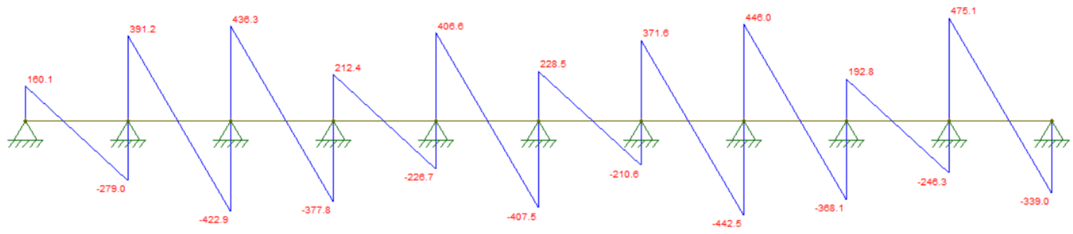


Figure 90 - Preliminary design - Shear 4

Load condition 5

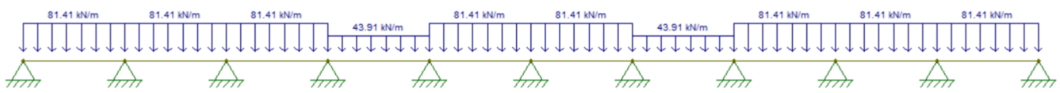


Figure 91 - Preliminary design - Load condition 5

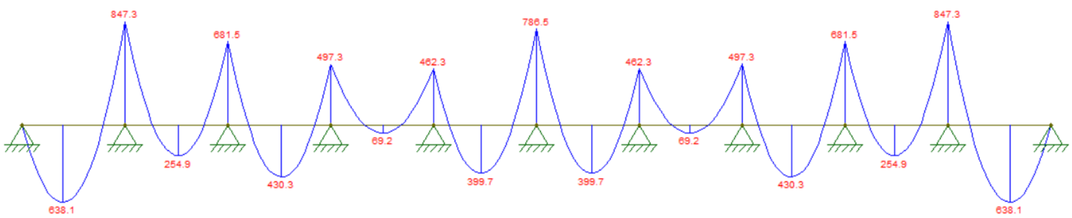


Figure 92 - Preliminary design - Moment 5

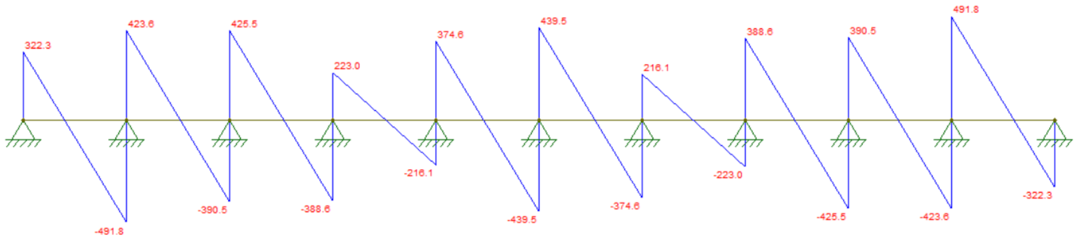


Figure 93 - Preliminary design - Shear 5

ANNEX 6
CALCULATION TABLES

In this annex are gathered some of the *Excell*'s tables used for evaluate some specifics of this project, as the design of the foundations, cables and others elements of the definitive structure.

