CZECH TECHNICAL UNIVERSITY IN PRAGUE

CIVIL ENGINEER

“CHICHE BRIDGE DESIGN”

MASTER THESIS

MANOLO MENDIZABAL MELO

Supervisor: Doc. Ing Marek Foglar. PhD

PRAGUE, JANUARY 2018

CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Civil Engineering
Thákurova 7, 166 29 Prague 6, Czech Republic

DIPLOMA THESIS ASSIGNMENT FORM

I. PERSONAL AND STUDY DATA

Surname: Mendizabal Melo Name: Manolo Personal number: 467954

Assigning Department: Department of Concrete and Masonry Structures

Study programme: Building Structures Master program CIVIL ENGINEERING

Branch of study: Building Structures

II. DIPLOMA THESIS DATA

Diploma Thesis (DT) title: Design of Chiche Bridge (Návrh mostu Chiche)

Diploma Thesis title in English: Design Of Chiche Bridge

Instructions for writing the thesis:
State-of-the-art in the field of pre-stressed concrete bridges over deep unaccessible valleys
Design and static assessment of the Chiche bridge including construction stages analysis
Basic drawings (plan, longitudinal section, cross-section, construction stages plan, pre-stressing scheme)

List of recommended literature:
EN 1991-2, EN 1992-1-1, EN 1992-2 and corresponding standards
Navratil: Pre-stressed concrete

Name of Diploma Thesis Supervisor: doc Ing. Marek Foglar, Ph.D.

DT assignment date: 02.10.2017 DT submission date: 07.01.2018

DT Supervisor's signature Head of Department's signature

III. ASSIGNMENT RECEIPT

I declare that I am obliged to write the Diploma Thesis on my own, without anyone's assistance, except for provided consultations. The list of references, other sources and consultants' names must be stated in the Diploma Thesis and in referencing I must abide by the CTU methodological manual "How to Write University Final Theses" and the CTU methodological instruction "On the Observation of Ethical Principles in the Preparation of University Final Theses".

02. 10. 2017
Assignment receipt date

Student's name

STATEMENT

I hereby confirm that I have worked on this diploma thesis on my own with the methodical support of my supervisor Doc. Ing. Marek Foglar, PhD.

In addition, I declare that the references used to prepare this diploma thesis are stated in the bibliography.

In Prague, 7 of January 2018

……………………………………..

Manolo Mendizábal Melo

Acknowledgement

I would like to thank my supervisor Doc. Ing. Marek Foglar, PhD with the help, knowledge and guidance provided for me to be able to develop this diploma thesis. At the same time, I would like to thank the Czech Technical University in Prague for the opportunity given to follow my master's degree at this great institution.

Also, I'd like to thank the professors of the university that have helped me throughout my studies and this diploma thesis, this project is a reflection of all the knowledge you have given me during my period at Prague.

I would like to thank to my family and friends that have supported me during my time in Prague, all of you have made me achieve this objective in my life.

ABSTRACT

This thesis project provides an alternative design for the Chiche Bridge, located in Quito-Ecuador. This project will provide studies of design for prestress concrete bridges and possible alternatives for the problem faced. Afterwards, I will provide the design of the bridge and the steps involved during construction process and serviceability of it. The procedures and information presented in this document follows the regulations from the Eurocode. As a result of this work, a proper design will be derived, based on professors advices, involved in the design and construction of bridges, and experiences adopted in classes during my master program. The final design will provide blueprints and the calculations for a prestress bridge.

Keywords: Bridge, design, alternatives, construction, design blueprints, prestress concrete, canyon, cross-section, span, architecture, engineering.

INDEX

TABLES INDEX

FIGURES INDEX

INTRODUCTION

Bridges in Ecuador are getting constructed more often due to the difficult terrains the country has. Topography in Ecuador is considered one of the most difficult ones. This is due to the location of the country in the Pacific Belt of Fire. The Wadati-Benioff zone in the coast has a slope of 35° according to PhD. Fabricio Yepez seismicity teacher designer at USFQ[1], which shows the amount of pressure the two plates have in front of the country. These derive in the creation of mountains and curve terrains.

Ecuador is a country that is growing on its population. In a period of ten years it has grown from 13.7 million to 16.1 million (2015). Considering that the public transportation is not a preferred choice by the local people due to the poor system the city has, mobility its common problem in the big cities of Ecuador, the automotive industry haven´t stop growing for the past few years. At the end of the year 2014 the number of vehicles in Quito, capital of Ecuador, grew in a 12%, years before that year the industry was with a 10% increment of vehicles sell each year (2014).

Taking in consideration the limits Quito has on the East and West limits due to natural canyons and mountains, the city can only grow in the North and South direction. This creates a transportation conflict in certain areas that connect the Capital with the important suburbs around it. All these areas have different projects contemplated to solve the problem, where the solutions that are given by the experts due to the difficult topography terrains, is the construction of bridges or tunnels, depending on which side of the city they will try to access.

[1] Doc. Ing. Fabricio Yépez is the vice-dean of the engineering department at Universidad San Francisco de Quito, expert in seismicity design.

The connections between the suburbs and the city are more important every year in the capital. As the data showed, the population grows and the city is growing wider in this areas too, being one of the reasons why the major Augusto Barrera on the year 2011 approved the construction of the project denominated “Ruta Viva”, a highway designed to: connect the new airport “Mariscal Sucre” in Quito with the city center area, providing access to different zones of two suburb called Valle de Cumbaya and Valle de Tumbaco, and to give a traffic solution from the main highway who crossed Quito in the South-North direction, on the East side limits of the city. It was calculated on the time that the vehicle amount was going to be reduced in a 50% (2011).

Chiche Bridge

Over many years a project to replace the bridges above this canyon was suggested, they were two different bridges in this area who worked as the connection between Pifo and Tumbaco in Quito. The creation of the new highway called “Ruta Viva” has been over the authority’s desk’s over 40 years, according to MSc. Fernando Romo[2], he presented 3 different alternatives to relieve the traffic in Quito. Both previous bridges had different uses, the first one and oldest, build on the year 1940 was used for commercial use, its design was an arc bridge made of stone.

The second one was a military temporary steel bridge placed on the year 1970 who was placed to connect both cities and its use was for low traffic only. However, this bridge used to be closed several times due to the high traffic ratio due to the demand many years after, this was not calculated at the time nor expected. Once the airport was moved from the main city to Tababela, a city next to Pifo, the amount of traffic grew even more,

[2] Ing. Fernando Romo is the head of the civil engineering department at Universidad San Francisco de Quito, also is the lead designer of the Chiche bridge located in Quito-Ecuador

reason why they have to connect the airport via a new highway. The project "Ruta Viva" was reconsidered and this time was developed.

The project was built in two different phases, summarized in 13.6 Km of highway and two main bridges above two rivers, the one above the river "San Pedro and the other crosses the river "Chiche" (2011). At the present time is 100% functional. The realization of this project brought a new focus in Ecuador on construction engineering and technology. The best example of this is the bridge over the river "Chiche" mentioned before, who is the biggest bridge in Ecuador constructed under prestress concrete with a span between supports of 210 meters, with a total longitude of 314.5 meters, over a canyon of 137 meters height, which for the country is considered a record (2015). Besides that, the bridge, due to the importance of it and the economic investment, needed to be protected of one of the most seismic countries in the world, reason why technology had to be used, a set of seismic rubber bearings where used to prevent disasters under earthquakes in the area. According to Romo, lead designer of the structural bridge project, this technology can resist up to an earthquake of 7.7 in the Richer Scale. More than enough, considering the highest earthquake scale expected in Quito, which is of 6.0 Richer.

The cross section of the bridge is box hollow, it was constructed under asymmetric segmental progressive cantilever, reason why the height of the lamellas vary throughout the span between 4.20 meters in the critical section of the bridge to 8.20 in the connection with the triangle supports (2016), giving a curve arc form on the main beam, also known as a hunched beam. Two main roads where created with this bridge, reason why is considered to be two different bridges separated by 2.35m, the two different main lamellas have a longitude of 3-4 meters, creating a total of 37 units cast on site. Each lamella carries three lanes, with a total width of 14 meters. (2012).

The bridge design has three spans, the critical one has a length of 174,50 meters. The other spans have an equal value of 70 meters each (2016). However, in the middle span we can consider a free span between supports of 210 meters. This is due to the way the pile was constructed, is not a vertical pile, it has an angle, where it creates a triangle to help support the big moments that were going to create in the construction phase according to Ing. Romo.

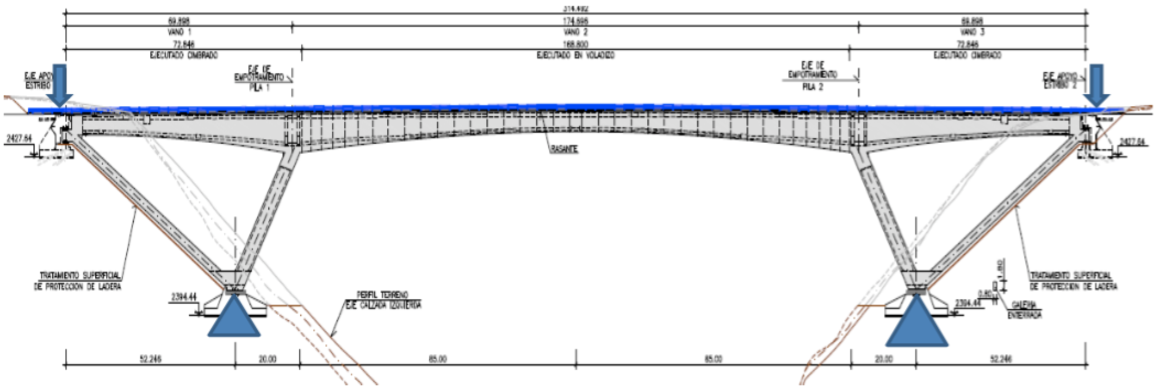


FIGURE 1: SECTIONAL VIEW OF THE CHICHE BRIDGE

If we just focus on the triangular cells of the bridge, they were design to hold the big moments that will be created due to the big lever arm in the critical phase of the construction, and the two of them were design to act like an embankment during this phase. The part of the triangle frame that is in the soil of the canyon, also called "pila dorsal" in the graph is concrete and its measurements are 2mts height by 2 meters width (2016). The other pile, named "Pila Frontal" is a hollow section of 0.50 meters wall thickness, and a full cross section of 4,00 X 6,00 meters. (2016)

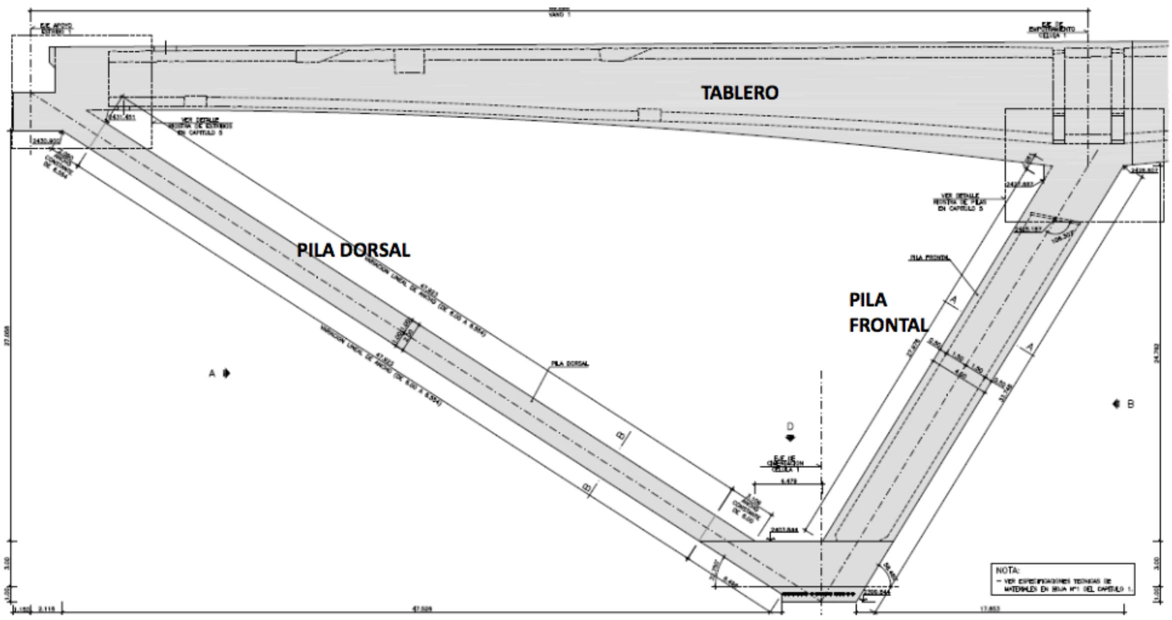


FIGURE 2: FRONT VIEW OF ONE CELL OF THE BRIDGE.

However, this project executed was not the original bridge design. According to the paperwork of licitation of the EPMMOP (2012), the design bridge did not consider a triangular frame, it was licitated as a "typical" bridge with two vertical piles, the measurements of the spans were different, but still was a prestressed bridge design. The total longitude of the bridge was of 330.80 meters, divided in three spans two of 88.30 meters and one middle span of 154 meters (2012). The cross section of the bridge had the same characteristics of the final and fully operational bridge. The main piles who were going to provide the supports were a hollow section of 8x8 meters and a total height of 83 meters. (2012).

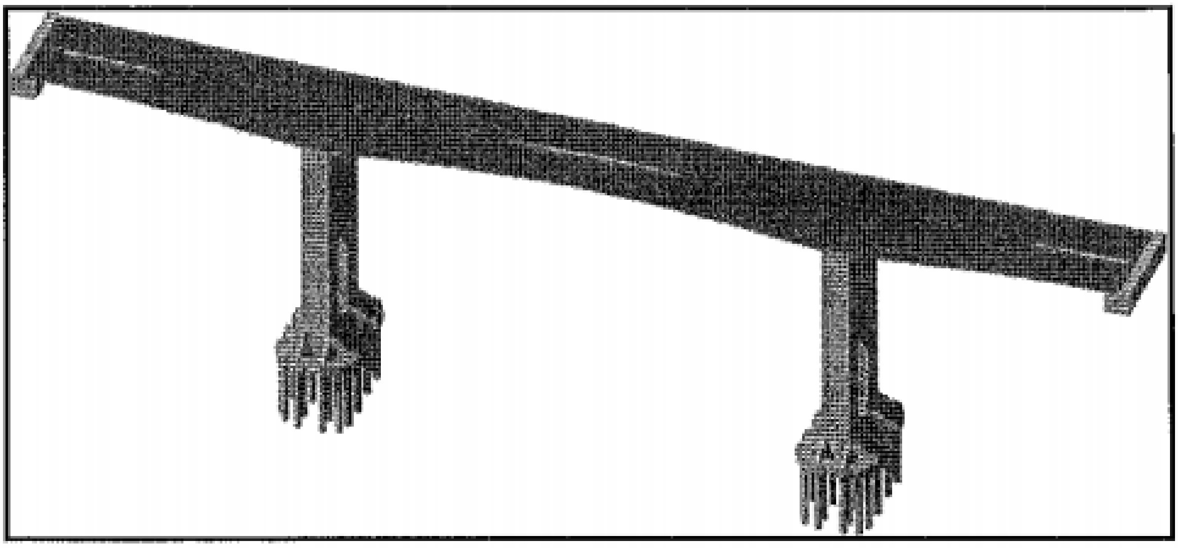


FIGURE 3: ORIGINAL DESIGN OF THE CHICHE BRIDGE.

According to MSc. Romo the bridge was designed this way due to the lack of technology that Ecuador had at the time for constructions of structures of this magnitude. However, the licitation included a paragraph were the design could be corrected or improved by the construction company with the approval of the main designer of the structure. Grupo Puente's, the name of the construction company provided the design that was finally build, after MSc. Romo approval on the design the bridge started to be build. The new design was better according to him. However, he suggested that the new bridge was able to be build due to the equipment the Spanish company was bringing to the country.

The construction of the bridge was done in 14 phases (2016). The first one was divided in two different tasks, terrain slope and foundations excavations and footing concrete pouring; as we can see in the next graph.

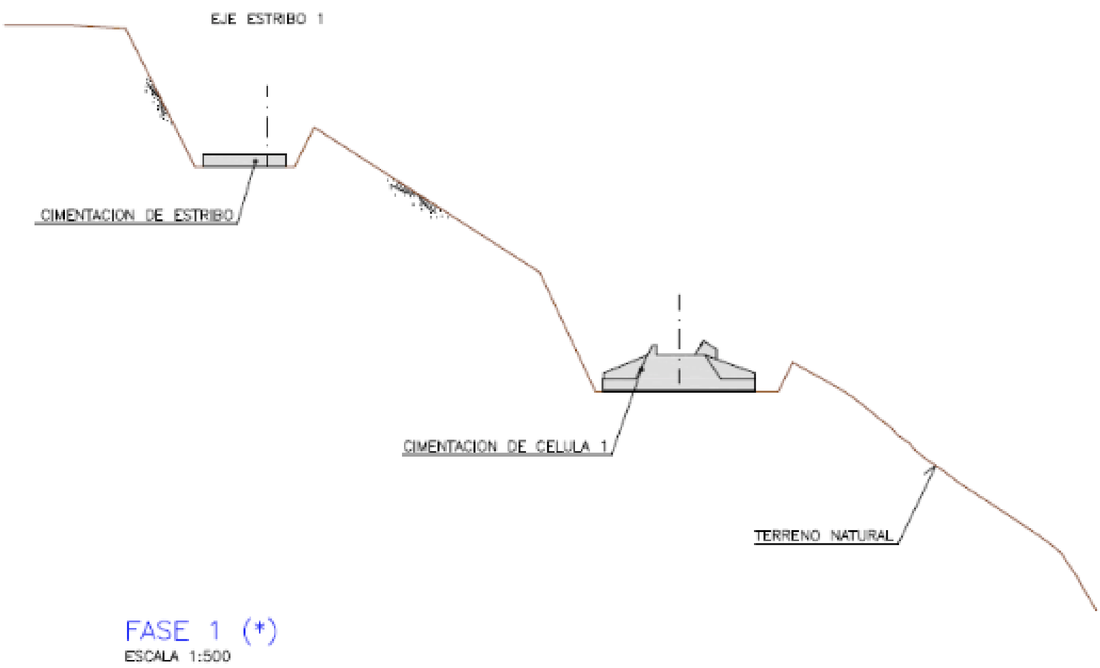


FIGURE 4: PHASE 1 OF CHICHE CONSTRUCTION

Phase two consisted in two steps, the first was the installation of the first technology in the bridge, the earthquake triple pendulum bearings resistance, who at the time were blocked until the end of the construction; also, the first cast of concrete cells, were the scaffolding will be supported while the construction of the inclined part of the cells will be held up to. It´s important to notice that this was the second technology that was presented in the country, due to this project. This scaffolding was the main reason why the bridge was change in design at the end, the scaffolding holds in the same cell in the called "pila frontal", this will climb in different segments and it worked for 3.15 meters on each segment to cast. We can see on figure 5 how the scaffolding was used for the inclined pile construction.

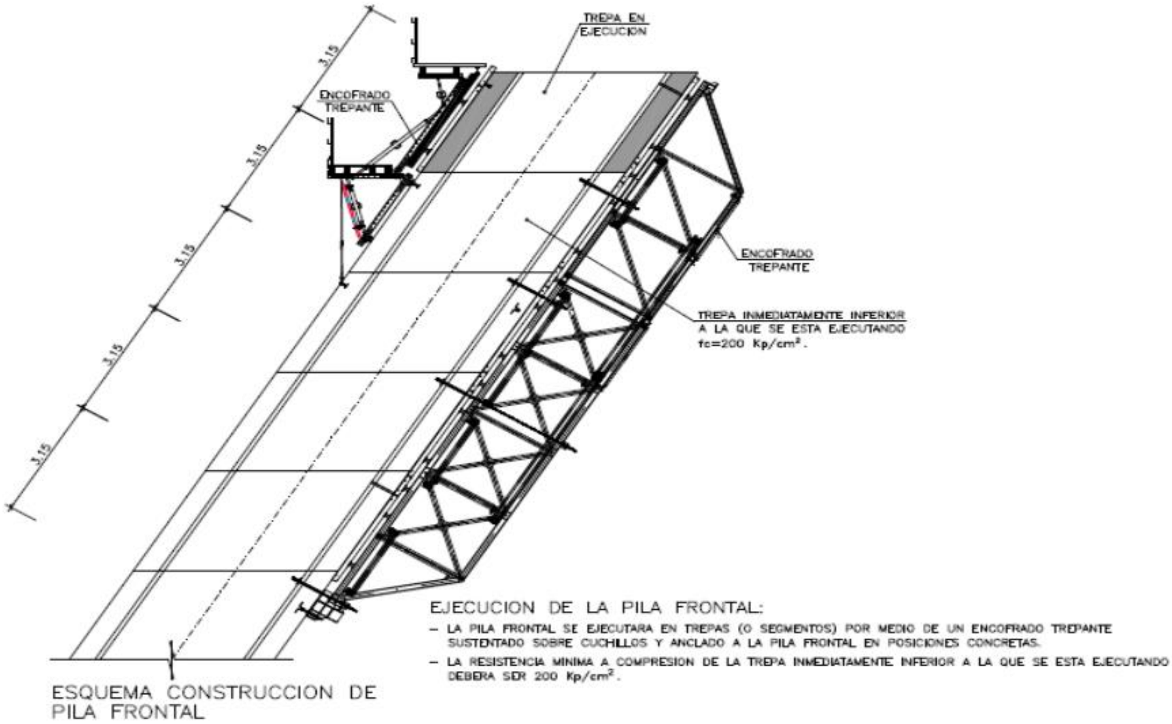


FIGURE 5: SCAFFOLDING SYSTEM

This scaffolding was able to reduce the size of the columns of support and the height from an 8x8 to a 2x6 meters. The terrain in the area had a big drop in the canyon from where the triangular cell was placed to where the column piles were planned to be located. All these factors made the first design a most expensive one.

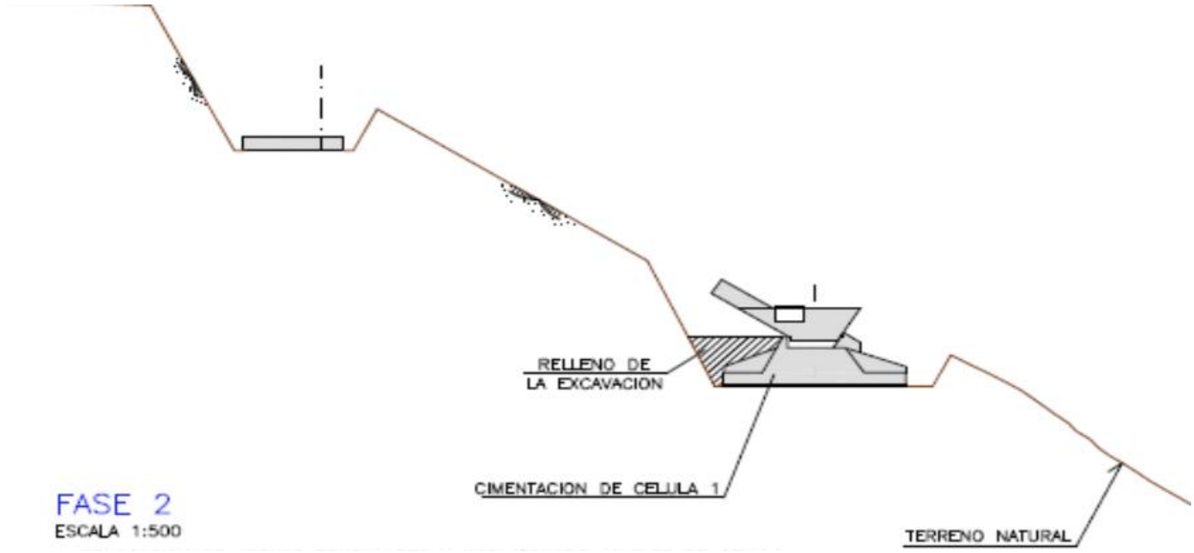


FIGURE 6: PHASE 2 OF CHICHE CONSTRUCTION

Phase number 3 also consisted in two main steps, it was the construction of the denominated “pila dorsal”, this pile was also constructed considering that the scaffolding for the small spans of the bridge will be supported on these ones, reason why special foundations where made in two specific areas. These foundations will hold lateral forces due to the tensed cable that will hold the inclined scaffolding and vertical forces due to the top scaffolding for the beam bridge.

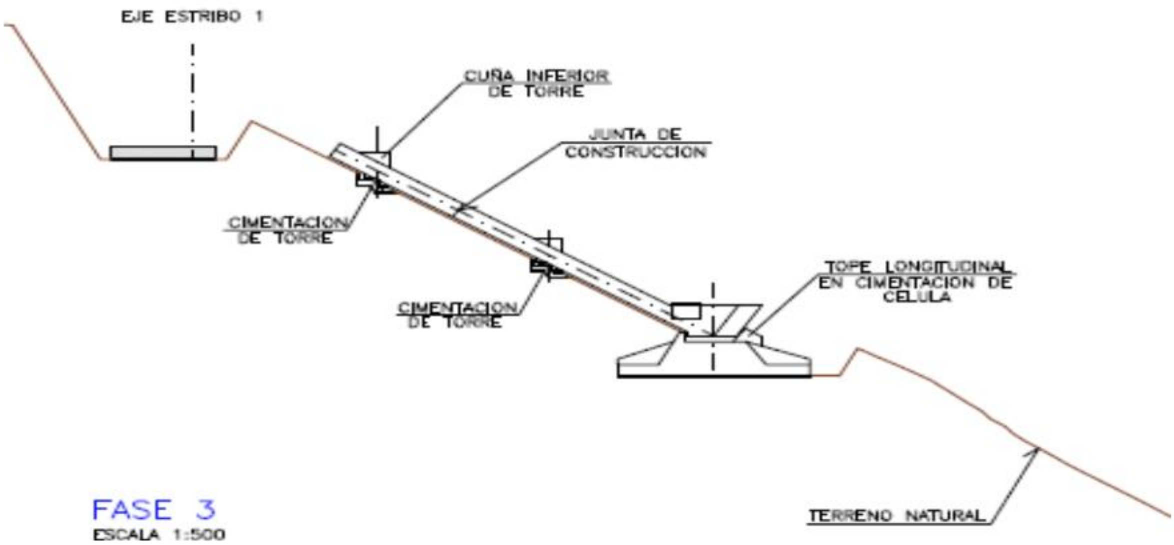


FIGURE 7: PHASE 3 OF CHICHE CONSTRUCTION

Phase number 4 consisted in the installation of the formwork in the pile, at the same time the inclined pile started to be casted, it was casted until the first support of the formwork that will be hold on the other pile.

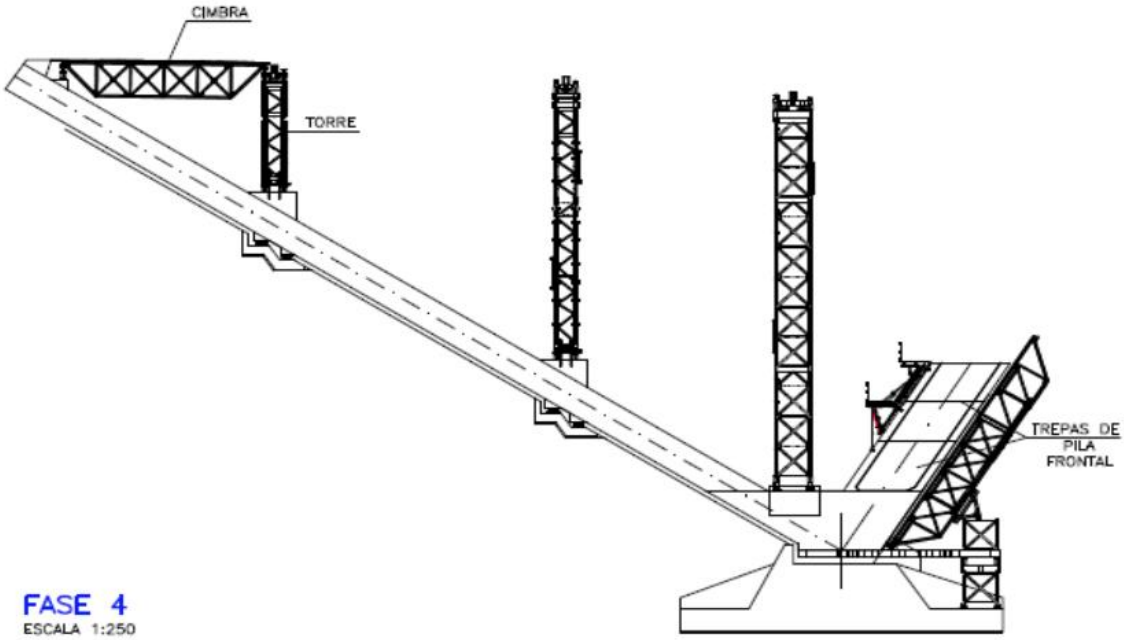


FIGURE 8: PHASE 4 OF CHICHE CONSTRUCTION

Phase number 5 was focused on the first tensed beams and the installation of them. For them to be installed they had to wait until the concrete of the inclined pile reached certain characteristics, the most important one was for it to reach a compression resistance of 250 Kip/cm^2 so it can resist the tension stresses on the beam that was going to hold the inclined scaffolding. At the same time the beam scaffolding for the main beam of the bridge was being installed.

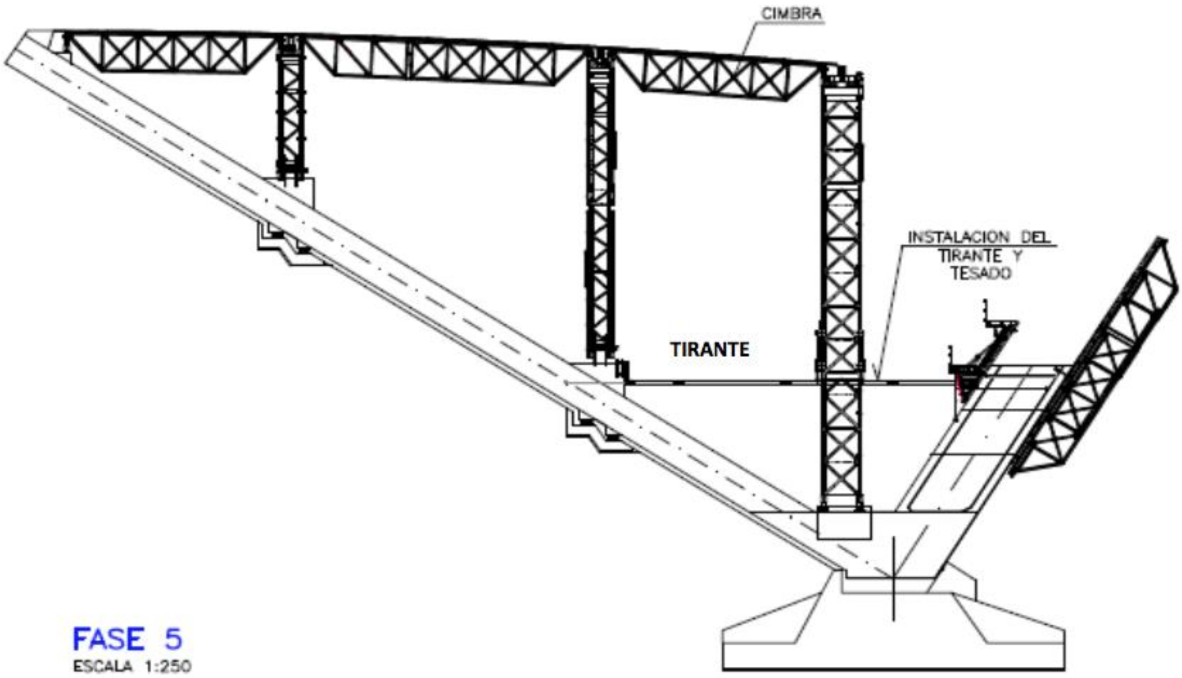


FIGURE 9: PHASE 5 OF CHICHE CONSTRUCTION

Phase number 6 was the same as number 5, this time the scaffolding was displaced after the concrete reached its expected properties, this phase was considered finished the moment the second prestressed beam was installed, after casting the concrete in the inclined beam.

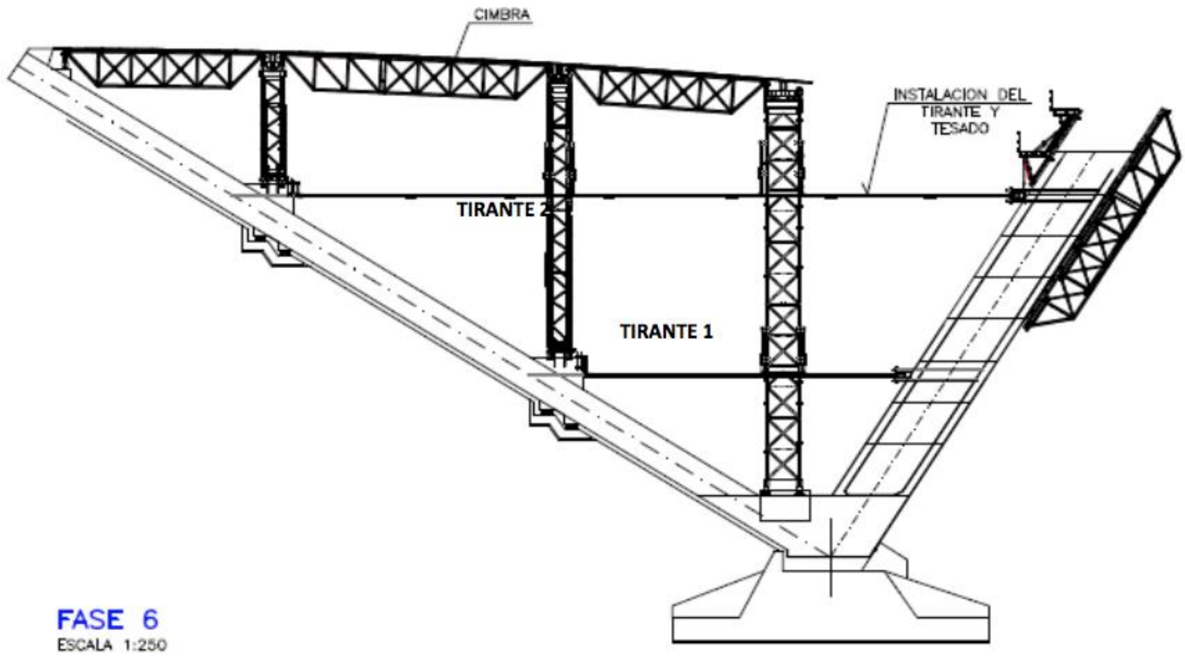


FIGURE 10: PHASE 6 OF CHICHE CONSTRUCTION

Phase number 7 of the bridge construction consisted in the culmination of the inclined pile and installation of the formwork for the main beam. After completing of this pile, and after it reaches the properties the inclined scaffolding was retired but the prestress beams and cables stayed there until the concrete reaches the final and expected properties.

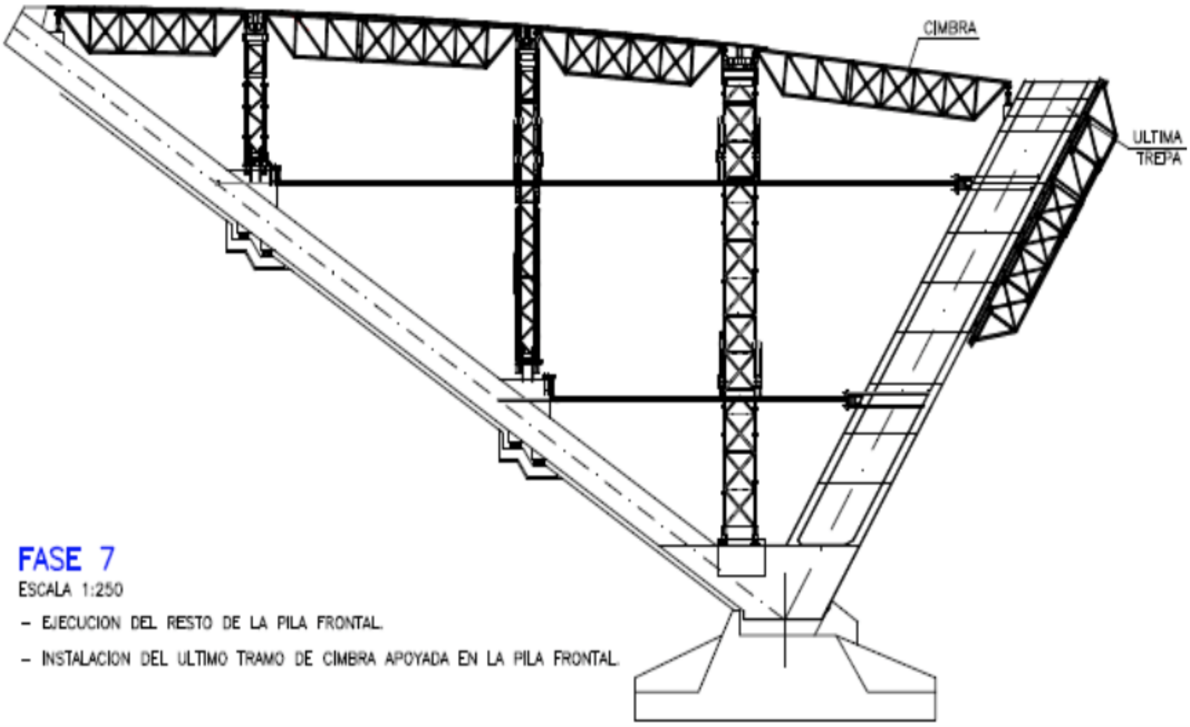


FIGURE 11: PHASE 7 OF CHICHE CONSTRUCTION

On phase number eight it's the moment where the main hollow box beam will start to be casted, however the first step was to begin the construction of the abutment. This specific area of the substructure has to be design in a way to hold the horizontal, vertical and moment forces during construction and operation of the bridge. Reason why 40 pretense bars at 110 tons and 16 anchor prestress cables of 30 meters each of 30 meters length where placed in each abutment (2016). The bridge will rest on this element, where the bridge had controlled displacements on the support.

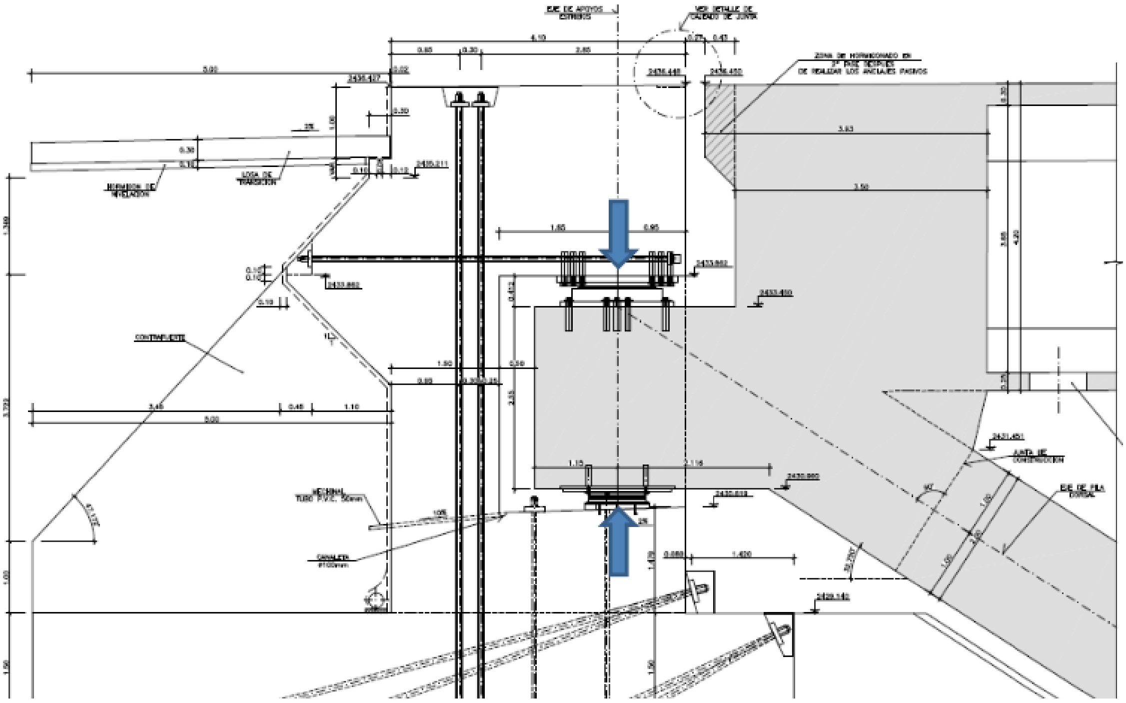


FIGURE 12: ABUTMENT

After finishing this part of the substructure, the superstructure starts to be casted. It is divided in 3 sequences for its development, each lamella will be at this point have the ducts to later provide the posttension cables that will provide the prestress effect. Figure 13 explains the sequences.

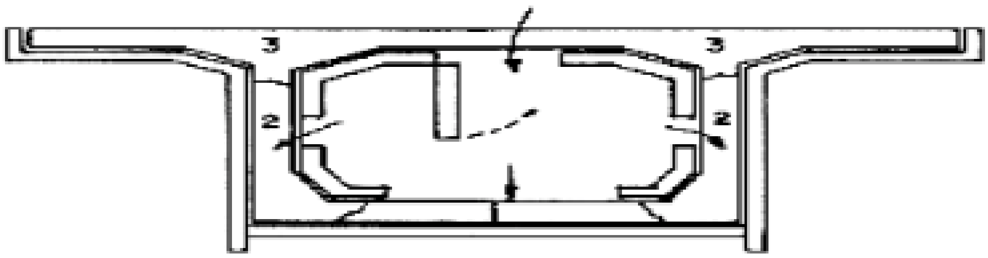


FIGURE 13: CASTING SEQUENCE

Phase eight consider the whole casting of the U part (number one and two of the casting sequence) concrete superstructure between the two piles, creating the triangular frame of the bridge.

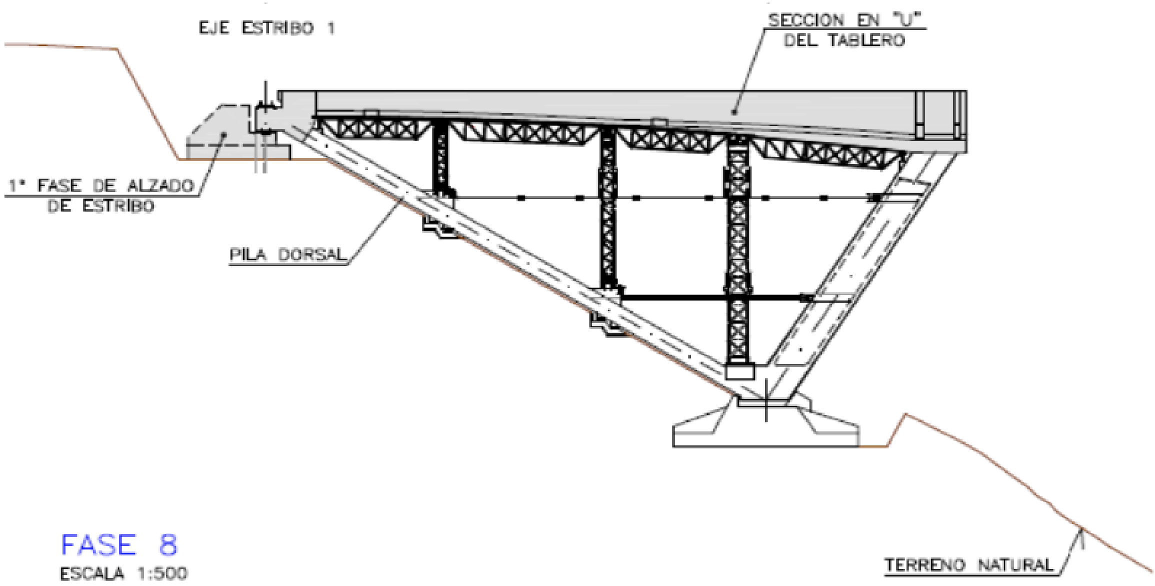


FIGURE 14: PHASE 8 OF CHICHE CONSTRUCTION

At this point we can see that the tensed beams connecting the inclined pile that hold the formwork can be taken out.

In phase number 9 the bottom part of the formwork will be taken out once the U part of the box beam will reach to compression strength of 250 Kip/cm^2. At this point the casting car will be constructed in the U part of the superstructure, it has to be placed once the formwork is out of the section, and it can start the casting to complete the cross section of the beam. For the car to be displaced to the next part of the section, the concrete recently poured has to reach a compressive strength of 170 Kip/cm^2. Once the triangular cell is closed, the scaffolding retired from the piles and beams, excluding the vertical ones that provide help during the construction, and all the concrete poured in the superstructure, it is considered that phase 9 of the construction of the bridge has been finished. At this point the bridge construction changes to what we can describe as an asymmetric segmental progressive cantilever.

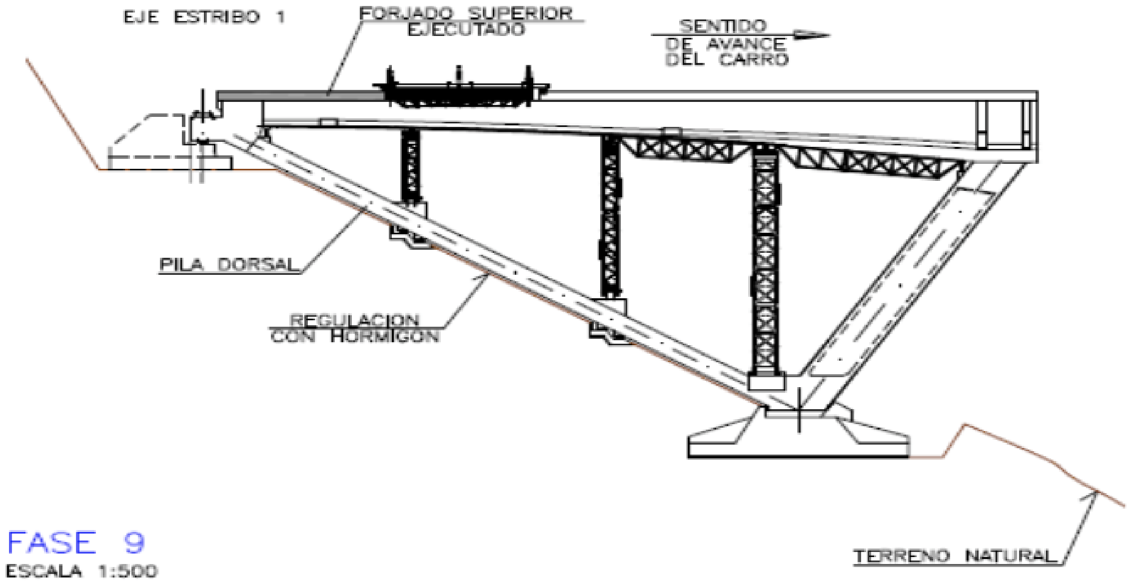


FIGURE 15: PHASE 9 OF CHICHE CONSTRUCTION

On phase 10 the challenge in the constructions starts, at this point is important to have the cables ready for posttensioning in different parts of the cross section, each of the parts will held an important effect whether it is on the construction or in-service phase. This step of construction considers the dismantling of the previous casting car, and the assembly of the lamella-casting car. This phase considers the full casting of lamella number 1, where no prestress cables are needed. The car will stay in its position until the concrete casted on the lamella reaches to a compressive strength of 350 Kip/cm^2 (2016).

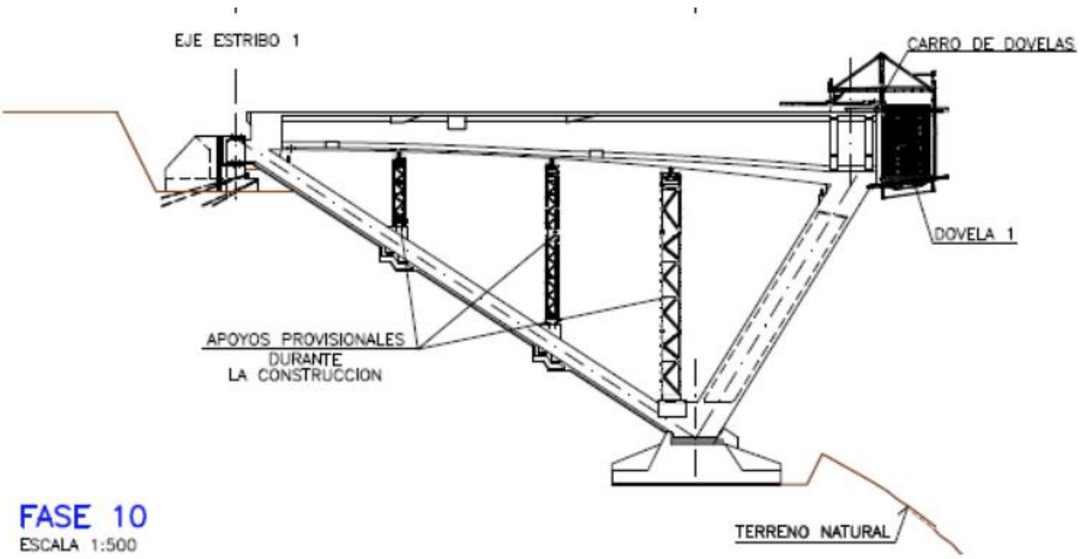


FIGURE 16: PHASE 10 OF CHICHE CONSTRUCTION

Phase 11 of the bridge starts being considered from the time the movable formwork can be displaced to start casting lamella number 2, at this point this lamella after casting will be prestress, but it will be done as soon the concrete reaches a compressive strength not specify on the documents.