VI.1 Cables design

Cable	Joint	combination	RV	Angle (22°)	Tension	fyk	frd(fyk/1.5)	Amin	Amin(max)	Nmin	N	Aeff	D	E	Tmax	Lf	Li	Δl	Displ.	Tension
	Text	Text	KN	Rad	KN	Mpa	Mpa	mm^2	mm^2	(150 mm^2)	Tendons	mm^2	mm	MPa	KN	m	m	m	m	kN
CAB1	A	FREQUENT1	203.78	0.38	543.97	190.00	126.67	4294.53		28.63	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.00		
	A	FREQUENT2	196.92	0.38	525.66	190.00	126.67	4149.97		27.67	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.00		
	A	FREQUENT3	218.37	0.38	582.93	190.00	126.67	4602.07		30.68	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	A	FREQUENT4	153.51	0.38	409.78	190.00	126.67	3235.12		21.57	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.00		
	A	ULS1	469.68	0.38	1253.78	190.00	126.67	9898.28		65.99	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	A	ULS2	357.97	0.38	955.59	190.00	126.67	7544.15		50.29	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	A	ULS3	261.27	0.38	697.45	190.00	126.67	5506.20		36.71	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	A	ULS4	216.09	0.38	576.85	190.00	126.67	4554.04		30.36	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	A	ULS5	335.87	0.38	896.58	190.00	126.67	7078.29		47.19	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	A	ULS6	205.84	0.38	549.49	190.00	126.67	4338.07		28.92	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.00		
	A	ULS7	260.83	0.38	696.27	190.00	126.67	5496.88		36.65	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	A	ULS10	218.35	0.38	582.86	190.00	126.67	4601.56		30.68	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	A	ULS11	251.18	0.38	670.51	190.00	126.67	5293.53		35.29	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	A	G+DEAD+CABLES	161.74	0.38	431.75	190.00	126.67	3408.57		22.72	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.00		
	H	FREQUENT1	325.53	0.38	869.00	190.00	126.67	6860.54		45.74	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H	FREQUENT2	325.07	0.38	867.77	190.00	126.67	6850.83		45.67	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H	FREQUENT3	348.76	0.38	931.00	190.00	126.67	7350.03		49.00	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H	FREQUENT4	258.04	0.38	688.84	190.00	126.67	5438.19		36.25	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H	ULS1	749.22	0.38	2000.02	190.00	126.67	15789.62		105.26	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.95	0.02		
	H	ULS2	588.78	0.38	1571.72	190.00	126.67	12408.30		82.72	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.95	0.01		
	H	ULS3	415.95	0.38	1110.36	190.00	126.67	8766.04		58.44	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H	ULS4	362.86	0.38	968.65	190.00	126.67	7647.20		50.98	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H	ULS5	534.97	0.38	1428.09	190.00	126.67	11274.40		75.16	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.95	0.01		
	H	ULS6	359.39	0.38	959.38	190.00	126.67	7574.07		50.49	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H	ULS7	448.13	0.38	1196.27	190.00	126.67	9444.20		62.96	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H	ULS10	516.19	0.38	1377.95	190.00	126.67	10878.59		72.52	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H	ULS11	568.45	0.38	1517.46	190.00	126.67	11979.96		79.87	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.95	0.01		
	H	G+DEAD+CABLES	258.60	0.38	690.31	190.00	126.67	5449.84		36.33	106.00	15900.00	142.28	190000.00	2014.00	26.97	26.96	0.01		
	H				2000.02	190.00	126.67	15789.62	15789.62	105.26	106.00	15900.00	142.28		2014.00				0.006	690.31

Figure 94 – Design: Cable 1

Cable	Joint	combination	RV	Angle (22°)	Tension	fyk	frd(fyk/1.5)	Amin	Amin(max)	Nmin	N	Aeff	D	E	Tmax	Lf	Li	Δl	Displ.	Tension
	Text	Text	KN	Rad	KN	Mpa	Mpa	mm^2	mm^2	(150 mm^2)	Tendons	mm^2	mm	MPa	KN	m	m	m	m	kN
CAB2	B	FREQUENT1	194.54	0.38	519.32	190.00	126.67	4099.86		27.33	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	FREQUENT2	205.88	0.38	549.60	190.00	126.67	4338.93		28.93	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	FREQUENT3	208.42	0.38	556.37	190.00	126.67	4392.36		29.28	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	FREQUENT4	168.15	0.38	448.87	190.00	126.67	3543.68		23.62	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.01		
	B	ULS1	447.72	0.38	1195.18	190.00	126.67	9435.67		62.90	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	ULS2	373.64	0.38	997.42	190.00	126.67	7874.35		52.50	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	ULS3	249.43	0.38	665.85	190.00	126.67	5256.71		35.04	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	ULS4	238.63	0.38	637.00	190.00	126.67	5028.96		33.53	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	ULS5	320.38	0.38	855.24	190.00	126.67	6751.86		45.01	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	ULS6	250.32	0.38	668.22	190.00	126.67	5275.45		35.17	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	ULS7	302.66	0.38	807.94	190.00	126.67	6378.50		42.52	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	ULS10	208.62	0.38	556.91	190.00	126.67	4396.65		29.31	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	ULS11	239.85	0.38	640.27	190.00	126.67	5054.76		33.70	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	B	G+DEAD+CABLES	154.54	0.38	412.53	190.00	126.67	3256.79		21.71	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.00		
	G	FREQUENT1	148.21	0.38	395.65	190.00	126.67	3123.55		20.82	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.00		
	G	FREQUENT2	151.17	0.38	403.55	190.00	126.67	3185.91		21.24	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.00		
	G	FREQUENT3	158.80	0.38	423.90	190.00	126.67	3346.56		22.31	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.01		
	G	FREQUENT4	121.27	0.38	323.73	190.00	126.67	2555.75		17.04	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.00		
	G	ULS1	341.20	0.38	910.83	190.00	126.67	7190.74		47.94	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	G	ULS2	274.81	0.38	733.59	190.00	126.67	5791.53		38.61	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	G	ULS3	190.38	0.38	508.21	190.00	126.67	4012.19		26.75	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	G	ULS4	171.90	0.38	458.87	190.00	126.67	3622.66		24.15	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.01		
	G	ULS5	244.41	0.38	652.43	190.00	126.67	5150.79		34.34	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	G	ULS6	173.92	0.38	464.27	190.00	126.67	3665.28		24.44	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.01		
	G	ULS7	213.54	0.38	570.04	190.00	126.67	4500.28		30.00	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.57	0.01		
	G	ULS10	105.87	0.38	282.62	190.00	126.67	2231.20		14.87	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.00		
	G	ULS11	129.68	0.38	346.18	190.00	126.67	2732.99		18.22	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.00		
	G	G+DEAD+CABLES	117.72	0.38	314.25	190.00	126.67	2480.92		16.54	63.00	9450.00	109.69	190000.00	1197.00	21.58	21.58	0.00		
	B				1195.18	190.00	126.67	9435.67	9435.67	62.90	63.00	9450.00	109.69		1197.00				0.005	412.53