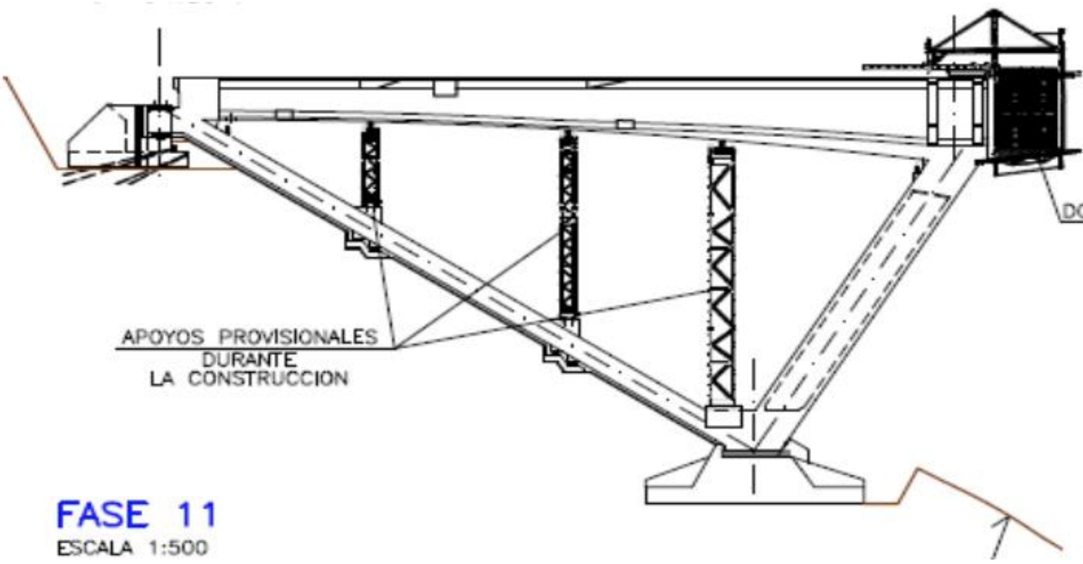


FIGURE 17: PHASE 11 OF CHICHE CONSTRUCTION

For phase 12 the previous phase will be repeated, however this will be done until they reach to lamella number 5, at this point they will start retiring the vertical formwork in the triangular frame, also the abutment will be fully casted, and the inverted supports will be placed, this will prevent a possible vertical displacement of the superstructure.

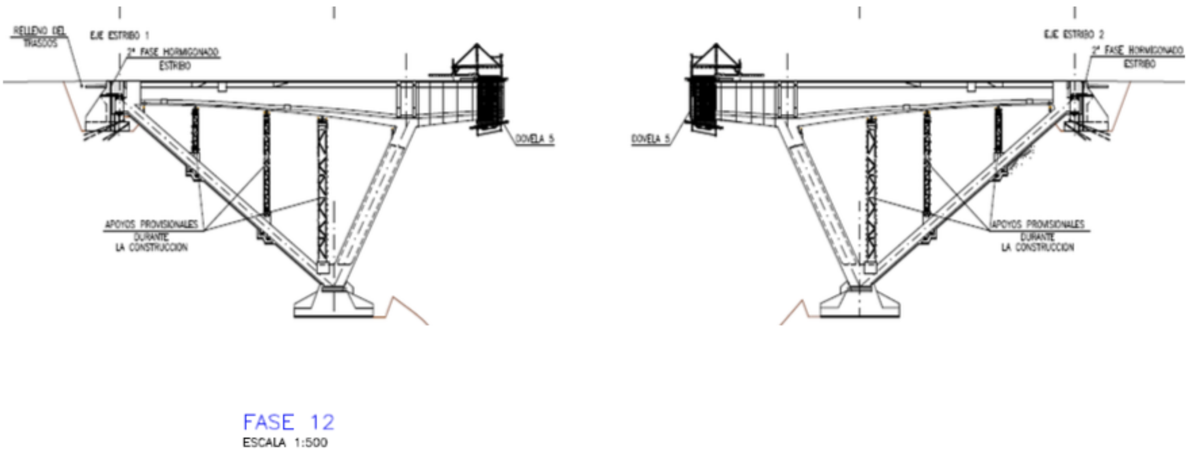


FIGURE 18: PHASE 12 OF CHICHE CONSTRUCTION

In phase 13, the bridge lamellas will be casted until the last and final connection lamella, one car of the movable scaffolding will be retired and it will be casted as connection. It is important to point out that at this point, in Quito an earthquake of magnitude 5.1 in the Richer scale occurred. The final lamella was not casted, and the seismic supports were not in function at the time, reason why it's considered the event occurred in the most critical phase of construction, according to MSc. Romo after an inspection of the bridge no damage was reported in the bridge. Finally, the connection lamella will be casted and the post tension cables will be tensed, this way the superstructure will start acting as in service, and the continuity of the beam is guaranteed. Finally, the bearings will be put to work and earthquake seismicity prevention starts.

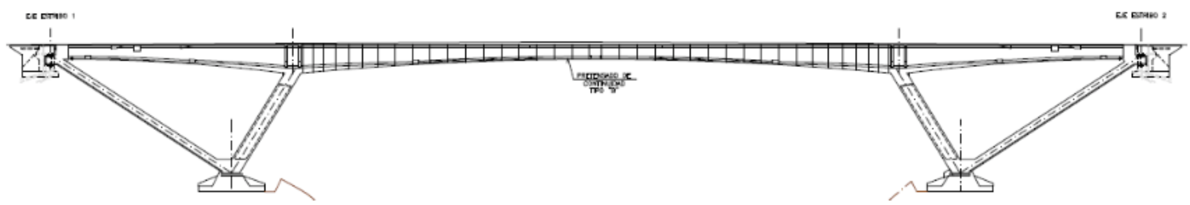


FIGURE 19: PHASE 13 OF CHICHE CONSTRUCTION

For the final phase of the construction the bridge will start to be provided with pavement, lamps, paint and handrails. It the terrain topography, a final protection on the upper layer of the soil is placed.

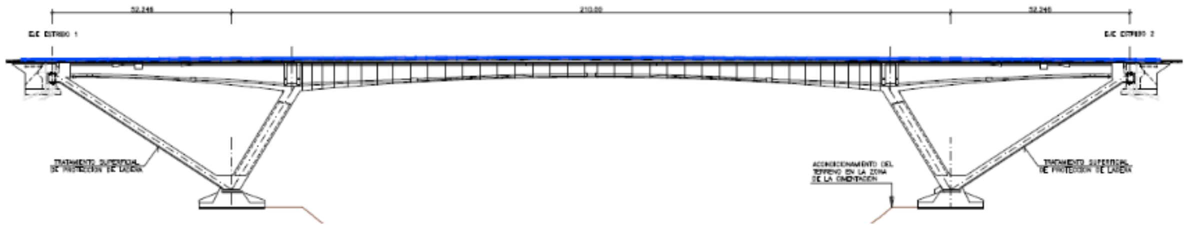


FIGURE 20: PHASE 14 OF CHICHE CONSTRUCTION

After the completing the phases in both bridges, the bridge can start functioning for the live loads.

Construction Alternatives

As we could see on the Chiche bridge, construction goes in hand between technology and different difficulties that make the design a different challenge on each project. It is known that each of them will be completely different than previous ones, due to the geography, topography, local resources, economy, work labor, and many other factors that affects each construction site. However, in bridges we can consider that they have certain guidelines that have been proof during many years to give initial steps of which type of bridge should be used for the design.

Classification of Bridges

First, we need to clarify that bridges can be categorized by different characteristic like due to the span, type of material, type of cast, etc. (2017) Each of them can be added to describe a bridge fully, however the most important ones for the purposes of this thesis will be described next

According to the materials.

- Timber
- Concrete
- Stone
- Reinforced Concrete
- Composite
- Steel
- Aluminum
- Prestress concrete

According to the form of the bridge.

- Arch
- Slab
- Beam
- Truss
- Cable Stayed.

According to inter-span relationships.

- Cantilever
- Simply supported
- Continuous.

Bridge design selection.

These three classifications mentioned above are the most known in bridges and the ones that will decide on the final price of the project to be developed. However, as it was said before the combination of these three main classifications can derivate in an appropriate bridge design. We need to consider that an investment in a structure like this is not easy to do. Reasons why, having all the details of the future functionality of it are necessary.

Step number one it should always know the area where the bridge will be placed. In the case of the Chiche canyon we can see that we should consider a span of 150 meters maximum length. As we can see in the figure 21, the canyon horizontally has a drop of terrain that can be manageable up to 90 meters on each side. At that point the curve lines of the topography tend to get closer very quick, meaning that the angle is significant, leaving a middle span of approximately of 160 meters, with a height of 135 meters.

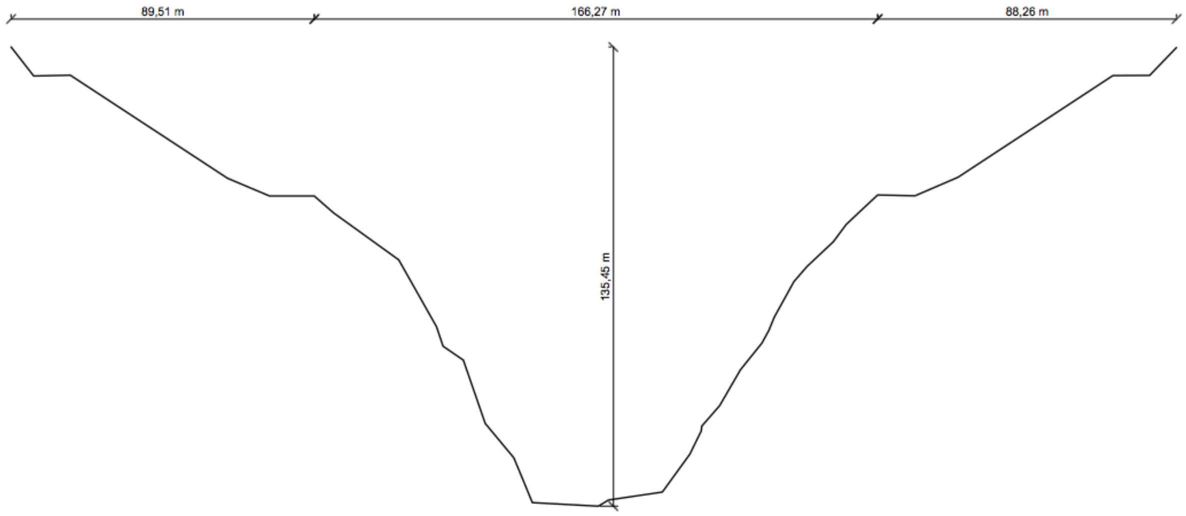


FIGURE 21: CHICHE BRIDGE TERRAIN TOPOGRAPHY

Once we have the maximum span we can reference to some data of previous constructions, we can see that they exist suggestions of the type of bridge to be placed due to the length of the span as we can see in the next figure 22. (2012) This is what we can consider the in-service design suitable type of bridge.

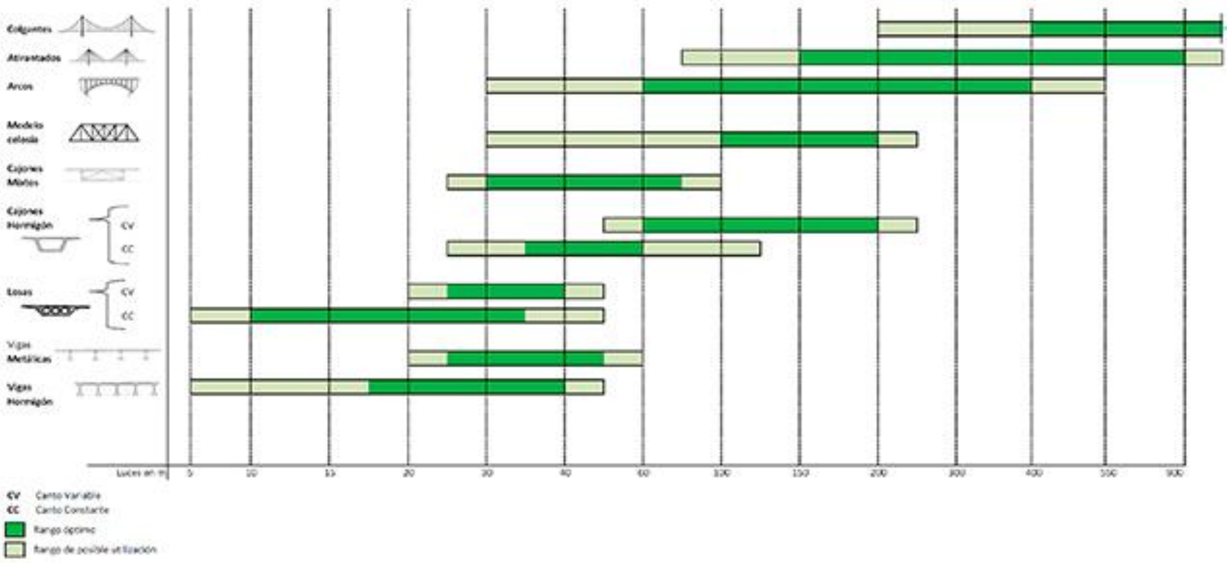


FIGURE 22: TYPE OF STRUCTURE VS LENGHT OF SPAN

It’s important to notice that many options of charts can be found with different suggestions, for example on figure 23 we have the same comparison from a different source. However, we can see that in both cases the suggestions are similar.

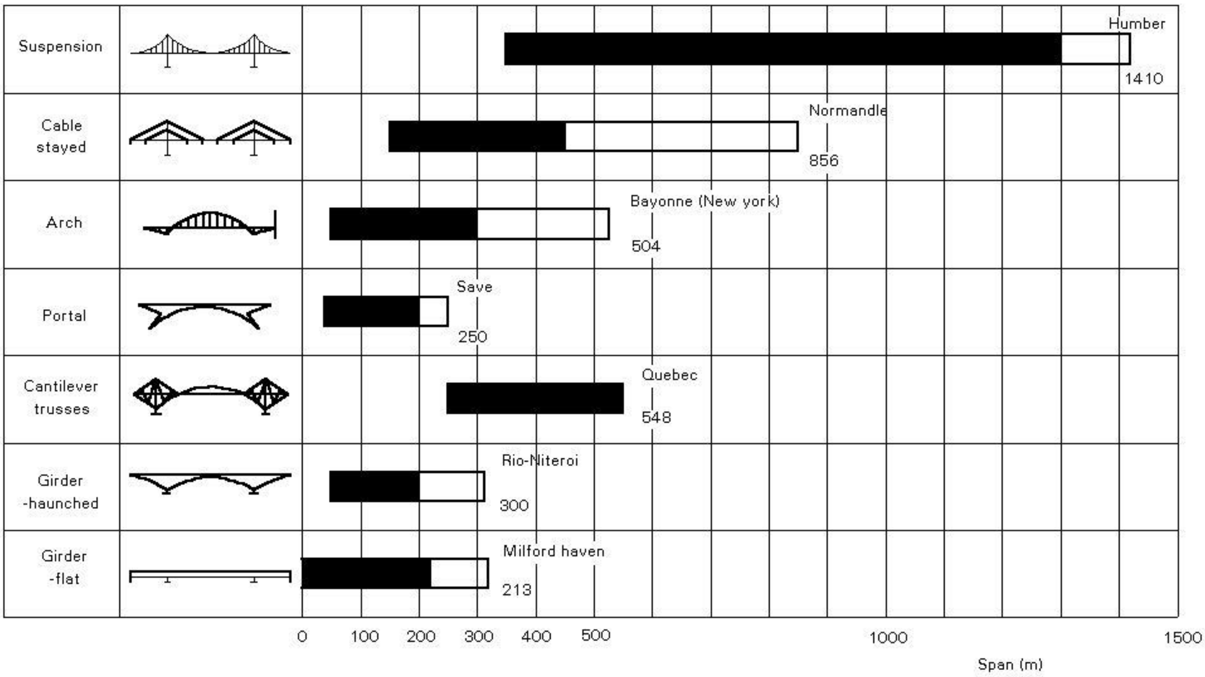


FIGURE 23: TYPE OF STRUCTURE ALTERNATIVE VS LENGHT OF SPAN

The second important design we need to make is the construction design, that´s were we reference to figure 24. It provides construction alternatives suitable for certain span lengths.

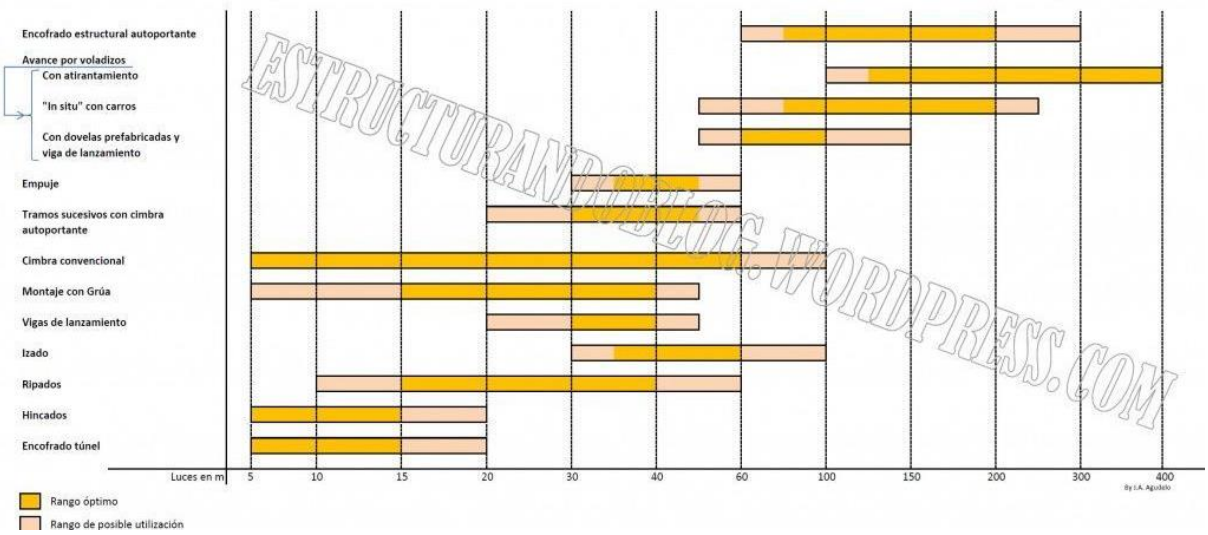


FIGURE 24: CONSTRUCTION PROCESSES VS LENGHT OF SPAN

The Chiche bridge that is on service was a combination of all these charts. It was constructed with a unbalanced cantilever method in the middle span, with movable scaffolding. The material was prestress concrete suitable with the design construction method, and in the triangular frame it´s a self-supported framework. The superstructure was a box girder with different height of lamellas, or also called hunched beam.

However, this may not be the only option of it, the combinations of different construction methods with bridges types and materials could be different. Two alternatives that will be presented as a possible solution for the Chiche Canyon are:

1. Arch Bridge.
2. Two pile beam bridge, with cantilever method construction technology, cast in situ with movable framework.

Arch Bridges

The arch bridges are a combination of embedment a superstructure in an arch form. The basic principle of it is to distribute the load not in a vertical way, but to transfer the loads in a conveyed way to the supports. The primary loads that the arch bridge carries are compression only; most of the time tension forces are neglected. As we can see on figure 25 the main compression on the arch goes through it towards the supports. (2013)

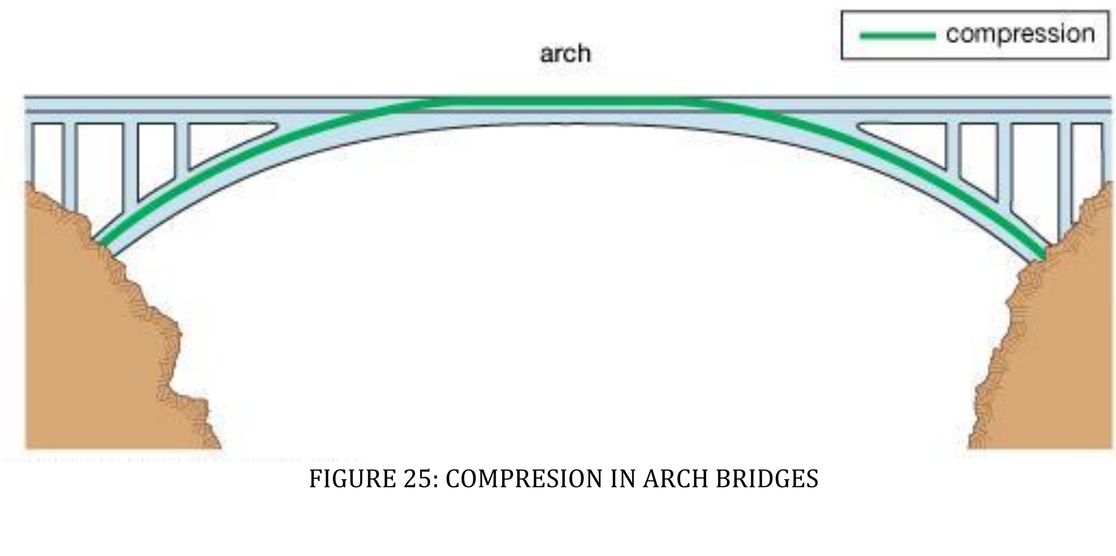


FIGURE 25: COMPRESION IN ARCH BRIDGES

The arch bridges can be divided in two main parts according to the superstructure shape, the first one is the deck arch and the characteristic is that this bridge will have the superstructure under the service area. And the second option is through arch, where the superstructure will be above the service area, the cross section of the bridge at ground level of service area will show the arch on top of it. (2013).

According to Safar (2015) the deck arch will be more convenient for bridges that will be placed in deep valleys, however it needs good geological conditions on soil to support the vertical and horizontal forces that will be present in the bridge after service. In the case of the through arch or lower deck arch, this is a structure that should be placed in flat terrain or across rivers.

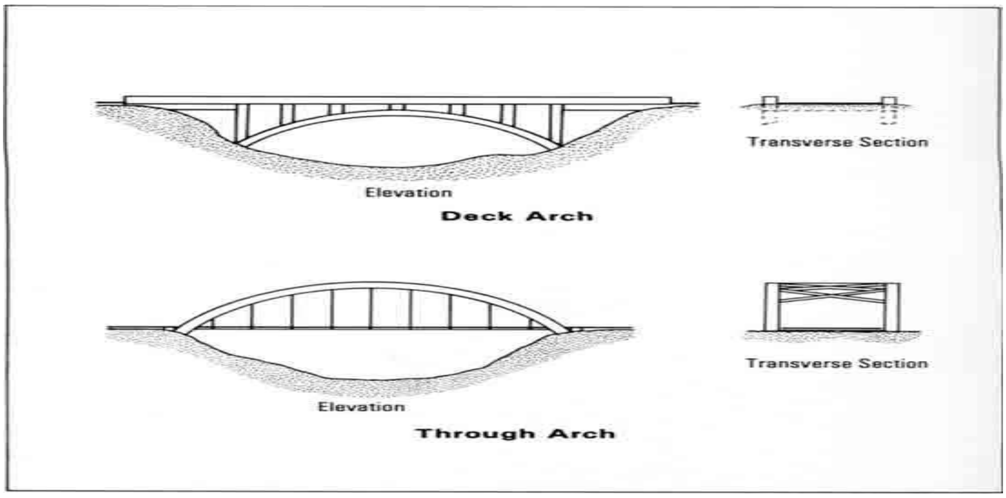


FIGURE 26: ARCH TYPES BRIDGES

The type of supports in the arch can also divide these structures. They are:

1. Fixed arch
2. Two hinged arches, represented on both supports
3. Three hinged arches with a hinge on each support and one in the middle.

The number of hinges will determine the amount of indetermination on the structure. (2015).

Its established by Safar that arches bridges should define three basic parameters before design. They are:

- Span length of the arch.
- F, which is the rise from the supports to the top of the middle of the arch in perpendicular way.
- f/L should be between 1/3 to 1/6 ratio, although the limit is between 1/1 and 1/15.

A fourth-degree parabola defines the ideal shape of the arch; however, a second-degree parabola can be used to. For the cross sections its established that if the type of arch is upper deck, a solid rectangular cross section can be used, however if the span length of the arch is considerable in distance, the cross section needs to be box girders or any other section that will lighten up the structure. (2015).

The deck arch is supported by other element called struts, this one connects the arch with the superstructure, to distribute the compression loads to the arch and finally to the supports. These elements are usually designed as columns; the separation between them will depend on the cross section of the arch and the arrangement of the deck. Many times, this separation may define the construction method that will be used on the structure. The main members of the arch bridge are presented in figure 27.

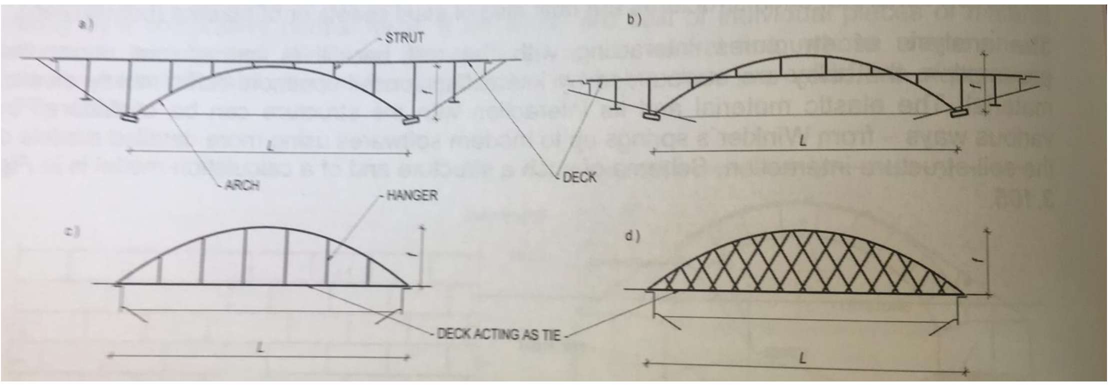


FIGURE 27: PRINCIPAL MEMBERS ON AN ARCH BRIDGE

Incremental launching method for the deck construction and cast in situ supported by temporary stayed cables hold to pylons are usually used as construction technology, we can see on figures 28 and 29 how they should be placed. Any material can make the deck, usually concrete but steel is also used. Composite structures are usually used when the bridge span is large. (2015)

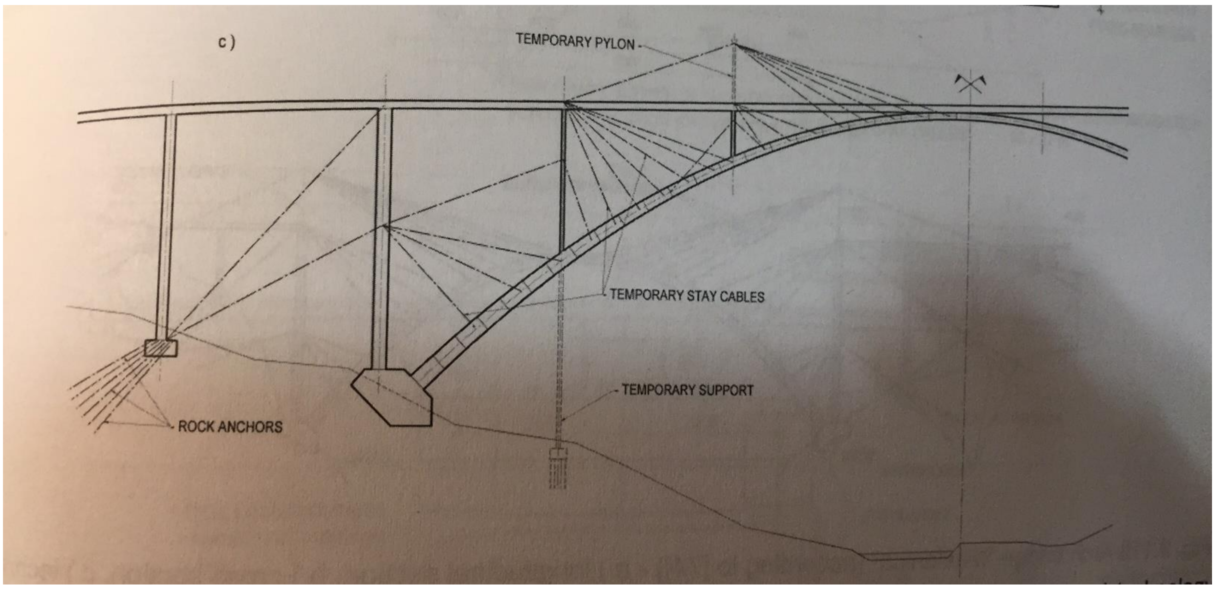


FIGURE 28: CONSTRUCTION TECHNOLOGY WITH TEMPORARY PILES AND STAYED CABLES

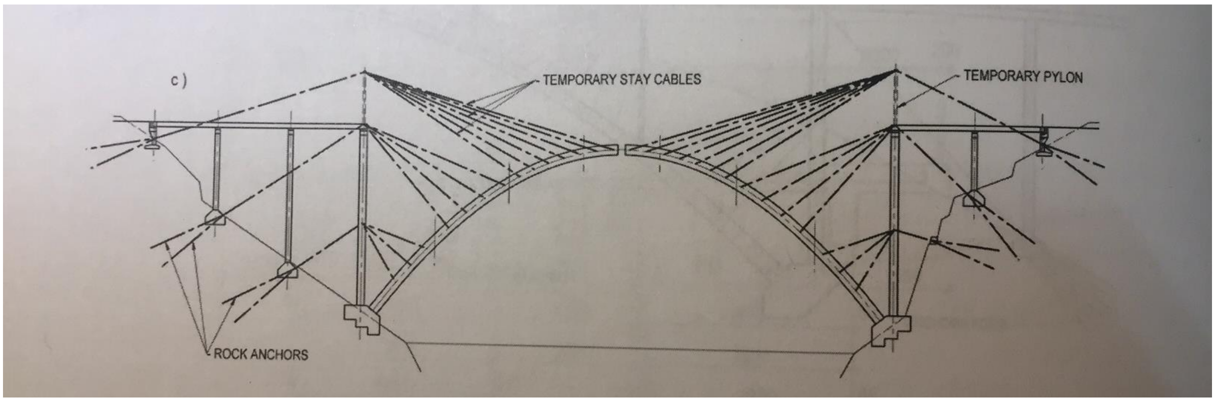


FIGURE 29: CONSTRUCTION TECHNOLOGY CONSTRUCTION FROM BOTH ENDS

For the case of the Chiche canyon, a representation of how the bridge will be placed is shown in figure 30. The basic parameters calculated are shown next:

$$\text{L of arch} = 166.27\ \text{m}$$

$$f_1 = \frac{L}{3} = \frac{166.27}{3} = 55.42\ \text{m}$$

$$f_2 = \frac{L}{6} = \frac{166.27}{6} = 27.71\ \text{m}$$

$$f_{final} = 35\ \text{m}$$

The height of the arch,

$$\frac{L}{80} \geq h \geq \frac{L}{100}$$

$$\frac{166.27}{80} \geq h \geq \frac{166.27}{100}$$

$$2.078 \geq h \geq 1.66$$

$$h = 2\ \text{m}$$

For predesign purposes it will be assumed a second-degree arch shape and no height difference between the cross sections of the deck.

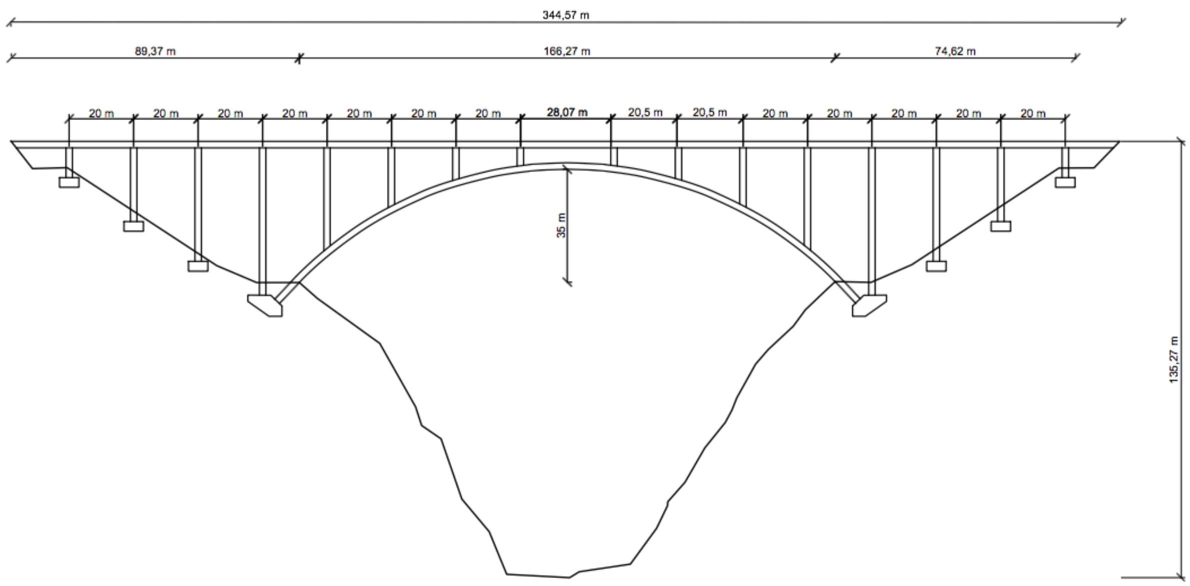


FIGURE 30: REPRESENTATION OF DECK ARCH BRIDGE IN CHICHE CANYON PROPOSAL.

Two Pile Beam Bridges

The beam structures in bridges are the most common ones around the world, they are easy to build and can be done in different materials like reinforced concrete, prestress concrete, steel, etc. Usually the type of material and the cross section of the deck beam used might limit the maximum span. The number of piles is decision of the designer. Usually for short spans, which are decided commonly by the number of piles, reinforced concrete can be used, for spans in a medium range prestress concrete is used to control self-weight of the beam, since the cross section is smaller than the reinforced concrete, and for longer spans steel might be the best material. A variety of different beam bridges are presented on figure 31.

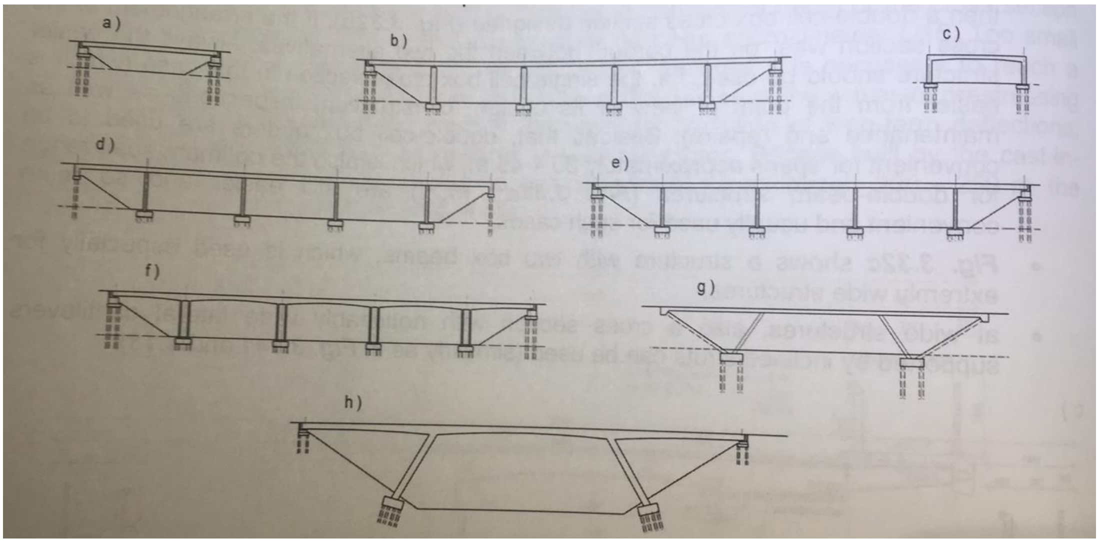


FIGURE 31: BEAM BRIDGES STRUCTURES

The beam bridge can be designed to work as simply supported beams or continuous beams. Each type has its advantages and disadvantages. The designer should pick the most suitable for the project. The main difference is established on the deflections in the middle span, continuous beams have smaller deflections, however the negative moments in the supports will be present.

According to Safar the beam structures are composed by three main members:

1. Main beams, which transmits the load effects to the supports.
2. Deck, which distribute the load effects to the main beam.
3. Cross beams, they will increase the rigidity of the main beams in the transversal direction. (2015)

The cross section of the main beams will depend on the type of material use mainly, however for long spans where the selfweight of the structure might be the dominant load, box girders are use. In case of a cross section that is wide, sometimes, double box girders can be considered. For predesign is common to calculate the height of the cross section with the next formulas, in case of no middle supports is L/35 should be used, if an intermediate support is available the height can be calculated with a relationship of L/16. (2015)

For our project at Chiche canyon, a representation of a two-pile beam bridge is shown in figure 32, it was chosen a two-pile beam due to the complications of the terrain to provide more members. Its suggested that it will be used prestress concrete due to the properties such as avoiding tensile stresses, ending up in a smaller cross section height in the superstructure, the calculation should be done by each span, ruling the longest one in connection of two different spans. In our case we will have three spans.

In the case of three span bridges, Safar suggests that the spans connecting to the terrain should be an approximate of 65% to 80% of the middle span. That way the moments can be lowered in the supports and the critical points in the middle spans. In our case the two lengths of span we have will have the next relationship:

$$0.7 * L_2 = L_1$$

$$0.7 * 143.86 = 100 \text{ m}$$

So,

$$L_1 = 100 \text{ m}$$

$$L_2 = 143.86 \text{ m}$$

The height of the cross section in the span L1, should be approximately,

$$h_{\text{cross section}} = \frac{L}{35} = \frac{100}{35} = 2.857 \text{ m}$$

In the middle span in the piers, the height of the cross section should be,

$$h_{\text{cross section}} = \frac{L}{35} = \frac{143.86}{35} = 4.110 \text{ m}$$

In the middle span of L2, the height should be,

$$h_{\text{cross section}} = \frac{L}{16} = \frac{143.86}{16} = 8.991 \text{ m}$$

The final predesign model will look like figure 32.

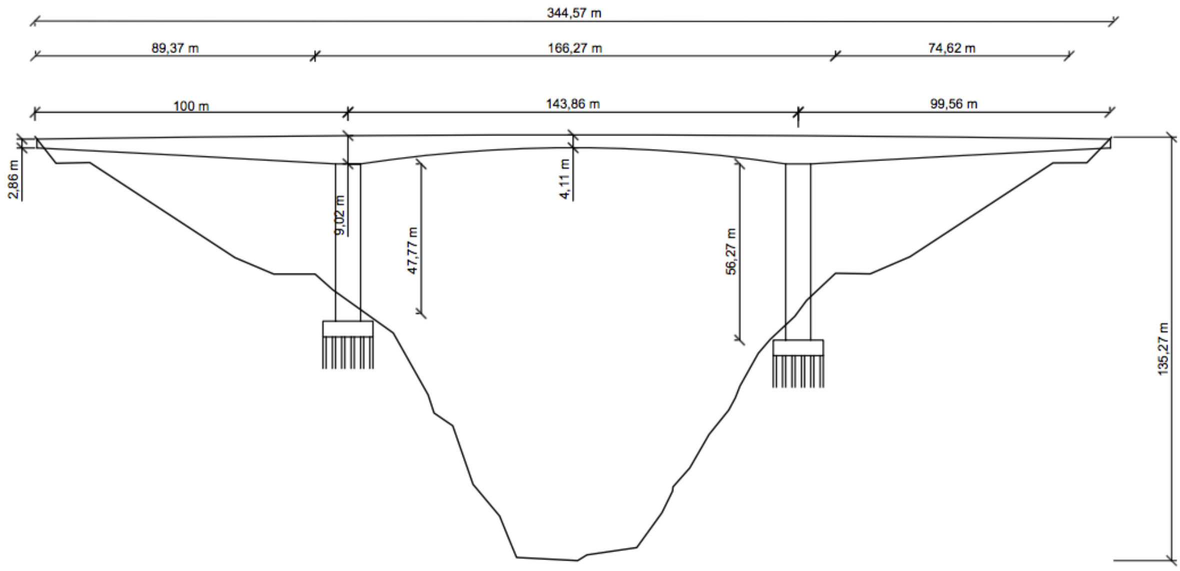


FIGURE 32: REPRESENTATION OF A TWO PILE BEAM BRIDGE IN CHICHE CANYON

Free Cantilever Construction Method

This construction technology is normally used when the topography of the site is irregular and you cannot place static formwork to support the casting of the superstructure. This is a perfect construction method when you have to piers to support a big span bridge, reason why this is the best choice for our two-pile beam bridge pre design.

The process of construction of this technology starts from the piles, once they are finished, the superstructure will be casted in situ symmetrically by lamellas one on each side of the column, balancing the moments created by each side and maintaining the equilibrium in the main pile. This way as exposed before the terrain, the topography and any other ground conditions will not affect at all the construction of the superstructures. According to Safar this construction method is used in spans up to 250 meters. (2015). Figure 33 represents the construction system.

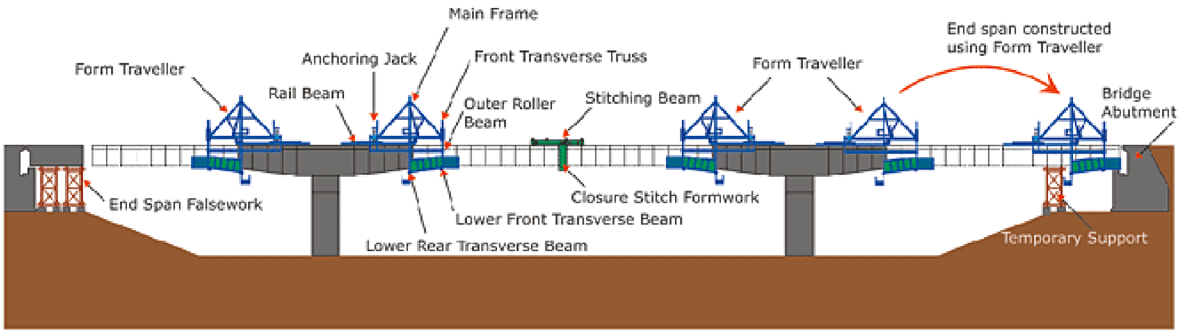


FIGURE 33: SCHEMA OF FREE CANTILEVER METHOD CONSTRUCTION TECHNOLOGY

In this technology is usually used what are called continuity tendons, this are used to hold each construction stage and create continuity between the casted lamellas. A construction stage is considered when the movable scaffolding is retired from the paired lamellas. The movable scaffolding is an element that supports itself in the previous casted lamella and helps cast the next lamellas.

The negative moments during construction stages are created by the selfweight of the superstructure, wind loads, construction loads, and other loads that depend of the location of the project. All this loads cause tensile stresses in the upper fibers, reason why the use of prestress tendons is the best solution, usually this are unbounded, which means the tendons can be cut off after the connection of the final lamella, where no further effect on the superstructure can be seen. (2015). It has to be using a tendon by each pair of lamellas or lamella as seen on figure 34.

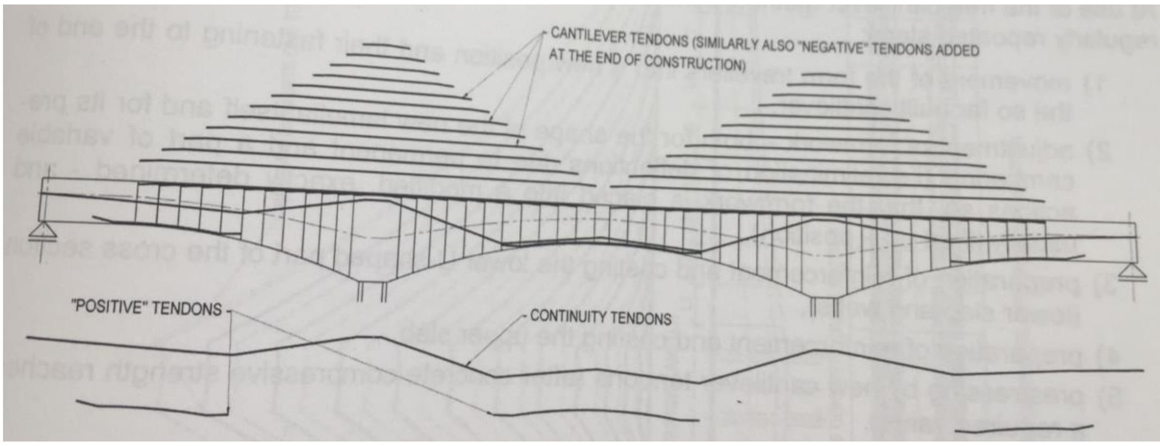


FIGURE 34: SCHEMA OF CONTINUITY TENDONS

The cantilever method is based on repetitive steps, this are:

1. Move the form travelers to the position where a cantilever can be casted.
2. Adjust the formwork to the desire shape.
3. Installation of reinforcement and casting of the U shape
4. Prepare the reinforcement for the slab and cast it.
5. Prestress the new lamella.

Before the casting of the closing lamella we find the superstructure in the most critical phase, after the last lamella has been casted and the appropriate prestress has been tensed, the superstructure has a continuity and it starts acting as a bridge in service. The unbounded tendons can be cut off if necessary.

Cross Sections

According to the original project, the cross section is shown in figure 35, as we can see is a representation of the minimum cross section of the box girder that goes from 4.2 meters in the middle span up to 8.2 meters in the supports. These values do not match the suggestion made by Safar. In case we use Safar formula for the Span of 210 meters, which is the longest one, we will obtain a value of 6 meters height and 13.125 meter on the support.

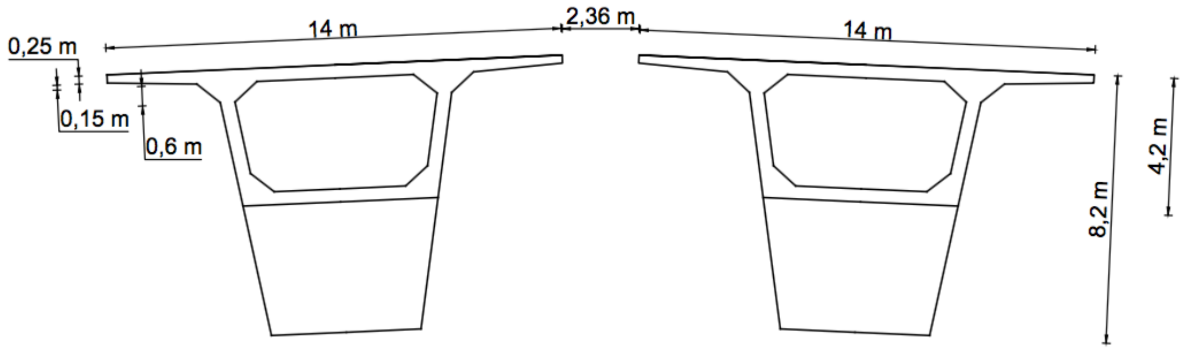


FIGURE 35: CROSS SECTION OF CHICHE BRIDGE

According to Safar solution and the one used in the two alternatives shown, the arch bridge and the beam with piles, the cross section of the bridge should be 4.11 in the middle span and 8.99 in the supports, we need to take in consideration that the spans of it are different from the Chiche bridge solution.

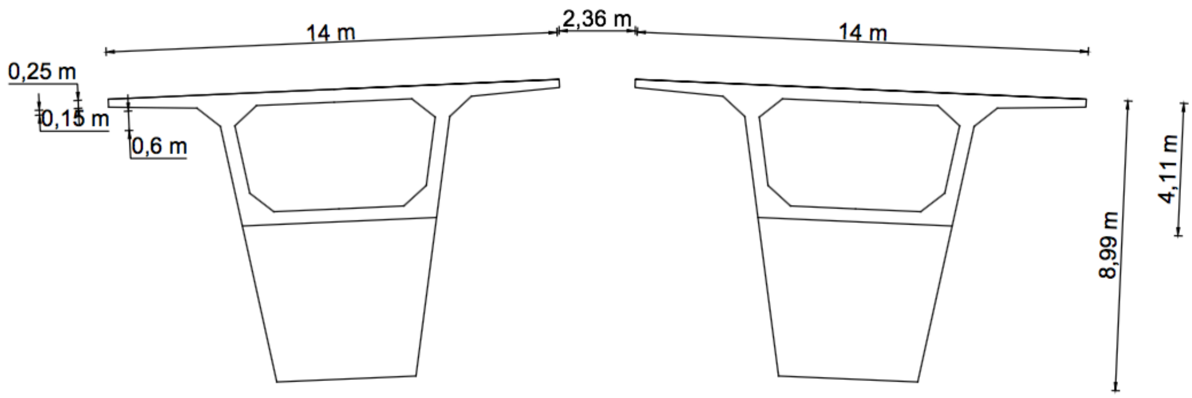


FIGURE 36: CROSS SECTION PROPOSED BY SAFAR FORMULAS

In both solutions as we can see, we have a slope of 2.5% that will help to discharge the rain water and a separation of 2.36 meters between the two main superstructures, that way we can consider two bridges instead of one, each of them will held three lanes in each direction.

Final Design Selection

After presenting the two options and explaining the process of construction of the real solution for the Chiche Canyon, the smartest solution presented is the original design, this solution provides a intelligent design where economically and construction wise is the most suitable option for the problem in front. The use of frame structures with a triangular frame that hold the big moments created during the construction phase, due to the cantilever created by the superstructure, and a relatively small cross section, that should be investigated more in depth, with selfweight and crack control due to the prestress makes the original method suitable for studying it.

We don't have to leave behind the fact that the other options presented are not good; in a matter of fact they are possible solutions. However, they are more expensive due to the technology needed. We need to consider also the fact that the canyon has a big slope in the terrain, where the other options may be unsuitable due to the difficulty of the construction of the main piles and foundations needed. The fact of having smaller spans are a great advantage due to the moment we will have, however as a predesign we know that the original option presents cross section suitable for construction.

Objectives

Main.

- Provide a design of the original bridge of the Chiche canyon.

Secondary.

- Provide alternatives of construction for the bridge in Quito-Ecuador "Rio Chiche"
- Provide alternatives of design for the bridge in Quito-Ecuador "Rio Chiche".
- Calculation of construction stages.

CHICHE DESIGN DEVELOPENT

Design approach

After the decision of the final design of the bridge type to be used, the approach to be developed will be the use of a software Scia Engineering, the calculations will be held by hand at the beginning of the project, this way I can be sure that the data imputed in the program will be no more than 5% different from the hand calculations, data obtained by the program is trustworthy with this approach. At the same time this hand calculations will be inputted later on the program for a better control of the result we look for, this will mainly happen on the construction stages section.

Beam Slab.

The beam slab is the top part of the bridge, it will be developed by cantilever segmentation. This part consist of three main beams, two of them of 70 meters each, which create the triangle frame stability member and the center span of 210 meters, which challenges the bridge on its construction phase, as stated before this will be developed by cantilever segments, creating a total of 14 lamellas of 7.5 meters for this project, as stated in the figure 37, it also shows the design of the bridge, however we can see that the 1st element has a haunch from 5.5 meters until 12.65 meters. The bridge design states that supports of the beam should be design with a height of 12.65 meters, the figure shows the height of each lamella on the left and the right side of it. We can call figure 37 the base of the Chiche design bridge.

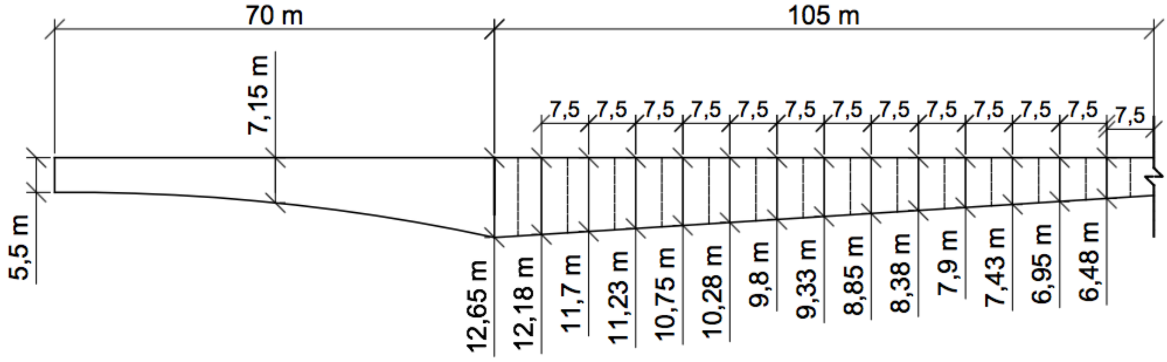


FIGURE 37: CHICHE DESIGN BASE

However, due to the problematic of imputing the data in the program, the final approach to the bridge will be held as in figure 38. As we can see we will maintain the hunched beams on each section of the bridge. The distances will be kept the same. The triangular frames will have different angles than the original ones and different lengths.

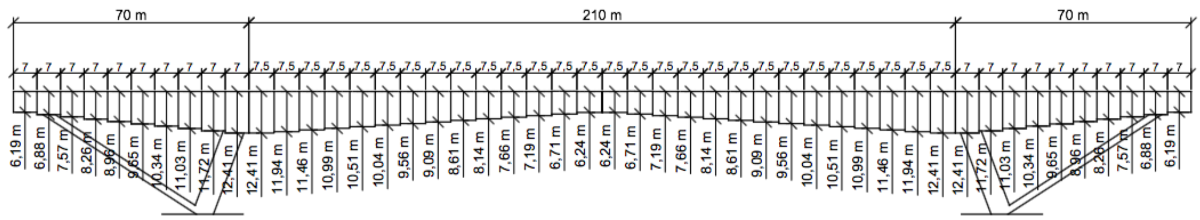


FIGURE 38: CHICHE DESIGN PROPOSITION FOR SCIA ENGINEERING

With this design proposition the bridge will have the 350 meters that will solve the problem of the canyon depression presented.

Triangular Frame Structure.

As stated previously this frame structure will help to hold the moments created during the construction phase of the free segmental cantilever method unbalanced, this is the smartest way to design the bridge taking in consideration the terrain and construction difficulties that can be present during the time of development of the bridge. This triangular cell will be held by two elements. The first element is a 2x2 solid concrete column that will be supported throughout the terrain of the canyon, the total length will be of 67.04 meters, and will create an angle of 33 degrees with the primary beam slab, the second element will be a 6x8 solid concrete column, this element will have a length of 39.02 meters and will create a 69-degree angle with the primary beam. These two elements will create a 78-degree angle between them. Refer to figure 39 for the final design proposed.

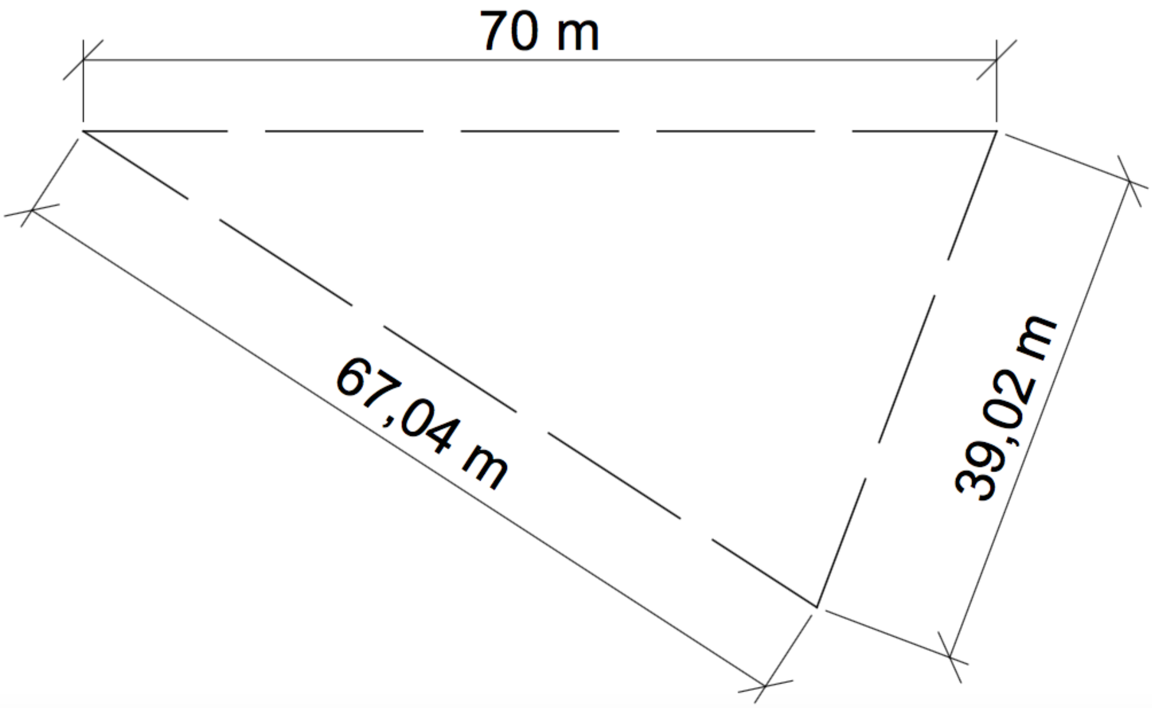


FIGURE 39: FRAME SECTION LEFT SIDE OF BRIDGE

Chiche Final design proposal for Scia.

The design proposal holds a problem with the data that will be imputed on the Scia engineering program due to the frame structure, the easiest way to calculate the structural model is by having the center of gravity of each of the cross sections, and at that point imputing the loads for the calculations, however we have hunched beams on the bridge, creating a problem, reason why it has made the decision to input a same line on the beam slab on top of each of the cross sections, reason why the model is as shown on figure 38. However, in the triangular frame section of the bridge the two elements will keep the regular center of gravity, this will be corrected further on once obtain the calculation of the moments on the connections of this centers of gravity's, the final model is shown on figure 40. We will have lamellas on each part of the beam; the triangular frame will have lamellas of 7 meters, while the middle beam will have 7.5 meters lamellas for design purposes.

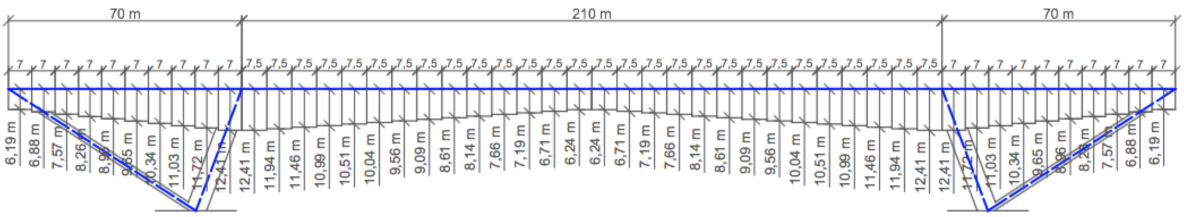


FIGURE 40: STRUCTURAL MODEL WITH CENTER OF GRAVITY

Dimensions, Cross-Sections, Geometry.

Cross-Section Approach.

The bridge cross sections can be divided in two, we will refer to them as D1.x and Dx, where x represents the lamella number on each side of the bridge. The entire bridge beams will be considered hunched, the cross section is a box girder, with a 14-meter slab width to assure 3 lanes on the bridge.

The middle span of 210 meter or lamellas Dx will have cross sections that will vary from 12.65 meters on the supports, until 6.24 in the middle for the design as seen on figure 41. This is planned to be casted under the free unbalanced cantilever method.

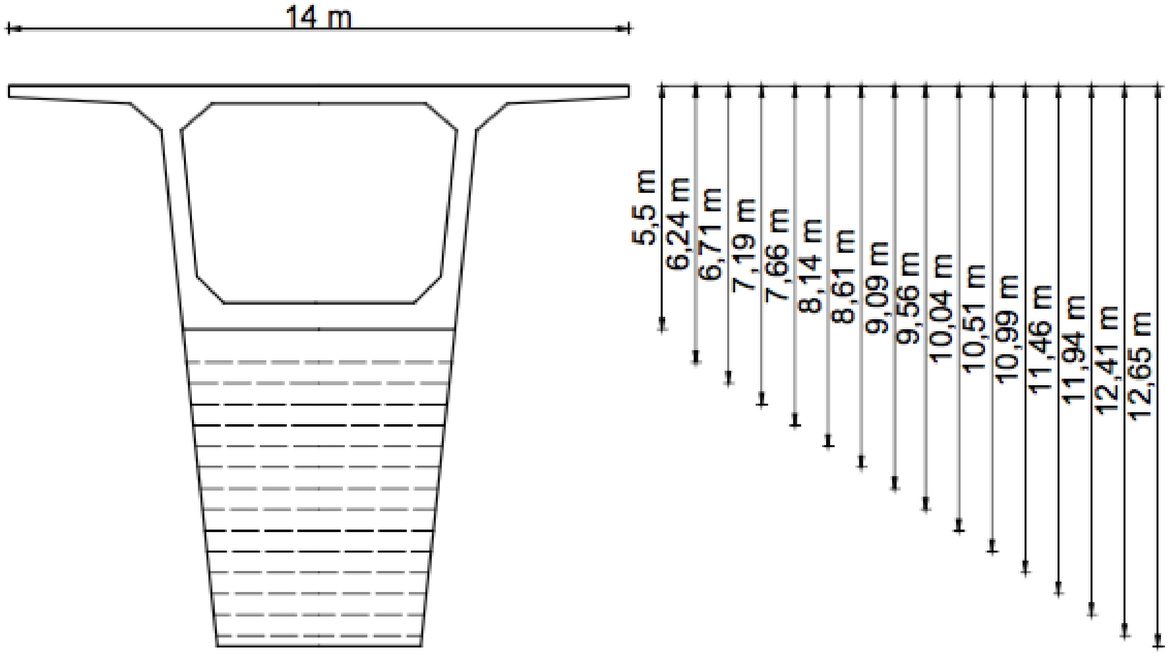


FIGURE 41: CROSS SECTIONS TO BE CONSIDERED FOR THE DESIGN FOR THE DOVELS DX

For the lamellas marked as D1.x, which correspond to the 70-meter span, we will have 10 lamellas of 7 meters for the design, they will be casted with framework during the construction phase, they will have 7 meters width, a variable height creating a hunched beam. As we can see it varies from 6.19 meter until 12.41 meters for the design if we refer to figure 42. This cross-section height will be used on Scia. It's important to notice that in reality this beams will be casted as one, however, for the program we will divide them as lamellas to obtain better results.

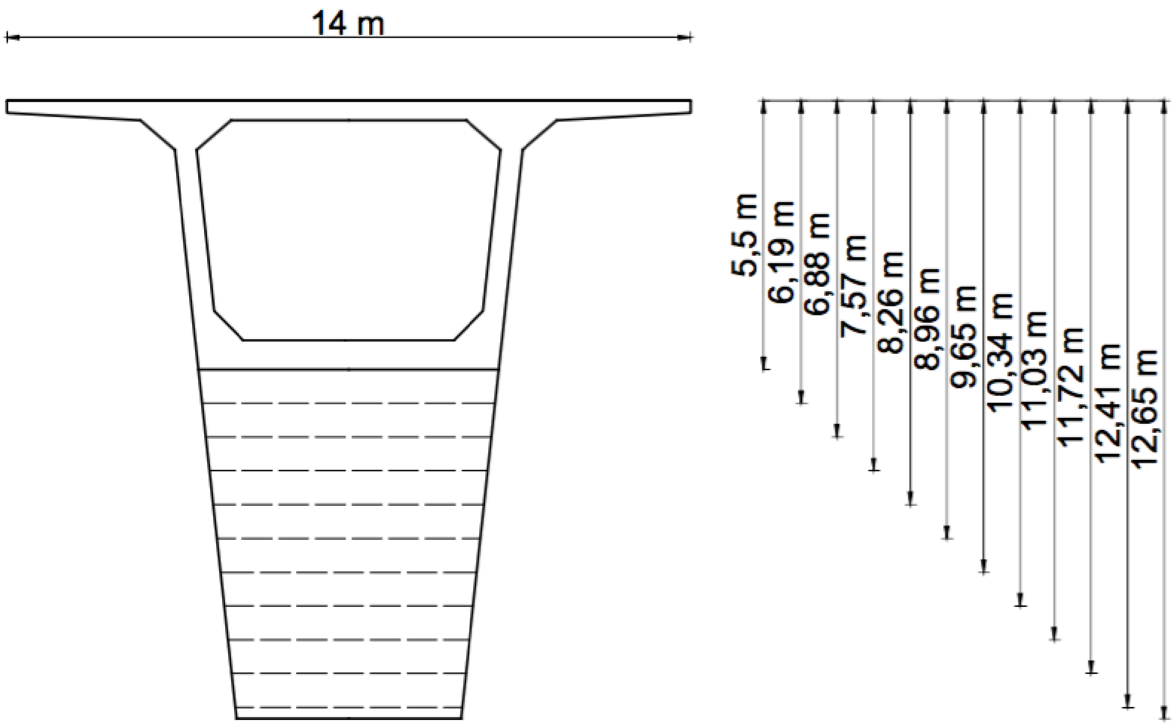


FIGURE 42: CROSS SECTIONS TO BE CONSIDERED FOR THE DESIGN FOR THE DOVELS D1.X

Summarizing the data obtained, we can refer ourselves to table 1, where it specifies the main heights of each part of the cross sections of the bridge.

	Length (mts)	Middle cross section height (mts)	Support cross section span (mts)
Span 1	70	7.15	12.65
Middle Span	210	6.00	12.65
Span 2	70	7.15	12.65

Tabla 1 Critical Heights of the Bridge Cross-section

Hunched Beam, span 70 meters.

This beam has a different height throughout the whole cross section as stated before; it's a prestress concrete element, casted with stationary framework. All the cross sections will be calculated by hand and by the computer programs to compare area, moment of inertia and center of gravity. The tables with the summary results are shown next for this part of the beam:

		Hand Calculations		
# Dovel	**H average (m)**	**Area (m^2)**	**Iy (m^4)**	**Y bar**
D1.1	6.19	14.66	86.782	3.555
D1.2	6.88	15.19	110.320	3.954
D1.3	7.57	15.72	136.938	4.353
D1.4	8.26	16.25	166.603	4.753
D1.5	8.96	16.78	200.016	5.159
D1.6	9.65	17.32	236.37	5.56
D1.7	10.34	17.85	276.09	5.96
D1.8	11.03	18.39	319.39	6.36
D1.9	11.72	19.02	370.21	6.72
D1.10	12.41	19.42	415.72	7.17

Tabla 2 HAND CALCULATION FOR THE CROSS-SECTIONS D1.X

		Computer Calculations		
# Dovel	**H average (m)**	**Area (m^2)**	**Iy (m^4)**	**Y bar**
D1.1	6.19	14.66	86.783	3.555
D1.2	6.88	15.19	110.320	3.954
D1.3	7.57	15.76	137.070	4.350
D1.4	8.26	16.25	166.710	4.752
D1.5	8.96	16.84	201.060	5.146
D1.6	9.65	17.36	237.500	5.545
D1.7	10.34	17.86	276.260	5.959
D1.8	11.03	18.39	319.390	6.356
D1.9	11.72	18.95	366.600	6.754
D1.10	12.41	19.48	416.770	7.152

Tabla 3 COMPUTER CALCULATIONS FOR THE CROSS SECTIONS D1.X

		%Error		
# Dovel	**H average (m)**	**Area (m^2)**	**Iy (m^4)**	**Y bar**
D1.1	6.19	-0.002%	0.001%	-0.009%
D1.2	6.88	0.002%	0.000%	0.003%
D1.3	7.57	0.212%	0.097%	-0.059%
D1.4	8.26	0.034%	0.064%	-0.026%
D1.5	8.96	0.300%	0.519%	-0.256%
D1.6	9.65	0.254%	0.477%	-0.239%
D1.7	10.34	0.037%	0.061%	0.021%
D1.8	11.03	0.000%	-0.001%	-0.007%
D1.9	11.72	-0.386%	-0.984%	0.470%

D1.10	12.41	0.324%	0.251%	-0.206%

Tabla 4 ERROR PORCENTAGE BETWEEN THE CALCULATIONS FOR THE CROSS-SECTIONS

The lamellas will be having the heights as established on table 5 in the computer program, we will use the values of the column lamella height at medium, values which will be used for the design approach.

Section	Dovel Height on left (mts)	Dovel height at medium (mts)
D1.1	5.50	6.19
D1.2	6.19	6.88
D1.3	6.88	7.57
D1.4	7.57	8.26
D1.5	8.26	8.96
D1.6	8.96	9.65
D1.7	9.65	10.34
D1.8	10.34	11.03
D1.9	11.03	11.72
D1.10	11.72	12.41

Tabla 5 DOVELS HEIGHT D1.X

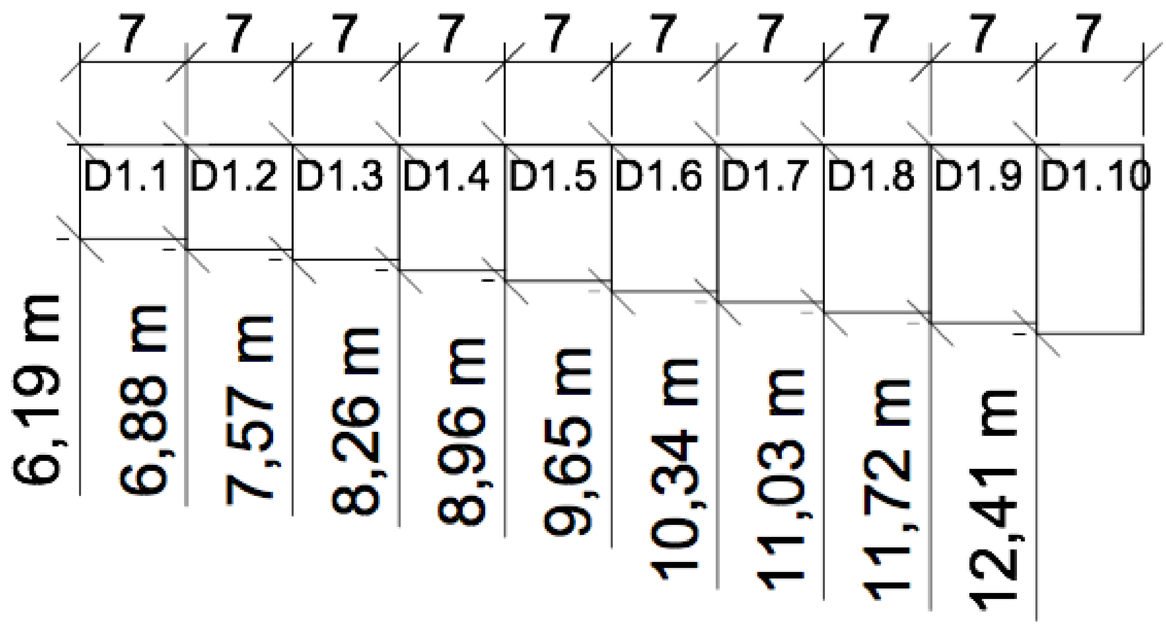


FIGURE 43: CROSS SECTIONS TO BE CONSIDERED FOR THE DESIGN FOR THE DOVELS D1.X

The procedure followed to obtain the data on this cross sections are shown in figure 44 and table 6 for reference, we picked a random cross section to show the procedure followed.

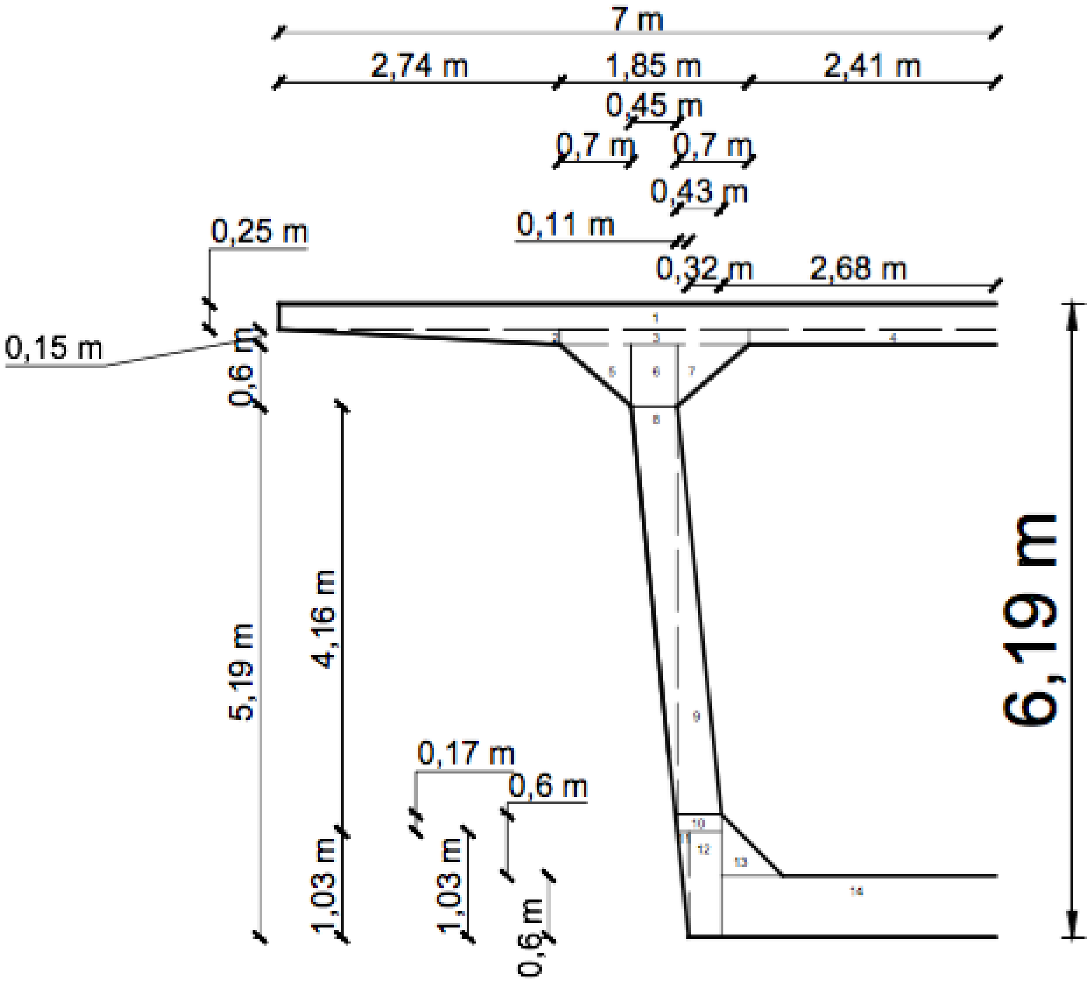


FIGURE 44: CROSS SECTIONS DRAWING FOR CALCULATION OF AREA, INERTIA AND Y BAR

Number	Shape	Base (m)	Height (m)	Area (m^2)	Y bar (m)	YA	Distance from symmetry	Iy	Iyy
1	**Rectangle**	7.00	0.25	1.750	6.065	10.614	-2.510	0.009	11.032
2	**Triangle**	2.74	0.15	0.206	5.890	1.210	-2.335	0.000	1.120
3	**Rectangle**	1.85	0.15	0.278	5.865	1.628	-2.310	0.001	1.481
4	**Rectangle**	2.41	0.15	0.362	5.865	2.120	-2.310	0.001	1.929
5	**Triangle**	0.70	0.60	0.210	5.590	1.174	-2.035	0.004	0.874
6	**Rectangle**	0.45	0.60	0.270	5.490	1.482	-1.935	0.008	1.019
7	**Triangle**	0.70	0.60	0.210	5.590	1.174	-2.035	0.004	0.874

8	**Triangle**	0.45	4.16	0.936	3.803	3.560	-0.248	0.900	0.957
9	**Triangle**	0.43	3.99	0.861	2.530	2.178	1.025	0.762	1.667
10	**Rectangle**	0.43	0.17	0.073	1.115	0.082	2.440	0.000	0.437
11	**Triangle**	0.11	1.03	0.057	0.687	0.039	2.869	0.003	0.476
12	**Rectangle**	0.32	1.03	0.330	0.515	0.170	3.040	0.029	3.078
13	**Triangle**	0.60	0.60	0.180	0.800	0.144	2.755	0.004	1.370
14	**Rectangle**	2.68	0.60	1.607	0.300	0.482	3.255	0.048	17.079
				7.329		**26.057**			**43.391**

Tabla 6 HAND CALCULATION FOR A RANDOM CROSS-SECTION

<u>Beam 2x2 solid concrete-Tie.</u>

This element is a 2x2 solid concrete C35/40. It will be supported on the soil of the canyon. This element is placed due to the probability of having big reactions that need to be absorbed during the construction process. This element more likely will be acting as a tie, reason why we will refer to it after this name. After the calculations we will define the function of this. The cross section is shown on figure 45.

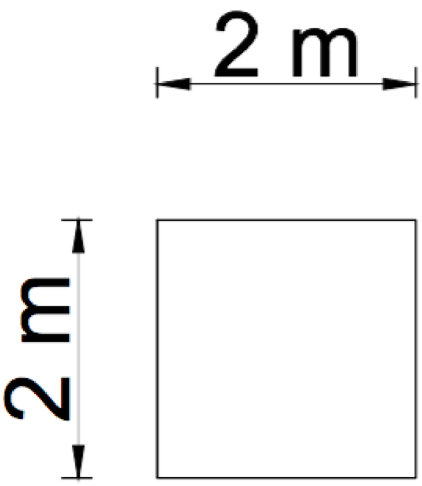


FIGURE 45: CROSS SECTIONS 2X2

The hand calculations will be calculated by the next formulas due to the simplicity of the shape of the section

$$I_{yy} = \frac{1}{12}(2 * 2^3) = 1.333 \text{ m}^4$$

$$A = (2^2) = 4 \text{ m}^2$$

$$y = \frac{2}{2} = 1 \text{ m}$$

Column 6x4 meter-Strut.

This element is considered as a column, reason why we will name it a Strut, it basic function is to translate the compressive forces of the bridge beam to the soil. Since it works under compression, it receives the name of Strut element. The dimension is 6x4 meters for the design; this element will be calculated as reinforced concrete C35/45 and following the specifications of the Eurocode. Figure 46 reflects the cross section.

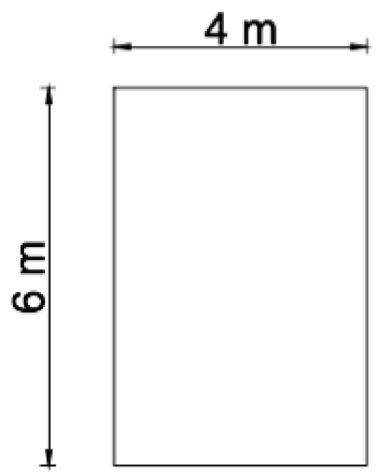


FIGURE 46: CROSS SECTIONS HOLLOW COLUMN 6X4 METERS

Due to the simplicity of the calculations, the basic information is calculated with the same formulas as the Tie element.

$$I_{yy} = \frac{1}{12}(6 * 8^3) = 256 \text{ m}^4$$

$$A = (6 * 8) = 48 \text{ m}^2$$

$$y = \frac{8}{2} = 4 \text{ m}$$

Haunched Beam, 210 meters span.

This beam as it is mention is a hunched; this element will be composed of 14 lamellas of 7.5 meters each. All the lamella will be calculated with concrete C35/45, and will be consider in prestress concrete. Figure 47 will reflect the convention of the lamellas and their assigned numbers for this design.

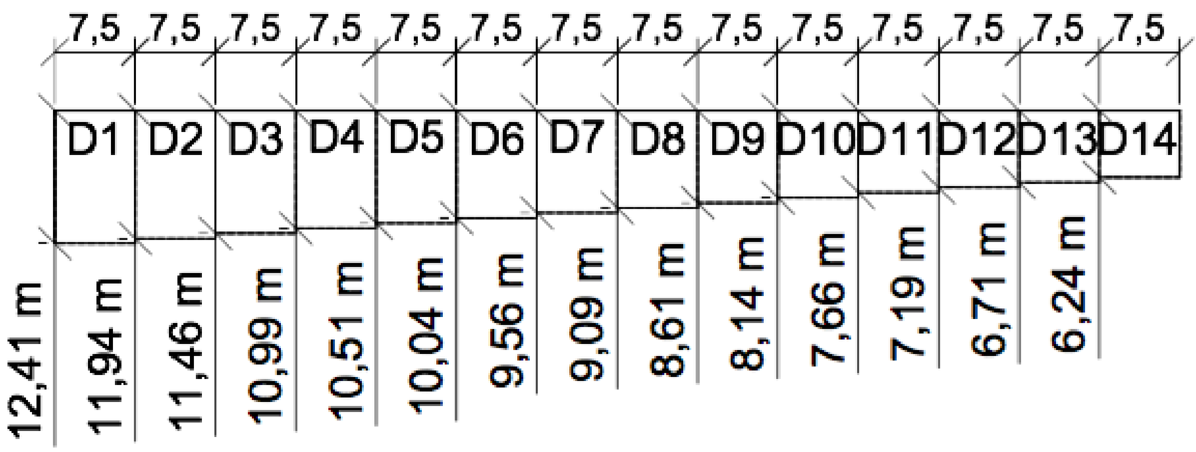


FIGURE 47: CROSS SECTIONS DOVELS CONVENTION

The lamellas will be having the heights as established on table 7, we will use the values of the column lamella height at medium and they will be used for the design approach in the computer program.

Section	Dovel Height on left (mts)	Dovel height at medium (mts)
15	6.00	6.24
14	6.48	6.71
13	6.95	7.19
12	7.43	7.66
11	7.90	8.14
10	8.38	8.61
9	8.85	9.09

8	9.33	9.56
7	9.80	10.04
6	10.28	10.51
5	10.75	10.99
4	11.23	11.46
3	11.70	11.94
2	12.18	12.41
1	12.65	

Tabla 7 LAMELLA HEIGHT DX

The calculations of the cross sections for this beam are summarized on the next tables, as before is shown hand and computer calculations also a table that shows the error percentage between them.

		Hand Calculations		
# dovel	**H average (m)**	**Area (m^2)**	**Iy (m^4)**	**Y bar**
14	6.24	14.71	88.321	3.582
13	6.71	15.03	104.001	3.863
12	7.19	15.45	124.429	4.107
11	7.66	15.76	140.597	4.410
10	8.14	16.16	161.207	4.681
9	8.61	16.51	182.925	4.959
8	9.09	16.89	206.585	5.231
7	9.56	17.27	231.832	5.504
6	10.04	17.63	258.532	5.779
5	10.51	18.00	286.927	6.053
4	10.99	18.35	316.304	6.335
3	11.46	18.71	354.938	6.578
2	11.94	19.05	380.751	6.891
1	12.41	19.42	415.723	7.167

Tabla 8 HAND CALCULATIONS FOR CROSS SECTIONS D1.X

		Computer Calculations		
# dovel	**H average (m)**	**Area (m^2)**	**Iy (m^4)**	**Y bar**
14	6.24	14.69	88.390	3.584
13	6.71	15.05	104.240	3.856
12	7.19	15.44	121.970	4.131
11	7.66	15.81	140.720	4.403
10	8.14	16.18	161.410	4.680
9	8.61	16.54	183.170	4.952

8	9.09	16.91	206.960	5.230
7	9.56	17.28	231.800	5.502
6	10.04	17.65	258.790	5.779
5	10.51	18.01	286.820	6.052
4	10.99	18.38	317.100	6.330
3	11.46	18.75	348.410	6.602
2	11.94	19.12	382.090	6.880
1	12.41	19.48	416.770	7.152

Tabla 9 COMPUTER CALCULATIONS FOR CROSS-SECTIONS D1.X

		%Error		
# dovel	**H average (m)**	**Area (m^2)**	**Iy (m^4)**	**Y bar**
14	6.24	-0.129%	0.078%	0.047%
13	6.71	0.103%	0.229%	-0.187%
12	7.19	-0.054%	-2.016%	0.578%
11	7.66	0.266%	0.087%	-0.166%
10	8.14	0.120%	0.126%	-0.015%
9	8.61	0.196%	0.134%	-0.145%
8	9.09	0.129%	0.181%	-0.026%
7	9.56	0.037%	-0.014%	-0.031%
6	10.04	0.098%	0.100%	-0.004%
5	10.51	0.048%	-0.037%	-0.023%
4	10.99	0.199%	0.251%	-0.072%
3	11.46	0.201%	-1.874%	0.361%
2	11.94	0.325%	0.350%	-0.155%
1	12.41	0.324%	0.251%	-0.206%

Tabla 10 ERROR PERCENTAGE BETWEEN THE CALCULATIONS FOR THE CROSS-SECTIONS

The procedure followed on these cross-sections is shown in figure 48 and table 11 for reference, we picked a random cross section for explanatory purposes.

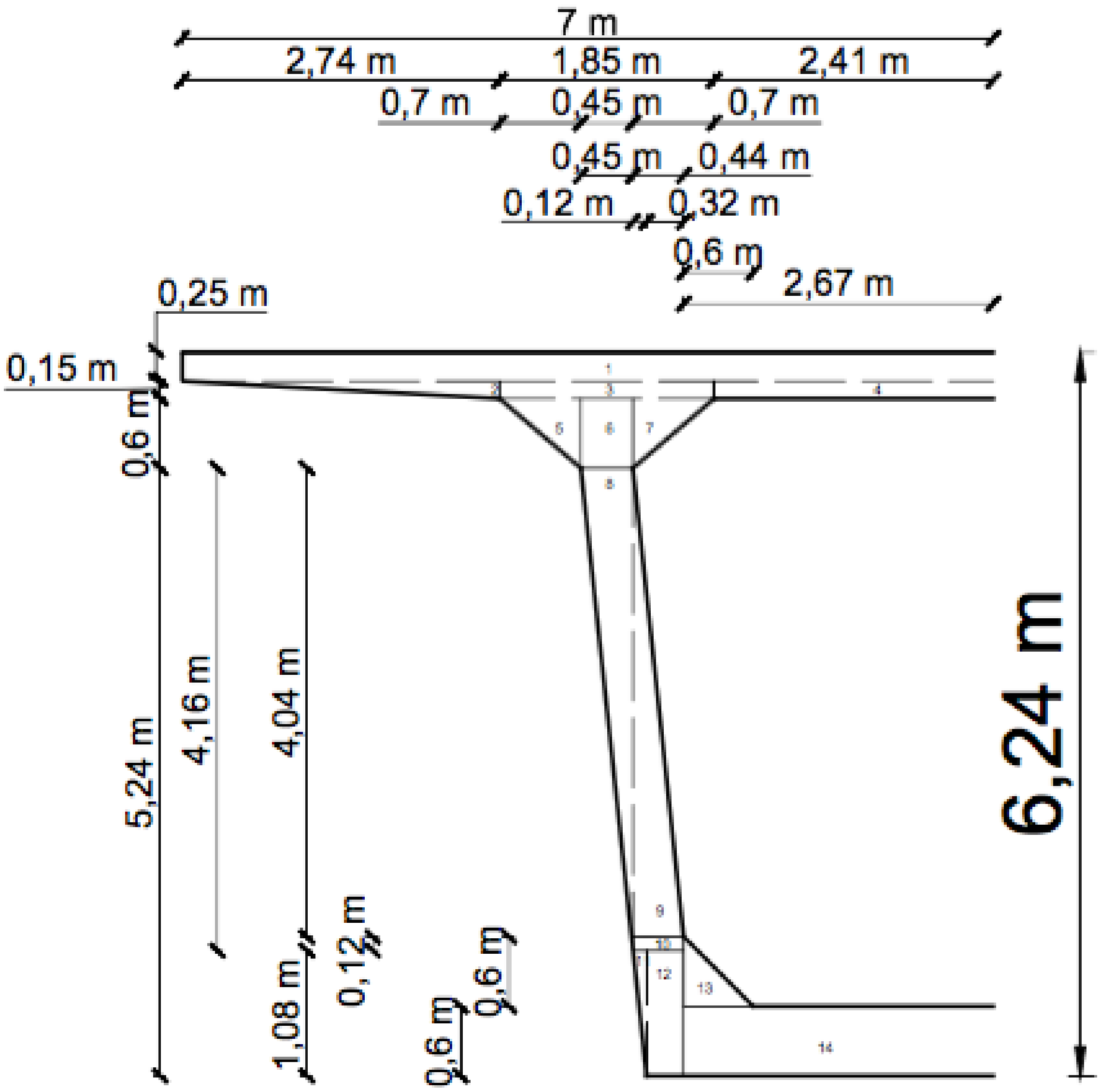


FIGURE 48: CROSS SECTIONS DRAWING FOR CALCULATION OF AREA, INERTIA AND Y BAR

Number	Shape	Base (m)	Height (m)	Area (m^2)	Y bar (m)	YA	Distance from symmetry	Iy	Iyy
1	Rectangle	7	0.25	1.750	6.113	10.697	-2.530	0.009	11.212
2	Triangle	2.74	0.15	0.206	5.938	1.220	-2.355	0.000	1.140
3	Rectangle	1.85	0.15	0.278	5.913	1.641	-2.330	0.001	1.507
4	Rectangle	2.41	0.15	0.362	5.913	2.137	-2.330	0.001	1.964
5	Triangle	0.7	0.6	0.210	5.638	1.184	-2.055	0.004	0.891
6	Rectangle	0.45	0.6	0.270	5.538	1.495	-1.955	0.008	1.040
7	Triangle	0.7	0.6	0.210	5.638	1.184	-2.055	0.004	0.891
8	Triangle	0.45	4.16	0.936	3.853	3.607	-0.271	0.900	0.969
9	Triangle	0.44	4.04	0.889	2.547	2.263	1.036	0.806	1.759
10	Rectangle	0.44	0.12	0.053	1.140	0.060	2.442	0.000	0.315

11	**Triangle**	0.12	1.08	0.065	0.720	0.047	2.862	0.004	0.535
12	**rectangle**	0.32	1.08	0.346	0.540	0.187	3.042	0.034	3.232
13	**Triangle**	0.6	0.6	0.180	0.800	0.144	2.782	0.004	1.397
14	**Rectangle**	2.67	0.6	1.602	0.300	0.481	3.282	0.048	17.308
				7.355		**26.346**			**44.161**

Tabla 11 HAND CALCULATIONS FOR A RANDOM CROSS-SECTION D1.X

<u>Eh and Ed.</u>

The values obtained for Ed and Eh, which represent the distance from the bottom and the top fibers to the center of gravity of each lamella are represented on the next table. These values will be used lately for the design of the tendons and bridge design calculation.

# Dovel	Y bar	Eh	Ed
D1.1	3.555	2.636	3.555
D1.2	3.954	2.928	3.954
D1.3	4.350	3.223	4.350
D1.4	4.752	3.512	4.752
D1.5	5.146	3.809	5.146
D1.6	5.545	4.101	5.545
D1.7	5.959	4.378	5.959
D1.8	6.356	4.672	6.356
D1.9	6.754	4.965	6.754
D1.10	7.152	5.258	7.152
D1	3.584	2.654	3.584
D2	3.856	2.857	3.856
D3	4.131	3.057	4.131
D4	4.403	3.260	4.403
D5	4.680	3.458	4.680
D6	4.952	3.661	4.952
D7	5.230	3.858	5.230
D8	5.502	4.061	5.502
D9	5.779	4.259	5.779
D10	6.052	4.461	6.052
D11	6.330	4.658	6.330
D12	6.602	4.860	6.602
D13	6.880	5.058	6.880

D14	7.152	5.260	7.152

Tabla 12 EH AND ED

Figure 49 is a representation of the values obtained per lamella on the location in the bridge. As it is seen Eh (distance to top fibers) is represented on the left side of the bridge, while Ed is represented on the right side of it.

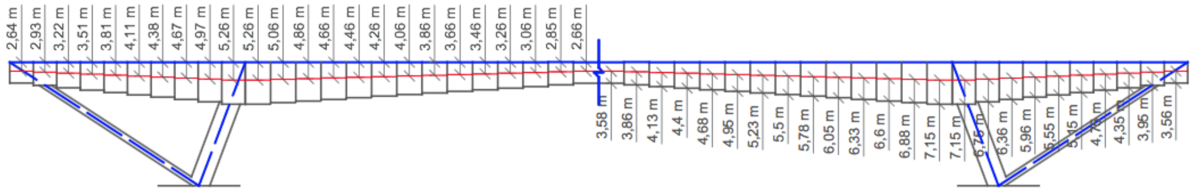


FIGURE 49: EH (LEFT) AND ED (RIGHT) REPRESENTED ON THE BRIDGE MODEL DESIGN.

Material Characteristics.

Concrete.

The concrete to be used throughout the whole bridge design will be C35/45. The values that will be needed for the Scia program and hand calculations are obtained next:

$$f_{ck} = 35 \text{ MPa}$$

$$f_{cd} = \frac{f_{ck}}{1.5} = \frac{35}{1.5} = 23.33 \text{ MPa}$$

Prestress Steel Rods.

The prestress steel rods will be diameter 15mm, and it will be calculated with groups of 12,15,19, etc., depending on the necessity faced. The values needed for design are calculated next:

$$f_{pk} = 1770 \text{ MPa}$$

$$f_{0,1k} = 1560 \text{ MPa}$$

Where, fpk describes the ultimate stress supported by the prestress steel, and the f0.1k describes the conventional yield stress.

Loading.

Permanent Loads.

Selfweight of the elements will be taken in consideration. We assume 25kN/m2 for dry concrete and 27kN/m2 for wet concrete for the design. The selfweight in a project like the one we deal with is the most considerable load usually, this is a permanent load and can only be dealt to provide smaller sections to optimize it, by doing that we can deal with this forces that will be always present. We will also consider a superimposed load as the carriageway weight and other elements of the bridge.

Variable Loads.

The next load cases will be used as variable forces to obtain the internal forces, they are represented by:

1. Load Model 1-middle point force
2. Load Model 1-middle point force on triangular frame
3. Load Model 1-element connection point forces
4. Temperature variation.
5. Settlements

Load Model 1

This load will be calculated based on the Eurocode 1991_8. As we stated before the bridge will have 3 carriageways of 4 meters each lane so,

$$\sum \propto \mathrm{qq_k} = 1 * 9 * 4 + 1 * 6 * 4 + 1 * 3.5 * 4 + 1 * 2.5 * 2 = 79\,\frac{\mathrm{kN}}{\mathrm{m}}$$

$$\sum \propto \mathrm{QQ_k} = 1 * 300 + 1 * 200 + 1 * 100 = 600\,\frac{\mathrm{kN}}{\mathrm{m}}$$

The model will be analyzed by three different cases, this way we can get to see the behavior of the structure due to the variable loading. 1.2 meters as stated on the code will separate the point force. Figure 50 represents the model cases.

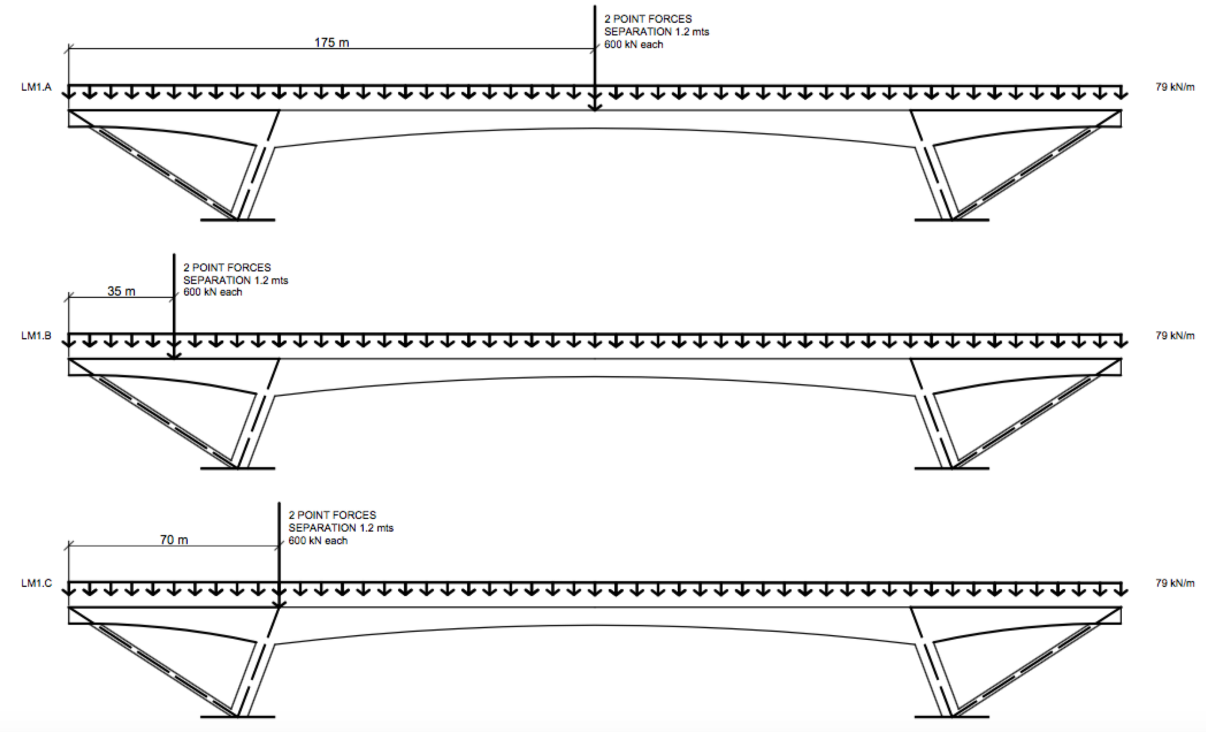


FIGURE 50: LM1-A, B, C REPRESENTATION TO BE USED.

Temperature Variation

We will analyze the bridge with a variation of temperature of 20 K; this will be added and subtracted to see the effects. This case is under consideration due to the fact that the bridge is a frame structure; concrete will have problems with shrinkage and expansion due to the fixed connections this type of structure comes with.

Settlements

Settlements will be analyzed on each of the supports, we will consider a drop of 5mm downwards, and we will analyze this as a combination of the settlements in an envelope result.

Superimposed load

This load will be taken in consideration as a permanent; this will describe the elements of the bridge such as lights, pedestrian parapet, carriageway weight, etc. We consider an 80-mm height of carriageway and a load of 24 Kn/m3 so the final value is calculated,

$$\gamma_0 = 24\frac{\mathrm{kN}}{\mathrm{m}^3} * 0.085\ \mathrm{m} * 14\mathrm{m} = 28.56\frac{\mathrm{kN}}{\mathrm{m}}$$

Preliminary Internal Forces Graphs.

After creating the model in the Scia Engineering program, wee obtain the internal forces, bending moment (M), Shear (V), and axial forces (N), this is the first step to get to know the structure and it´s behavior under each load case.

Selfweight.