Figure 95 – Design: Cable 2

Cable	Joint	combination	RV	Angle (22°)	Tension	fyk	frd(fyk/1.5)	Amin	Amin(max)	Nmin	N	Aeff	D	E	Tmax	Lf	Li	Δl	Displ.	Tension
	Text	Text	KN	Rad	KN	Mpa	Mpa	mm^2	mm^2	(150 mm^2)	Tendons	mm^2	mm	MPa	KN	m	m	m	m	kN
CAB3	C	FREQUENT1	147.38	0.38	393.41	190.00	126.67	3105.89		20.71	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	C	FREQUENT2	115.59	0.38	308.56	190.00	126.67	2435.97		16.24	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	C	FREQUENT3	157.85	0.38	421.38	190.00	126.67	3326.65		22.18	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	C	FREQUENT4	79.04	0.38	210.99	190.00	126.67	1665.73		11.10	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	C	ULS1	338.66	0.38	904.03	190.00	126.67	7137.07		47.58	50.00	7500.00	97.72	190000.00	950.00	16.19	16.18	0.01		
	C	ULS2	210.25	0.38	561.27	190.00	126.67	4431.05		29.54	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	C	ULS3	189.15	0.38	504.92	190.00	126.67	3986.25		26.57	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	C	ULS4	108.36	0.38	289.27	190.00	126.67	2283.68		15.22	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	C	ULS5	242.67	0.38	647.79	190.00	126.67	5114.12		34.09	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	C	ULS6	68.74	0.38	183.49	190.00	126.67	1448.64		9.66	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	C	ULS7	108.12	0.38	288.62	190.00	126.67	2278.60		15.19	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	C	ULS10	158.20	0.38	422.31	190.00	126.67	3334.00		22.23	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	C	ULS11	181.77	0.38	485.22	190.00	126.67	3830.71		25.54	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	C	G+DEAD+CABLES	117.19	0.38	312.82	190.00	126.67	2469.64		16.46	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	F	FREQUENT1	153.26	0.38	409.12	190.00	126.67	3229.91		21.53	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	F	FREQUENT2	156.88	0.38	418.79	190.00	126.67	3306.25		22.04	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	F	FREQUENT3	164.16	0.38	438.21	190.00	126.67	3459.57		23.06	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	F	FREQUENT4	126.20	0.38	336.89	190.00	126.67	2659.67		17.73	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	F	ULS1	352.22	0.38	940.24	190.00	126.67	7422.95		49.49	50.00	7500.00	97.72	190000.00	950.00	16.19	16.18	0.01		
	F	ULS2	284.65	0.38	759.86	190.00	126.67	5998.88		39.99	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	F	ULS3	196.66	0.38	524.97	190.00	126.67	4144.50		27.63	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	F	ULS4	178.66	0.38	476.92	190.00	126.67	3765.17		25.10	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	F	ULS5	252.34	0.38	673.61	190.00	126.67	5317.94		35.45	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	F	ULS6	181.48	0.38	484.45	190.00	126.67	3824.58		25.50	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	F	ULS7	222.48	0.38	593.90	190.00	126.67	4688.65		31.26	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	F	ULS10	170.91	0.38	456.24	190.00	126.67	3601.86		24.01	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	F	ULS11	195.43	0.38	521.69	190.00	126.67	4118.57		27.46	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.01		
	F	G+DEAD+CABLES	121.86	0.38	325.29	190.00	126.67	2568.08		17.12	50.00	7500.00	97.72	190000.00	950.00	16.19	16.19	0.00		
	F				940.24	190.00	126.67	7422.95	7422.95	49.49	50.00	7500.00	97.72		950.00				0.004	325.29