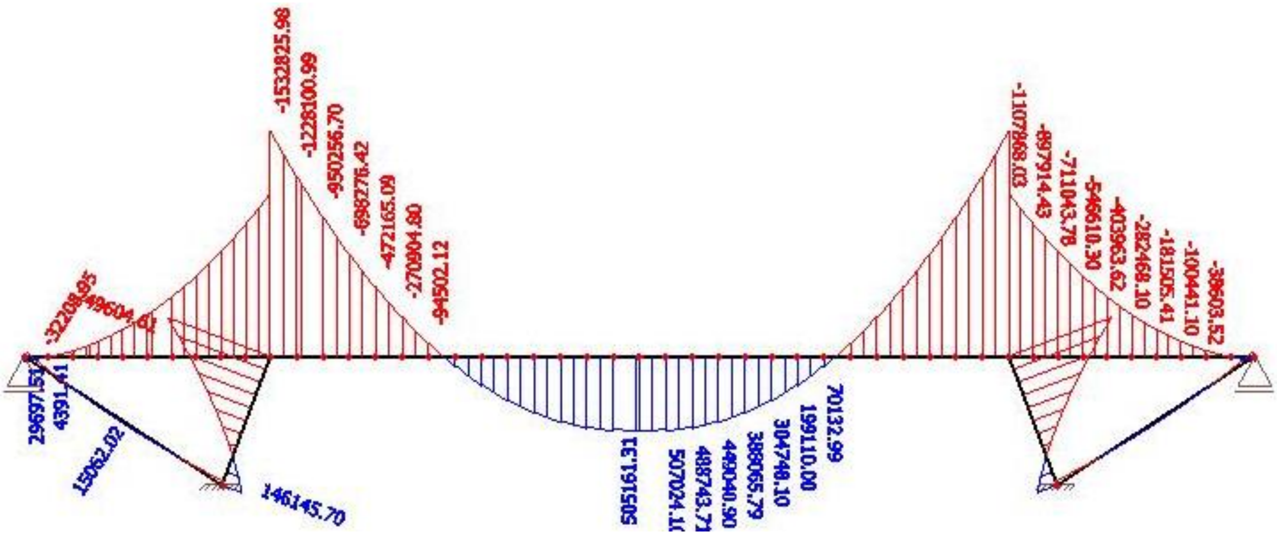


FIGURE 51: MOMENT DIAGRAM DUE TO SELFWEIGHT

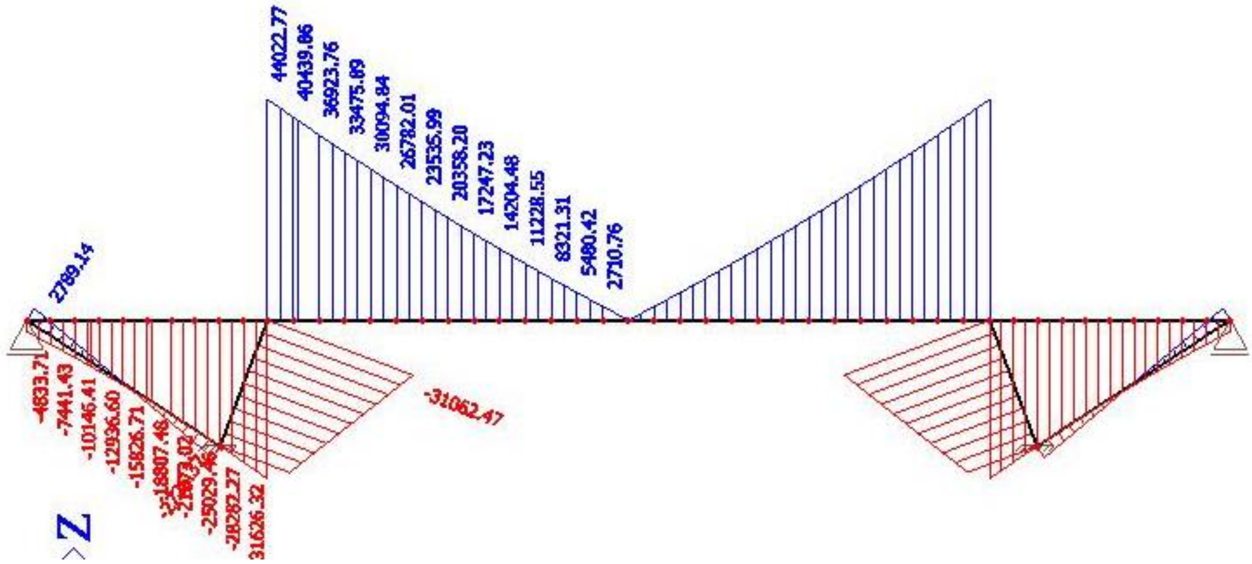


FIGURE 52: SHEAR DIAGRAM DUE TO SELFWEIGHT

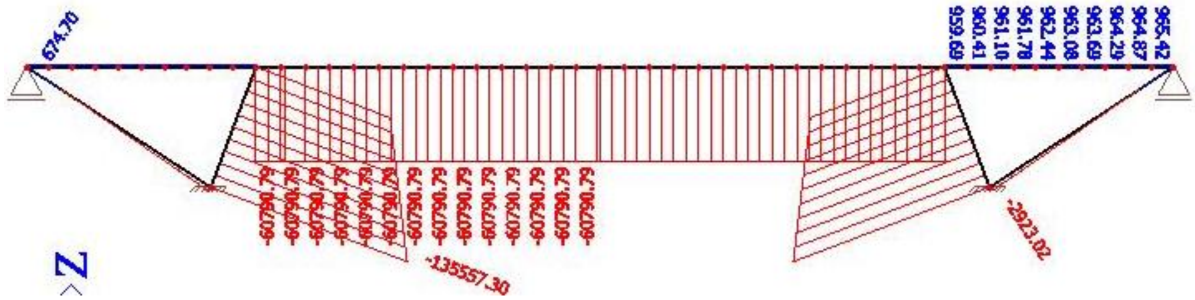


FIGURE 53: AXIAL FORCE DIAGRAM DUE TO SELFWEIGHT

Superimposed Load.

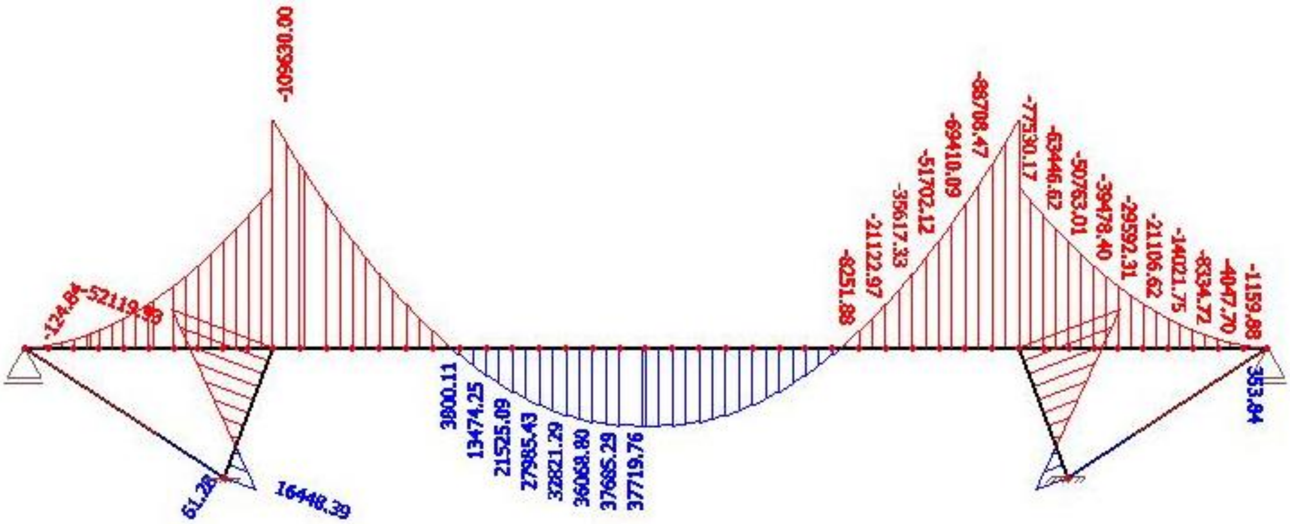


FIGURE 54: MOMENT DIAGRAM DUE TO SUPERIMPOSED LOAD.

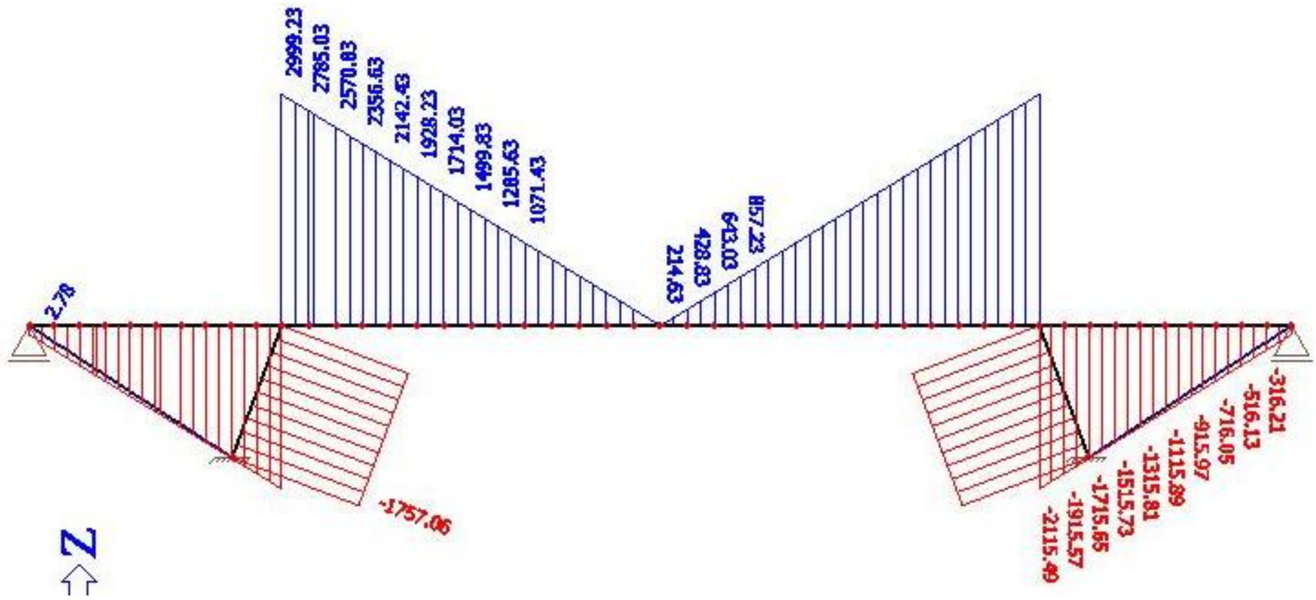


FIGURE 55: SHEAR DIAGRAM DUE TO SUPERIMPOSED LOAD.

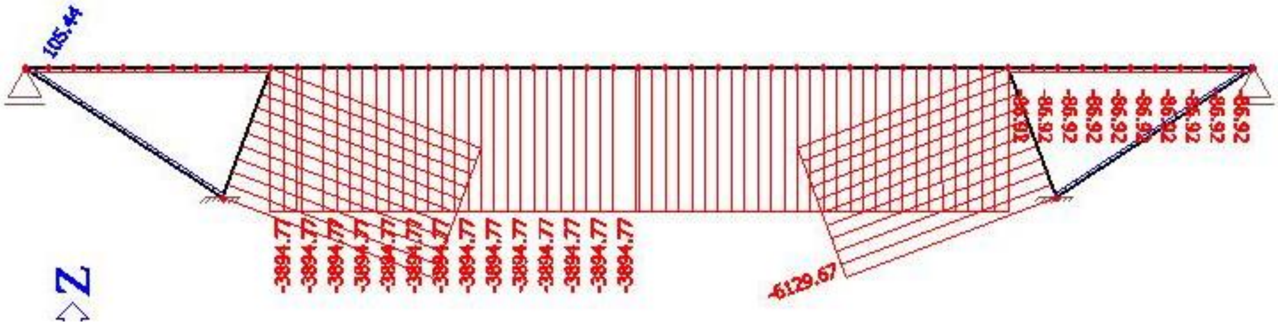


FIGURE 56: AXIAL FORCE DIAGRAM DUE TO SUPERIMPOSED LOAD.

Temperature +20K.

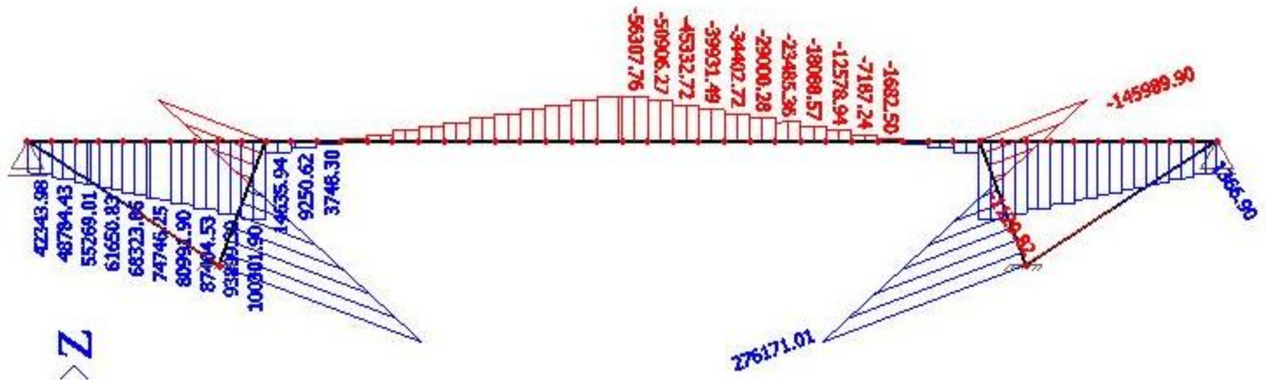


FIGURE 57: MOMENT DIAGRAM DUE TO T+.

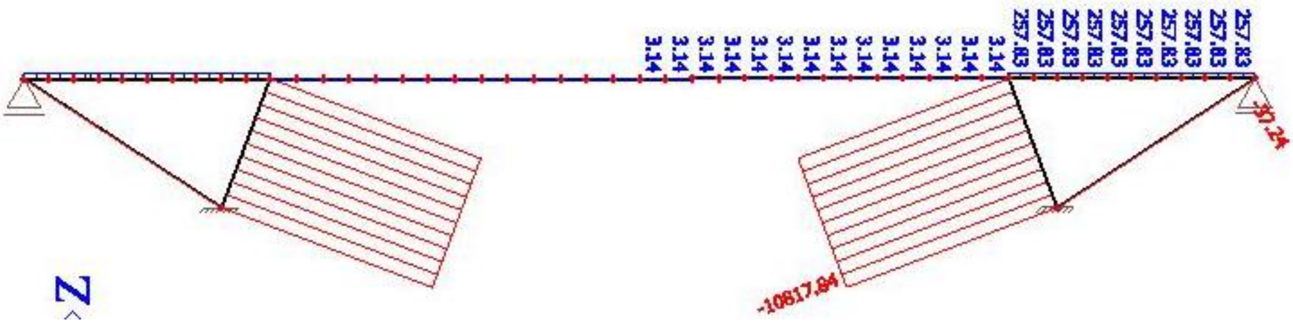


FIGURE 58: SHEAR DIAGRAM DUE TO T+.

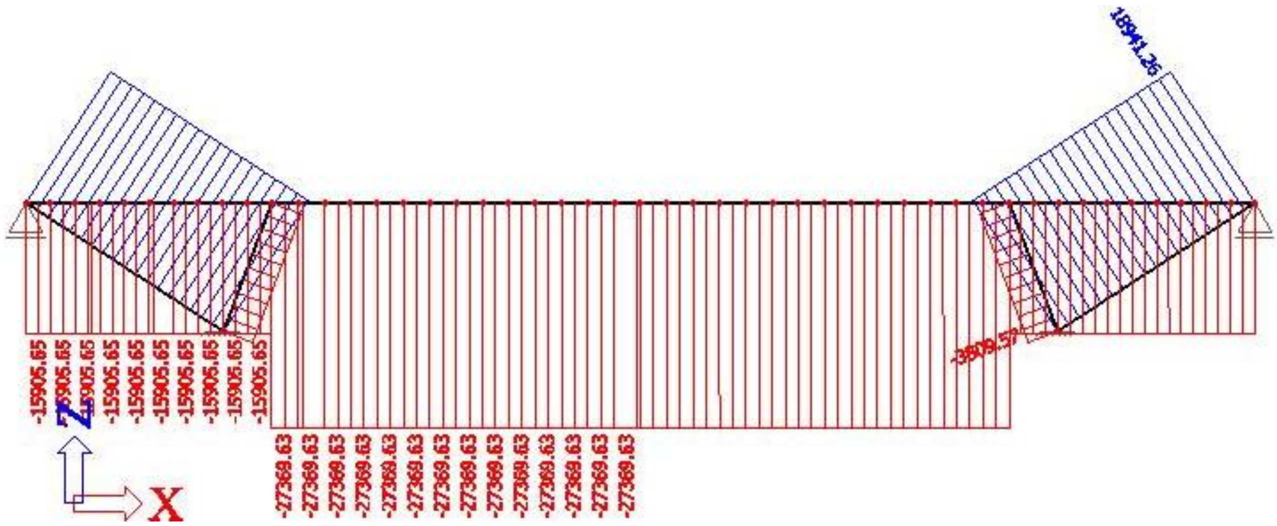


FIGURE 59: AXIAL FORCE DIAGRAM DUE TO T+.

Temperature -20K.

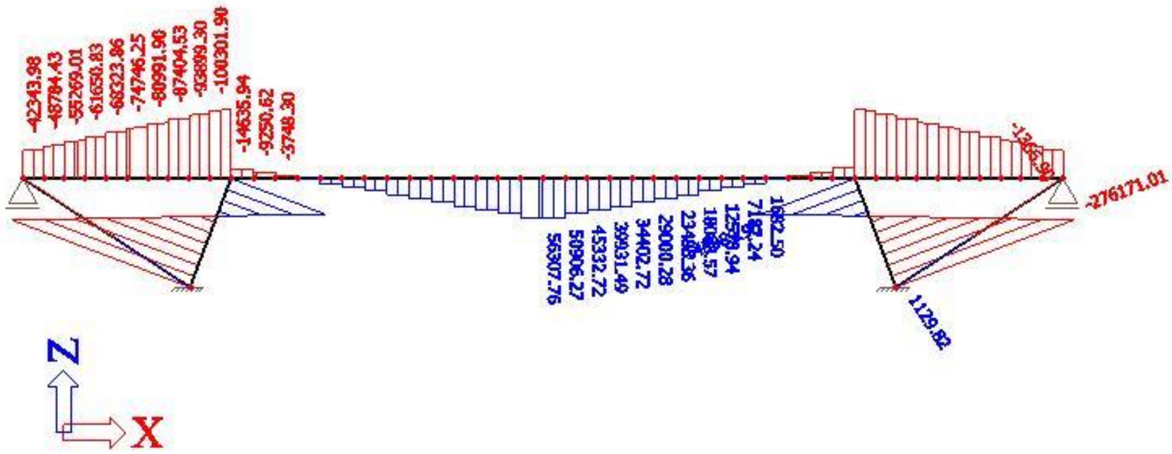


FIGURE 60: MOMENT DIAGRAM DUE TO T-.

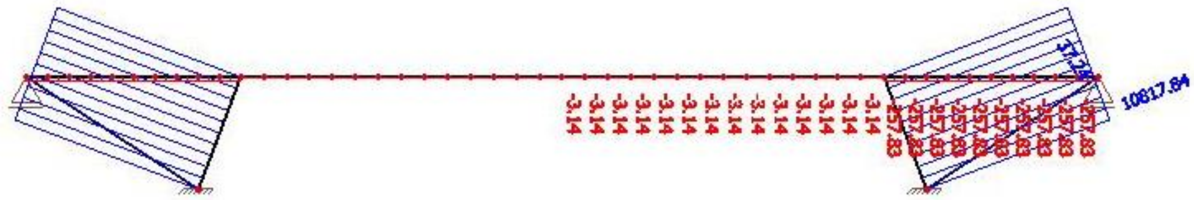


FIGURE 61: SHEAR DIAGRAM DUE TO T-.

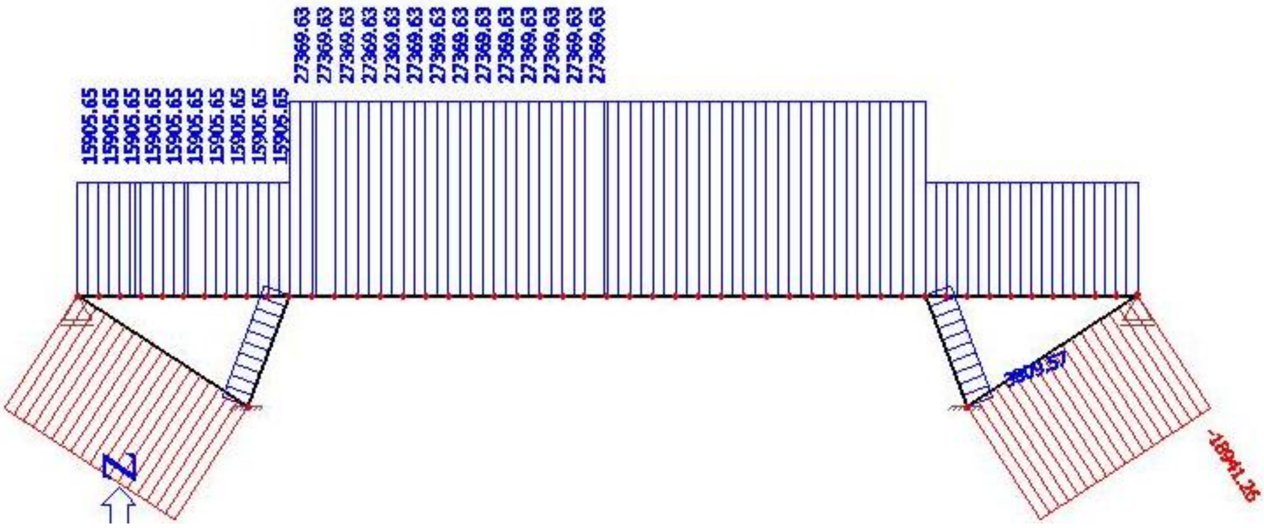


FIGURE 62: AXIAL FORCE DIAGRAM DUE TO T-.

LM1-A.

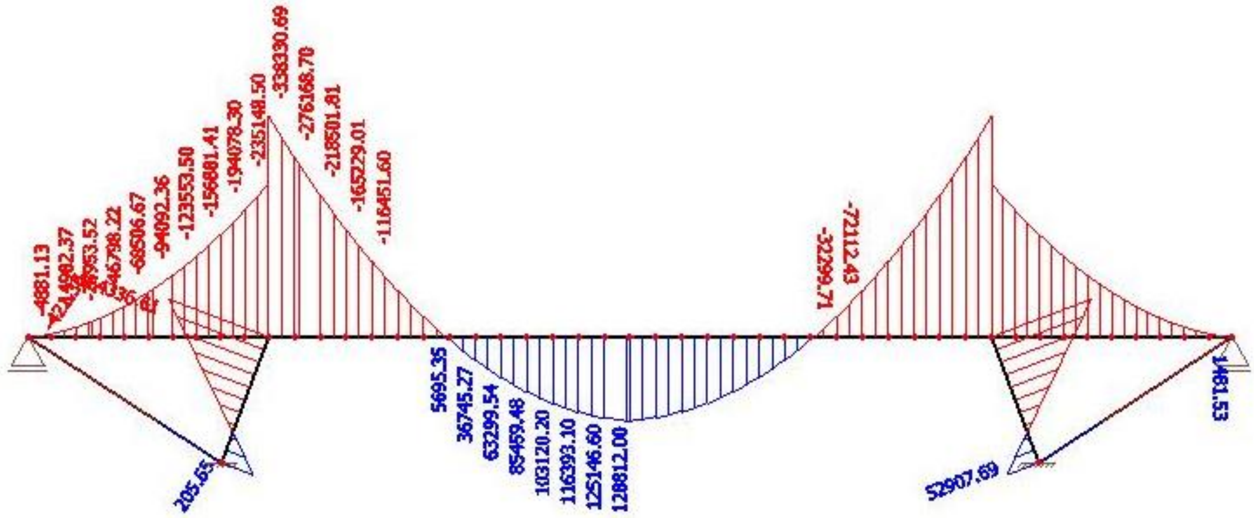


FIGURE 63: MOMENT DIAGRAM DUE TO LM1-A.

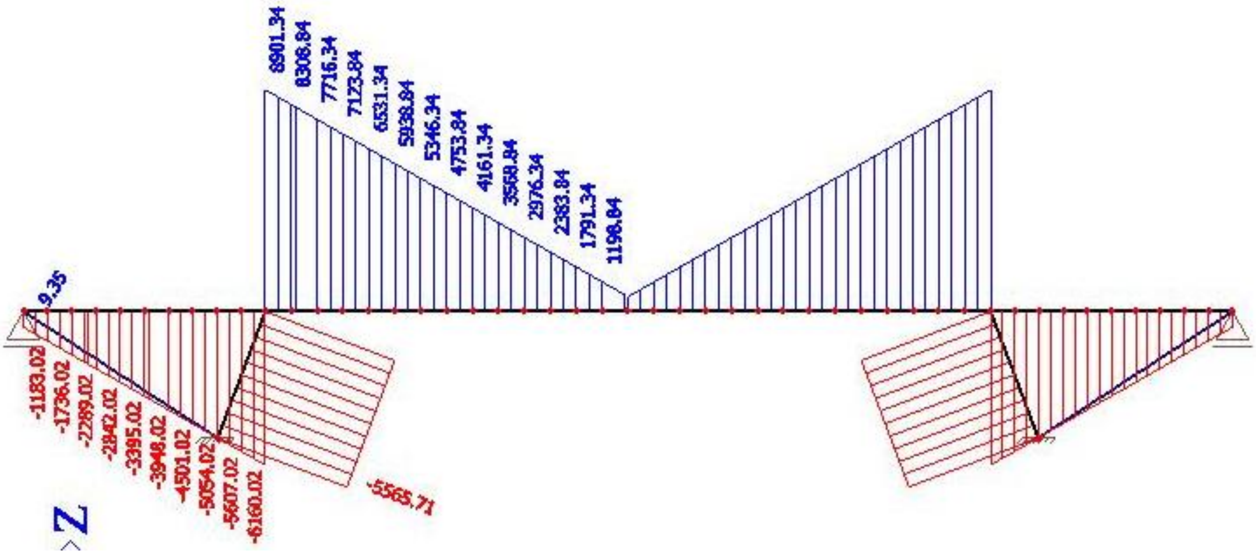


FIGURE 64: SHEAR DIAGRAM DUE TO LM1-A.

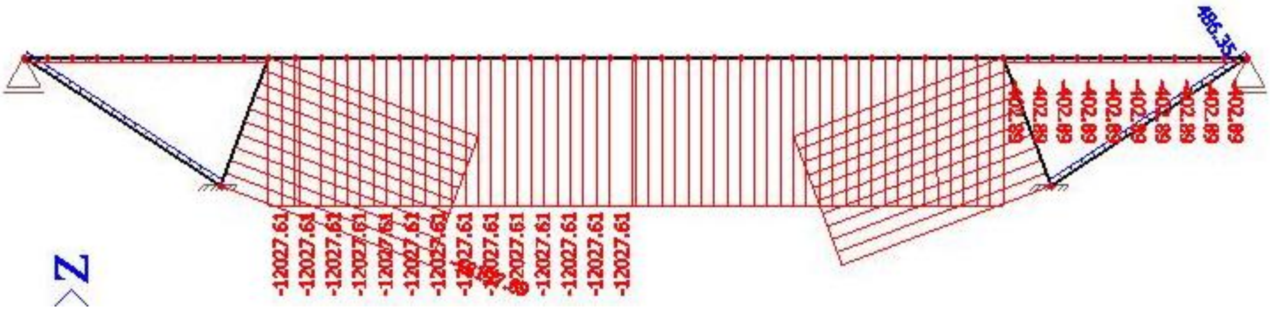


FIGURE 65: AXIAL FORCE DIAGRAM DUE TO LM1-A.

LM1-B.

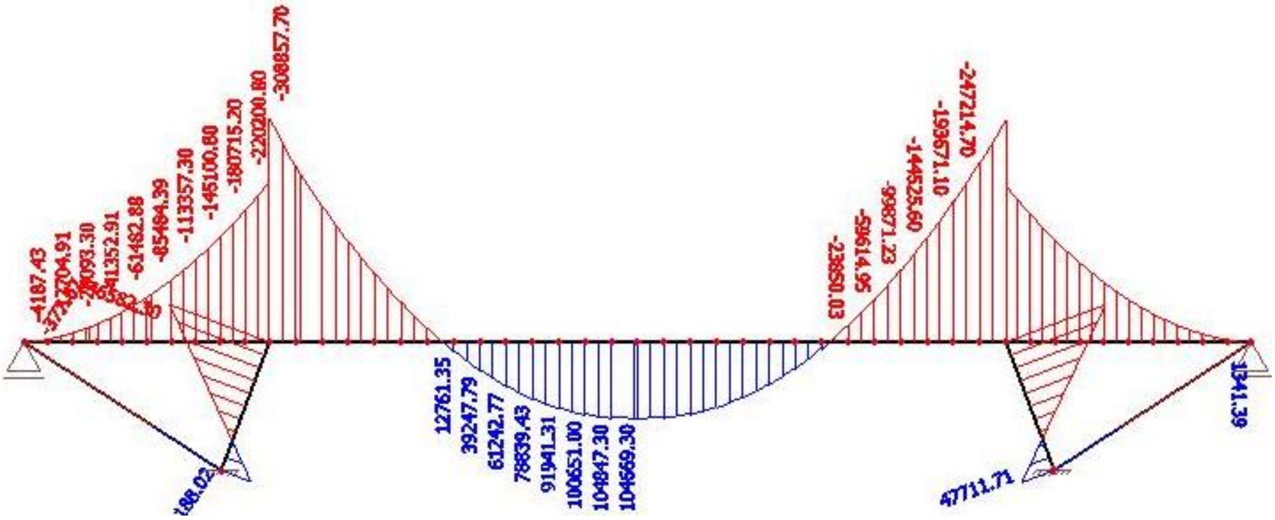


FIGURE 66: MOMENT DIAGRAM DUE TO LM1-B.

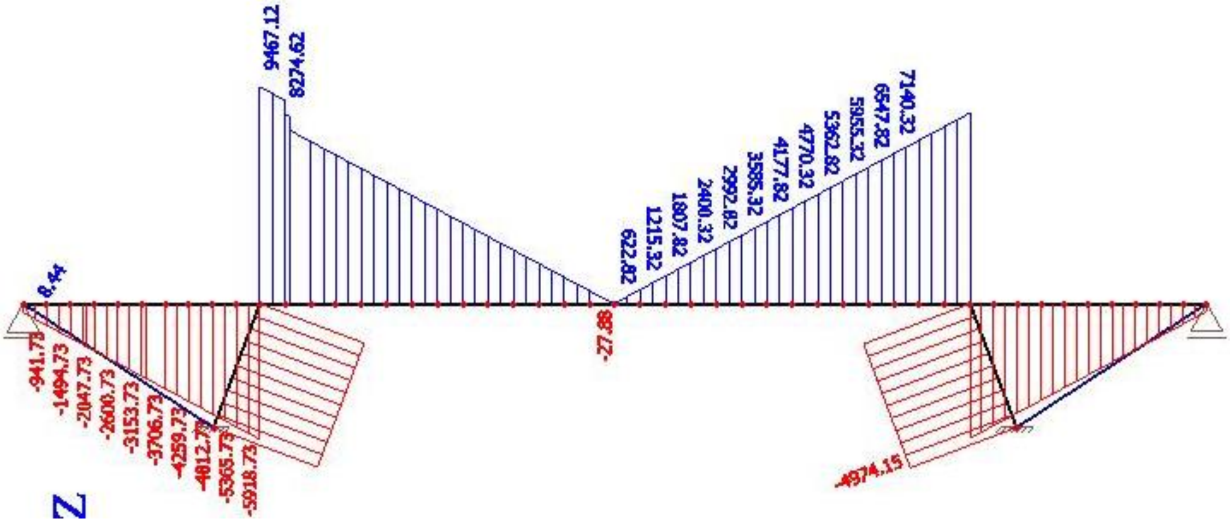


FIGURE 67: SHEAR DIAGRAM DUE TO LM1-B.

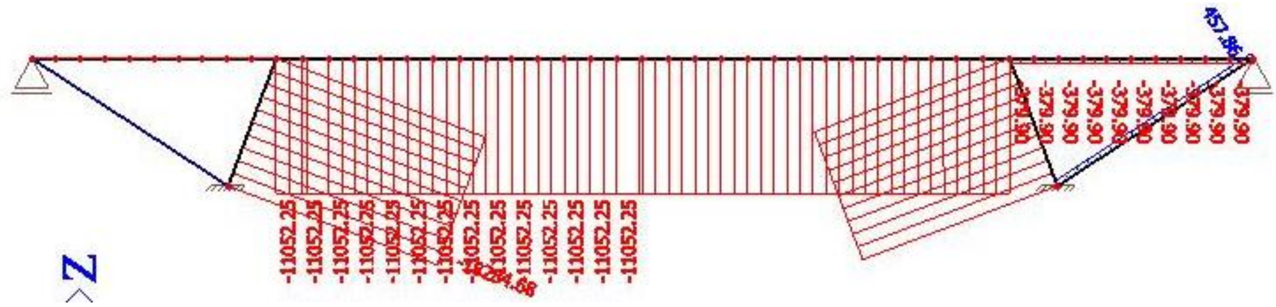


FIGURE 68: AXIAL FORCE DIAGRAM DUE TO LM1-B.

LM1-C.

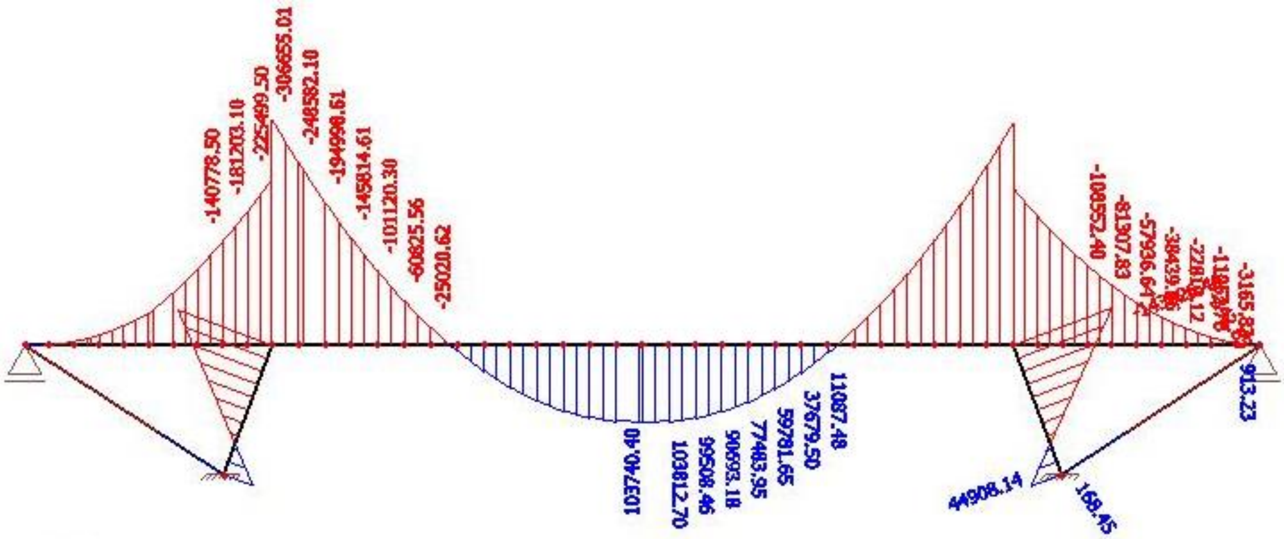


FIGURE 69: MOMENT DIAGRAM DUE TO LM1-C.

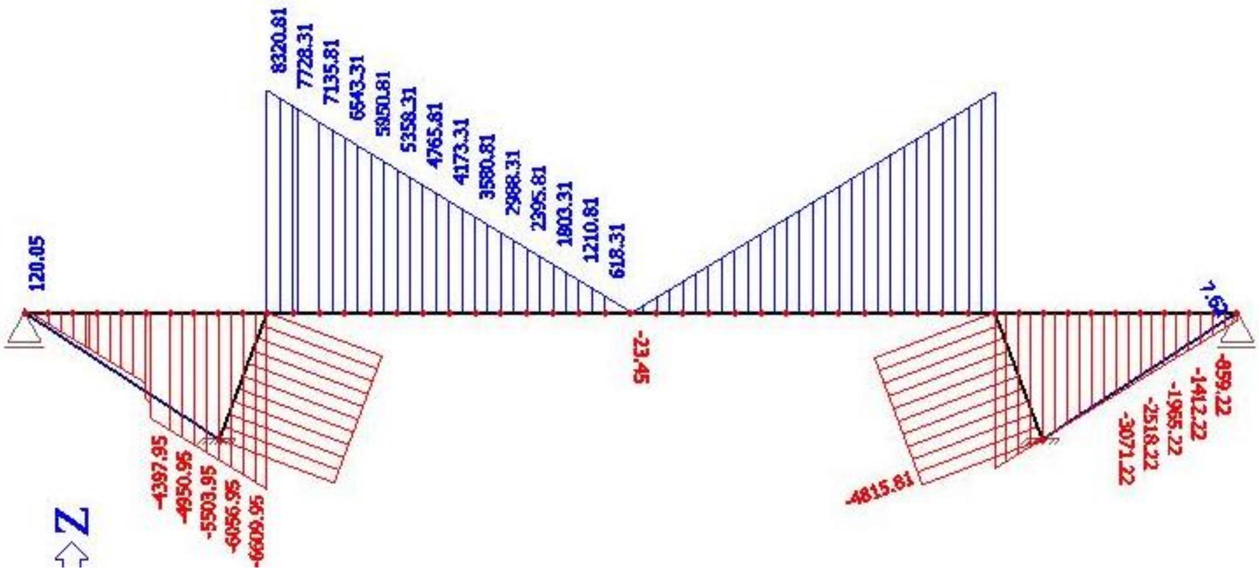


FIGURE 70: SHEAR DIAGRAM DUE TO LM1-C.

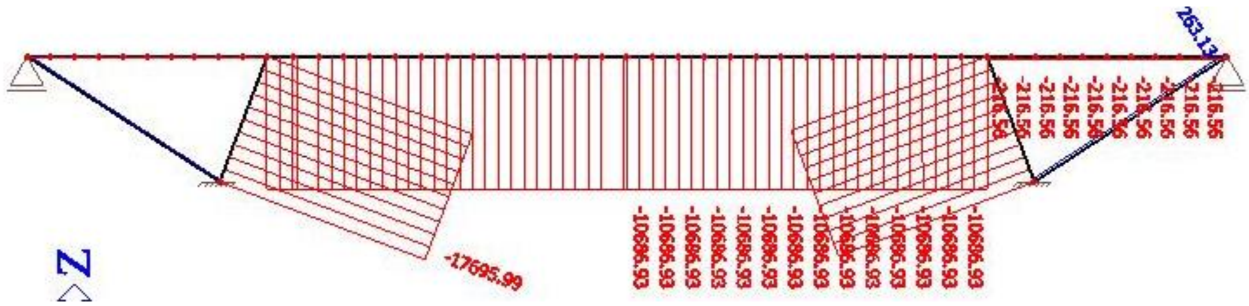


FIGURE 71: AXIAL FORCE DIAGRAM DUE TO LM1-C.

Settlements, envelope 5mm.

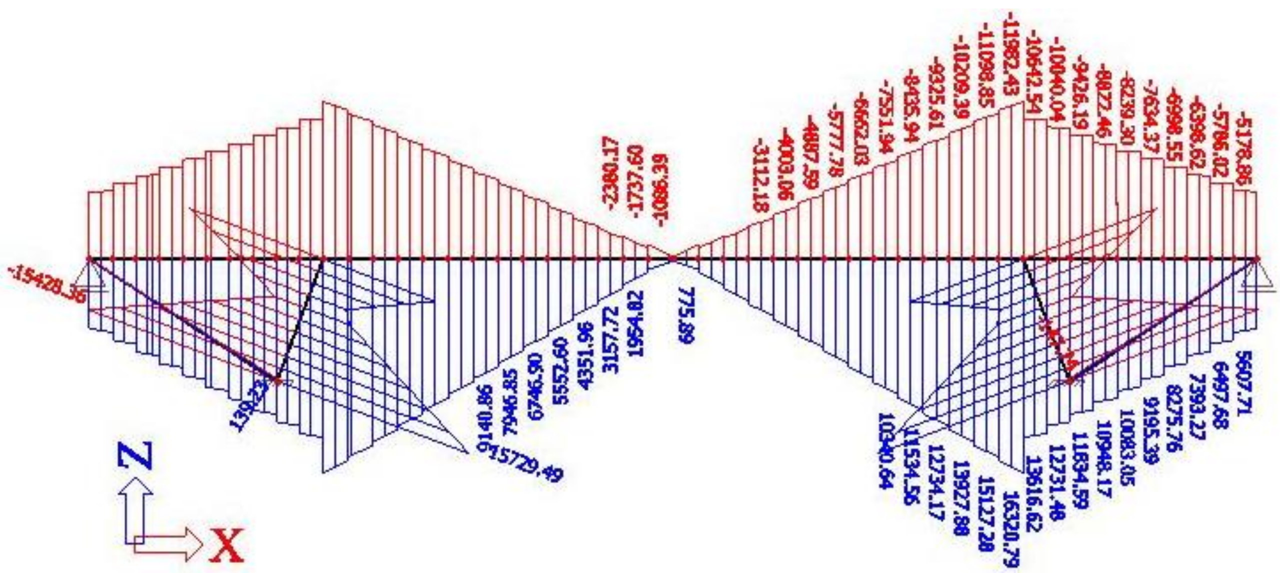


FIGURE 72: MOMENT DIAGRAM DUE TO SETTLEMENT ENVELOPE 5MM.

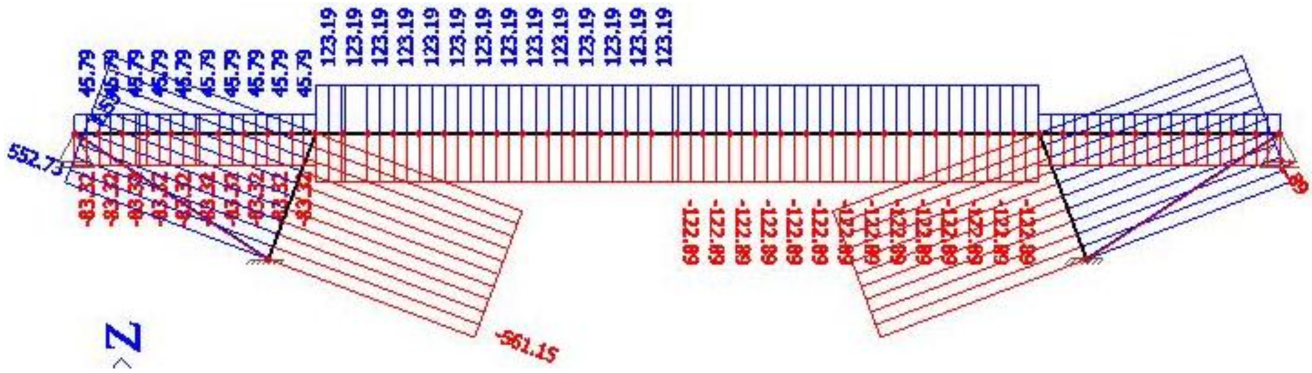


FIGURE 73: SHEAR DIAGRAM DUE TO SETTLEMENT ENVELOPE 5MM.

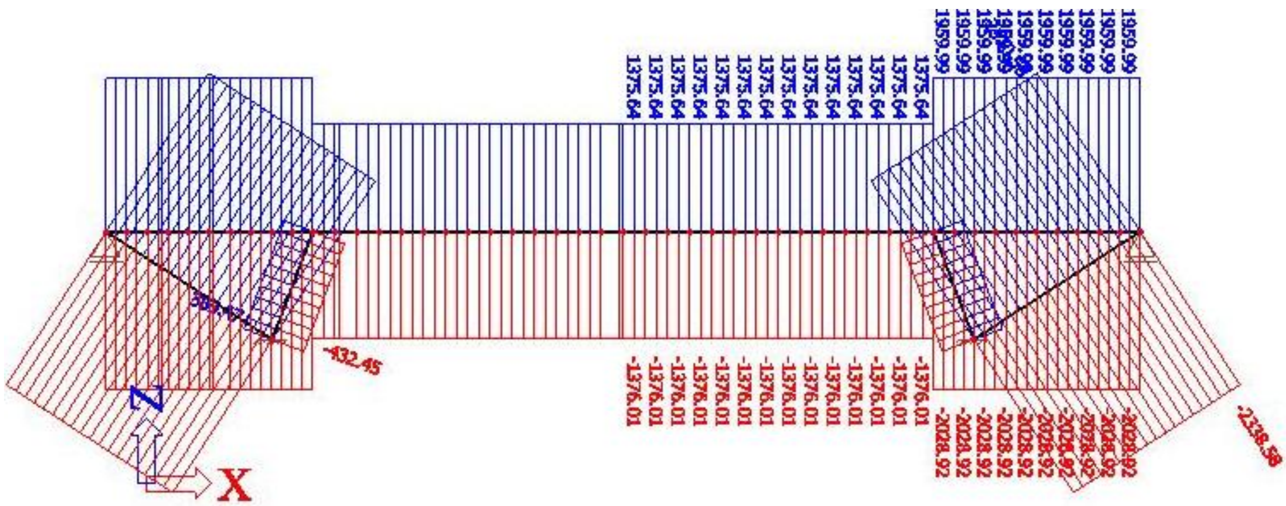


FIGURE 74: AXIAL FORCE DIAGRAM DUE TO SETTLEMENT ENVELOPE 5MM.

Preliminary Results summary and analysis

The results obtained are shown on the next tables, as we can see on them, the selfweight is the dominant load in sections 10, 20, 30, 40, 50. When it comes to moment and shear forces. However, in section 0 and 60 we can see that the decrease of temperature of 20 kelvin has the biggest moments and axial forces. Shear is dominated by selfweight in all sections. For references of the sections, figure 75 has the proposed convention.

The biggest moment present is -1300000 KNm located on section 20 and 40. An interest point for us since is the main connection between our strut element and the bridge beam. Here we can see the negative effects of the frame design selected for the bridge.

Considering the values, we can see that the temperature is a factor to be consider. This is a result of the fixity and the high stiffness of the structure. As we can see we have cross sections that are quite big, reason why the stiffness of the bridge might tend to infinite.

In our strut we can see that the temperature also has some negative effects, the moments under this condition are tension moments, reason why the design of this particular element has to consider the thermal loads.

As previously stated our tie element has no much forces acting on it due to this load cases presented, but its function will be to provide the support for the scaffolding in the casting of the strut element. We still need to see if this element will help on our design.

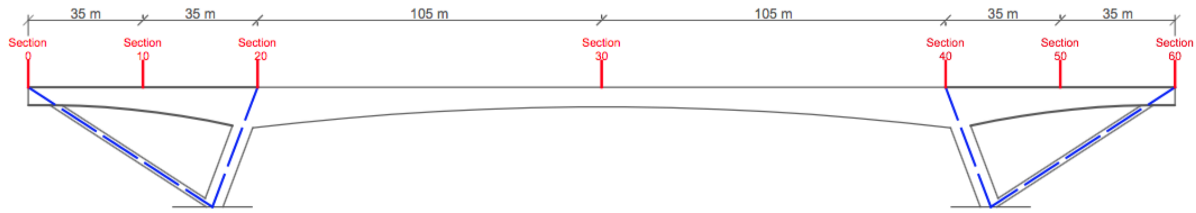


FIGURE 75: SECTION LOCATION NAMES

	Load	INTERNAL FORCES SCIA						
		Section						
		0	10	20	30	40	50	60
M (kNm)	Selfweight	29697.5	-282437.7	-1532825.98	505161.3	-1532826	-282437.7	29697.5
	superimposed load	353.8	-21106.6	-109630	37719.8	-109630	-21106.6	353.8
	T+ (20k)	40539.6	68323.9	100301.9	-56284.2	100301.9	68323.9	40539.6
	T- (20K)	-40539.6	-68323.9	-100301.9	56284.2	-100301.9	-68323.9	-40539.6
	LM1.1	1464.5	-68506.7	-338330.69	128812	-338330.7	-68506.7	1464.5
	LM1.2	469.2	-61482.9	-308857.7	104669.3	-308857.7	-61482.9	469.2
	LM1.3	584.1	-43447.4	-306655	103740.4	-306655	-43447.4	584.1
V (kN)	Selfweight	-2317.2	-15826.7	44022.8	7	44022.8	-15826.7	-2317.2
	superimposed load	-116.3	-1115.9	2999.2	0.4	2999.2	-1115.9	-116.3
	T+ (20k)	257.8	257.8	257.8	2.9	257.8	257.8	257.8
	T- (20K)	-257.8	-257.8	-257.8	-2.9	-257.8	-257.8	-257.8
	LM1.1	-630	-3395	8901.3	6.3	8901.3	-3395	-630
	LM1.2	-388.7	-3153.7	9467.1	-27.9	9467.1	-3153.7	-388.7
	LM1.3	120	-2645	8320.8	25.8	8320.8	-2645	120
N (kN)	Selfweight	953.2	953.2	-60790.8	-60790.2	-60790.8	953.2	953.2
	superimposed load	-86.9	-86.9	-3894.8	-3894.8	-3894.8	-86.9	-86.9
	T+ (20k)	-15905.6	-15905.6	-15905.6	-27369.6	-15905.6	-15905.6	-15905.6
	T- (20K)	15905.6	15905.6	15905.6	27369.6	15905.6	15905.6	15905.6
	LM1.1	-395.9	-395.9	-12027.6	-12027.6	-12027.6	-395.9	-395.9
	LM1.2	-34.7	-34.7	-11052.3	-11052.3	-11052.3	-34.7	-34.7
	LM1.3	-130.9	-130.9	-10686.9	-10686.9	-10686.9	-130.9	-130.9

Tabla 13 INTERNAL FORCES SUMMARY

Preliminary Stresses.

The stresses obtained for each section are shown next, it important to state that the graphs will only show + stresses for the tension stresses and – for the compression stresses, they will not show the shape of the stress. Shape and combination of graphs for hand calculations will be establish later on table 16 and 17.

Selfweight.

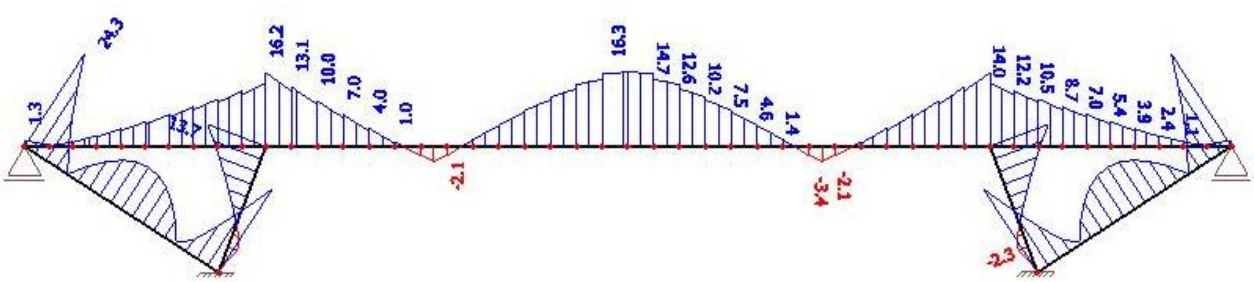


FIGURE 76: G+ DIAGRAM DUE TO SELFWEIGHT.

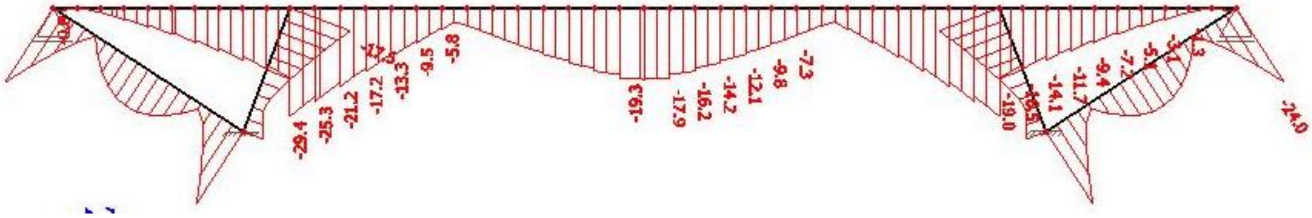


FIGURE 77: G- DIAGRAM DUE TO SELFWEIGHT.

Superimposed load.

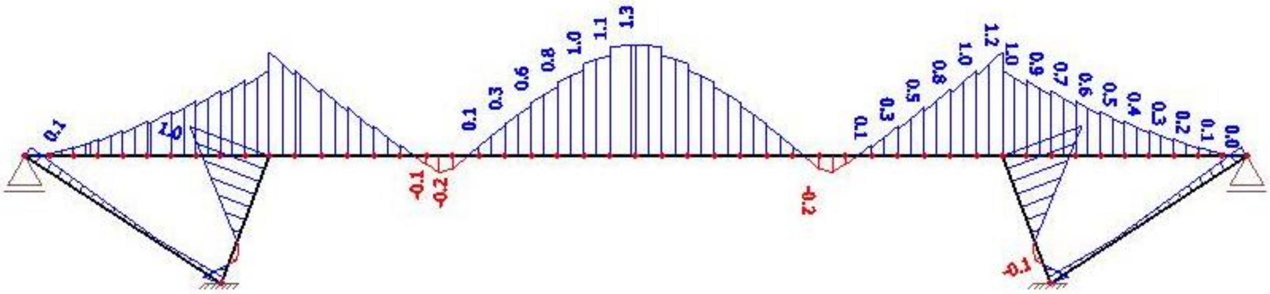


FIGURE 78: G+ DIAGRAM DUE TO SUPERIMPOSED LOAD.

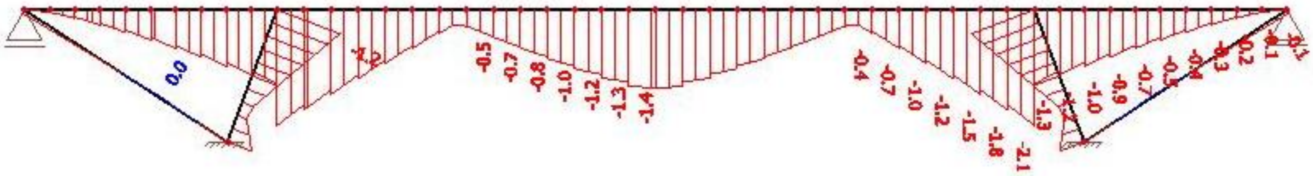


FIGURE 79: G- DIAGRAM DUE TO SUPERIMPOSED LOAD.

T+.

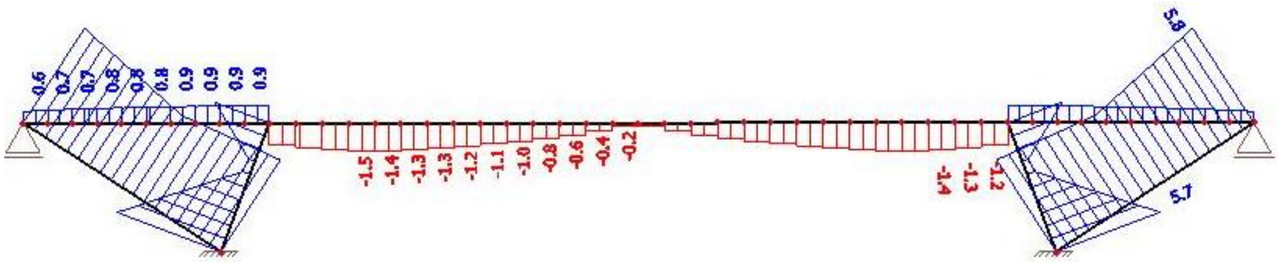


FIGURE 80: G+ DIAGRAM DUE TO T+.

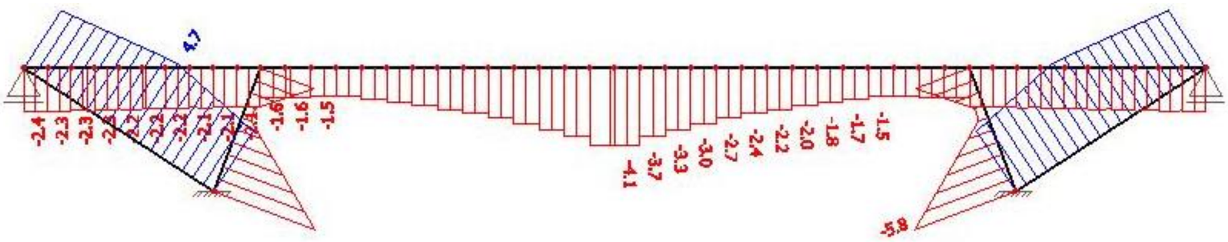


FIGURE 81: G- DIAGRAM DUE TO T+.

T-.

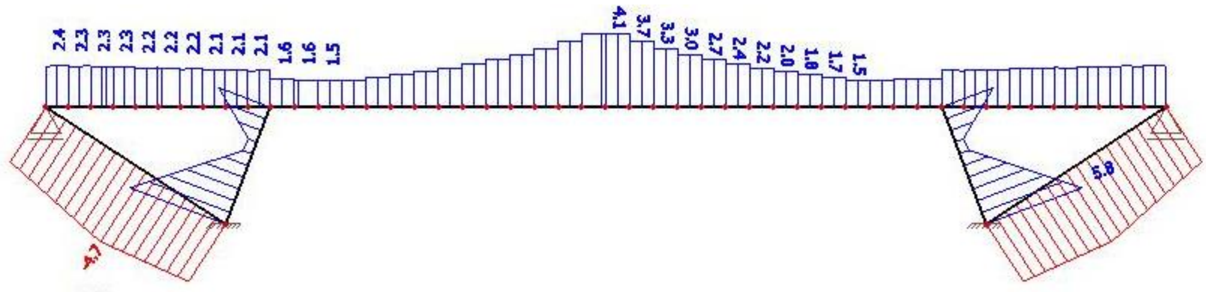


FIGURE 82: G+ DIAGRAM DUE TO T-.

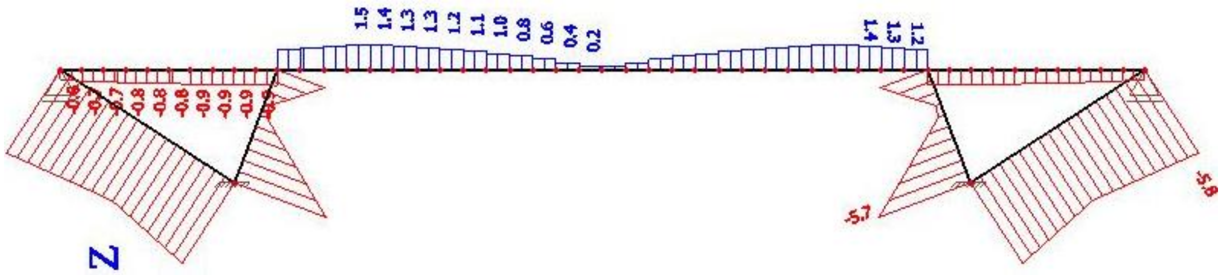


FIGURE 83: G- DIAGRAM DUE TO T-.

LM1-A.

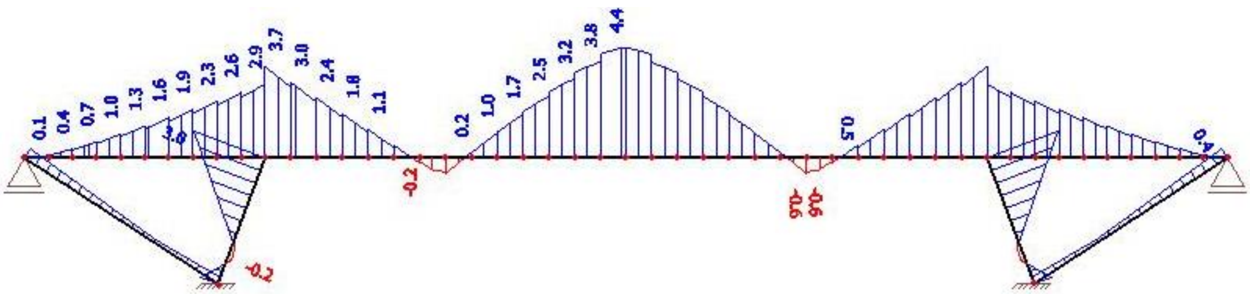


FIGURE 84: G+ DIAGRAM DUE TO LM1-A.

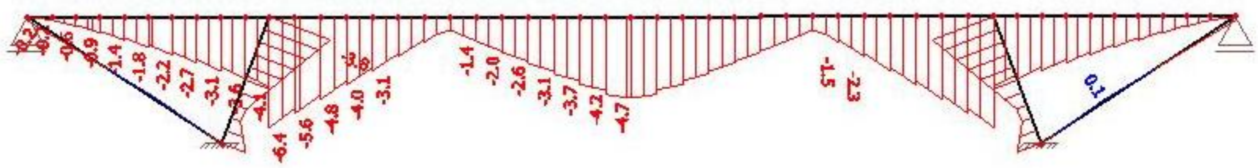


FIGURE 85: G- DIAGRAM DUE TO LM1-A.

LM1-B.

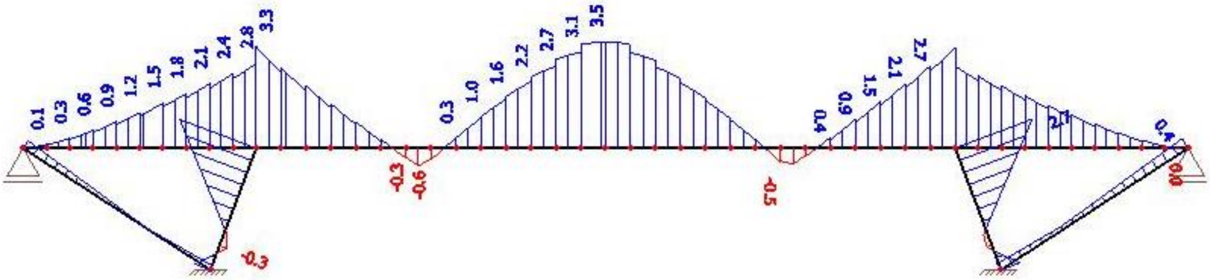


FIGURE 86: G+ DIAGRAM DUE TO LM1-B.

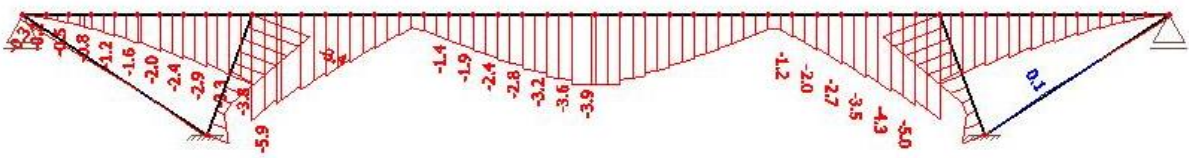


FIGURE 87: G- DIAGRAM DUE TO LM1-B.

LM1-C.

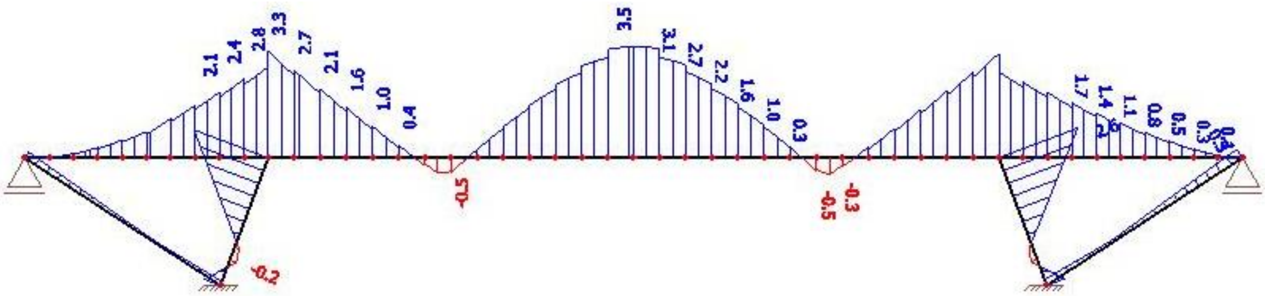


FIGURE 88: G+ DIAGRAM DUE TO LM1-C.

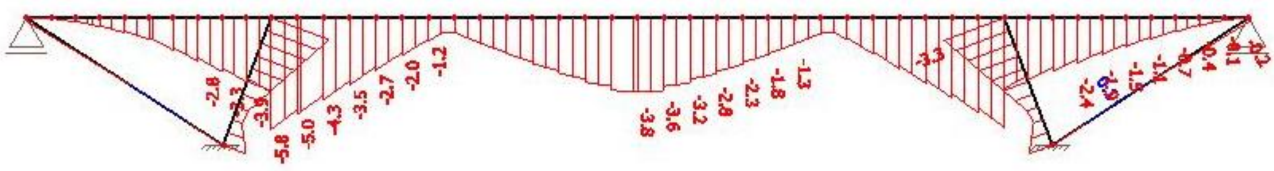


FIGURE 89: G- DIAGRAM DUE TO LM1-C.

Settlement envelope 5mm.

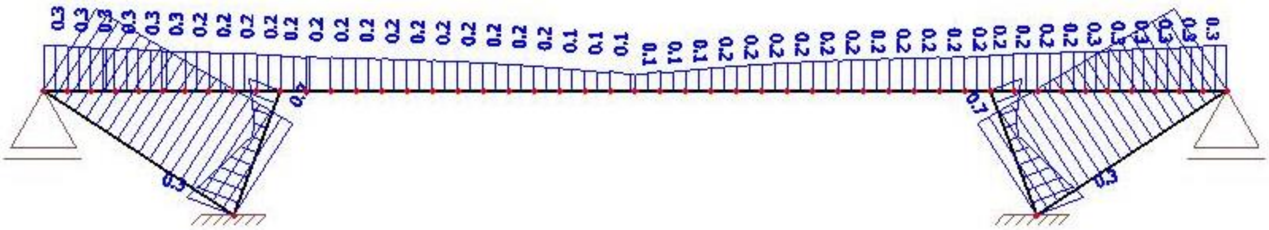


FIGURE 90: G+ DIAGRAM DUE TO SETTLEMENT ENVELOPE 5MM.

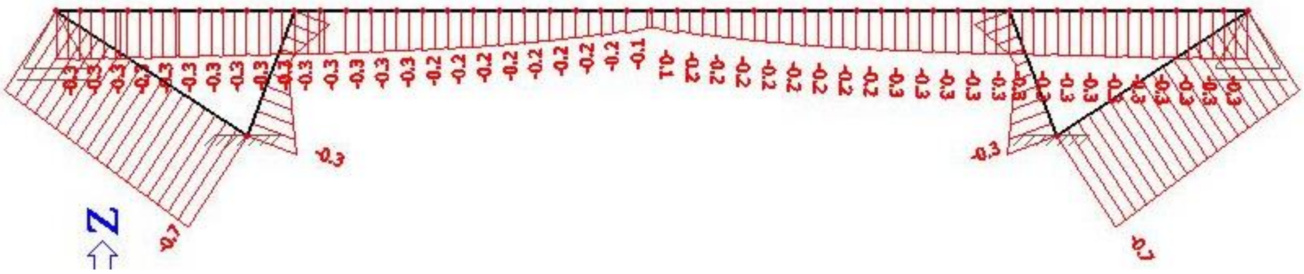


FIGURE 91: G- DIAGRAM DUE TO SETTLEMENT ENVELOPE 5MM.

Preliminary Stress Analysis.

The stresses that will be considered are the normal stresses; this will be affected by bending moments and axial forces only. Table 14 has the summary of the stresses obtained by the Scia engineering program when the center of gravity is on top in the program. The plus sign will refer to the top fibers stresses and the negative to the bottom fibers stresses.

		STRESSES (Mpa) SCIA						
		Section						
	Load	0	10	20	30	40	50	60
G+	Selfweight	-0.8	5.4	16.2	-19.3	16.2	5.4	-0.8
	superimposed load	0	0.4	1.2	-1.4	1.2	0.4	0
	T+ (20k)	-2.3	-2.2	-1.6	-0.2	-1.6	-2.2	-2.3
	T- (20K)	2.3	2.2	1.6	0.2	1.6	2.2	2.3
	LM1.1	-0.1	1.3	3.7	-4.7	3.7	1.3	-0.1
	LM1.2	0	1.2	3.3	-3.9	3.3	1.2	0
	LM1.3	0	0.8	3.3	-3.8	3.3	0.8	0
G-	Selfweight	1.3	-7.2	-29.4	16.3	-29.4	-7.2	1.3
	superimposed load	0	-0.5	-2.1	1.2	-2.1	-0.5	0
	T+ (20k)	0.6	0.8	-1.2	-4.1	-1.2	0.8	0.6
	T- (20K)	-0.6	-0.8	1.2	4.1	1.2	-0.8	-0.6
	LM1.1	0	-1.8	-6.4	4.4	-6.4	-1.8	0
	LM1.2	0	-1.6	-5.9	3.5	-5.9	-1.6	0
	LM1.3	0	-1.1	-5.8	3.5	-5.8	-1.1	0

Tabla 14 STRESSES BY SCIA CG TOP

We hand calculated the stresses for the cross sections, this will be a comparison between them, using the internal forces obtained with the computer, table 15 shows our results.

		STRESSES (Mpa) BY HAND CALCULATION						
		Section						
	Load	0	10	20	30	40	50	60
G+	Selfweight	-0.84	-4.82	-6.64	-25.93	-6.64	-4.82	-0.84
	superimposed load	0.00	-0.36	-0.50	-1.98	-0.50	-0.36	0.00
	T+ (20k)	-0.15	-0.26	1.31	5.21	1.31	-0.26	-0.15
	T- (20K)	-0.15	-0.26	1.31	5.21	1.31	-0.26	-0.15
	LM1.1	-0.02	-1.16	-1.54	-6.85	-1.54	-1.16	-0.02
	LM1.2	-0.01	-1.06	-1.40	-5.48	-1.40	-1.06	-0.01
	LM1.3	-0.01	-0.74	-1.40	-5.45	-1.40	-0.74	-0.01
G-	Selfweight	1.28	6.65	16.30	45.01	16.30	6.65	1.28
	superimposed load	0.02	0.50	1.14	3.32	1.14	0.50	0.02
	T+ (20k)	2.75	2.51	1.28	6.42	1.28	2.51	2.75
	T- (20K)	2.75	2.51	1.28	6.42	1.28	2.51	2.75
	LM1.1	0.09	1.62	3.53	11.24	3.53	1.62	0.09
	LM1.2	0.02	1.44	3.22	9.22	3.22	1.44	0.02
	LM1.3	0.03	1.02	3.19	9.12	3.19	1.02	0.03

Tabla 15 HAND CALCULATION CG TOP

As we can see on both tables the mayor stresses are located on cross section 20, 30, 40. This shows us that those cross sections need to be taken in consideration in every step of the design, this are the ruling cross sections due to the stresses that are present on them.

Also, we need to consider that the cross sections are located on negative and positive bending moments, table 16 shows us the type of graph the stress has on the particular cross section, the letter A refers to compression on the bottom part of the cross section, B refers to compression on the top part of the cross section, C refers to pure compression on the cross section and D to pure tension. Figure 92 has the convention that will be used on this project.

		STRESS TYPE OF GRAPH						
		Section						
	Load	**0**	**10**	**20**	**30**	**40**	**50**	**60**
G	**Selfweight**	B	A	A	B	A	A	B
	superimposed loa	B	A	A	B	A	A	B
	T+ (20k)	B	B	C	C	C	B	B
	T- (20K)	A	A	D	D	D	A	A
	LM1.1	B	A	A	B	A	A	B
	LM1.2	B	A	A	B	A	A	B
	LM1.3	B	A	A	B	A	A	B

Tabla 16 STRESSES GRAPH TYPE CG TOP

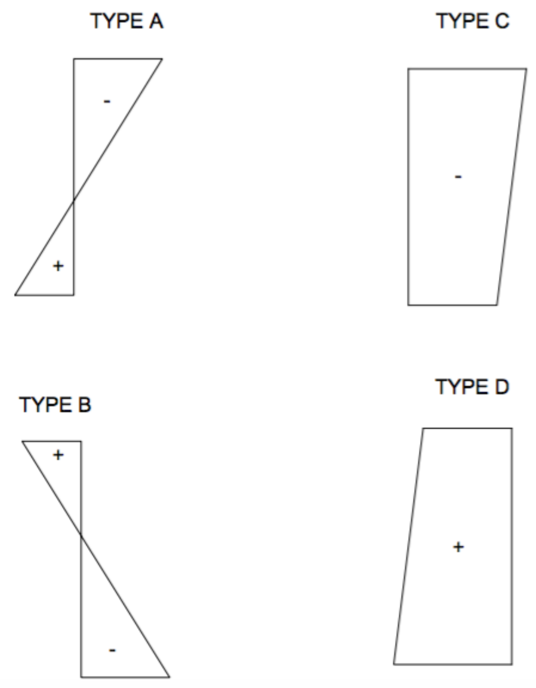


FIGURE 92: BENDING MOMENT STRESSES CONVENTION USED.

This table shows us that cross section 30 has, under the temperature loading, pure tension or pure compression, this is due to the fact that under temperature variations the concrete might shrink or expand, since its restrained this particular cross section will be under pure tension or compression. For T+ the cross section will be under pure compression since the concrete expands, since it can do physically the expansion, the beam will be compressed on the middle span, for T- is pure tension, is the same effect but with shrinkage. Sections 0 and 60 have pure tension under LM1.1, however the values are almost zero, so no big consideration needs to be made.

For the calculations by hand due to the center of gravity of the cross sections on the top fibers, we have these possible combinations, we have use numbers to refer and know the usage of each cross-section stresses under the bending moment and the axial forces. Table 17 refers to the resultant combinations, and figure 93 represents the convention used for the combinations.

	COMBINATION OF GRAPHS						
	Section						
Load	**0**	**10**	**20**	**30**	**40**	**50**	**60**
Selfweight	1	2	3	4	3	2	1
superimposed load	4	3	3	4	3	3	4
T+ (20k)	4	4	7	7	7	4	4
T- (20K)	2	2	6	6	6	2	2
LM1.1	4	3	3	4	3	3	4
LM1.2	4	3	3	4	3	3	4
LM1.3	4	3	3	4	3	3	4

Tabla 17 COMBINATIONS USED FOR STRESSES CG TOP

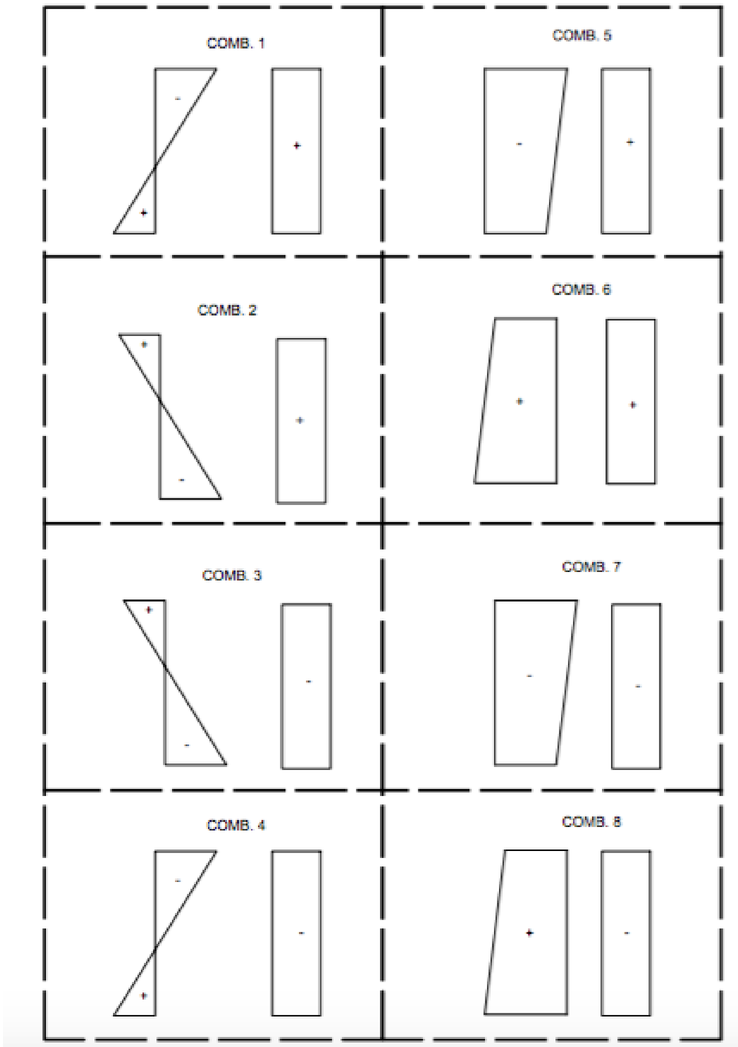


FIGURE 93: COMBINATION NORMAL STRESSES CONVENTION USED.

Deformations.

After imputing the data in the Scia Engineering program, we run our first calculation, we obtain a maximum translation of 386 mm under selfweight only, characteristic. This value is within the limits established by Eurocode.

Construction Stages

In this part of the design we will try to understand how the bridge functions under the different loading that we will have present. For that we will explore different options in the bridge to see which are the best options for design. As we know, the construction part of a project may rule sometime the procedure of design, as a designer we need to consider all possibilities and we need to make it functional for construction during each stage of it. In this specific part of the thesis we will focus on every step to make the bridge functional, we will design the prestress for construction, and propose the best way to build it on situ, considering the problems we can face due to the canyon geography.

Proposed calendar.

The Scia engineering program requires to input data that refers to time, loads, and factors that will affect the time dependent analysis, with this tool we will be able to consider creep of concrete in time and have a more accurate analysis for a better design of the bridge. We will recreate the process of construction on each stage, until the bridge is in service. As a first step we propose the next calendar for the construction process. We will assume that the process established here will be done at the same time in both ends of the valley, the beam will be connected at Section 30.

1. Stage 1 (tie element and foundation construction) time expected 57.5 days.

   a. Earth movement.
   b. Foundation casting.
   c. Tie element steel scaffolding installation.
   d. Tie element casting.
   e. Abutment steel installation.
   f. Abutment scaffolding.
   g. Abutment casting.
   h. Abutments dry out.
2. Stage 2 (strut element construction) time expected 64 days.
   a. Steel installation.
   b. Installation of movable scaffolding.
   c. Casting of the element.
   d. Scaffoldings removal.

This process will be repeated until the strut element is completed, we will assume each cast will be of 2.5 meters height. The scaffolding will be supported in the Tie element by tendons.

3. Stage 3 (D1.1-D1.10) time expected 130 days
   a. Formwork installation for U shape of the section.
   b. Casting of the U shape of the section.
   c. Water dry-out.
   d. Removal of formwork after concrete reaches resistance needed expected 85% resistance.
   e. Installation of moving scaffolding for the slab.
   f. Casting of slab.

g. Slab water dry out.

h. Movement of formwork.

Process a, b, c, d will be done as a first step, once the whole section reaches the minimum compression resistance of concrete process d can be done. Process e and f will be done once the U shape formwork is remove on each part that the beam scaffolding will cast.

4. Stage 4 (D1-D10) time expected 126 days

   a. Installation of the movable formwork.

   b. Casting of the U shape.

   c. Casting of the slab.

   d. Dry out of concrete.

   e. Prestress of concrete.

   f. Movement of the Scaffolding.

This process will be reflected 14 times until the beam is connected between the two sides.

As we can see on table 18, we are expecting a total time of construction of 377.5 days. This will cover half of the bridge, however since its done from both sides of the valley at the same time, two different construction teams are needed until final connection of lamellas 14.

Calendar day proposal				
	Substage	Description	Days	total days
Stage 1	A	Earth movement	20	22
		Foundation casting	2	
	B	Tie element steel and scaffolding installation	5	5.5
		Tie element casting	0.5	
	C	Abutment steel installation	5	30
		Abutment formwork installation	2	
		Abutment casting	2	
		Abutment dry out	21	
Stage 2	A	Steel installation	1	64
		Movable scaffolding installation	0.5	
		Casting of the element	1	
		Water dry out	1	
		Scaffolding removal	0.5	
Stage 3	A	Steel and formwork installation u shape	2	70
		Casting of the u shape	1	
		Water dry out	3	
		Removal of formwork	1	
	B	Installation of moving scaffolding for the slab	1	60
		Casting of Slab	1	
		Slab water dry out	3	
		Movement of formwork	1	
Stage 4	A	Installation of the movable formwork, steel and ducts	2	126
	B	Casting of the u shape	1	
	C	Casting of the slab	1	
	B&C	Dry out concrete	3	
	D	Presstressing	1	
	E	Movement of scaffolding	1	
				377.5

Tabla 18 PROPOSED CALENDAR FOR CONSTRUCTION STAGES

Load cases on Construction Stages

The Scia engineering program will require load cases present on each stage, based on the calendar we can divide each load case between steps. The load cases present on each of them will be establish here, so is the name convention for each of the construction stages.

1. Stage 1 (tie element and foundation construction).
   a. Formwork + Casting
   b. Water Dry
2. Stage 2 (strut element construction).
   a. Scaffolding + Casting

   b. Water Dry out.
   c. Scaffolding removal.
3. Stage 3-A (D1.1).
   a. Scaffolding+Casting
   b. Water dry out.
   c. Scaffolding Removal.
4. Stage 3-B (D1.2).
   a. Scaffolding+Casting
   b. Water dry out.
   c. Scaffolding Removal.
5. Stage 3-C (D1.3).
   a. Scaffolding+Casting
   b. Water dry out.
   c. Scaffolding Removal.
6. Stage 3-D (D1.4).
   a. Scaffolding+Casting
   b. Water dry out.
   c. Scaffolding Removal.
7. Stage 3-E (D1.5).
   a. Scaffolding+Casting
   b. Water dry out.
   c. Scaffolding Removal.
8. Stage 3-F (D1.6).
   a. Scaffolding+Casting

    b. Water dry out.
    c. Scaffolding Removal.

9. Stage 3-G (D1.7).
    a. Scaffolding+Casting
    b. Water dry out.
    c. Scaffolding Removal.

10. Stage 3-H (D1.8).
    a. Scaffolding+Casting
    b. Water dry out.
    c. Scaffolding Removal.

11. Stage 3-I (D1.9).
    a. Scaffolding+Casting
    b. Water dry out.
    c. Scaffolding Removal.

12. Stage 3-J (D1.10).
    a. Scaffolding+Casting
    b. Water dry out.
    c. Scaffolding Removal.

13. Stage 4-A (D1)
    g. Movable Scaffolding+Casting.
    h. Water dry out.
    i. Prestress of lamella.
    j. Formwork removal.

5. Stage 4-B (D2)

   a. Movable Scaffolding+Casting.
   b. Water dry out.
   c. Prestress of lamella.
   d. Formwork removal.

6. Stage 4-C (D3)
   a. Movable Scaffolding+Casting.
   b. Water dry out.
   c. Prestress of lamella.
   d. Formwork removal.
7. Stage 4-D (D4)
   a. Movable Scaffolding+Casting.
   b. Water dry out.
   c. Prestress of lamella.
   d. Formwork removal.
8. Stage 4-E (D5)
   a. Movable Scaffolding+Casting.
   b. Water dry out.
   c. Prestress of lamella.
   d. Formwork removal.
   e.
9. Stage 4-F (D6)
   a. Movable Scaffolding+Casting.
   b. Water dry out.
   c. Prestress of lamella.

d. Formwork removal.

10. Stage 4-G (D7)

    a. Movable Scaffolding+Casting.
    b. Water dry out.
    c. Prestress of lamella.
    d. Formwork removal.

11. Stage 4-H (D8)

    a. Movable Scaffolding+Casting.
    b. Water dry out.
    c. Prestress of lamella.
    d. Formwork removal.

12. Stage 4-I (D9)

    a. Movable Scaffolding+Casting.
    b. Water dry out.
    c. Prestress of lamella.
    d. Formwork removal.

13. Stage 4-J (D10)

    a. Movable Scaffolding+Casting.
    b. Water dry out.
    c. Prestress of lamella.
    d. Formwork removal.

14. Stage 4-K (D11)

    a. Movable Scaffolding+Casting.
    b. Water dry out.

c. Prestress of lamella.

d. Formwork removal.

15. Stage 4-L (D12)

a. Movable Scaffolding+Casting.

b. Water dry out.

c. Prestress of lamella.

d. Formwork removal.

16. Stage 4-M (D13)

a. Movable Scaffolding+Casting.

b. Water dry out.

c. Prestress of lamella.

d. Formwork removal.

17. Stage 4-N (D14)

a. Movable Scaffolding+Casting.

b. Water dry out.

c. Prestress of lamella.

d. Formwork removal.

Table 19 shows the proposed calendar in days to put as factors in the program Scia.

Calendar day factors proposal Scia		
Stage	Description	Days
1	Formwork + casting	9
	Water dry out	21
2	Scaffolding + casting	2.5
	Water dry out	1
	Scaffolding removal	1
3	Scaffolding + casting	3
	Water dry out	3
	Scaffolding removal	1

4	Movable Scaffolding + casting	4
	Water dry out	3
	Prestress	1
	Formwork removal	1

Tabla 19 DAY PROPOSAL FACTORS SCIA

Weight Calculation and Load Proposal

We will calculate the weight of scaffolding, wet concrete and dry concrete for each section so we can input the data on the program. We will use a value of 10 KN/m3 for scaffolding, for wet concrete 27 KN/m3, and for dry concrete a value of 25 KN/m3. The next table shows the results obtained, and the data that will be inputted on the program to run the analysis of construction stages.

CONCRETE WEIGHT IMPUT AT SCIA (kN/m)				
Stage	substage			
	A-Sf+C	B-WD	C-Wd+P	D-Fw-
3-A-D1.1	405.77	391.11	N/A	-10
3-B-D1.2	420.13	404.94	N/A	-10
3-C-D1.3	435.41	419.66	N/A	-10
3-D-D1.4	448.83	432.58	N/A	-10
3-E-D1.5	464.55	447.71	N/A	-10
3-F-D1.6	478.80	461.44	N/A	-10
3-G-D1.7	492.14	474.28	N/A	-10
3-H-D1.8	506.42	488.04	N/A	-10
3-I-D1.9	521.57	502.62	N/A	-10
3-J-D1.10	535.93	516.45	N/A	-10
4-A-D1	535.93	516.45	516.45	-10
4-B-D2	526.13	507.02	507.02	-10
4-C-D3	516.12	497.37	497.37	-10
4-D-D4	506.31	487.93	487.93	-10
4-E-D5	496.27	478.26	478.26	-10
4-F-D6	486.47	468.82	468.82	-10
4-G-D7	476.45	459.18	459.18	-10
4-H-D8	466.65	449.74	449.74	-10
4-I-D9	456.63	440.09	440.09	-10
4-J-D10	446.83	430.65	430.65	-10
4-K-D11	436.76	420.96	420.96	-10
4-L-D12	426.88	411.44	411.44	-10
4-M-D13	416.35	401.30	401.30	-10
4-N-D14	406.63	391.94	391.94	-10

Tabla 20 WEIGHT IMPUTS SCIA PER LAMELLA

The Scia program for construction stages supports different options of construction of a bridge, in our case, the proposal will be the construction of the triangular frame with a stationary formwork, cast in situ and after 28 days will be removed, however in the program we will try to imputed as lamellas to have better understanding of the effects at each stage.

For the 210-meter beam where the construction will be held under unbalanced cantilever method, we will use the same procedure. However, the loads will be different in this case. It's important to notice that each stage will have 4 sub stages, where the loads will be input manually.

Stage 1 Casting and Formwork

In this stage we will add the weight of wet concrete as a distributed load. 10 KN/m of scaffolding along the whole lamella is also considered plus we will consider a point force of 100 KN on the previous node of each lamella to replicate a proper weight of the scaffolding. Figure 94 represents the load case.

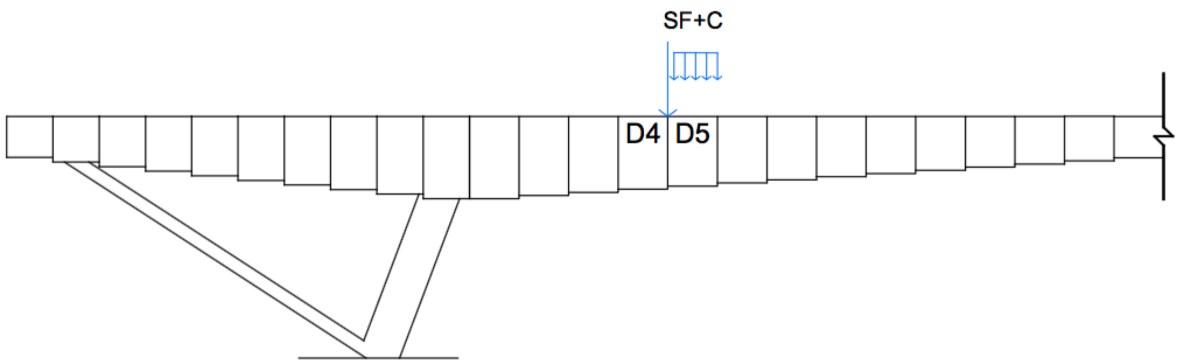


FIGURE 94: LOAD CASE 1 FOR CONSTRUCTION STAGES

Stage 2 Water Dry out

In this part we will replicate the drying of concrete after 3 days, we assume that the concrete will dry out by 1kN/m3. At this point the movable scaffolding is still present so the distributed load and the point force that represents this load case are input. Figure 95 represents the load case. As we can see on table 20, the values are smaller than previous stage 1.

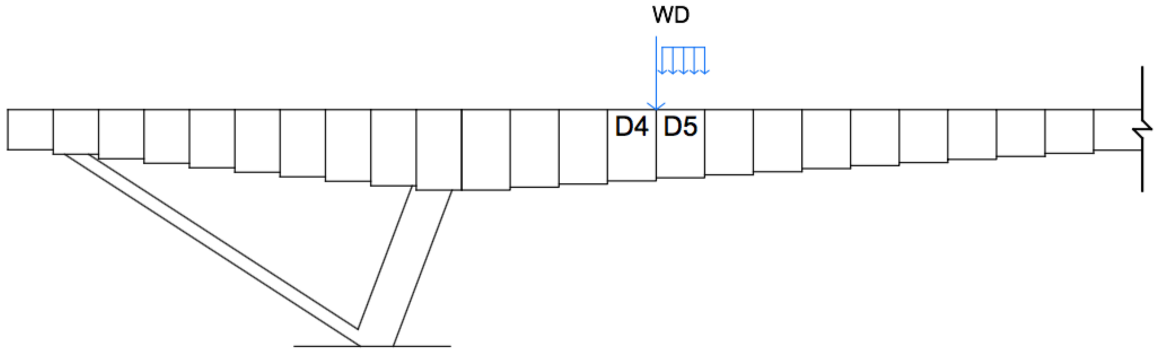


FIGURE 95: LOAD CASE 2 FOR CONSTRUCTION STAGES

Stage 3 Prestress

We will add the prestress at this point; we expect that at this time the concrete reach at least 85% of its fck. The concrete weight will be the same as the previous stage, however we put it in the load case so it can be present, for this we keep the same distributed load. Besides that, we will add the corresponding prestress to reduce the tension fibers on the top fiber of each lamella. The scaffolding will still be present so we consider these loads still. Figure 96 represents the load case. It's important to notice that at this point we have input a cable to simulate the prestress, however we will not input the prestress data, this way we can have the initial values for an appropriate design of them. We need to remember that at this point we need to find out how the bridge will behave during the construction phases.

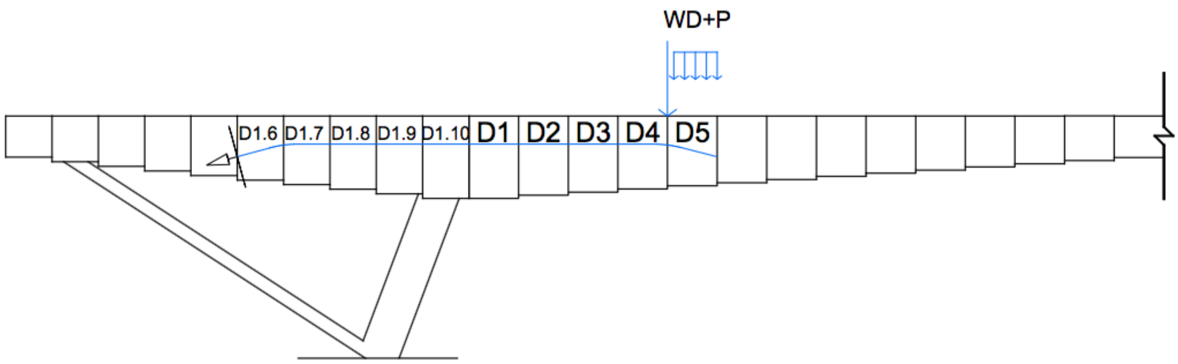


FIGURE 96: LOAD CASE 3 FOR CONSTRUCTION STAGES

First tendon design

As seen on the investigation on this project made in the introduction we need to put the tendons for construction stages on the top fibers for the construction stages. We propose this first tendon layout, as we can see on figure 97, we have place the beginning of each tendon on the center of gravity of the cross section, we assume a 3-5-meter radius on most of them as a first try. Since we have 14 unbalanced lamellas and only 10 lamellas on the triangular section, all first 10 lamellas will have the same shape, and they will be separated between each 100 mm, this will cover the minimum distance stated by Eurocode, which is the same value as the pipe tendon diameter. Again, this is a first layout to see if the proposal works, after we have a positive result we will focus on a proper design that is a mix between an accurate and a optimized solution.

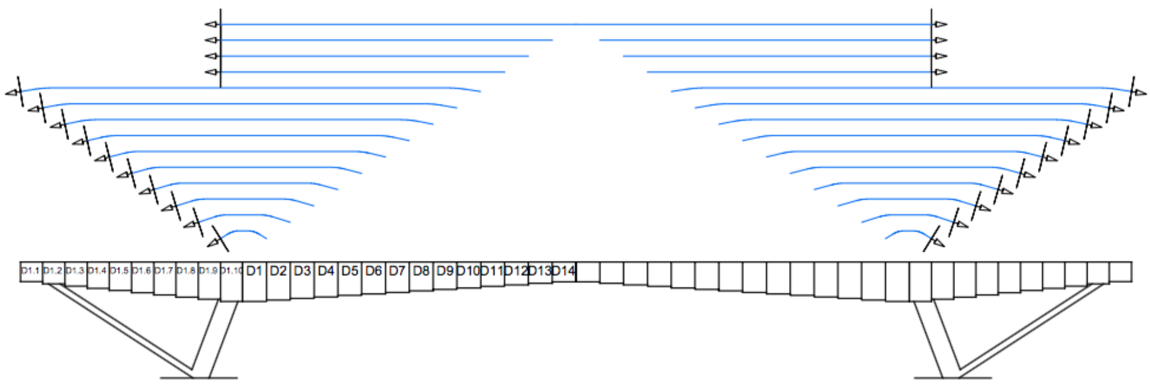


FIGURE 97: TENDON LAYOUT PROPOSAL TENDONDS 1-10

As we can see in the graphs, tendons 11-14 are straight, this will continue until lamella D.10 where it will be anchored. Tendons from 1-10 are parabolic as stated before, and it will anchor in the mirrored lamella from the triangular part. For example, tendon 5 will anchor on tendon D.5 and lamella D1.5. The tendons layout will be replicated on both sides of the bridge.

Stage 4 Scaffolding removal

At this stage we will remove the Scaffolding, distributed load will be taken out and the point force too, so we will put the same forces upward to replicate it. Figure 98 represents the load case.

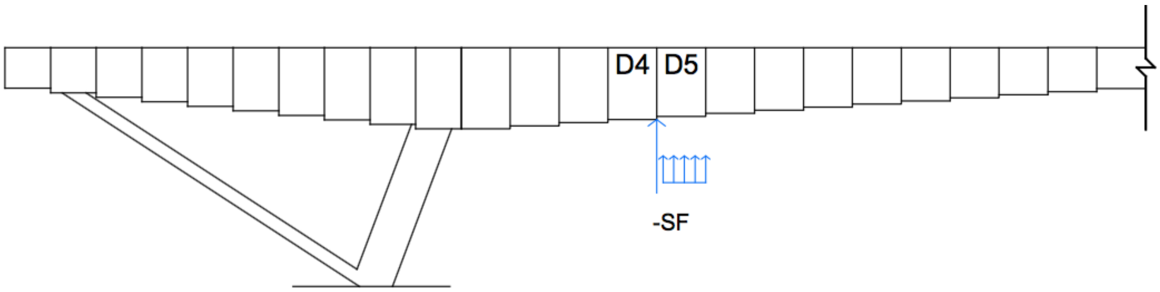


FIGURE 98: LOAD CASE 4 FOR CONSTRUCTION STAGES

Results and analysis-Knowing the bridge.

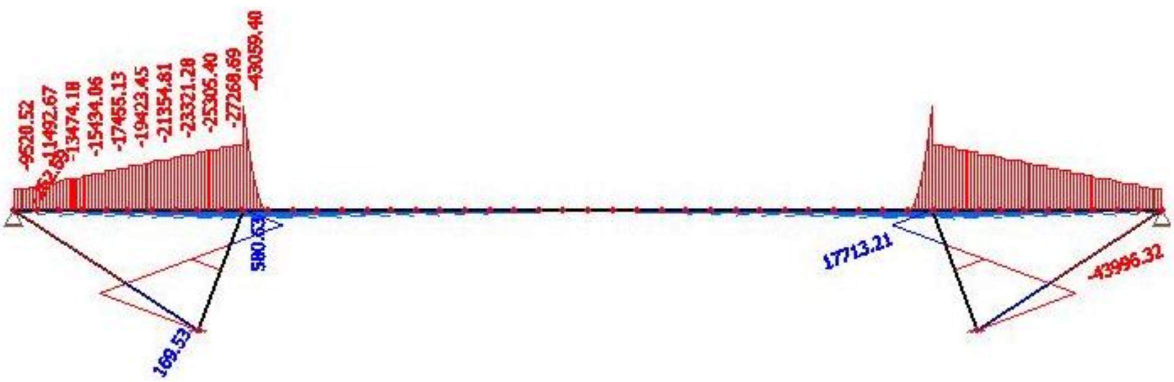


FIGURE 99: MOMENT DIAGRAM FOR LAMELLA 1.

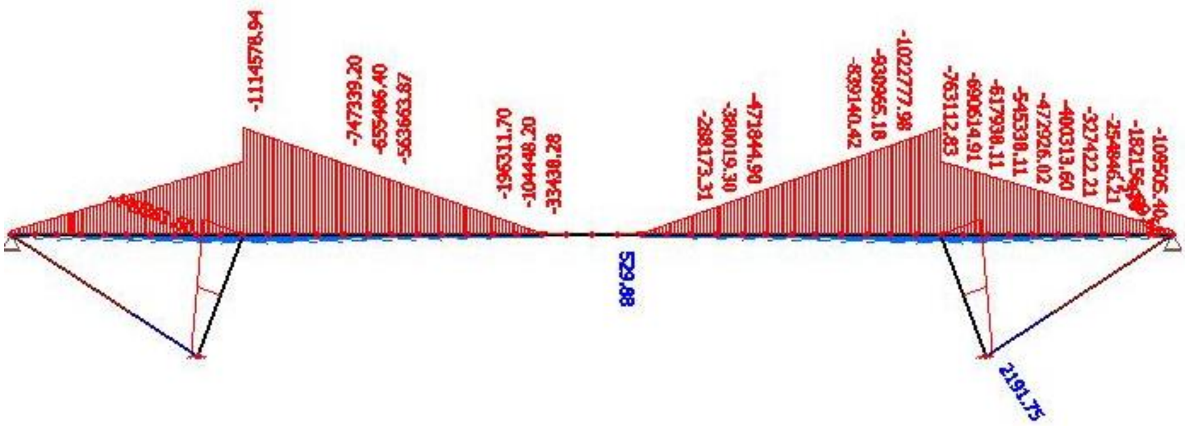


FIGURE 100: MOMENT DIAGRAM FOR LAMELLA 13.