Figure 96 - Design: Cable 3

Cable	Joint	combination	RV	Angle (22°)	Tension	fyk	frd(fyk/1.5)	Amin	Amin(max)	Nmin	N	Aeff	D	E	Tmax	Lf	Li	Δl	Displ.	Tension
	Text	Text	KN	Rad	KN	Mpa	Mpa	mm^2	mm^2	(150 mm^2)	Tendons	mm^2	mm	MPa	KN	m	m	m	m	kN
CAB4	D	FREQUENT1	312.26	0.38	833.56	190.00	126.67	6580.76		43.87	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	D	FREQUENT2	370.48	0.38	988.97	190.00	126.67	7807.66		52.05	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	D	FREQUENT3	334.55	0.38	893.07	190.00	126.67	7050.53		47.00	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	D	FREQUENT4	317.89	0.38	848.60	190.00	126.67	6699.45		44.66	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	D	ULS1	718.80	0.38	1918.80	190.00	126.67	15148.46		100.99	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.01		
	D	ULS2	671.48	0.38	1792.49	190.00	126.67	14151.22		94.34	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.01		
	D	ULS3	400.07	0.38	1067.98	190.00	126.67	8431.39		56.21	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.00		
	D	ULS4	454.71	0.38	1213.83	190.00	126.67	9582.83		63.89	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.00		
	D	ULS5	514.09	0.38	1372.34	190.00	126.67	10834.23		72.23	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.01		
	D	ULS6	521.55	0.38	1392.27	190.00	126.67	10991.59		73.28	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.01		
	D	ULS7	605.84	0.38	1617.26	190.00	126.67	12767.82		85.12	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.01		
	D	ULS10	334.84	0.38	893.84	190.00	126.67	7056.67		47.04	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	D	ULS11	385.00	0.38	1027.73	190.00	126.67	8113.69		54.09	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.00		
	D	G+DEAD+CABLES	248.03	0.38	662.11	190.00	126.67	5227.15		34.85	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	E	FREQUENT1	311.81	0.38	832.37	190.00	126.67	6571.36		43.81	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	E	FREQUENT2	281.64	0.38	751.83	190.00	126.67	5935.53		39.57	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	E	FREQUENT3	334.07	0.38	891.78	190.00	126.67	7040.38		46.94	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	E	FREQUENT4	211.48	0.38	564.53	190.00	126.67	4456.82		29.71	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	E	ULS1	717.73	0.38	1915.95	190.00	126.67	15125.89		100.84	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.01		
	E	ULS2	511.56	0.38	1365.60	190.00	126.67	10781.06		71.87	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.01		
	E	ULS3	399.50	0.38	1066.45	190.00	126.67	8419.32		56.13	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.00		
	E	ULS4	295.12	0.38	787.81	190.00	126.67	6219.54		41.46	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	E	ULS5	513.33	0.38	1370.31	190.00	126.67	10818.21		72.12	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.01		
	E	ULS6	255.90	0.38	683.12	190.00	126.67	5393.09		35.95	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	E	ULS7	340.06	0.38	907.77	190.00	126.67	7166.61		47.78	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	E	ULS10	333.92	0.38	891.40	190.00	126.67	7037.34		46.92	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	E	ULS11	384.00	0.38	1025.07	190.00	126.67	8092.64		53.95	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.80	0.00		
	E	G+DEAD+CABLES	247.68	0.38	661.17	190.00	126.67	5219.79		34.80	101.00	15150.00	138.89	190000.00	1919.00	10.81	10.81	0.00		
	D				1918.80	190.00	126.67	15148.46	15148.46	100.99	101.00	15150.00	138.89		1919.00				0.002	662.11