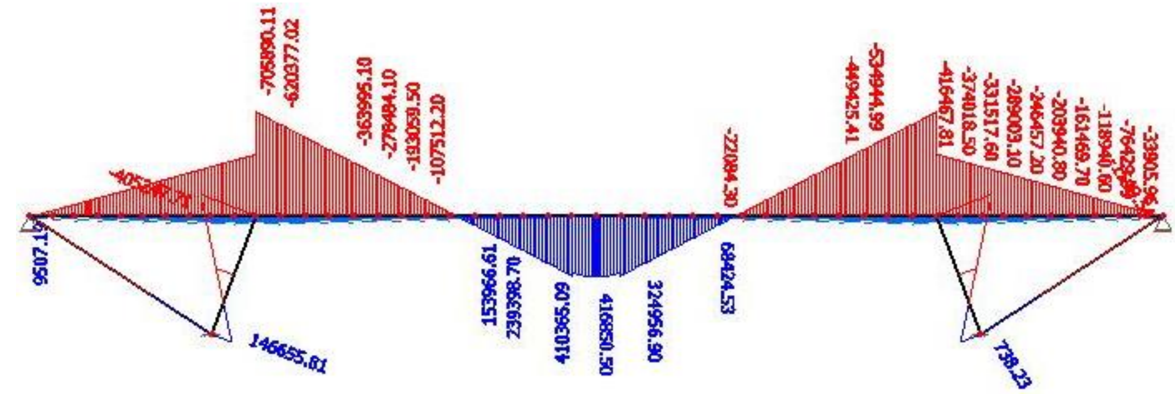


FIGURE 101: MOMENT DIAGRAM FOR LAMELLA 14.

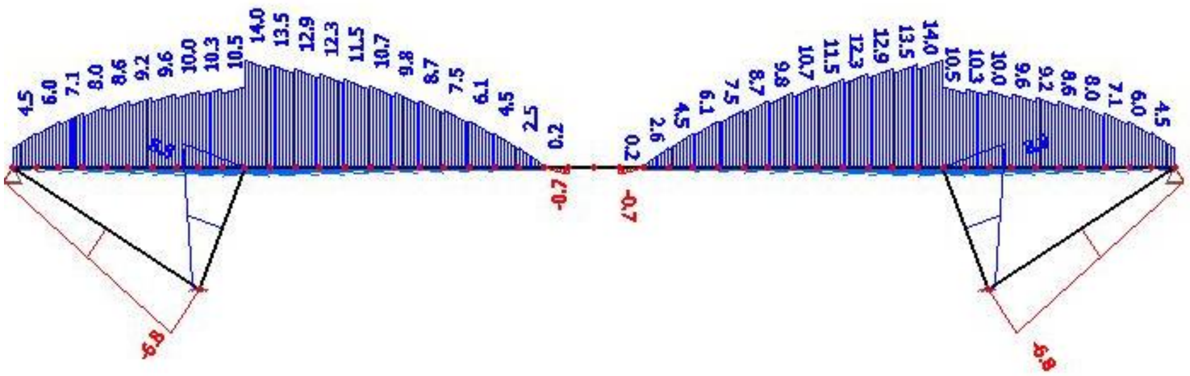


FIGURE 102: TOP FIBER TENSION LAMELLA 13.

FIGURE 103: STRESS MOMENT DIAGRAM WITH ERROR

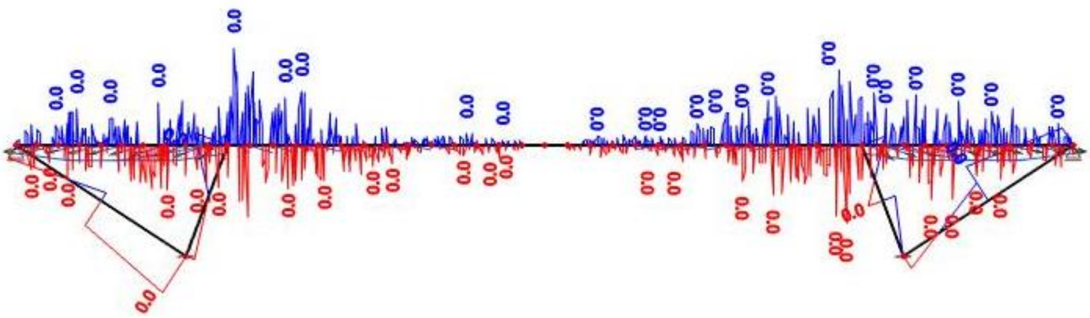


FIGURE 104: STRESSES RESULTS EXAMPLE ON PRE-STAGE WD.

The first results we obtain show us that the model heads up through the right direction, the shapes of the moment diagrams are what we are expecting. Figure 99, 100 shows how the progress of the moments is made under the development of each lamella. In figure 101 we can see that the lamellas on the center join, reason why the moment diagram on shows a redistribution of the internal forces as expected, this is the effect we try to replicate with the unbalance cantilever method in the program, these results show we are heading through the right direction. However, we encountered some possible problems on them. As we can see on figure 99, where we show the diagram moments, we can see that there is a jump on the lamella 1, this repeats on each lamella shown, figure 101 has the same effect on lamella 13. This jump is located where we were expecting the biggest moments, the connection between the three elements node, we can see that as we expected the strut member is holding part of the moment diagram, however gives as a first flag that some information inputted on the program may not correct since the values will not add up.

Another problem we encountered is that the information we are obtaining is not as expected, we can see that the bridge calculation is not giving us any data during the stages of construction 1,2, and 3. The values we obtain are nearly zero as shown on figure 104. This is due to the fact that formwork is present, eliminating the internal forces on those stages.

After we see the graphs obtained, we can see that the solution of cables we apply might be correct, we can see that the moments are mainly focused on the top part as a cantilever beam, reason why during the construction phases need to be focused on the top fibers, the tendons have to be placed on the top fibers so we can reduce the tension on them, our goal will be to reduce them to zero, or in different cases we will try to keep them between the limits accepted on the Eurocode. However, is important to notice that we need to stay within the compression limits in the bottom fibers, is usual that if we lose prestress on the top fibers, bigger compression can be expected in the bottom fibers.

Other problem encountered is that when we focus on the stress fibers on the triangular frame only, we can see that the graph obtained only shows part of it as seen on figure 103, having zero values on most part of it, this shows us some data input is not correct on the program.

Figure 102 shows us that the tensions on the top fibers on stage 13 are in a value too high for the concrete resistance, this graph also shows us how much prestress should cover for us to have a good design of the bridge, we need to remind that the values along the whole beam has to be 0 to be ideal, otherwise the tension has to be below the tensile limits.

Solutions of the problems encountered on our first attempt.

For the jump in the moment diagrams, as a first assumption we consider is the point force on the nodes that will affect the diagram, however we will not change this since it replicates the scaffolding and show us a replica of what it has done. We consider it as a not big problem, however is something we need to take in consideration in the further attempts. We will find solution for this later in the project. We will mainly focus on being able to design the prestress and have an accurate number of tendons and correct shape of them. Once we have this, the solution proposed would be inputting the whole data of the weight load on the previous node as a point force that can be replicated on it. Once we apply the prestress on the lamella, we will then replicate the same values on them. We assume the jump present on figure 99 and 100, is big so we expect the elimination or great diminution after we input the new loads, which is the solution we found for the other problems encountered that will be explained later on.

The values of moments being too big from what we were expecting we found as a possible solution after some investigation, we realize that the program add the loads, reason why each time we put a load it adds to the previous. We will change the weight calculation and load proposal to what is shown on table 21. This way we will try to replicate the behavior and the main changes will be on the reduction of the water dry out of the casting, adding the prestress and removing the movable scaffolding.

CONCRETE WEIGHT IMPUT AT SCIA (kN/m)				
Stage	substage			
	A-Sf+C	B-WD	C-Wd+P	D-Fw-
3-A-D1.1	405.77	-14.66	N/A	-10.00
3-B-D1.2	420.13	-15.19	N/A	-10.00
3-C-D1.3	435.41	-15.76	N/A	-10.00
3-D-D1.4	448.83	-16.25	N/A	-10.00
3-E-D1.5	464.55	-16.84	N/A	-10.00
3-F-D1.6	478.80	-17.36	N/A	-10.00
3-G-D1.7	492.14	-17.86	N/A	-10.00
3-H-D1.8	506.42	-18.39	N/A	-10.00
3-I-D1.9	521.57	-18.95	N/A	-10.00
3-J-D1.10	535.93	-19.48	N/A	-10.00
4-A-D1	535.93	-19.48	-19.48	-10.00
4-B-D2	526.13	-19.12	-19.12	-10.00
4-C-D3	516.12	-18.75	-18.75	-10.00
4-D-D4	506.31	-18.38	-18.38	-10.00
4-E-D5	496.27	-18.01	-18.01	-10.00
4-F-D6	486.47	-17.65	-17.65	-10.00
4-G-D7	476.45	-17.28	-17.28	-10.00
4-H-D8	466.65	-16.91	-16.91	-10.00
4-I-D9	456.63	-16.54	-16.54	-10.00
4-J-D10	446.83	-16.18	-16.18	-10.00
4-K-D11	436.76	-15.81	-15.81	-10.00
4-L-D12	426.88	-15.44	-15.44	-10.00
4-M-D13	416.35	-15.05	-15.05	-10.00
4-N-D14	406.63	-14.69	-14.69	-10.00

Tabla 21 WEIGHT IMPUT SCIA PER LAMELLA SOLUTION

Stage 2 loads

In this part we will reduce the load by 1kN/m3 since the concrete dries out, at this point the movable scaffolding is still present so it will be still present the point force and the distributed load that represents this load case. Figure 105 represents the new load case.

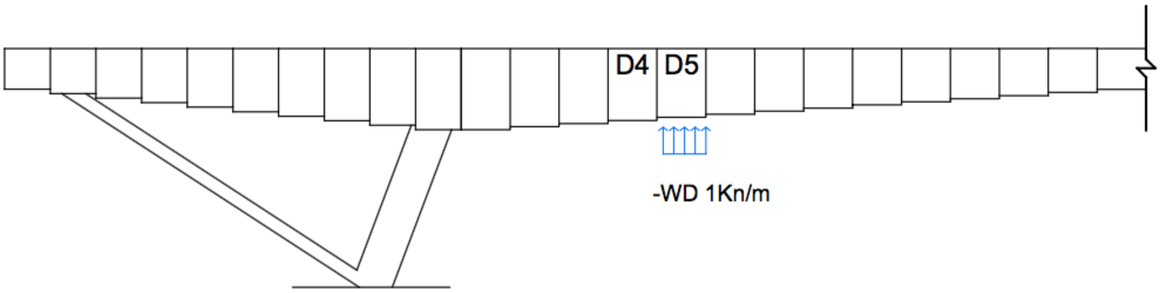


FIGURE 105: LOAD CASE 2 FOR CONSTRUCTION STAGES

Stage 3 loads

We will add the prestress, the concrete weight reduction will be the same as the previous stage, this way we will reach finally to a concrete weight of 25 KN/m. It has been done in two stages since the program obligates us to input a permanent load. Besides that, we will add the corresponding prestress to reduce the tension fibers. The scaffolding will still be present so we consider these loads still. Figure 106 represents the new load case.

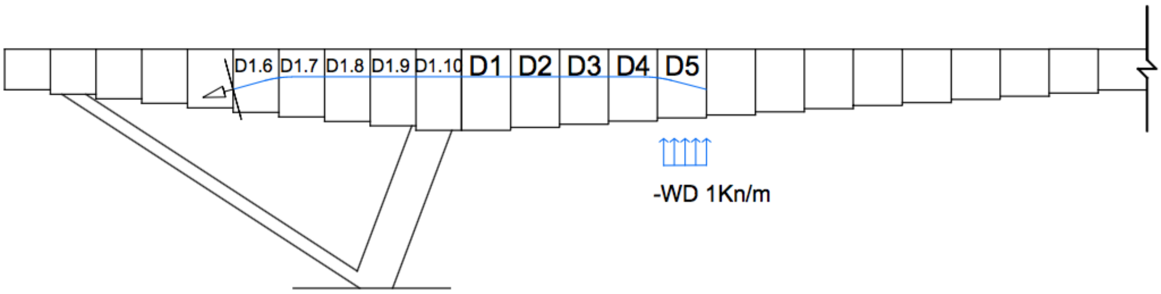


FIGURE 106: LOAD CASE 3 FOR CONSTRUCTION STAGES

Stress on triangular frame

To correct the stress problems on the triangular stiffed frame part of the bridge, we discover the problem is present on the beam settings; I will try to simulate the construction of the beam with the permanent scaffolding, having to be retiring after 28 days of the cast of each D1.x lamella. The timeline on the program shows us that the scaffolding is present still during the next stages of the unbalanced cantilever construction, reason why we will reduce the days for the scaffolding to be removed, we will have a different day on each of the lamellas so for the moment we will start the construction of the unbalanced lamellas, we obtain the results that we need of the triangular frame. With this solution we will have a limitation on reality, the limits for tension and compression on the top fibers will not reach 100%, we will have to calculate the limits for each period of time. Having the period of time of 7 days as the lowest once the last formwork is taken away from lamella D1.10, we introduce the next values for our concrete selected previously. These values will also be a referral to the unbalanced cantilever lamellas, since we consider 7 days of concrete cast when we retire stationary formwork.

Also, we are considering that we will have big stresses on this section once its arranged, reason why we will apply a prestress cable to, this will be imputed on sub stage 3 of Stage 3j-SF.

Stresses along the 210-meter beam.

As we can see on figure 102 the top fiber tensions which we need to reduce to a zero value are around 14 MPa, this value is high, however we plan to lower it with the application of the prestress as stated previously, this will still not be a design solution for us at the moment, however we will attempt to change the tendon layout.

Second Tendon Layout

As a second tendon layout, I will put all the ducts on the same level, distributed through the width of the cross section as shown on fig 107 and 108. This way we will compare if these values change for lower values, if this happens we will see lower stresses on the sections, If we obtain this new values, this will show us that the previous layout has been optimized. According to the theory this optimization will happen, it will be lowered since we are getting closer to the top fibers and replicating the moment diagram created by the cantilever method, where the main effects will happen during the construction stages. The distance we will place them at is 100 mm from the top fibers; this value is according to the Eurocode, which is the same distance as the diameter of the tendon duct. The new tendon layout that will be applied is shown from figure 109 to 110.

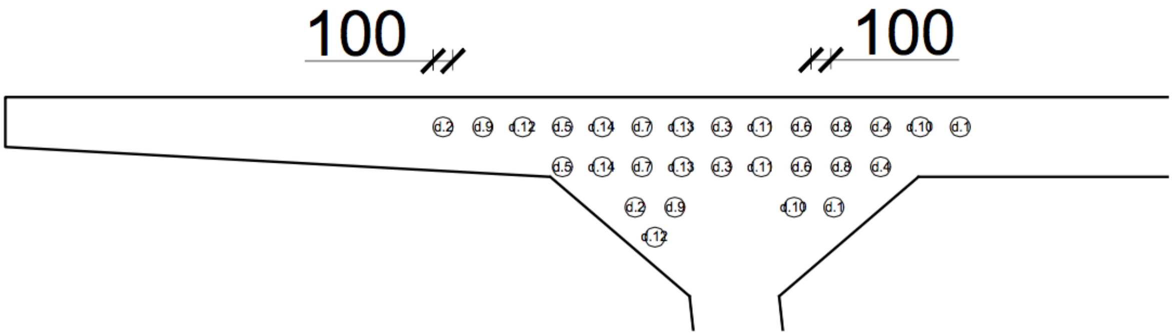


FIGURE 107: TENDON LAYOUT DISTRIBUTION IN THE CROSS SECTION LEFT SIDE

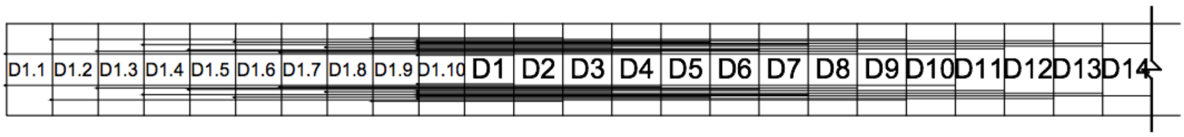


FIGURE 108: TENDON LAYOUT CONSTRUCTION STAGES VIEW FROM TOP OF THE BRIDGE

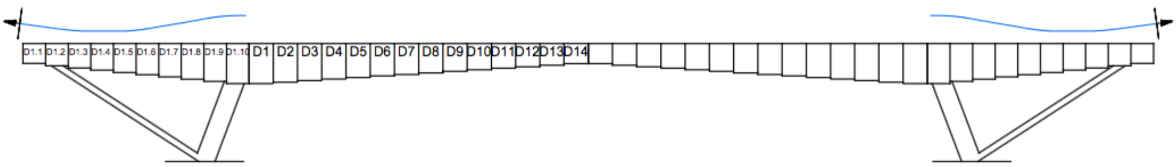


FIGURE 109: FIRST TENDON LAYOUT FOR TRIANGULAR FRAME

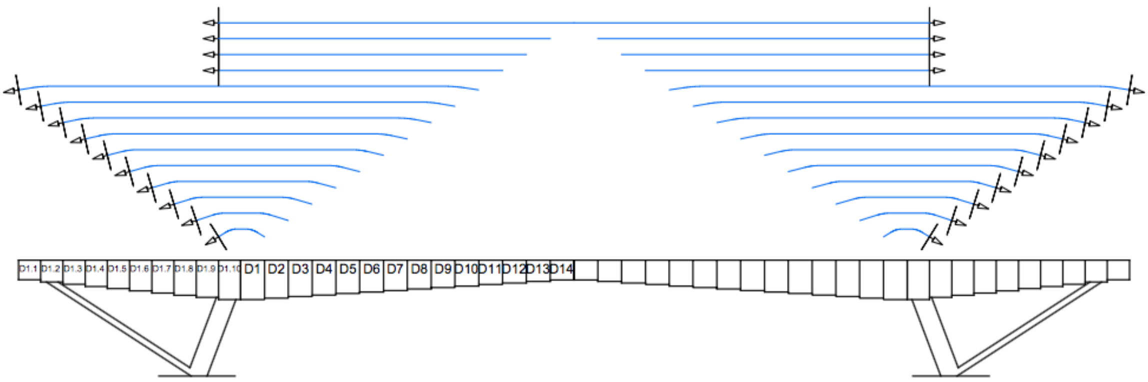


FIGURE 110: SECOND TENDON LAYOUT PROPOSAL

Equation for limits of stresses during construction stages

We will refer to Safar book (2015), where we will obtain the design compressive strength for concrete after 7 days, with concrete class R, which refers to rapid hardening, this will give us the limitations for the stresses on the top and bottom fibers, these values will have to be accomplished for us to consider a successful tendon design.

Since we have a concrete class R, our S value is 0.20.

$$B_{cc}(7) = \exp\left\{0.20\left[1 - \sqrt{\frac{28}{7}}\right]\right\} = 0.819.$$

Compression strength of concrete-7 days.

$$f_{ctm}(7) = B_{cc}(7) * fcm = 0.819 * 35 = 28.665\text{MPa}$$

$$f_{ck}(7) = f_{cm}(7) - 8 = 28.665 - 8 = 20.665 \text{ MPa}$$

Tensile strength of concrete at age 7 days.

$$f_{ctm}(t) = \left(B_{cc}(t)\right)^{\propto} * f_{ctm}$$

For a time less than 28 day of curing, Alfa should be considered as 1, since we are assuming 7 days after it will be prestress, we take those values.

$$f_{ctm}(t) = (0.819)^{1} * 3.2 = 2.62 \text{ MPa}.$$

Second Results and Analysis-Construction Stage Model Approval.

The results on this second attempt where we have made the previous changed proposed have shown us a better result. The next figures will be analyzed.

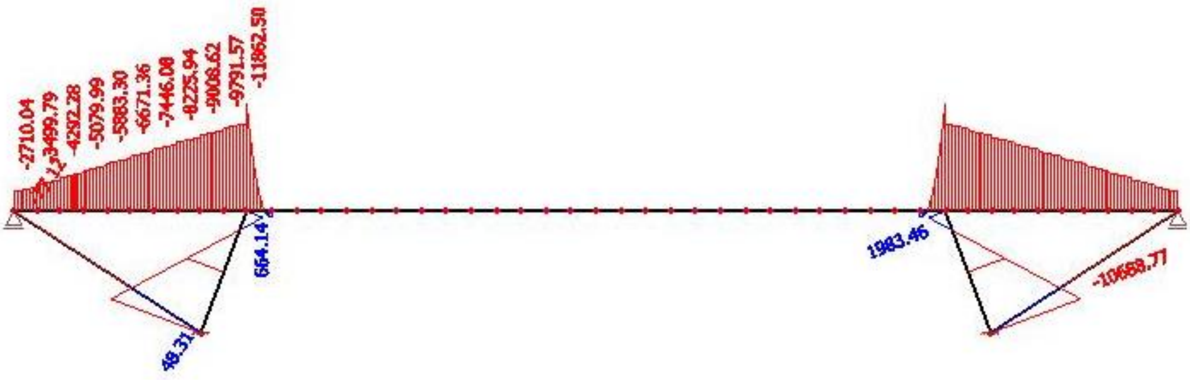


FIGURE 111: MOMENT DIAGRAM FOR LAMELLA 1.

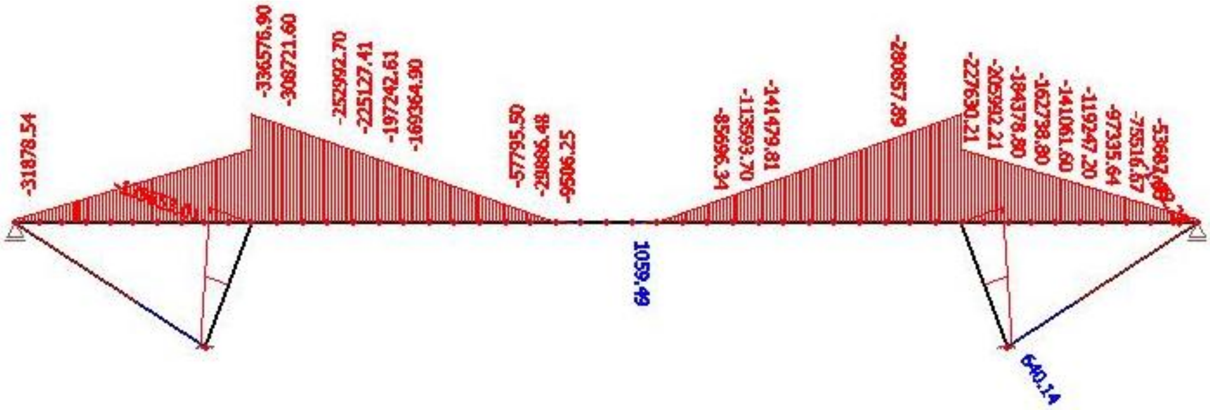


FIGURE 112: MOMENT DIAGRAM FOR LAMELLA 13.

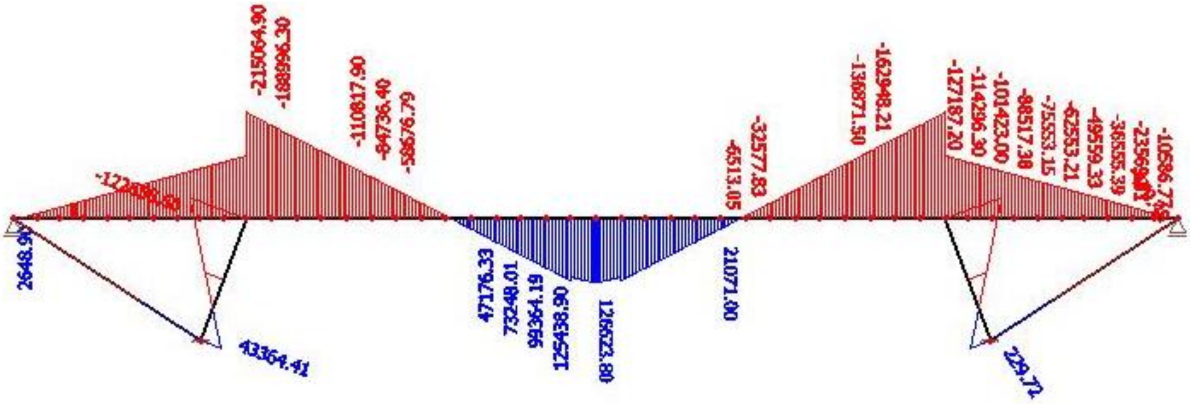


FIGURE 113: MOMENT DIAGRAM FOR LAMELLA 14.

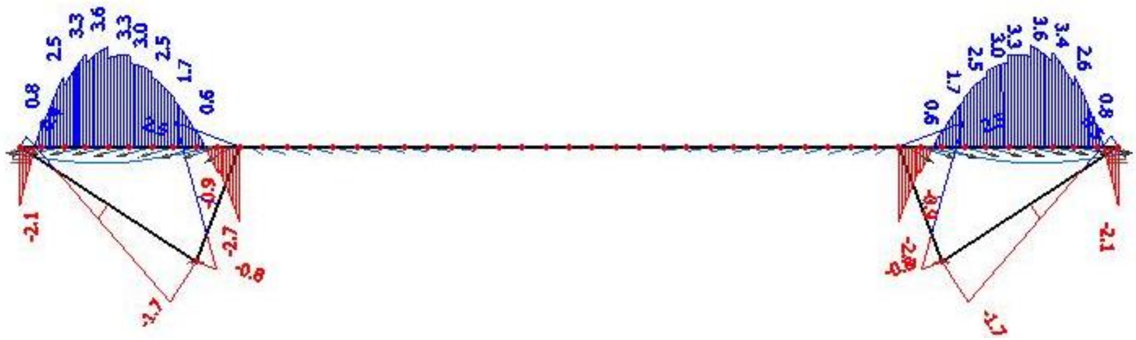


FIGURE 114: STRESS MOMENT DIAGRAM BOTTOM FIBERS

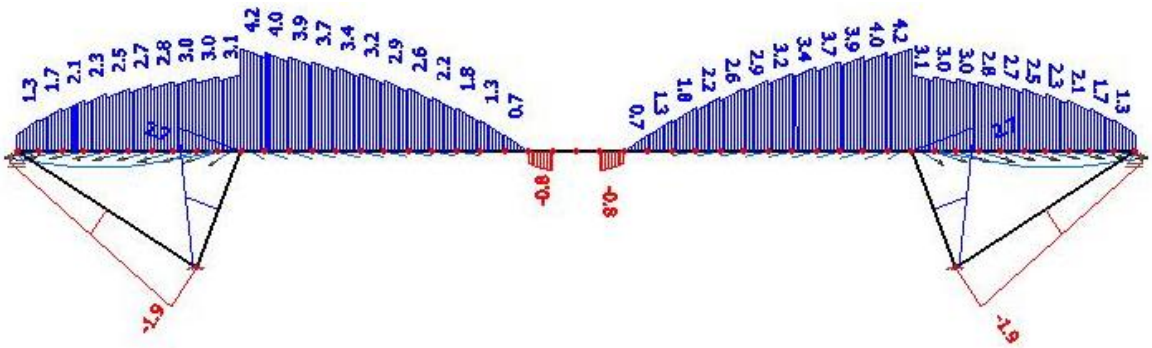


FIGURE 115: TOP FIBER TENSION LAMELLA 13 TENDONS LAYOUT CHANGES.

As we can see on figure 111 and 112, the moments present at this point have been reduce significative, on figure 444 we can see that the highest moment is -43059.40 KNm on figure 111, the final moment obtained is 11862,50 KNm, this is a clear indication that the loads change was correct, with these values reduced in about 4 times, we can see that the program was adding the loads in the time analysis.

When it comes to figure 113, we can see that it still has a redistribution of internal moments, the values have also been reduced, but the shape stays equal, is important to notice that the stage analyzed on this graph is lamella 14, so the final moments are not equal as the selfweight, since we haven't activated the final stage yet.

The stress fibers obtained on the triangular frame have been corrected, as we can see on figure 114, we have them present now, and as expected the bottom fibers have a significant value of tension, it is not covered by the concrete compression and tension strength. So, the cable layout proposed will work once is prestress.

As we can see on figure 115 the top fibers on the 210-meter beam have been reduced, this is partially due to the fact that the loads were reduced, however it also the fact that the new tendon layout helps to decrease the values. From this point on we will work with this layout to find a solution to the prestress.

With the data shown I will start an iteration of tendons to see how the structure works under the prestress.

Third Results-Tendon Iterations

This iteration was focused on introducing values to the tendons in the program and see how the structure behaves, we will see that there are several sub stages of iterations that need to be taken in consideration. This is due to the different conflicts I have faced during my tendon design. None of these iterations considers the final continuity cable, is only to analyze the construction stages.

First group of iterations-Triangular Frame data.

This first group of iterations once we confirmed the main focus was corrected and the results as expected had the main objective of knowing the behavior of the bridge with the tendon proposal that we are analyzing. In this subgroup I have encountered a main problem with the program input data. I will explain each of the iterations to show the process of recognition and solution of the problem encountered.

First iteration

This iteration was composed of no tendons, this was the base of calculation to have comparable results and table 22 shows us the summary of results obtained.

NO TENDONS APPPLY FIRST ITERATION														
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	TENDON OK
Stage 3	2	1	5.2	1.6	1	1	OK	2.9	4.5	1	0	CHANGE	CHANGE
Lamela 1	2	1	5	1.7	1	1	OK	3.1	4.4	1	0	CHANGE	CHANGE
Lamela 2	2	1	4.6	2.2	1	1	OK	3.6	4	1	0	CHANGE	CHANGE
Lamela 3	2	1	4.1	3	1	1	OK	4.4	3.6	1	0	CHANGE	CHANGE
Lamela 4	2	1	3.4	4	1	0	CHANGE	5.6	2.9	1	1	OK	CHANGE
Lamela 5	2	1	2.5	5.3	1	0	CHANGE	7.1	2	1	1	OK	CHANGE
Lamela 6	2	1	1.4	6.9	1	0	CHANGE	9.7	1	1	1	OK	CHANGE
Lamela 7	2	1	0.7	8.7	1	0	CHANGE	13	0	1	1	OK	CHANGE
Lamela 8	2	1	0.7	10.8	1	0	CHANGE	16.8	0	1	1	OK	CHANGE
Lamela 9	2	1	0.7	13.5	1	0	CHANGE	21	0	1	1	OK	CHANGE
Lamela 10	2	1	0.7	16.8	1	0	CHANGE	25.7	0	1	1	OK	CHANGE
Lamela 11	2	1	0.8	20.5	1	0	CHANGE	30.7	0	1	1	OK	CHANGE
Lamela 12	2	1	0.8	24.4	1	0	CHANGE	36.2	0	0	1	CHANGE	CHANGE
Lamela 13	2	1	0.8	26.6	1	0	CHANGE	42.1	0	0	1	CHANGE	CHANGE
Lamela 14	2	1	5	30.9	1	0	CHANGE	46.1	4	0	0	CHANGE	CHANGE

Tabla 22 SUMMARY OF STRESSES RESULTS-NO TENDONS APPLIED

The first important data that we need to pick from this tables that will be presented is the row that says Tendon Ok, every time it says change means that there is a rule that the prestress is not accomplishing. The data columns explain us the amount of prestress input on a cable. Then it separates to top fibers and bottom fibbers, these columns will get the maximum stress value in the whole structure for tension and compression.

From what we can see in this table from the beginning we will encounter a problem with the triangular frame, the values we start are not within the limits accepted by the concrete strength on tension and in compression. We plan to reduce these values by the prestress that will be applied. However, is important to notice that the structure has a value of compression of 56.1 MPa on lamella 14, this value is a combination created in the program where we add each previous effect of the prestress.

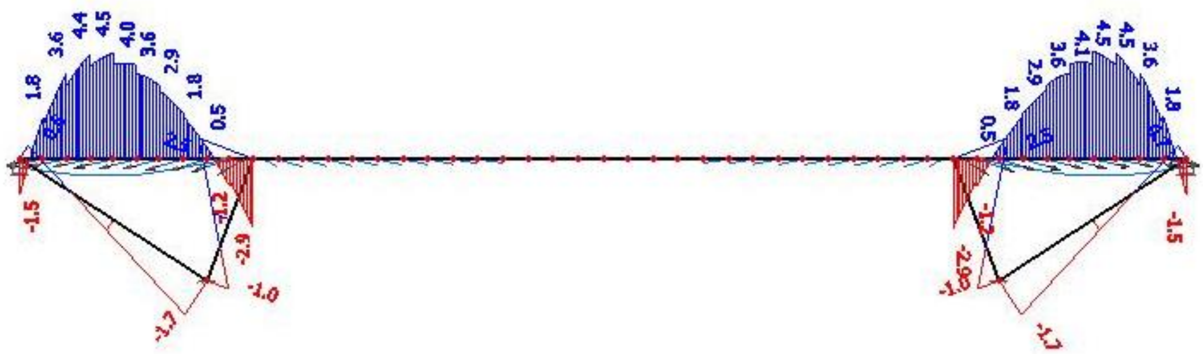


FIGURE 116: BOTTOM FIBERS NO TENDONDS STRESSES TRIANGULAR FRAME.

As we can see on figure 116 our tensions are present on the bottom part of the triangular area, we reach values of 4.5MPa. Our tendon was drawn simulating the moment diagram in the area, so we expect that once we put the values it will decrease.

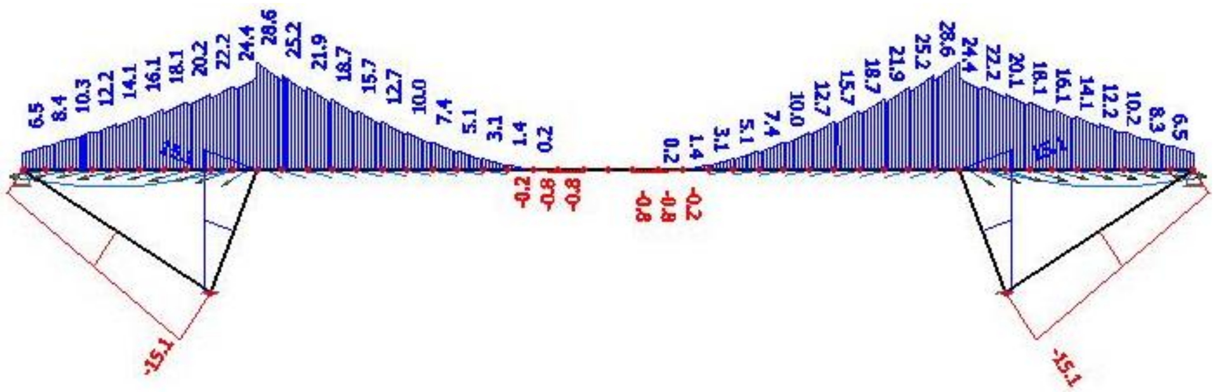


FIGURE 117: NO TENDONS LAMELA 13 TOP FIBERS STRESSES

The previous figure shows us that the top fibers of the superstructure of 210 meters are extremely high on the connection. This was expected, reason why once we approach the next iterations we will expect these values to decrease so we can get a final solution.

Second Iteration

The second iteration as we can see on table 23 the prestress on every tendon is introduced, still we can see that the values haven't made a huge change, we need to consider that the moments expected on the structure are big due to the structure cross section and length.

FIRST ATTEMPT TENDON APPLY SECOND ITERATION 2G-27T														
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass Compression	Pass Tension	Pass Both	Compresion	Tension	Pass Compression	Pass Tension	Pass Both	TENDON OK
Stage 3	2	27	5.2	1.6	1	1	OK	2.9	4.5	1	0	CHANGE	CHANGE
Lamela 1	2	9	5	1.7	1	1	OK	3	4.4	1	0	CHANGE	CHANGE
Lamela 2	2	12	4.8	2.1	1	1	OK	3.4	4.2	1	0	CHANGE	CHANGE
Lamela 3	2	12	4.3	2.7	1	1	OK	4.1	3.8	1	0	CHANGE	CHANGE
Lamela 4	2	12	3.7	3.5	1	0	CHANGE	5.1	3.2	1	1	OK	CHANGE
Lamela 5	2	12	3	4.6	1	0	CHANGE	6.4	2.5	1	1	OK	CHANGE
Lamela 6	2	12	2.2	5.9	1	0	CHANGE	8.3	1.6	1	1	OK	CHANGE
Lamela 7	2	15	1.6	7.4	1	0	CHANGE	11.1	0.6	1	1	OK	CHANGE
Lamela 8	2	15	1.7	9	1	0	CHANGE	14.5	0	1	1	OK	CHANGE
Lamela 9	2	15	1.7	10.8	1	0	CHANGE	18.2	0	1	1	OK	CHANGE
Lamela 10	2	15	1.8	13.2	1	0	CHANGE	22.4	0	1	1	OK	CHANGE
Lamela 11	2	19	2.1	16.3	1	0	CHANGE	27.1	0.1	1	1	OK	CHANGE
Lamela 12	2	19	2.6	19.8	1	0	CHANGE	32.3	0.4	1	1	OK	CHANGE
Lamela 13	2	19	2.9	23.4	1	0	CHANGE	37.7	0.4	0	1	CHANGE	CHANGE
Lamela 14	2	19	5.8	25.7	1	0	CHANGE	41.9	3.9	0	0	CHANGE	CHANGE

Tabla 23 SUMMARY OF STRESSES RESULTS-FIRST ATTEMPT TENDONS APPLY

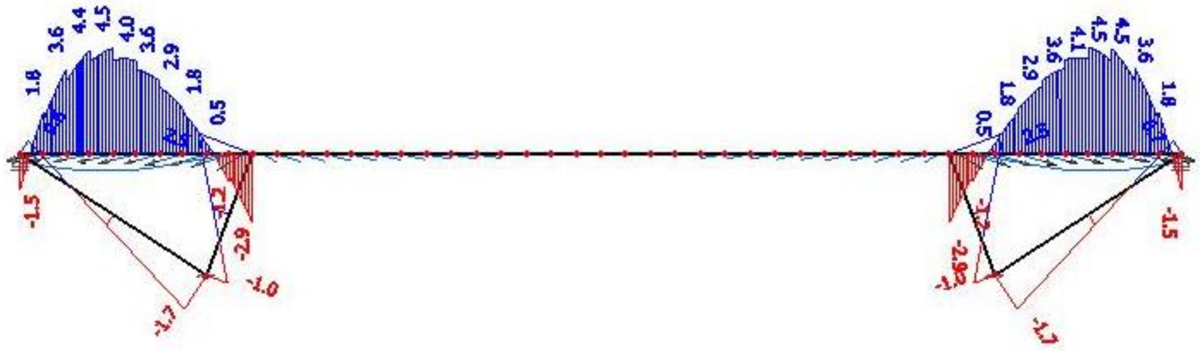


FIGURE 118: TRIANGULAR FRAME BOTTOM STRESSES SECOND ITERATION.

It's important to notice that the values that we obtained on the triangular frame are not varying after applying a total of 54 tendons. However, the shape of the curvature is as expected. As a possible solution we will overstress the triangle frame to see the possible variation.

Third Iteration

The third iteration is focused on the problem we are facing on the triangular part, we can see the values are not changing, so we focus on overstressing the triangular frame, I will double the area of prestress input previously, and as we will see on table 24 the results is not working.

THIRD ITERATION 4G-27T															
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	TENDON OK
Stage 3	4	27	5.2	1.6	1	1	OK	2.9	4.5	1	0	CHANGE	CHANGE
Lamela 1	2	12	5.1	1.7	1	1	OK	3	4.4	1	0	CHANGE	CHANGE
Lamela 2	2	19	4.8	2	1	1	OK	3.3	4.2	1	0	CHANGE	CHANGE
Lamela 3	2	19	4.5	2.5	1	1	OK	3.9	3.8	1	0	CHANGE	CHANGE
Lamela 4	2	19	3.9	3.2	1	1	OK	4.8	3.4	1	0	CHANGE	CHANGE
Lamela 5	2	19	3.3	4.2	1	0	CHANGE	5.9	2.7	1	1	OK	CHANGE
Lamela 6	2	19	2.6	5.3	1	0	CHANGE	7.4	1.9	1	1	OK	CHANGE
Lamela 7	2	22	2.2	6.5	1	0	CHANGE	10.1	1	1	1	OK	CHANGE
Lamela 8	2	22	2.3	8	1	0	CHANGE	13.1	0.2	1	1	OK	CHANGE
Lamela 9	2	22	2.5	9.6	1	0	CHANGE	16.7	0	1	1	OK	CHANGE
Lamela 10	2	22	2.5	11.3	1	0	CHANGE	20.6	0	1	1	OK	CHANGE
Lamela 11	4	19	3.3	14	1	0	CHANGE	25.1	1	1	1	OK	CHANGE
Lamela 12	4	19	4.5	17	1	0	CHANGE	29.9	1.8	1	1	OK	CHANGE
Lamela 13	4	19	5.7	20.2	1	0	CHANGE	35	0	1	1	OK	CHANGE
Lamela 14	4	19	7.9	22.5	1	0	CHANGE	39.2	4.8	0	0	CHANGE	CHANGE

Tabla 24 SUMMARY OF STRESSES RESULTS, THIRD ITERATION

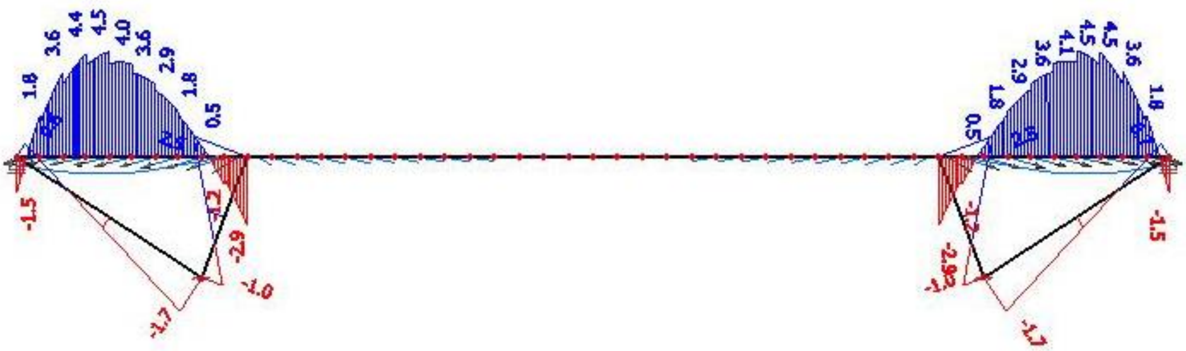


FIGURE 119: TRIANGULAR FRAME BOTTOM STRESSES THIRD ITERATION.

On figure 119 we notice that the values haven't change. Since the values are not changing we will try to approach an overstress of the whole structure, as we can see on the tables the tension values tend to decrease, this is because the whole prestress in the superstructure affects it, meaning that each lamella that is casted and prestress helps us decrease the tension in the next lamella.

Forth Iteration

The forth iteration shows us an overstress of the whole structure, we can see that the values of tendons input double the previous ones, this way we will see if the decrease of the tension fibers is significant so we can still focus in this solution.

FORTH ITERATION 3G-27T														
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	TENDON OK
Stage 3	8	27	5.2	1.6	1	1	OK	2.9	4.5	1	0	CHANGE	CHANGE
Lamela 1	4	12	5.1	1.6	1	1	OK	3	4.5	1	0	CHANGE	CHANGE
Lamela 2	4	19	4.9	1.8	1	1	OK	3.1	4.4	1	0	CHANGE	CHANGE
Lamela 3	4	19	4.8	2	1	1	OK	3.4	4.2	1	0	CHANGE	CHANGE
Lamela 4	4	19	4.5	2.4	1	1	OK	3.9	3.8	1	0	CHANGE	CHANGE
Lamela 5	4	19	4	3	1	1	OK	4.7	3.4	1	0	CHANGE	CHANGE
Lamela 6	4	19	4	3.7	1	0	CHANGE	5.7	2.8	1	1	OK	CHANGE
Lamela 7	4	22	4.4	4.4	1	0	CHANGE	7	2.3	1	1	OK	CHANGE
Lamela 8	4	22	4.7	5.2	1	0	CHANGE	9.4	1.6	1	1	OK	CHANGE
Lamela 9	4	22	5.1	6.2	1	0	CHANGE	12.2	1.3	1	1	OK	CHANGE
Lamela 10	4	22	5.4	7.2	1	0	CHANGE	15.5	1.1	1	1	OK	CHANGE
Lamela 11	4	27	5	9.2	1	0	CHANGE	19.9	0.9	1	1	OK	CHANGE
Lamela 12	4	27	4.7	11.3	1	0	CHANGE	24.7	0.9	1	1	OK	CHANGE
Lamela 13	4	27	4.3	14.6	1	0	CHANGE	29.9	1.1	1	1	OK	CHANGE
Lamela 14	4	27	6.5	16.8	1	0	CHANGE	33.9	4	1	0	CHANGE	CHANGE

Tabla 25 SUMMARY OF STRESSES RESULTS, FORTH ITERATION

TABLE #25: SUMMARY OF STRESSES RESULTS, FORTH ITERATION.

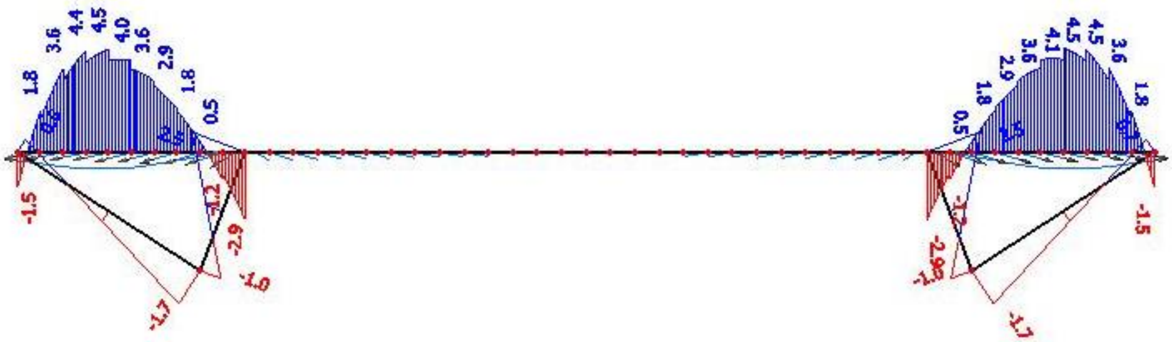


FIGURE 120: TRIANGULAR FRAME BOTTOM STRESSES FORTH ITERATION.

On figure 120 we can see the values stay the same, it will be applied as a possible solution an extra tendon on the triangular part, this will help us cover the tension on the bottom fibers. Also on figure 121 we are introducing the top fibers on the triangular section, we consider it important since we start focusing on the fact that we start the unbalanced cantilever method construction with a tension value of 1.6 MPa, the fact that a new cable will be drawn will show us a possible change on these values.

FIGURE 121: TRIANGULAR FRAME TOP STRESSES FORTH ITERATION.

It's also important to notice that on this solution we compare lamella 13 with our iteration with no tendons, we can see that the prestress is working on the structure, we can see that from 28.6 MPa has dropped down to 14.6 MPa, however we notice that the structure tends to grow the stresses from the moment we start the cantilever construction. We can see that the values on the triangular frame are a limitation.

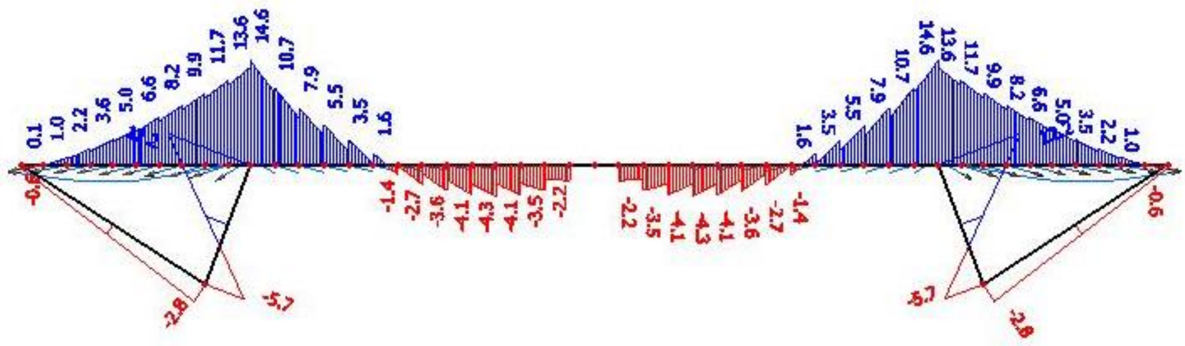


FIGURE 122: LAMELLA 13 TOP STRESSES.

As a next approach we will add more prestress to the triangular frame to control the tension we start in figure 121. I have added a second tendon that will try to absorb the tension on the bottom part of the structure.

Fifth Iteration

The main change is the presence of the new tendon on the triangular frame; figure 122 shows us the tendons present in this area.

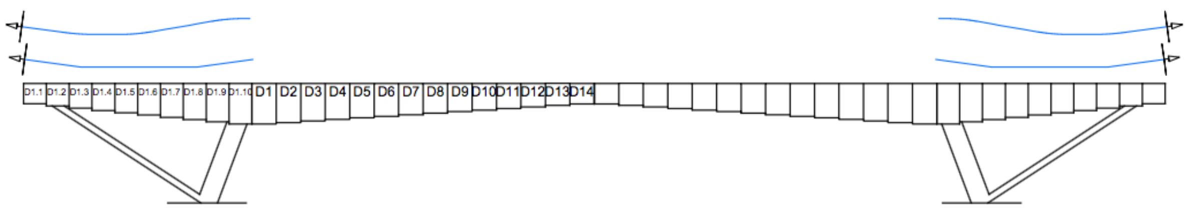


FIGURE 123: TRIANGULAR FRAME TENDONS BOTTOM FIBERS FOCUS

As seen on table 26, the values haven't change at all, they are marked on yellow and this is a clear indication that there is some data wrong on the program, however we can see that the behavior is as expected when we increment the tendons.

FIFTH ITERATION 4G-27 TOP FIBER TENDON														
DATA			Top Fibers					BOTTOM FIBERS						
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	TENDON OK
Stage 3	4	27	5.2	1.6	1	1	OK	2.9	4.5	1	0	CHANGE	CHANGE
Lamela 1	4	12	5	1.7	1	1	OK	3	4.5	1	0	CHANGE	CHANGE
Lamela 2	4	12	4.8	1.9	1	1	OK	3.2	4.3	1	0	CHANGE	CHANGE
Lamela 3	4	12	4.5	2.4	1	1	OK	3.8	3.9	1	0	CHANGE	CHANGE
Lamela 4	4	12	4.1	3	1	1	OK	4.5	3.5	1	0	CHANGE	CHANGE
Lamela 5	4	12	3.5	3.8	1	0	CHANGE	5.6	2.9	1	1	OK	CHANGE
Lamela 6	2	12	2.7	5.1	1	0	CHANGE	7.1	2	1	1	OK	CHANGE
Lamela 7	2	15	1.9	6.5	1	0	CHANGE	9.8	1	1	1	OK	CHANGE
Lamela 8	2	15	1.7	8.1	1	0	CHANGE	13.1	0.2	1	1	OK	CHANGE
Lamela 9	2	15	1.7	9.9	1	0	CHANGE	16.8	0	1	1	OK	CHANGE
Lamela 10	2	15	1.8	11.8	1	0	CHANGE	20.9	0	1	1	OK	CHANGE
Lamela 11	2	19	2	14.4	1	0	CHANGE	25.6	0.1	1	1	OK	CHANGE
Lamela 12	2	19	2.6	17.8	1	0	CHANGE	30.7	0.4	1	1	OK	CHANGE
Lamela 13	4	22	3.9	21	1	0	CHANGE	35.9	1.5	0	1	CHANGE	CHANGE
Lamela 14	4	22	7.3	23.3	1	0	CHANGE	40.1	4.8	0	0	CHANGE	CHANGE

Tabla 26 SUMMARY OF STRESSES RESULTS, FIFTH ITERATION

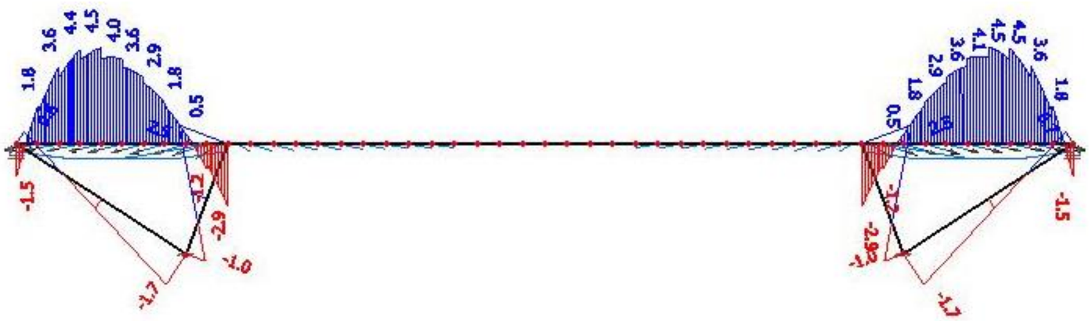


FIGURE 124: TRIANGULAR FRAME BOTTOM STRESSES FIFTH ITERATION.

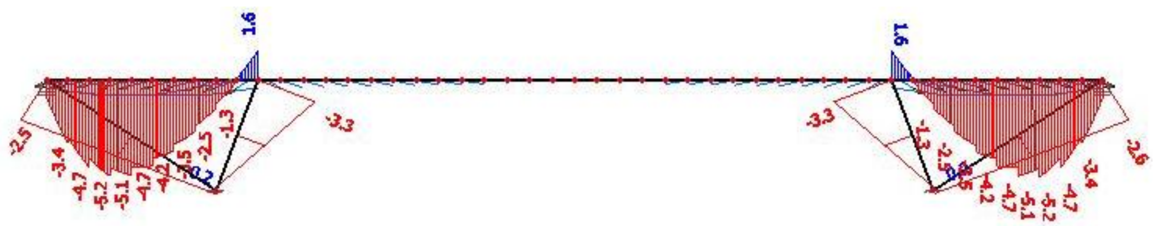


FIGURE 125: TRIANGULAR FRAME TOP STRESSES FORTH ITERATION.

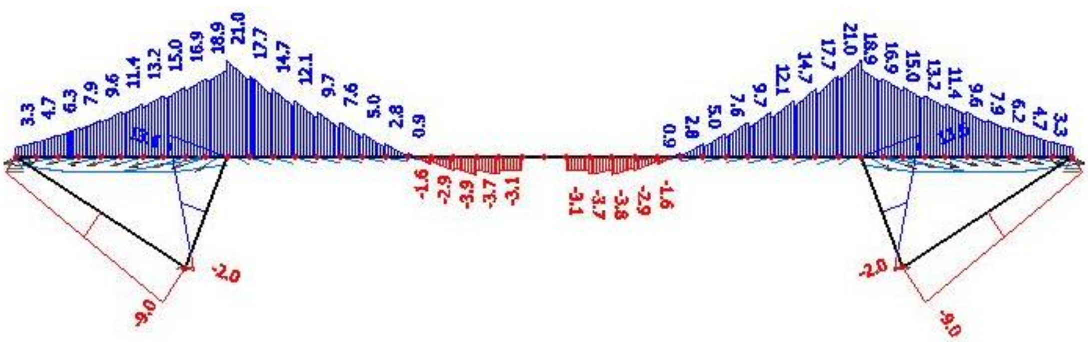


FIGURE 126: BOTTOM STRESSES LAMELLA 13

We can see that as the forth iteration both figures 124 and 125 stay the same, this is the main reason to find out that the cable introduced as tendon was not taken in consideration. With this last iteration for this sub stage, we have discovered that the triangular frame is important on the structure behavior, the internal forces and stresses that we have before the cantilever starts its construction phase, these values needs to be reduced from the beginning otherwise we will be affected in the next stages since it keeps accumulating. If we analyzed each table we can see that the most tendons we put the stresses get lowered so the tendon layout will still be the same.

The problem found is the data that I input in the last moment of stage 3, the prestress is applied at the same time that the stationary formwork will be remove. This has shown us the internal forces of the triangular frame, but the prestress actions are not being taken in account by the program, the difference in the stresses calculated, have been only due to the cables from the lamellas in the cantilever area, this is shown on figure 126, where we compare to figure 122, we can see that the values are again bigger, this is because on this last iteration I put lesser area on the tendons on the cantilever lamellas.

Second group of iterations-cable layout.

I have group this iterations as the solution for the cable layout that should be used, throughout the iterations, once we have corrected the problems found in the previous groups, and maintaining the layout that showed a better result on the previous one, I will be changing the amount of prestress and the location of the tendons on the triangular frame to find out which is the most suitable. I will try to keep the same number of tendons in the 210-meter beam, this way I expect to find out the importance of prestress and the results in the internal forces on the rigid area of the structure, the triangular frame.

First iteration

Two tendons are used on the triangular frame, we maintain them as figure 123, this way we will see a result that the problem has been solved, we can refer to figure 128, where we can see that the values on the bottom fibers of the structure have change.

FIRST ITERATION-CABLE LAYOUT FOCUS													
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass Compression	Pass Tension	Pass Both	Compression	Tension	Pass Compression	Pass Tension	Pass Both	TENDON OK
Stage 3	2+	27+	6.8	0	1	1	OK	3	3.7	1	0	CHANGE	CHANGE
Lamela 1	2	12	6.6	0.1	1	1	OK	3	3.7	1	0	CHANGE	CHANGE
Lamela 2	2	12	6.3	0.5	1	1	OK	3.1	3.4	1	0	CHANGE	CHANGE
Lamela 3	2	12	5.9	1.1	1	1	OK	3.6	2.9	1	1	OK	OK
Lamela 4	2	12	5.4	1.9	1	1	OK	4.6	2.3	1	1	OK	OK
Lamela 5	2	12	4.7	3	1	1	OK	5.8	1.5	1	1	OK	OK
Lamela 6	2	15	3.8	4.2	1	0	CHANGE	8.2	0.6	1	1	OK	CHANGE
Lamela 7	2	15	2.9	5.6	1	0	CHANGE	11	0	1	1	OK	CHANGE
Lamela 8	2	15	2.1	7.7	1	0	CHANGE	14.3	0	1	1	OK	CHANGE
Lamela 9	2	15	1.7	10.2	1	0	CHANGE	18.1	0	1	1	OK	CHANGE
Lamela 10	2	15	1.8	12.9	1	0	CHANGE	22.3	0	1	1	OK	CHANGE
Lamela 11	2	19	2.1	16.1	1	0	CHANGE	27	0.1	1	1	OK	CHANGE
Lamela 12	2	19	2.6	19.5	1	0	CHANGE	32.1	0.4	1	1	OK	CHANGE
Lamela 13	2	19	2.9	23.1	1	0	CHANGE	37.6	0.4	0	1	CHANGE	CHANGE
Lamela 14	2	19	5.8	25.4	1	0	CHANGE	41.7	3.9	0	0	CHANGE	CHANGE

Tabla 27 STRESSES RESULT FIRST ITERATION-CABLE LAYOUT FOCUS

FIGURE 127: TOP STRESSES TRIANGULAR FRAME 2 TENDONS BOTTOM FIBERS

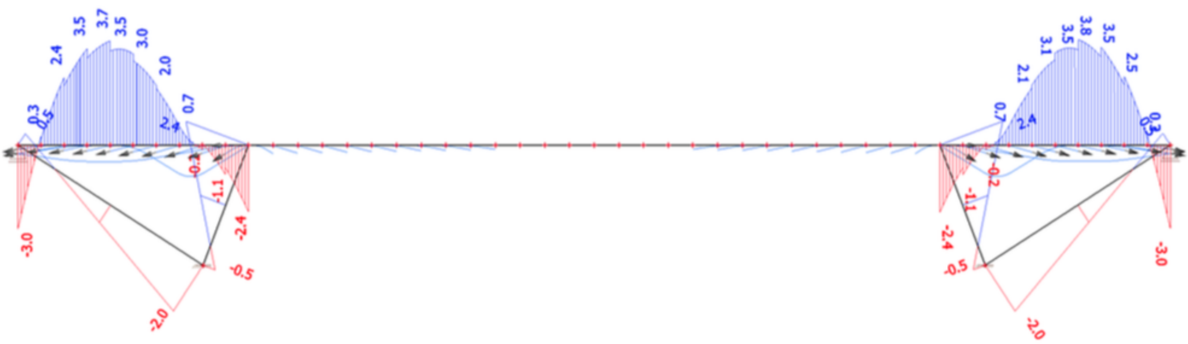


FIGURE 128: BOTTOM STRESSES TRIANGULAR FRAME 2 TENDONS BOTTOM FIBERS

The figures above mentioned shows us the results on both fibers in the triangular area, it's important to notice the shape, we encounter compression mostly on the bottom fibers as close as we get to the supports, however from lamella D1.2-D1.8 we have tension present, the values are above the limit of concrete tension after 28 days, however we will try to prestress more on further iterations to see the behavior shown. The top stresses are as expected, all in the compressive area.

FIGURE 129: FIRST TENSION VALUES 70 METER BEAM TOP FIBERS-2 TENDONS

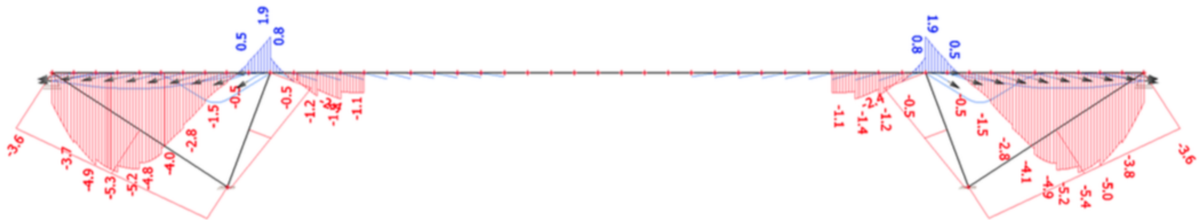


FIGURE 130: FIRST TENSION VALUES 210 METER BEAM TOP FIBERS-2 TENDONS

In this iteration we can see that we reach our first tension value on the triangular frame when we are done with the construction of lamella 1, this value from this point on will climb until we connect the bridge on lamella 14, where the internal forces will be redistributed. However, on the 210-meter beam, we have tension after lamella 5 is build, the value is small but as the previous case mentioned this will keep incrementing, we can see on the table the maximum value we will get is 25.4 MPa, an extremely high value that we will try to lower.

<u>Second iteration</u>

Focusing on the triangular frame and the weight it has on the structure behavior, I have added a third tendon with a prestress of 2 groups 15 cables, instead of the 2 groups of

27 cables I have been using previously, the idea is to see if the third cable has a positive effect. Figure 131 shows us the new tendon layout.

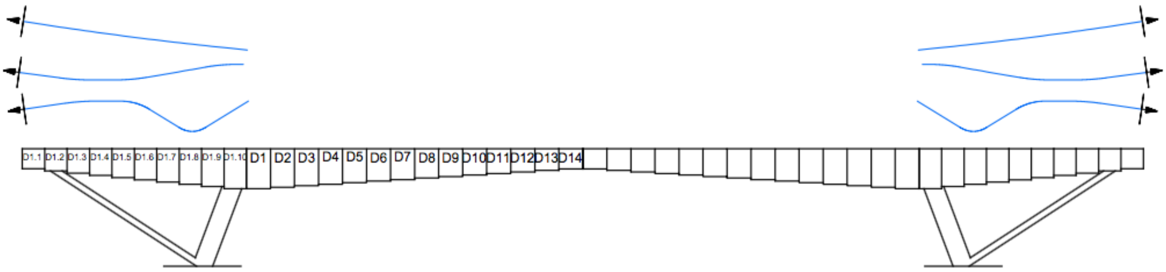


FIGURE 131: THREE TENDONS LAYOUT, BOTTOM FIBERS FOCUS

SECOND ITERATION-CABLE LAYOUT FOCUS													
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	TENDON OK
Stage 3	2+2	27+15	6.9	0	1	1	OK	3.4	3.1	1	1	OK	OK
Lamela 1	2	9	6.7	0.1	1	1	OK	3.5	3	1	1	OK	OK
Lamela 2	2	12	6.4	0.4	1	1	OK	3.5	2.7	1	1	OK	OK
Lamela 3	2	12	6	1	1	1	OK	4.1	2.2	1	1	OK	OK
Lamela 4	2	12	5.4	1.9	1	1	OK	5.1	1.6	1	1	OK	OK
Lamela 5	2	12	4.7	3	1	1	OK	6.4	0.8	1	1	OK	OK
Lamela 6	2	12	3.9	4.2	1	0	CHANGE	8.3	0	1	1	OK	CHANGE
Lamela 7	2	15	3	5.8	1	0	CHANGE	11.2	0	1	1	OK	CHANGE
Lamela 8	2	15	2.1	8	1	0	CHANGE	14.5	0	1	1	OK	CHANGE
Lamela 9	2	15	1.7	10.4	1	0	CHANGE	18.3	0	1	1	OK	CHANGE
Lamela 10	2	15	1.8	13.2	1	0	CHANGE	22.5	0	0	1	CHANGE	CHANGE
Lamela 11	2	19	2.1	16.3	1	0	CHANGE	27.2	0.1	0	1	CHANGE	CHANGE
Lamela 12	2	19	2.6	19.8	1	0	CHANGE	32.3	0.4	0	1	CHANGE	CHANGE
Lamela 13	2	19	2.9	23.4	1	0	CHANGE	37.8	0.4	0	1	CHANGE	CHANGE
Lamela 14	2	19	5.8	25.7	1	0	CHANGE	41.9	3.9	0	0	CHANGE	CHANGE

Tabla 28 STRESSES RESULTS SECOND ITERATION-CABLE LAYOUT FOCUS

FIGURE 132: TOP STRESSES TRIANGULAR FRAME 3 TENDONS BOTTOM FIBERS

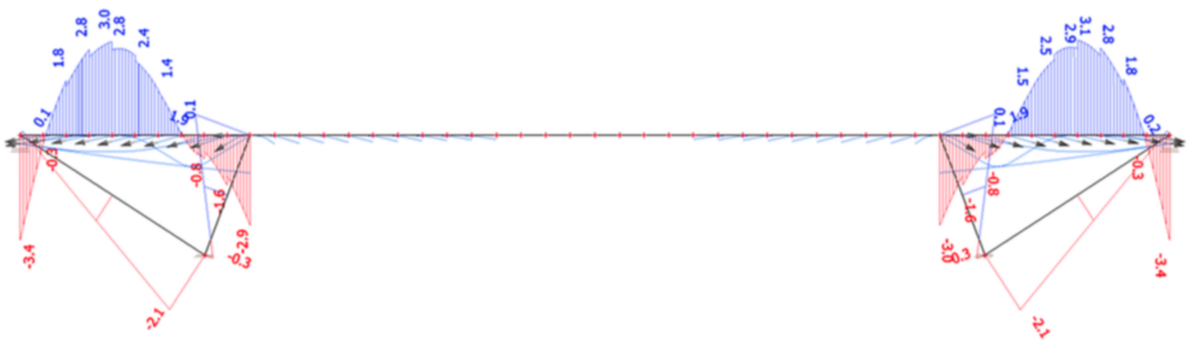


FIGURE 133: BOTTOM STRESSES TRIANGULAR FRAME 3 TENDONS BOTTOM FIBERS

From figures 132 and 133 we can see the next effects, bigger compression and lower tension values are on the table, the third tendon has made a positive effect for what we look, even thou the values we start with on the triangular frame are lower than the limits calculated previously on this project, they will still climb, reason why we should try changing the prestress area on this third cable and see how it behaves the triangular frame.

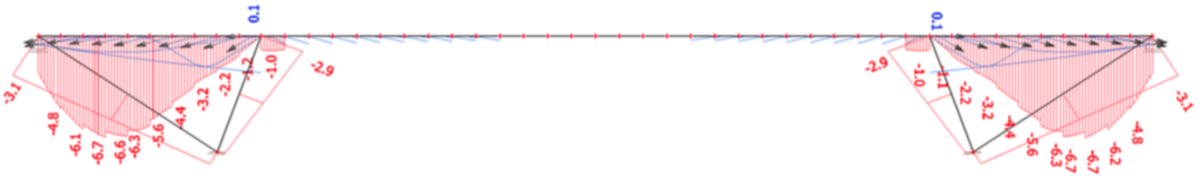


FIGURE 134: FIRST TENSION VALUES 70 METER BEAM-3 TENDONS

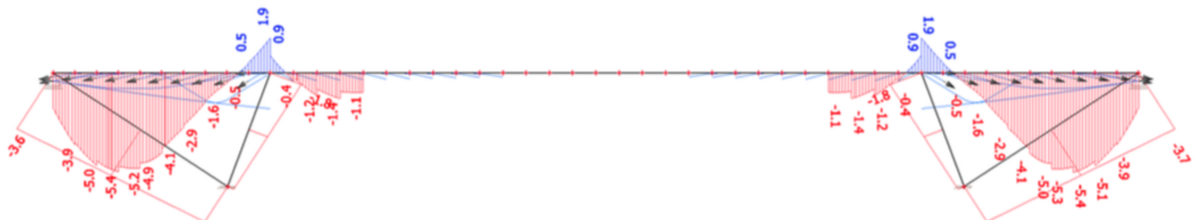


FIGURE 135: FIRST TENSION VALUES 210 METER BEAM-3 TENDONS

If we keep track on the tension values on both beams, we can see that still tension appears on the 70-meter beam after the first lamella is casted, so there is no positive effect on these top fibers, we expected this since we did not add prestress in the top fibers on the area. The same happens with the 210-meter beam, the values are the same. It's important to notice that with this solution we have 6 approved tendons, showing us that the construction stage until lamella 6 works as a solution.

<u>Third Iteration</u>

This iteration is focused on the third tendon appearance too; we will put the same prestress and see if there are bigger effects on the triangular frame for the tension fibers.

THIRD ITERATION-CABLE LAYOUT FOCUS													
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	TENDON OK
Stage 3	2++	27++	6.9	0	1	1	OK	3.8	2.5	1	1	OK	OK
Lamela 1	2	15	6.8	0	1	1	OK	3.8	2.4	1	1	OK	OK
Lamela 2	2	15	6.5	0.4	1	1	OK	3.8	2.2	1	1	OK	OK
Lamela 3	2	15	6.1	0.9	1	1	OK	4.5	1.8	1	1	OK	OK
Lamela 4	2	15	5.6	1.7	1	1	OK	5.4	1.1	1	1	OK	OK
Lamela 5	2	15	4.9	2.7	1	1	OK	6.6	0.4	1	1	OK	OK
Lamela 6	2	27	4.3	3.7	1	0	CHANGE	7.9	0.1	1	1	OK	CHANGE
Lamela 7	2	27	3.6	4.9	1	0	CHANGE	10.2	0.2	1	1	OK	CHANGE
Lamela 8	2	27	3	6.4	1	0	CHANGE	13.1	0.2	1	1	OK	CHANGE
Lamela 9	2	27	3	8.4	1	0	CHANGE	16.5	0.1	1	1	OK	CHANGE
Lamela 10	2	27	3.1	10.7	1	0	CHANGE	20.3	0	1	1	OK	CHANGE
Lamela 11	2	27	3.3	13.6	1	0	CHANGE	24.9	0.5	1	1	OK	CHANGE
Lamela 12	2	27	3.6	16.8	1	0	CHANGE	29.8	0.9	1	1	OK	CHANGE
Lamela 13	2	27	4.1	20.2	1	0	CHANGE	35.1	1.1	0	1	CHANGE	CHANGE
Lamela 14	2	27	17.7	22.5	1	0	CHANGE	39.2	4	0	0	CHANGE	CHANGE

Tabla 29 STRESSES RESULT THIRD ITERATION-CABLE LAYOUT FOCUS

FIGURE 136: TOP STRESSES TRIANGULAR FRAME 3 TENDONS BOTTOM FIBERS THIRD ITERATION

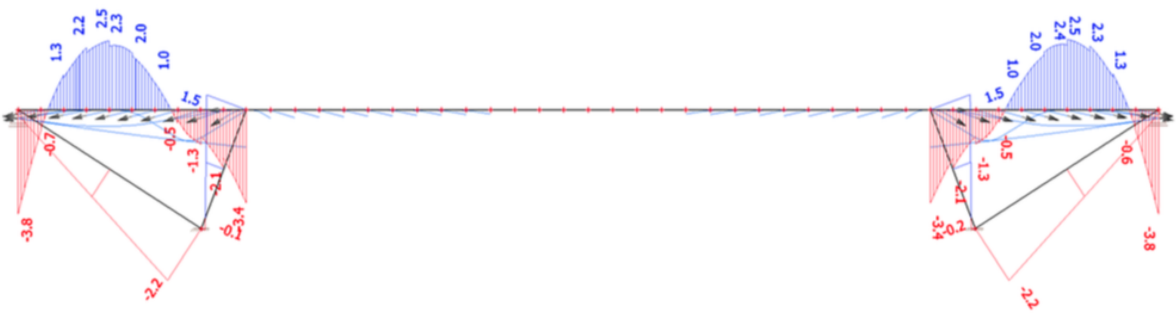


FIGURE 137: BOTTOM STRESSES TRIANGULAR FRAME 3 TENDONS BOTTOM FIBERS THIRD ITERATION

The effects shown in the figures above are basically bigger compression lower tension, this shows us that we are heading in the right direction, this third cable appearance has shown us a better effect, it has lowered the tensions in an important way.

FIGURE 138: FIRST TENSION VALUES 70 METER BEAM-3 TENDONS THIRD ITERATION

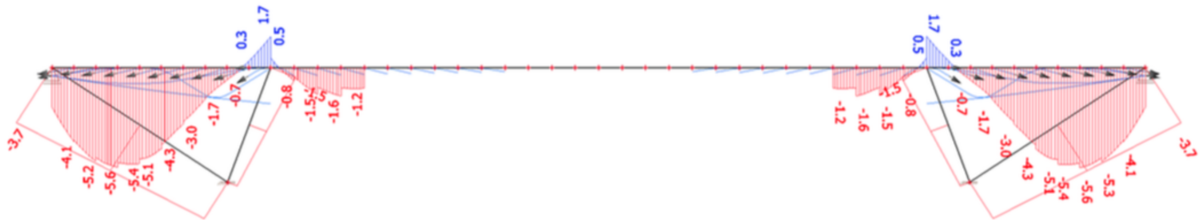


FIGURE 139: FIRST TENSION VALUES 210 METER BEAM-3 TENDONS THIRD ITERATION

The fact that we add more prestress has had a positive effect on the top fibers on the 70-meter beam, we can see that the tension appears after the second lamella is finish, another reason to stick with this cable in our iterations, in figure 139 we can see that the tension appears also after the development of the 4th lamella, however the tension value has been reduced. Still as shown on the table 29, we can see that 6 tendons are approved still, showing us that the effect is positive in the small picture, but the bigger picture not, we haven't improved our solution.

<u>Forth Iteration</u>

I will try to change the cable layout, instead of focusing on the bottom fibers as the previous iterations, I will mainly focus on the top fibers this time, three cables will be present, but a different layout will be introduced, please refer to figure 140.

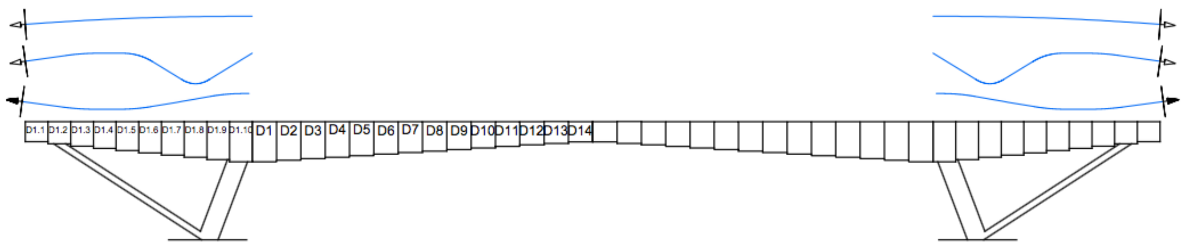


FIGURE 140: THREE TENDONS, TOP FIBER FOCUS

FOURTH ITERATION-CABLE LAYOUT FOCUS														
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass Compression	Pass Tension	Pass Both	Compresion	Tension	Pass Compression	Pass Tension	Pass Both	TENDON OK
Stage 3	2+2	27+15	7.3	0	1	1	OK	3.4	3.7	1	0	CHANGE	CHANGE
Lamela 1	2	9	7.2	0	1	1	OK	3.4	3.7	1	0	CHANGE	CHANGE
Lamela 2	2	12	7	0	1	1	OK	3.5	3.4	1	0	CHANGE	CHANGE
Lamela 3	2	12	6.5	0.5	1	1	OK	3.5	3	1	1	OK	OK
Lamela 4	2	12	5.9	1.4	1	1	OK	4.5	2.3	1	1	OK	OK
Lamela 5	2	12	5.3	2.4	1	1	OK	5.8	1.5	1	1	OK	OK
Lamela 6	2	12	4.4	3.9	1	0	CHANGE	8.2	0.5	1	1	OK	CHANGE
Lamela 7	2	15	3.5	5.7	1	0	CHANGE	11.1	0	1	1	OK	CHANGE
Lamela 8	2	15	2.5	7.9	1	0	CHANGE	14.4	0	1	1	OK	CHANGE
Lamela 9	2	15	1.7	10.4	1	0	CHANGE	18.2	0	1	1	OK	CHANGE
Lamela 10	2	15	1.8	13.1	1	0	CHANGE	22.3	0	0	1	CHANGE	CHANGE
Lamela 11	2	19	2.1	16.3	1	0	CHANGE	27.1	0.1	0	1	CHANGE	CHANGE
Lamela 12	2	19	2.6	19.7	1	0	CHANGE	32.2	0.4	0	1	CHANGE	CHANGE
Lamela 13	2	19	2.9	23.3	1	0	CHANGE	37.7	0.4	0	1	CHANGE	CHANGE
Lamela 14	2	19	5.8	25.5	1	0	CHANGE	41.8	3.9	0	0	CHANGE	CHANGE

Tabla 30 STRESSES RESULTS FOURTH ITERATION-CABLE LAYOUT FOCUS

FIGURE 141: TOP STRESSES TRIANGULAR FRAME 3 TENDONS TOP FIBERS FORTH ITERATION

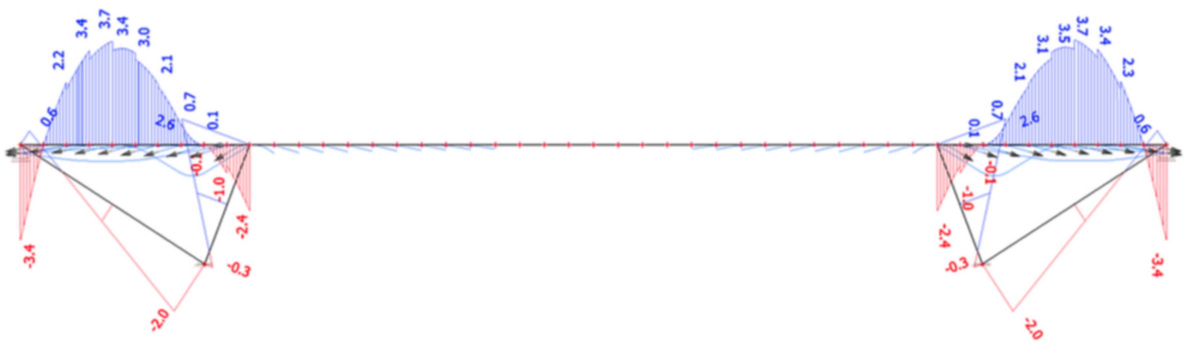


FIGURE 142: BOTTOM STRESSES TRIANGULAR FRAME 3 TENDONS TOP FIBERS FORTH ITERATION

The first results we can see is that there is no improvement, no progress has been accomplished with the triangular frame, the tension values climbed higher and the compression has been decreased, this was expected by theory. However, in this case we will focus more on the tension appearances on the top fibers once constructions start, since we can reduce the effects with the bottom cable previously design.

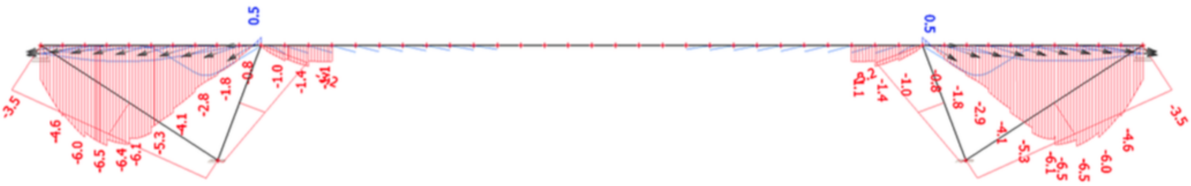


FIGURE 143: FIRST TENSION VALUES 70 METER BEAM-3 TENDONS TOP FIBERS FORTH ITERATION

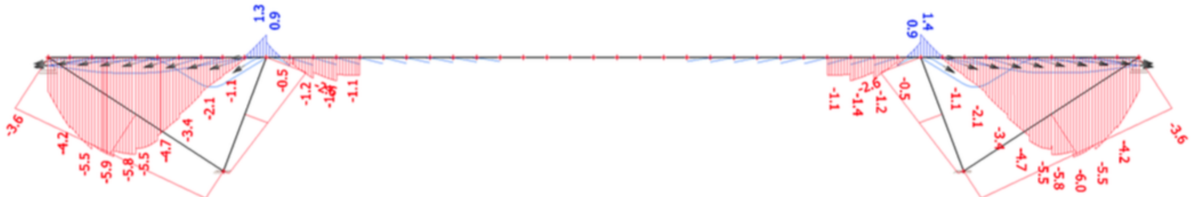


FIGURE 144: FIRST TENSION VALUES 210 METER BEAM-3 TENDONS TOP FIBERS FORTH ITERATION

As expected the tension stresses appear after the third lamella has been build, this is not the effect we were expecting, however shows us that the approach might be the correct, still on the 210-beam tension appears after the 4th lamella is developed, however, we haven't added more prestress on these tendons, this can be corrected later with more prestress.

Fifth Iteration

On this iteration we will try to found the effect of the previous two iterations, 4 tendons in the triangular frame will be introduced, where the tendons are being studied, 2 groups of 15 cables each will be placed, base tendons on the rest of the superstructure to focus on the effect. Figure 145 introduces to the tendon layout being applied.

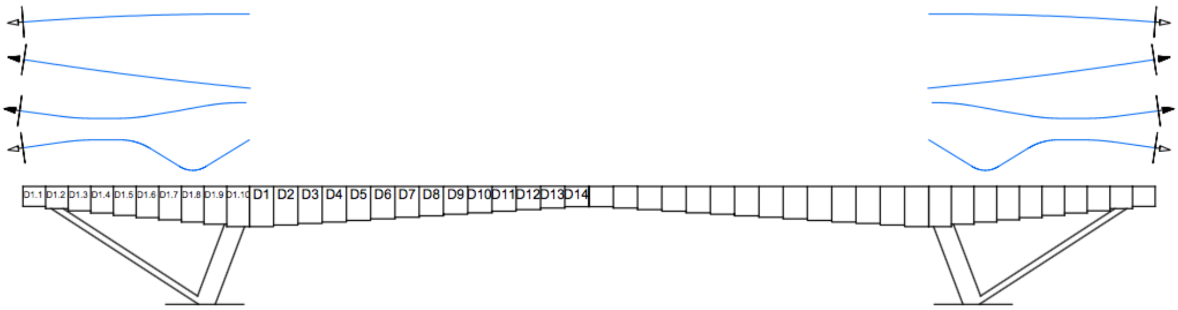


FIGURE 145: FOUR TENDONS LAYOUT

FIFTH ITERATION-CABLE LAYOUT FOCUS														
DATA			Top Fibers					BOTTOM FIBERS					TENDON OK
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	
Stage 3	2+2+	27+15+	7.4	0	1	1	OK	3.8	3	1	1	OK	OK
Lamela 1	2	9	7.3	0	1	1	OK	3.9	3	1	1	OK	OK
Lamela 2	2	12	7	0	1	1	OK	3.9	2.7	1	1	OK	OK
Lamela 3	2	12	6.6	0.5	1	1	OK	4.1	2.2	1	1	OK	OK
Lamela 4	2	12	6	1.3	1	1	OK	5.1	1.5	1	1	OK	OK
Lamela 5	2	12	5.3	2.4	1	1	OK	6.3	0.7	1	1	OK	OK
Lamela 6	2	12	4.4	3.9	1	0	CHANGE	8.3	0	1	1	OK	CHANGE
Lamela 7	2	15	3.6	5.8	1	0	CHANGE	11.2	0	1	1	OK	CHANGE
Lamela 8	2	15	2.7	7.9	1	0	CHANGE	14.5	0	1	1	OK	CHANGE
Lamela 9	2	15	1.8	10.4	1	0	CHANGE	18.2	0	1	1	OK	CHANGE
Lamela 10	2	15	1.8	13.1	1	0	CHANGE	22.4	0	1	1	OK	CHANGE
Lamela 11	2	19	2.1	16.3	1	0	CHANGE	27.2	0.1	1	1	OK	CHANGE
Lamela 12	2	19	2.6	19.7	1	0	CHANGE	32.3	0.4	1	1	OK	CHANGE
Lamela 13	2	19	2.9	23.4	1	0	CHANGE	37.7	0.4	0	1	CHANGE	CHANGE
Lamela 14	2	19	5.8	25.7	1	0	CHANGE	41.9	3.9	0	0	CHANGE	CHANGE

Tabla 31 STRESSES RESULTS FIFTH ITERATION-CABLE LAYOUT FOCUS

FIGURE 146: TOP STRESSES TRIANGULAR FRAME 4 TENDONS FIFTH ITERATION

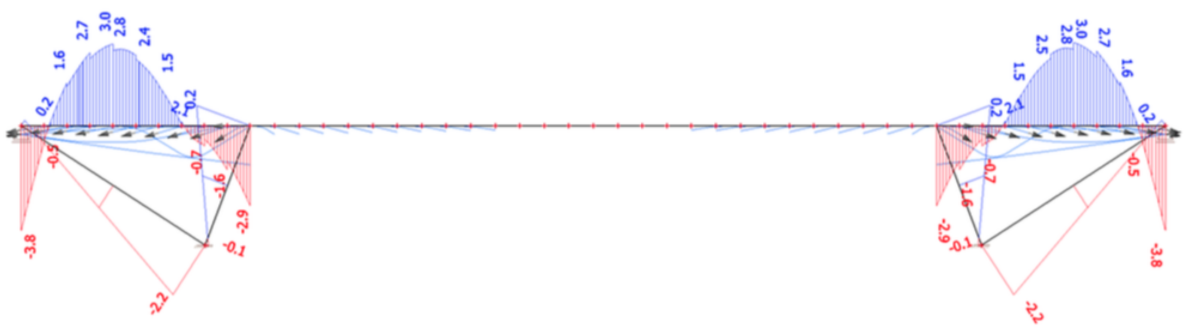


FIGURE 147: BOTTOM STRESSES TRIANGULAR FRAME 4 TENDONS FIFTH ITERATION

As results we can see that we have reach better top fibers results in general, but the first tension value on the top fiber is higher than the solution introduced on the third iteration, also we can see that on the table we have the highest compression value achieved on the bottom fibers, the value exceeds the limit for concrete we use, however this can be easily cover by changing the material resistance from C35/45 to C45/55, however at this point we won't make the final decision since we haven't reach a solution yet.

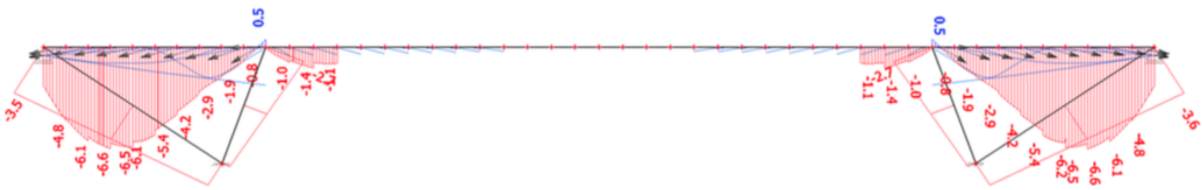


FIGURE 148: FIRST TENSION VALUES 70 METER BEAM-4 TENDONS FIFTH ITERATION

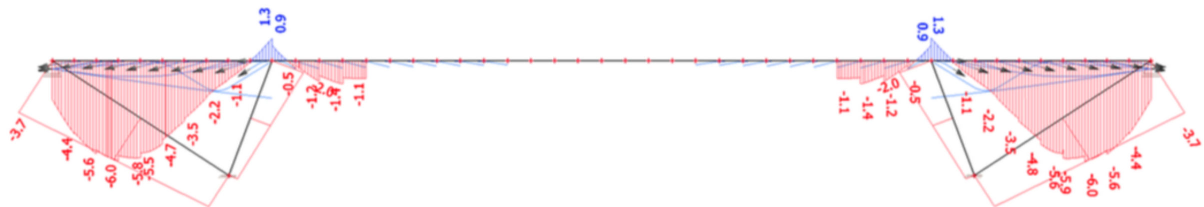


FIGURE 149: FIRST TENSION VALUES 210 METER BEAM-4 TENDONS FIFTH ITERATION

Out of these graphs we can see that there is no advantage on the 4 cables introduce, they have similar values than the cases studied above, the tensions will grow until 25.7 MPa, still a value too high for us. We can see that with this iteration the forth cable has no benefit for us.

Sixth Iteration

I will focus back to three tendons, we overstress the triangle frame, and put more tendons in the structure to see if this group will lead us somewhere, the idea is to pick the best solutions we have found in the iterations and see if they are getting us to a proper design.

3 TENDONS TRY 5 OVER PRESSTRESS TRIANGLE													
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	TENDON OK
Stage 3 new	8++	37	14.7	0	1	1	OK	13.4	0	1	1	OK	OK
Lamela 1	2	15	14.6	0	1	1	OK	13.4	0	1	1	OK	OK
Lamela 2	2	15	14.3	0	1	1	OK	13.4	0	1	1	OK	OK
Lamela 3	2	15	14	0	1	1	OK	13.4	0	1	1	OK	OK
Lamela 4	2	15	13.5	0.6	1	1	OK	13.5	0	1	1	OK	OK
Lamela 5	2	15	13	1.8	1	1	OK	13.5	0	1	1	OK	OK
Lamela 6	2	27	12.4	3.1	1	0	CHANGE	14.6	0.1	1	1	OK	OK
Lamela 7	2	27	12	4.6	1	0	CHANGE	15.9	0.2	1	1	OK	CHANGE
Lamela 8	2	27	11.4	6.4	1	0	CHANGE	17.4	0.1	1	1	OK	CHANGE
Lamela 9	2	27	10.8	8.4	1	0	CHANGE	19.1	0	1	1	OK	CHANGE
Lamela 10	2	27	10.2	10.7	1	0	CHANGE	20.9	0	1	1	OK	CHANGE
Lamela 11	2	27	9.5	13.6	1	0	CHANGE	25.2	0.5	1	1	OK	CHANGE
Lamela 12	2	27	9.2	16.8	1	0	CHANGE	30.2	0.9	1	1	OK	CHANGE
Lamela 13	2	27	8.9	20.1	1	0	CHANGE	35.5	0.9	0	1	CHANGE	CHANGE
Lamela 14	2	27	9	22.4	1	0	CHANGE	39.6	4	0	0	CHANGE	CHANGE

Tabla 32 STRESSES RESULTS SIXTH ITERATION-CABLE LAYOUT FOCUS

FIGURE 150: TOP STRESSES TRIANGULAR FRAME 3 TENDONS OVERSTRESS SIXTH ITERATION

FIGURE 151: BOTTOM STRESSES TRIANGULAR FRAME 3 TENDONS OVERSTRESS SIXTH ITERATION

As results we were able to get rid of the tension in the beginning in the bottom fibers of the triangle frame, the values follow a path that we try to replicate with cables, however the shape is unusual where due to the fact of the length of the cable, introducing many deviations will bring us problems with the losses in prestress.

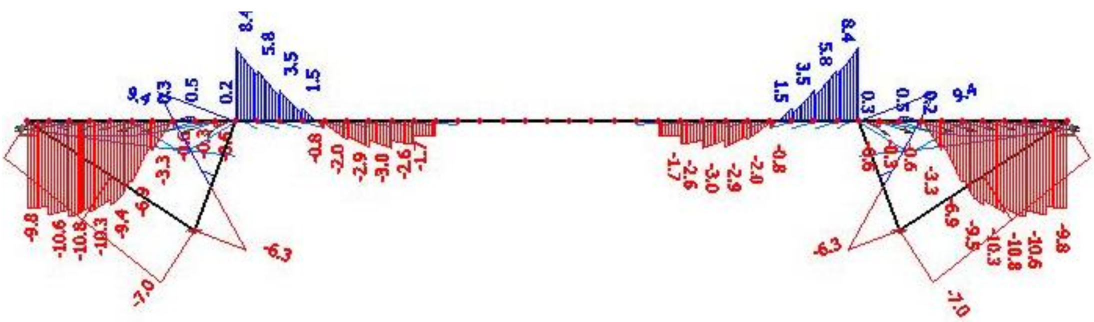


FIGURE 152: FIRST TENSION VALUES 70 METER BEAM-3 TENDONS OVERSTRESS SIXTH ITERATION

FIGURE 153: FIRST TENSION VALUES 210 METER BEAM-3 TENDONS OVERSTRESS SIXTH ITERATION

In the tension on top fibers during construction, we can see that we have tension present on the triangular frame on the ninth lamella, this has shown us that we have controlled most of the triangular frame, this value will reach up to 9.9 at lamella 14, showing us is not a result neither.

By figure 153 we reach tension at lamella 4th, however we can see that when we are in lamella ninth the value is 8.4 MPa, 3 times higher than we can deal with as a limit.

<u>General analysis of group iteration cable layout</u>

After analyzing we have notice there is a possibility of getting a solution, however this will not be the best approach, we need to overstress most of the cross sections, we have encountered after different iterations to change the behavior drastically in the stresses and internal forces with no success, most probably the best way to approach a solution is by changing the structure or the cable layout.

If we analyze the cable layout present here it was design to try avoiding the prestress losses, the fact that we have 14 lamellas on the cantilever and 10 on the triangle doesn't let us have a good solution for the prestress as it was a balanced cantilever construction, where the theory states that all the cables should go on the top fibers. This structure has shown us that is hard to bring an appropriate design, due to the fact that the spans are very different, we can have an approximate relationship in the length of 2:1 between the internal and external beams. This has made the length of the cables not effective. A possible solution might be changing the cable layout to different styles where we can have the first 5 lamellas get anchorage in the abutment, and then proceed with the prestress of the other lamellas in sequence as we had until now. However, I consider this might not be a good solution due to the fact of what I think is the main problem in the structure and is the triangular frame, this is a massive stiffed structure that holds the design back from the beginning, showing us that the approach is wrong.

Third group of iterations-redefining the structure and its construction.

This group of iterations will be focusing in thinking outside of the box, they are two main possible solutions, I will try to avoid the triangular effects by including stationary formwork on the triangular frame until the bridge is completed in the cantilever beam, but without the continuity cable, if the solution works the amount of tendons in the lamellas while construction will only have to held the effects of the unbalanced cantilever construction, they will not carry the effects of the triangular frame that has been prove has big effect by its own.

As a second possible solution, it can be alternating the shape of the structure on the triangular frame. It can be removed the tie element since we have seen there is no help in the structure, but to hold the stationary formwork and the movable formwork for the strut element, the idea is to lose stiffness on the frame, this in theory is a valid solution too, this model has been executed in different bridges around the world. In this project the tie element was placed to anchor the supports of the movable scaffolding of the strut element, and as a base point for the scaffolding of the triangular frame, however the effect might be replicated on the soil directly without having effects on the construction stages of the lamellas in the unbalanced cantilever method.

First Iteration

Stationary formwork will be present in all the triangular frame structure until the lamellas meet together, this way we will avoid the effects of the triangular frame, we should only focus on the cantilever construction, we will start with basic prestress as analyzed. The three tendons in the previous iterations will be deleted to see how the structure reacts, and later compared with the inclusion of them and its effects. No continuity cable designed yet.

FIRST ITERATION-FORMWORK APPLY FOCUS													
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	TENDON OK
Stage 3	0	0	0	0	1	1	OK	0	0	1	1	OK	OK
Lamela 1	2	9	1	0	1	1	OK	0.8	0	1	1	OK	OK
Lamela 2	2	12	1.6	0	1	1	OK	1.7	0	1	1	OK	OK
Lamela 3	2	12	2	0	1	1	OK	3.1	0	1	1	OK	OK
Lamela 4	2	12	2.1	0	1	1	OK	4.9	0	1	1	OK	OK
Lamela 5	2	12	2.1	0	1	1	OK	7.2	0	1	1	OK	OK
Lamela 6	2	12	2.1	0.9	1	1	OK	10	0	1	1	OK	OK
Lamela 7	2	15	2.2	2.2	1	1	OK	13.2	0	1	1	OK	OK
Lamela 8	2	15	2.4	3.9	1	0	CHANGE	16.8	0	1	1	OK	CHANGE
Lamela 9	2	15	2.5	5.9	1	0	CHANGE	20.9	0	1	1	OK	CHANGE
Lamela 10	2	15	2.5	8.2	1	0	CHANGE	25.4	0	1	1	OK	CHANGE
Lamela 11	2	19	2.9	10.5	1	0	CHANGE	30.2	0	1	1	OK	CHANGE
Lamela 12	2	19	3.2	13.1	1	0	CHANGE	35.3	0	0	1	CHANGE	CHANGE
Lamela 13	2	19	3.7	16	1	0	CHANGE	40.9	0	0	1	CHANGE	CHANGE
Lamela 14	2	19	11.4	13.5	1	0	CHANGE	43.9	4	0	0	CHANGE	CHANGE

Tabla 33 STRESSES RESULTS FIRST ITERATION-FORMWORK APPLIED

The first information we can see is that the stresses on the triangular part disappear until lamella 14, where we take all the formwork out. Also, is important to notice that with the basic cable design we have introduced, immediately we obtain 8 tendons approved, these ones reach the limits we expected.

FIGURE 154: TOP FIBER TENSION APPEREANCE 210 METER BEAM, FORMWORK CONSIDERED

FIGURE 155: TENSION ON TOP FIBERS BEAM 210 M, EXCEED LIMITS, FORMWORK CONSIDERED

The graphs presented above shows us the two main points where tension appears on our design, we can see that the first figure shows us the value, the first appearance of the tension stresses on the top fiber, this was reach on lamella 6, this is an improvement from the previous iterations, however it starts at 0.9MPa. Figure 155 is the moments when we have already exceeded the limit in the tension fibers, from this point on, the solutions are not accepted since the value will climb more. We need to focus avoiding these tensions to reach a solution.