Figure 97 - Design: Cable 4

IV.2 Foundations

TABLE: Joint Reactions at the base of the pylons						
Combination	F1	F2	F3	M1	M2	M3
Text	KN	KN	KN	KN-m	KN-m	KN-m
FREQUENT1	-6.82E-12	16.608	2272.38	-18.476	-5E-10	7.6E-12
FREQUENT2	-1.1E-11	109.58	2214.51	-451.76	-6E-10	3E-12
FREQUENT3	-32.352	21.007	2433.02	-29.94	-328.06	5.6687
FREQUENT4	-1.12E-11	115.507	1740	-505.43	-4E-10	-2E-12
ULS1	-242.638	99.142	5201.87	-237.09	-2460.4	42.5154
ULS2	-0.026	235.846	3999.72	-936.31	1.754	-0.0308
ULS3	-72.817	35.642	2902.92	-70.825	-736.38	12.7238
ULS4	-0.026	193.094	2437.31	-824.95	1.754	-0.0308
ULS5	-242.659	58.266	3724.9	-129.96	-2459	42.4908
ULS6	-0.02	304.192	2346.5	-1343.8	1.4032	-0.0247
ULS7	-2.02E-11	321.317	2955.47	-1389.1	-1E-09	1.3E-12
ULS10	1.867	95.16	2637.43	-313.12	-124.18	2.8761
ULS11	-70.924	105.057	2998.87	-338.91	-862.31	15.6308
G+DEAD+CABLES	-6.14E-12	3.941	1809.45	14.5196	-3E-10	3.6E-12
TORSION+WIND	-236.786	63.692	4173.97	-134.13	-2898.5	49.8229

Table 47 - Design: joint reactions at the base of the pylons

Soil characteristics			D (m)				qp (kN/m^2)			Ap (m^2)			Soil characteristics			qfi	Qp (kN)			Qf (kN)			Qh (kN)		
z1 (m)	z2 (m)	Nspt	D1	D2	D3	L (m)	qp(D1)	qp(D2)	qp(D3)	Ap1	Ap2	Ap3	z1 (m)	z2 (m)	Nspt	(kN/m^2)	Qp1	Qp2	Qp3	Qf1(z)	Qf2(z)	Qf3(z)	Qh1(z)	Qh2(z)	Qh3(z)
3.0	3.6	4	0.4	0.6	0.8	3	1200	800	600	0.125664	0.282743	0.502655	3.0	3.6	4	3.1	150.7964	226.1947	301.5929	11.62389	17.43584	23.24779	162.4203	243.6305	324.8407
6.0	6.6	14	0.4	0.6	0.8	3	4200	2800	2100	0.125664	0.282743	0.502655	6.0	6.6	14	5.2	527.7876	791.6813	1055.575	31.10177	46.65265	62.20353	558.8893	838.334	1117.779
9.0	9.6	17	0.4	0.6	0.8	3	5100	3400	2550	0.125664	0.282743	0.502655	9.0	9.6	17	5.8	640.8849	961.3274	1281.77	52.93584	79.40375	105.8717	693.8207	1040.731	1387.641
12.0	12.6	32	0.4	0.6	0.8	3	9600	6400	4800	0.125664	0.282743	0.502655	12.0	12.6	32	8.9	1206.372	1809.557	2412.743	86.55088	129.8263	173.1018	1292.922	1939.384	2585.845
15.0	15.6	24	0.4	0.6	0.8	3	7200	4800	3600	0.125664	0.282743	0.502655	15.0	15.6	24	7.3	904.7787	1357.168	1809.557	113.8827	170.8241	227.7655	1018.661	1527.992	2037.323
18.0	18.6	53	0.4	0.6	0.8	3	15900	10600	7950	0.125664	0.282743	0.502655	18.0	18.6	53	13.3	1998.053	2997.079	3996.106	163.9911	245.9867	327.9823	2162.044	3243.066	4324.088
21.0	21.6	70	0.4	0.6	0.8	3	21000	14000	10500	0.125664	0.282743	0.502655	21.0	21.6	70	16.8	2638.938	3958.407	5277.876	227.4513	341.177	454.9026	2866.389	4299.584	5732.778
14.0	24.6	60	0.4	0.6	0.8	3	18000	12000	9000	0.125664	0.282743	0.502655	14.0	24.6	60	14.8	2261.947	3392.92	4523.893	283.0575	424.5862	566.115	2545.004	3817.506	5090.008
27.0	27.6	72	0.4	0.6	0.8	3	21600	14400	10800	0.125664	0.282743	0.502655	27.0	27.6	72	17.3	2714.336	4071.504	5428.672	348.0885	522.1327	696.1769	3062.425	4593.637	6124.849
30.0	30.6	17	0.4	0.6	0.8	3	5100	3400	2550	0.125664	0.282743	0.502655	30.0	30.6	17	5.8	640.8849	961.3274	1281.77	369.9225	554.8838	739.8451	1010.807	1516.211	2021.615

Table 48 - Design: foundations' geometry