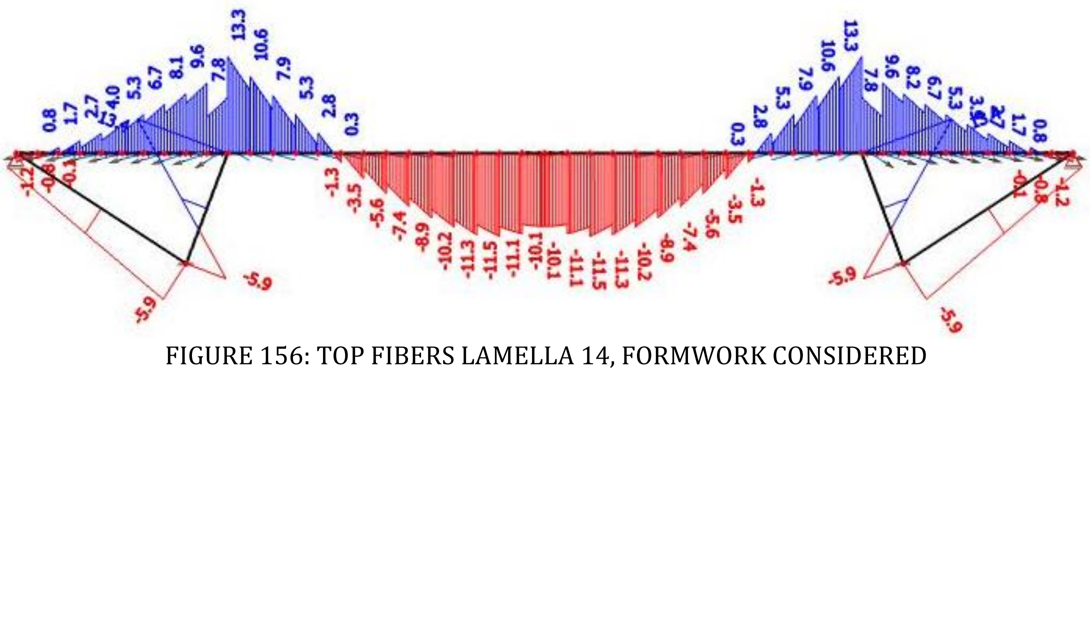


FIGURE 156: TOP FIBERS LAMELLA 14, FORMWORK CONSIDERED

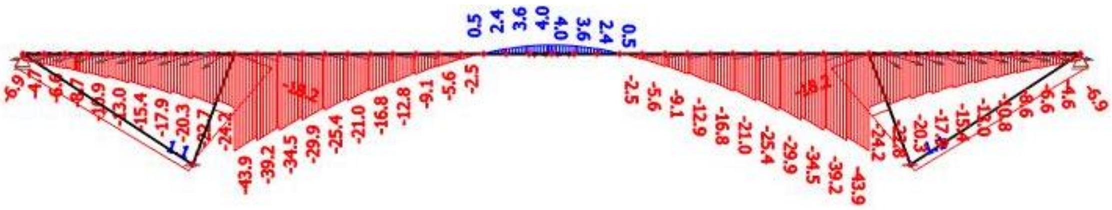


FIGURE 157: BOTTOM FIBERS LAMELLA 14, FORMWORK CONSIDERED

This figures 156 and 157 are important to analyze, at this time is the first time we introduce a graph on this particular lamella, in this case we can be see that the values in compression are above the limit as it happened before, but at the same time the tension fibers are above expected, this values should try to be corrected for us to get a proper design, more likely we will have more problems in this lamella, until we introduce the continuity cable for the structure to start be considered in service. Also, is important to notice that the triangular frame stresses appear, we will try neutralizing them with the cables on the previous layouts.

FIGURE 158: LAMELLA 10 BOTTOM FIBERS, FORMWORK CONSIDERED

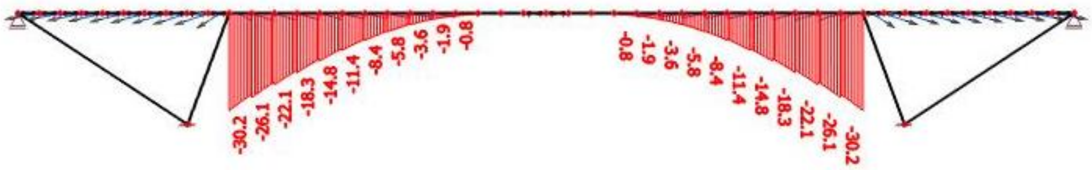


FIGURE 159: LAMELLA 11 BOTTOM FIBERS, FORMWORK CONSIDERED

These last figures 158 and 159 are introduced to see the effect the cable layout change has, as I explained in this project before, the tendons from 11-14 are straight in my design, however we can see that there is not a big jump, or something outside the normal values we were expecting, showing us as a solution until now will work. Also, is important to notice that the figures shown above demonstrate the cantilever behavior in the construction stages.

Second Iteration

We will replicate the previous iteration; however, we will introduce the 3 tendons in the triangular frame again, we will compare the results.

SECOND ITERATION-FORMWORK APPLY FOCUS													
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass compression	Pass Tension	Pass Both	Compresion	Tension	Pass compression	Pass Tension	Pass Both	TENDON OK
Stage 3	2+1	27+15	0	0	1	1	OK	0	0	1	1	OK	OK
Lamela 1	2	9	1	0	1	1	OK	0.8	0	1	1	OK	OK
Lamela 2	2	12	1.6	0	1	1	OK	1.7	0	1	1	OK	OK
Lamela 3	2	12	2	0	1	1	OK	3.1	0	1	1	OK	OK
Lamela 4	2	12	2.1	0	1	1	OK	4.9	0	1	1	OK	OK
Lamela 5	2	12	2.1	0	1	1	OK	7.2	0	1	1	OK	OK
Lamela 6	2	12	2.1	0.9	1	1	OK	10	0	1	1	OK	OK
Lamela 7	2	15	2.2	2.2	1	1	OK	13.2	0	1	1	OK	OK
Lamela 8	2	15	2.4	3.9	1	0	CHANGE	16.8	0	1	1	OK	CHANGE
Lamela 9	2	15	2.5	5.9	1	0	CHANGE	20.9	0	1	1	OK	CHANGE
Lamela 10	2	15	2.5	8.2	1	0	CHANGE	25.4	0	1	1	OK	CHANGE
Lamela 11	2	19	2.9	10.5	1	0	CHANGE	30.2	0	1	1	OK	CHANGE
Lamela 12	2	19	3.2	13.1	1	0	CHANGE	35.3	0	0	1	CHANGE	CHANGE
Lamela 13	2	19	3.7	16	1	0	CHANGE	40.9	0	0	1	CHANGE	CHANGE
Lamela 14	2	19	11.4	13.5	1	0	CHANGE	43.9	4.3	0	0	CHANGE	CHANGE

Tabla 34 STRESSES RESULTS SECOND ITERATION-FORMWORK APPLIED

FIGURE 160: TOP FIBER TENSION APPEARENCE 210 METER BEAM, FORMWORK CONSIDERED

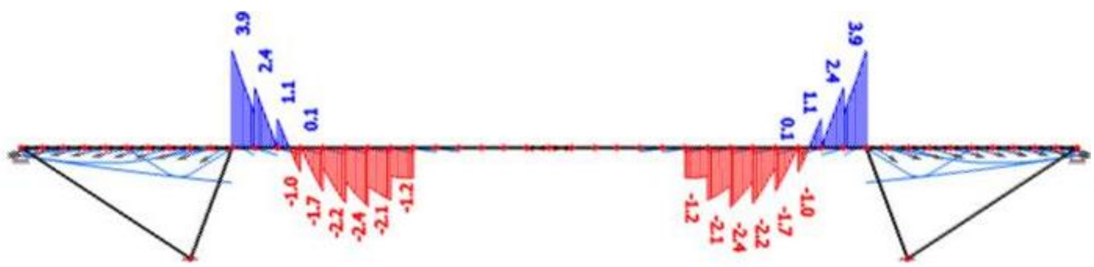


FIGURE 161: TENSION ON TOP FIBERS BEAM 210 M, EXCEED LIMITS, FORMWORK CONSIDERED

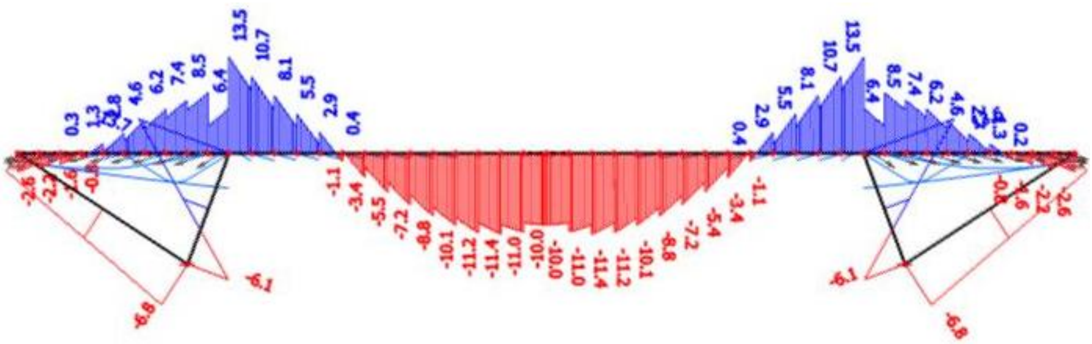


FIGURE 162: TOP FIBERS LAMELLA 14, FORMWORK CONSIDERED

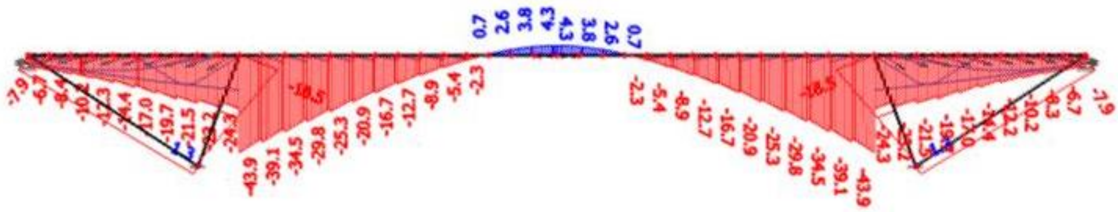


FIGURE 163: BOTTOM FIBERS LAMELLA 14, FORMWORK CONSIDERED

FIGURE 164: LAMELLA 10 BOTTOM FIBERS, FORMWORK CONSIDERED

FIGURE 165: LAMELLA 11 BOTTOM FIBERS, FORMWORK CONSIDERED

From all the graphs and results, we can see that the 3 tendons only affect at lamella 14, once the formwork is retired, the values seen doesn't bring us to much of a variation, we will discard this as a solution and try to cover these internal forces in other ways.

However, this has shown us that the effects are definitively discard if the stationary formwork is present

Third Iteration

We will overstress the structure, we will try to discard or show that we find the path on this possible solution. We will put in every tendon 4 groups of 27 cables and see the final effects.

THIRD ITERATION-FORMWORK APPLY FOCUS													
DATA			Top Fibers					BOTTOM FIBERS					
REFERENCE	Group	Tendons	Compresion	Tension	Pass Compression	Pass Tension	Pass Both	Compresion	Tension	Pass Compression	Pass Tension	Pass Both	TENDON OK
Stage 3	0	0	0	0	1	1	OK	0	0	1	1	OK	OK
Lamela 1	4	27	2.8	0	1	1	OK	0.8	0	1	1	OK	OK
Lamela 2	4	27	5.3	0	1	1	OK	0.8	0	1	1	OK	OK
Lamela 3	4	27	7.5	0	1	1	OK	1.1	0	1	1	OK	OK
Lamela 4	4	27	9.4	0	1	1	OK	2.2	0	1	1	OK	OK
Lamela 5	4	27	11	0	1	1	OK	3.7	0	1	1	OK	OK
Lamela 6	4	27	12.4	0	1	1	OK	5.7	0	1	1	OK	OK
Lamela 7	4	27	13	0	1	1	OK	8.1	0	1	1	OK	OK
Lamela 8	4	27	14.3	0	1	1	OK	10.9	0	1	1	OK	OK
Lamela 9	4	27	14.8	0	1	1	OK	14.2	0	1	1	OK	OK
Lamela 10	4	27	15	0	1	1	OK	17.9	0	1	1	OK	OK
Lamela 11	4	27	15.1	0	1	1	OK	21.9	0	1	1	OK	OK
Lamela 12	4	27	15.4	0	1	1	OK	26.2	0.3	1	1	OK	OK
Lamela 13	4	27	15.4	0	1	1	OK	31	0.2	1	1	OK	OK
Lamela 14	4	27	18.6	0.8	1	1	OK	34.5	2.8	1	1	OK	OK

Tabla 35 STRESSES RESULTS THIRD ITERATION-FORMWORK APPLIED

As we can see on table 35, we have found a solution for our structure in the construction stages, it can be seen that the data provided meets every requirement in every step of the construction in the cantilever; bottom and top fibers are not covered by our concrete selected of C35/45, from this point I will change the concrete used in the superstructure to C60/75, this is done since we will analyze the SLS on the bridge, and if we consider the limits, the values obtained won't be covered.

After we change the concrete I can conclude this is a first indicator that a solution can be found with the application of stationary formwork on the triangular frame.

Another information we can see on the table is that we do not have at any time tension on the top fibers, reason of most of our design discards, we only reach a 0.8 at the moment the lamellas 14 meet together and we retire the formwork on the triangular frame and the cantilever beam.

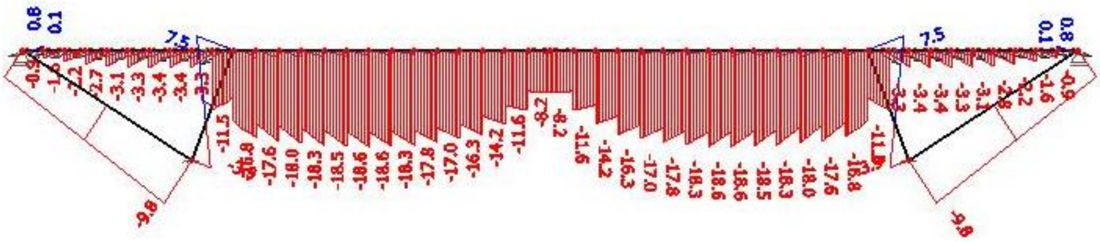


FIGURE 166: TOP FIBERS LAMELLA 14-FORMWORK CONSIDERED-OVERSTRESS STRUCTURE.

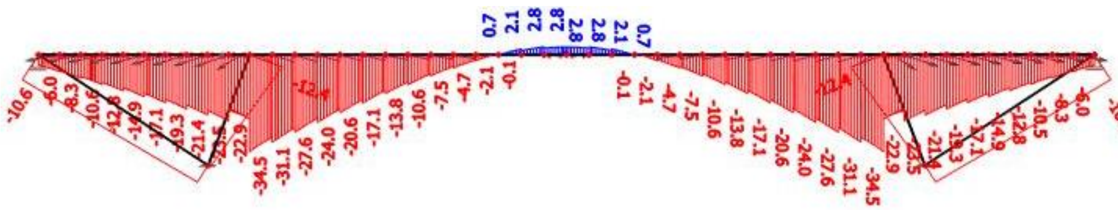


FIGURE 167: BOTTOM FIBERS LAMELLA 14-FORMWORK CONSIDERED-OVERSTRESS STRUCTURE.

Compared to the previous figures on the last iterations, we can see that on this particular case showed on figure 167, which we considered the most critical during the construction phase, we reach the limits too, compression is covered and tension too, however is important to notice that the compression is barely covered. If we will like to have a bigger gap, we can change the concrete to a more resistant.

FIGURE 168: LAMELLA 6 TOP FIBERS, FORMWORK CONSIDERED-OVERSTRESS STRUCTURE.

FIGURE 169: LAMELLA 8 TOP FIBERS, FORMWORK CONSIDERED-OVERSTRESS STRUCTURE.

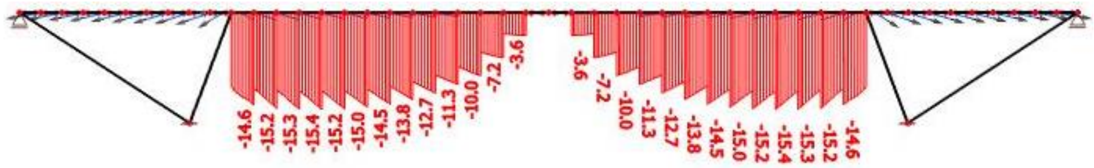


FIGURE 170: LAMELLA 13 TOP FIBERS, FORMWORK CONSIDERED-OVERSTRESS STRUCTURE.

These figures 168, 169 and 170 are a clear representation of how the stresses are incrementing throughout the bridge while its developed, we can see that the shape is as expected and the criteria meets. However, is important to notice how the higher compression values tend to go to lamella 4 while the bridge is being constructed, this is an effect to take in consideration in the future designs.

FIGURE 171: LAMELLA 3 BOTTOM FIBERS, FORMWORK CONSIDERED-OVERSTRESS STRUCTURE.

FIGURE 172: LAMELLA 8 BOTTOM FIBERS, FORMWORK CONSIDERED-OVERSTRESS STRUCTURE.

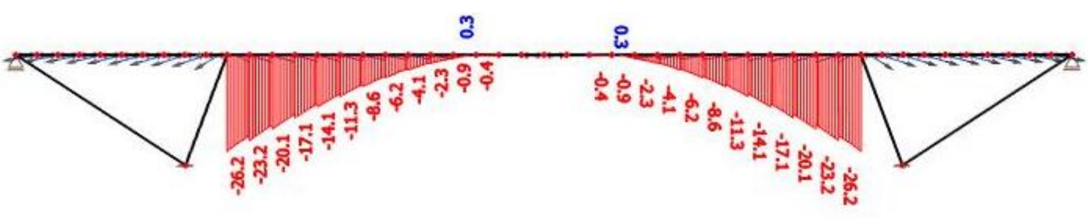


FIGURE 173: LAMELLA 12 BOTTOM FIBERS, FORMWORK CONSIDERED-OVERSTRESS STRUCTURE.

These figures 171, 172 and 173 are a representation on the results in the bottom fibers, the shape is as expected too, the values keep growing according the bridge is developed and the results are within the limits. As we can see on lamella 12 a small tension is appeared, in case we want to get rid of it, we should put more prestress. However, is important to notice that on figure 171 we can see a weird shape of the sum of the stresses, this was not expected, this might be a problem regarding the shape of the tendon.

General analysis of group redefining the structure and its construction stages

The first thing we can notice is that we have reach a possible solution, the fact of including the formwork on the triangular frame has given us the advantage to disregard the internal effects on that part that are carried later under the development of each lamella. The next positive point is that the shape of the member stresses on each fiber are expected, however the values are being close to the limits, this gives us not a safety factor to work with possible mistakes, so we should consider some optimizations of the tendons, that way we will be able to work more relaxed the design of the bridge.

We also need to remark the fact that the tendons on the triangular frame are no longer needed as we see on this group of optimizations, since once the framework is there no effect they will have under the cantilever development.

The other solution proposed by eliminating the tie element won’t be developed on this project since we have found already a solution for the construction stages.

Stages implemented for Construction Stages

Stage 5-Continuity cable

At this stage I will introduce the prestress for service life in the program, it's important to notice that the program always require a permanent load to function, however since at this point no permanent load I added in the bridge, I will introduce a load with value zero, this is done since it's an incremental method the time dependent analysis, the values need to keep incrementing due to each stage.

Stage 6-Superimposed Dead load

In this stage I will introduce a permanent load where it will represent the additional works that the bridge needs to be introduce, this is pavement, handrails, steel barriers, light poles, and any other permanent load the bridge will need for its proper functioning. The value introduce was calculated at the beginning of this project. This stage will consider a 30-day time line proposal

Stage 7-End of construction Stages

This is a stage where another zero permanent loads will be introduced; at this stage I will setup the program to finish the construction stages. This stage will consider a 30-day time line proposal.

Continuity Cable

For the continuity cable I will try to replicate the moment diagram of selfweight that we have on our bridge as we can see on figure 51, from that point the shape of the tendon has to be as close as it can so we can have an optimized tendon. I will try to eliminate the tensions throughout the structure. Also, these tendons should cover the live loads throughout the service life. However, at this point I will only focus on the stresses in the construction stages. Later on, at the service stage it can be checked that the tendon covers the live loads effects too.

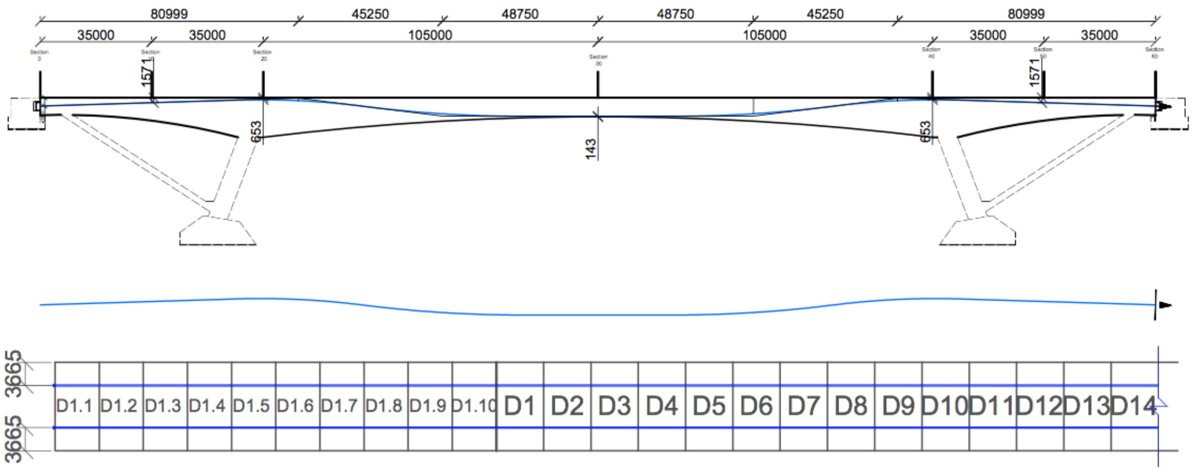
Design Approach

For the design on the prestress cable I will try to cover Serviceability limit states on prestress. I used the tendon editor of the Scia program to provide the layout. I have managed to keep the minimum distance as the Eurocode establishes from the bottom fibers of the cross section. This value will be 100 mm between the exterior parts of the tendons while the tendons will be 100 mm.

The beginning of the tendon will be placed at the center of gravity of the first cross section, from that point on; it will follow a smooth shape with the tangent-tangent-radius, where the radius will respect the minimum value as establish on the Eurocode.

Cable layout

Figure 174 represent the cable layout taken in consideration for the program. This layout will be analyzed with the program, I will try to eradicate the tensions on the top and bottom fibers throughout the whole superstructure, if that is accomplished the analysis for design should be done.



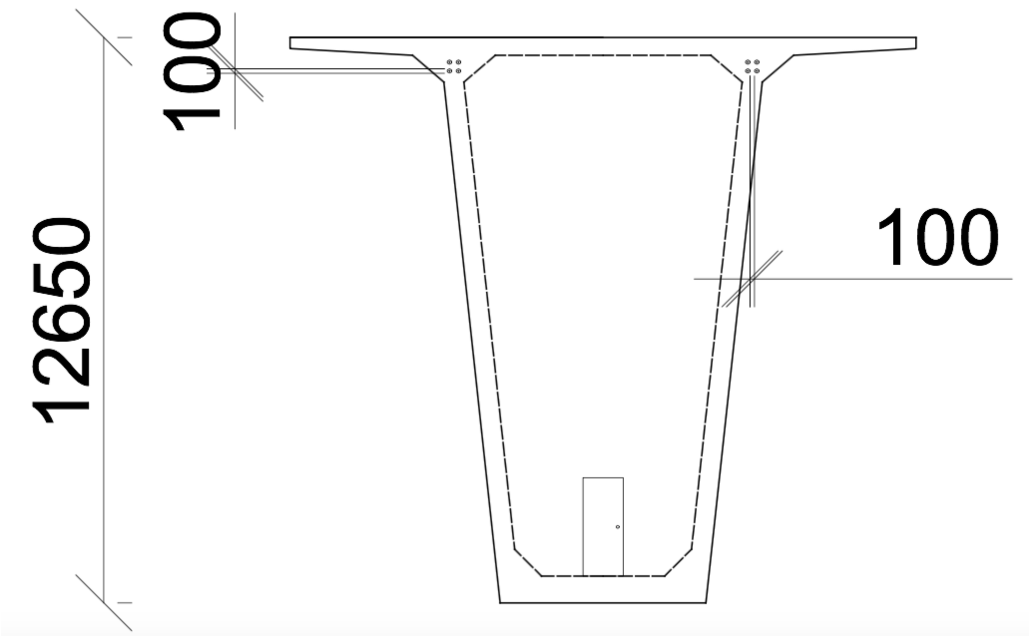


FIGURE 174: CONTINUITY CABLE LAYOUT PROPOSAL PLAN, LONGITUDINAL VIEW AND CROSS SECTION AT SECTION 20

Primary and secondary forces

The figures presented will be for 20 groups where each of them will have 19 tendons. This are the forces the cable has on the structure due to its layout and the fact that is a statically indeterminate structure, since this is present we will have primary and secondary moments, due to the presence of extra supports that create reactions that modifies the moment diagram of the structure as we can see on the figures.

It's important to notice that the main two factors to be taken in consideration is that the shape on the primary moments are the expected since our reactions will create this type of moment diagrams with the fixities it has. Also, the second important thing to notice is that the tendons has losses on the right side of the figure, this is due to the fact that I did not establish the settings of the tendon to be prestress from both sides, creating immediate losses throughout the distance of the tendon due to friction.

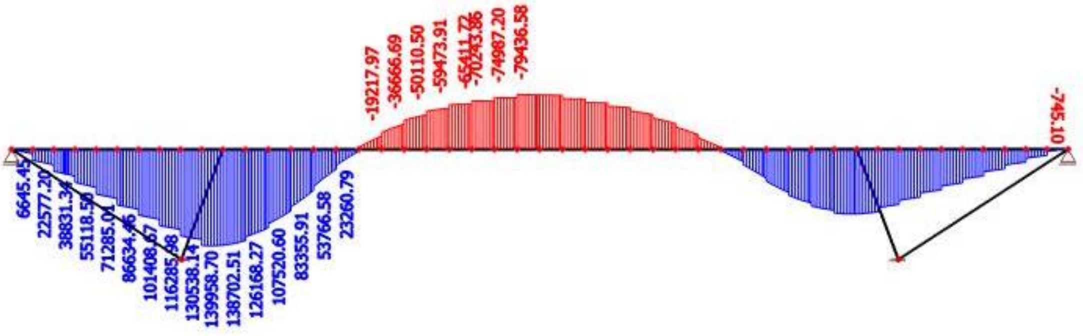


FIGURE 175: PRIMARY FORCES

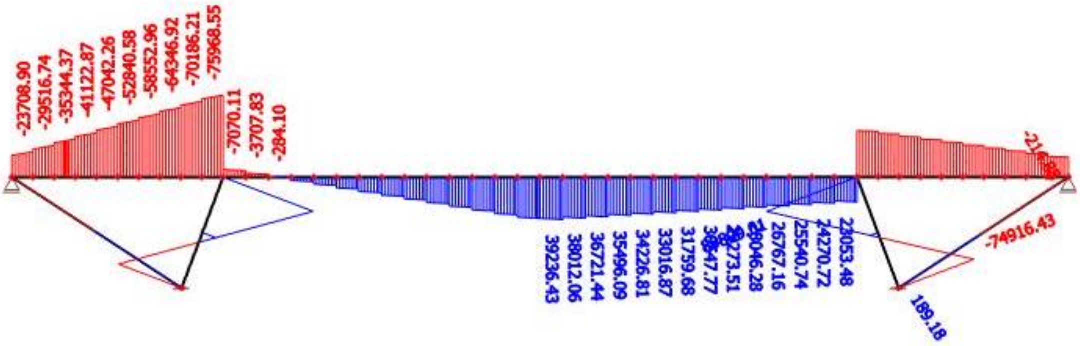


FIGURE 176: SECONDARY FORCES

Moment diagram Results

As we can see on the next figures this are the effects that the cable has on the structure. Figure 177 shows us the effect the prestress has as we can see the shape of the moment diagram is as expected, it follows the shape of the tendon, we can see that the point where the forces turn from tension to compression are located at lamella 7, the inflexion point of the cable. Also, is important to notice that the strut element has taken most of the effects, reason why we have a jump in the diagram at the connection point between the 210 and the 70-meter beam. This might show us that we can face a problem in the inner span since those effects should be translated to that part of the beam. I will continue the project with this tendon layout and analyze the effects it has on the service stages.

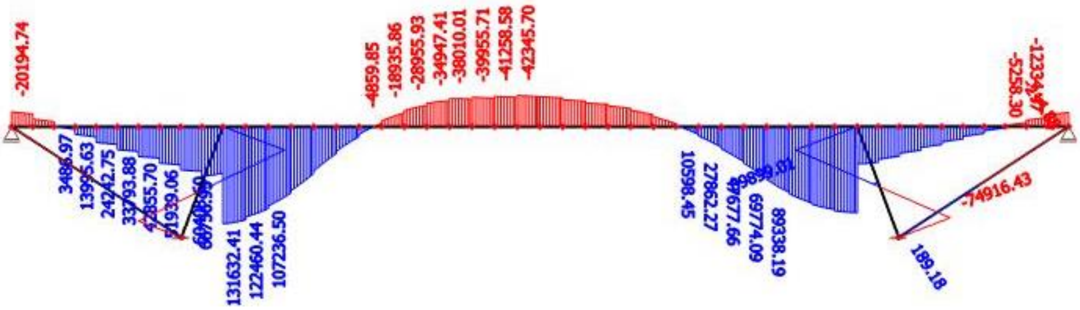


FIGURE 177: MOMENT DIAGRAM DUE TO CABLE

Final Construction Stages Proposal

After finding the solution for the construction stages, the final proposal will be explained by the next graphs. It's important to notice that the process described will be applied on both sides of the canyon, this bridge will be developed at the same time until they meet at the center span.

Stage 1-Excavation and Footings casting

On this stage the main focus is to excavate and stabilize the terrain, in both sides of the canyon, this way we will be able to start digging the holes for the footings. At the same time the footings on each side should be developed, this will be holding the scaffolding for the triangular frame. The footings will be developed on and angle to keep the forces go in the same direction as they come from the strut element.

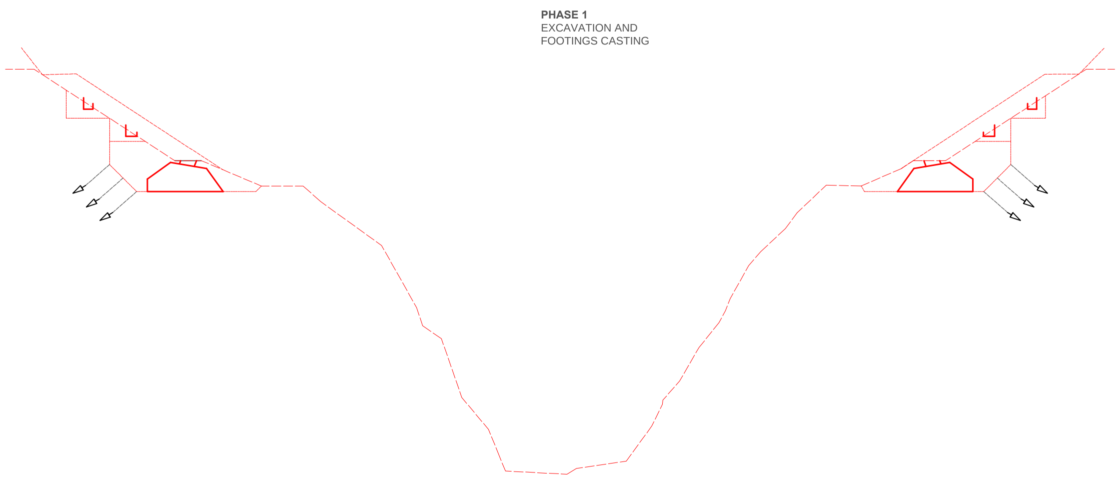


FIGURE 178: CONSTRUCTION STAGES STAGE 1

Stage 2-Tie and Strut elements

We develop the tie and the strut element, the tie element will be constructed by scaffolding supported at the rock soil and the strut element will be developed by parts, small lamellas of 2,5 meters with a movable scaffolding that can be held from the tie element and its footings.

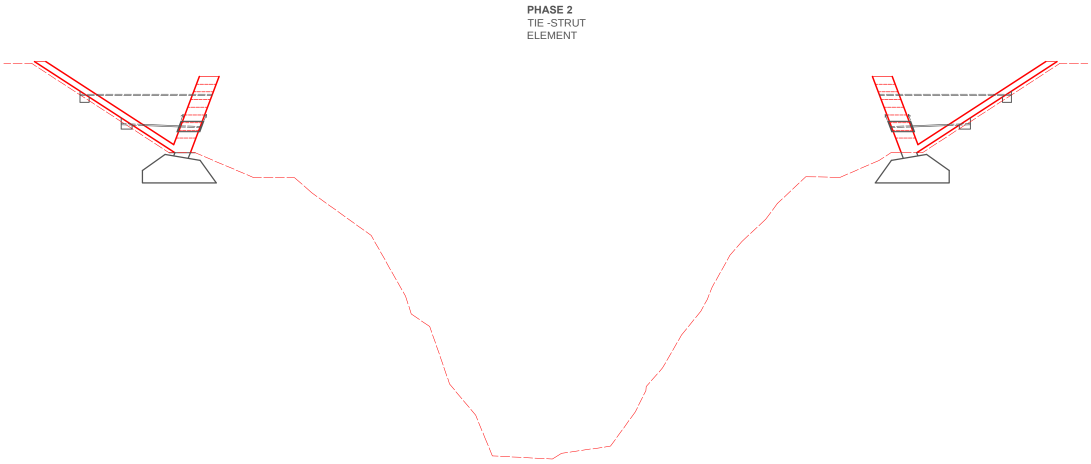


FIGURE 179: CONSTRUCTION STAGES STAGE 2

Stage 3-Triangular frame scaffolding installation

This stage will be specifically to install the scaffolding, at this point we will already have the shape to follow on the hunched beam of 70 meters, this scaffolding will stay until the finalization of the construction stages. We will have 3 main columns elements which will held 4 different scaffolding beams, which also will be resting onto the strut and tie elements.

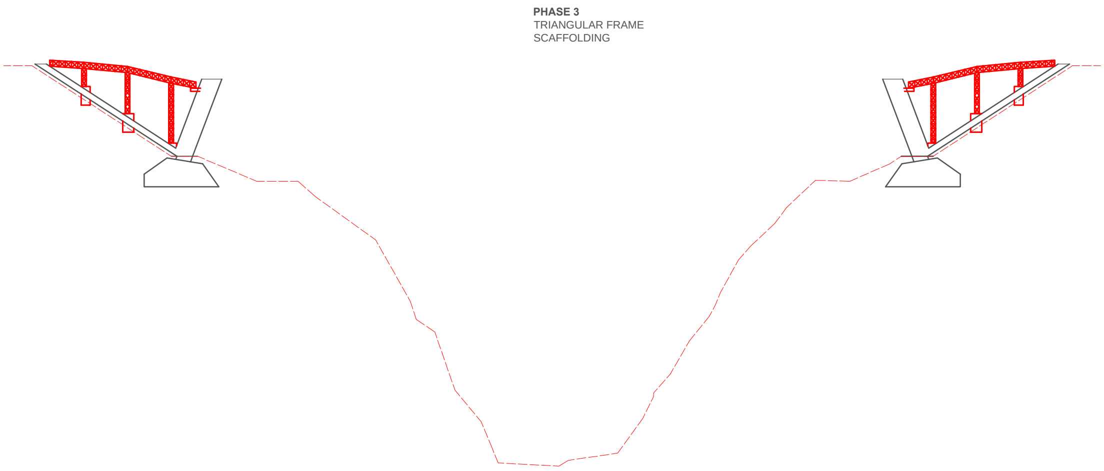


FIGURE 180: CONSTRUCTION STAGES STAGE 3

Stage 4 abutment construction

The abutment on both sides should be developed, this is where the bridge beam will rest, this element will also be responsible to avoid displacement on the beams in any direction more that estipulate. At the same time this will hold the soil from the lateral forces that may affect somehow the bridge. Since we haven't developed the design of it we will place an example

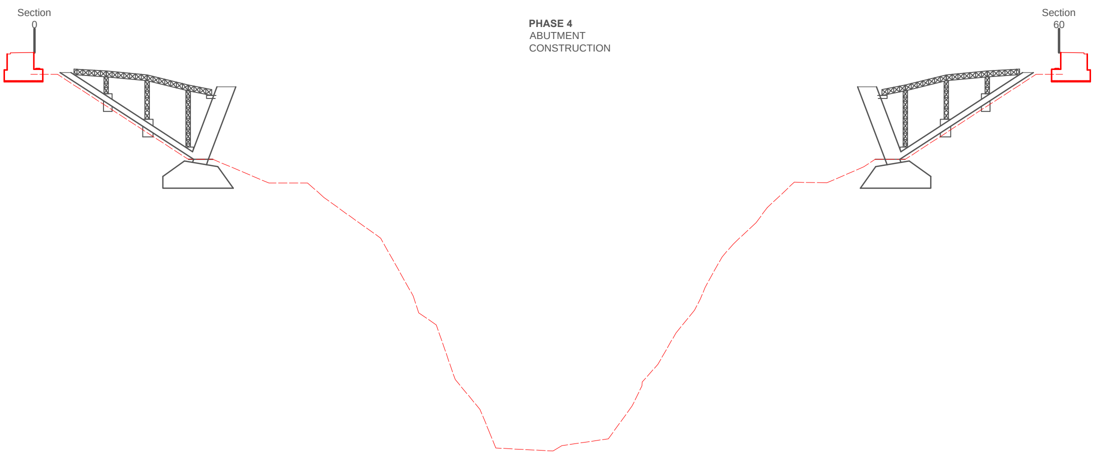


FIGURE 181: CONSTRUCTION STAGES STAGE 4

Stage5 Superstructure development, 70 meters

Even thou in the project until know we have considered them lamellas, we will cast them as one element, once the stationary scaffolding is in place. We prevent the appearance of internal forces on the beam while developing the construction of the cantilever beams, with the permanent scaffolding, figure 177 show the development of this section. Prestress and electric ducts should be placed while construction.

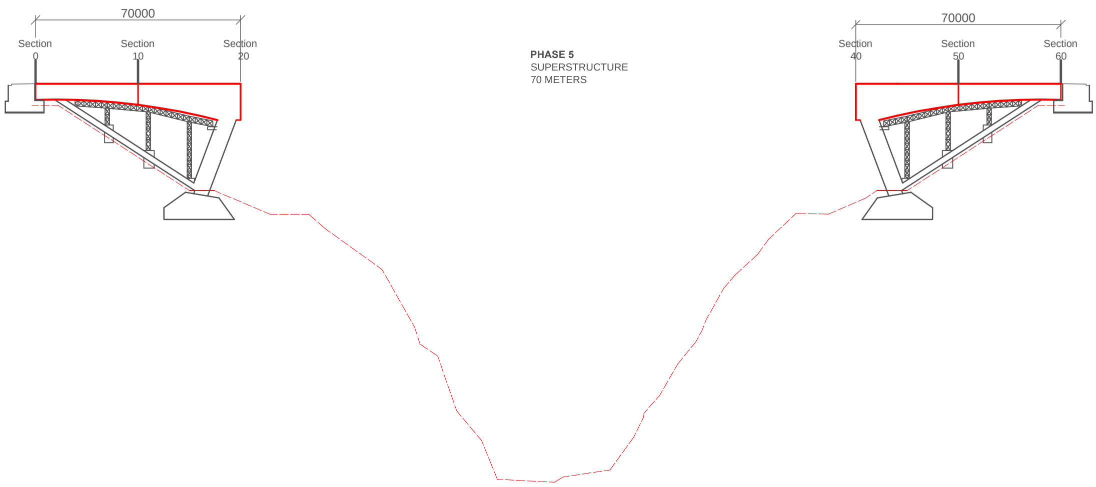


FIGURE 182: CONSTRUCTION STAGES STAGE 5

Stage 6 movable scaffolding installation

This stage is placed to install the two movable scaffoldings for the cantilever beam development, each scaffolding should be able to produce a lamella of 7.5 meters and we should place two of them, one on each side of the bridge to develop it at the same time.

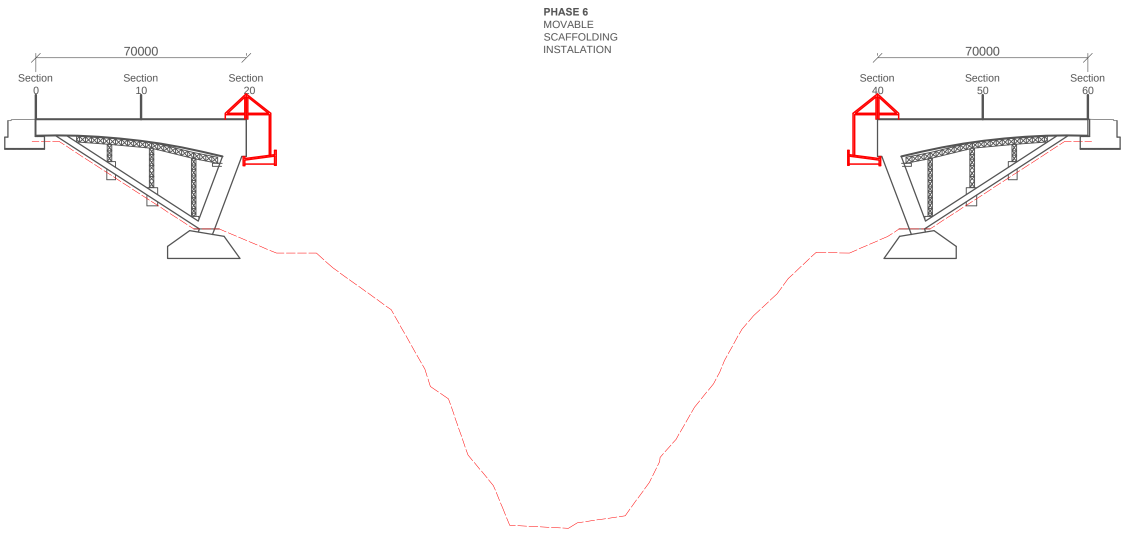


FIGURE 183: CONSTRUCTION STAGES STAGE 6

Stage 7-13 lamella D1-D14 210-meter beam

In these stages we will produce the cantilever lamellas, each of them should be 7,5 meters, and after 3 days of casted, we will apply the tendons to avoid tension during the construction phase, these tendons have to be referred to the solution found on this project.

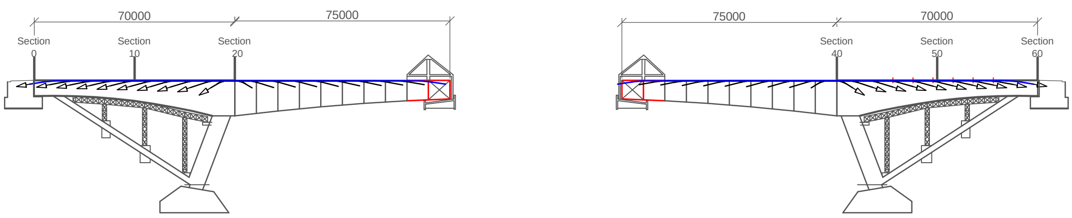
PHASE 7
LAMELLA 2

PHASE 8
LAMELLA 4

PHASE 9
LAMELLA 6

PHASE 10
LAMELLA 8

PHASE 11
LAMELLA 10



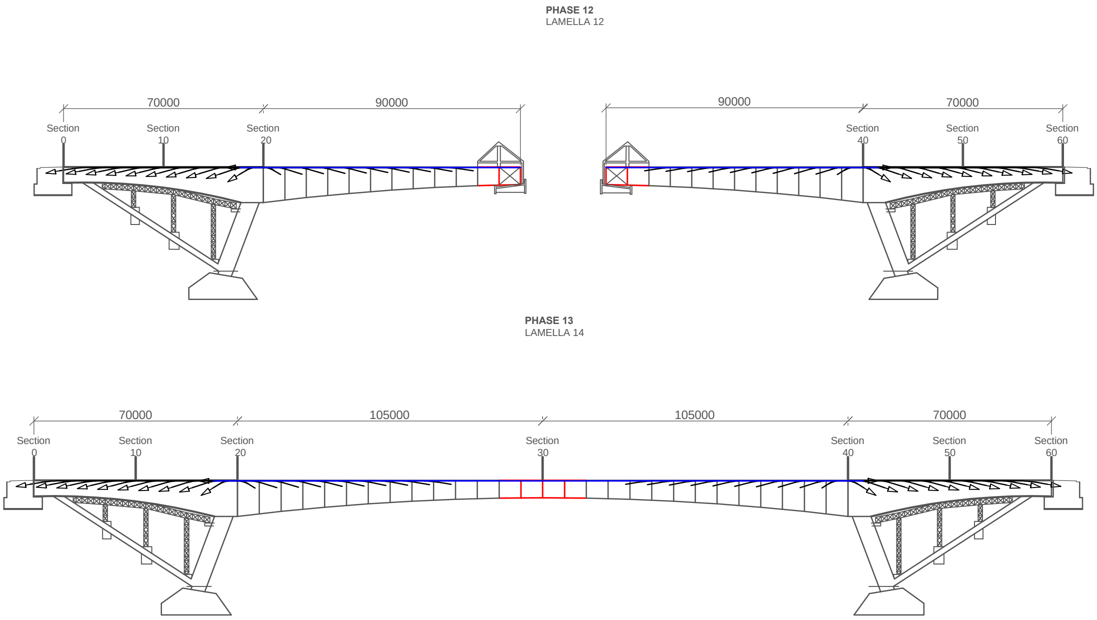


FIGURE 184: CONSTRUCTION STAGES STAGE 7-13

Stage 14 Continuity cables and Service stage

At this point we will install the continuity cables, the pavement and other services that the bridge needs to consider the end of construction stages, at this point the bridge will start to function as in service, where the mobile loads will be applied. Once the continuity cable is placed and functioning we will take the permanent scaffolding of the triangular frame out.

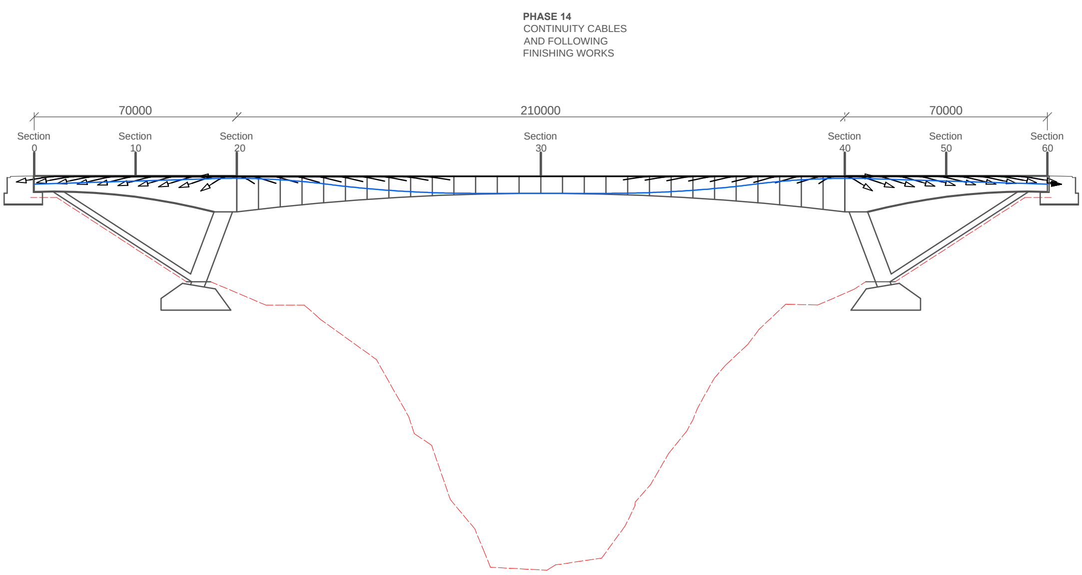


FIGURE 185: CONSTRUCTION STAGES STAGE 14

Service Stage

I consider service life 100 years for this design, since the maximum time the Scia program allows to be used on time dependent analysis is 35499.99 days. In this part of the project I will try to analyze the whole service stage of the bridge, I will mainly focus on SLS analysis and making sure the tendons of the continuity cables cover the tension fibers thought the whole structure at all points. In this stage we will consider the live loads as Eurocode provides, superimposed dead load, which cover pavement, handrails, steel barriers, protection layers, electricity and many other factors that will be present on the bridge. The values of the loads are explained previously on this thesis.

Stages added for service functioning

Additionally, at this service's stage I have created 3 new stages on the program, this way I will be able to obtain the results needed and analyze the structure at each stage of service life. And prove the tendon layout proposal is the correct.

Stage 8-Start of bridge operation no Live load considered

At this point I will introduce another zero-permanent load, this is the point where the bridge will be finished, but haven't been open for traffic. This will be an important stage since we can see the stress effects the bridge has at the end on the service life if we compare it with this stage. This stage is considered the day after stage 7 is introduced.

Stage 9-Start of bridge operation Live Load considered

At this point the bridge is in service, operation for the public is valid, live loads should be considered, the mobile loads are considered and are the same as explained at the beginning of this project, no permanent action is considered in this point. This stage is considered immediately after stage 8 is introduced.

Stage 10-End of bridge service

This is an empty permanent load stage too however at this point the analysis of creep should be done, it's a load where I will be able to compare to stage 8 and see the effects creep has on the superstructure in 100 years, at this point SLS should be covered to be consider a functional and successful structure.

Results and analysis of tendon proposal

Out of the results obtained on the previous analysis, the results to be analyzed are presented next. If we analyze the previous results obtained on the iterations in the cable layout proposal we can see that the layout provided is probably not the best option, in figure 186 I introduce the final moment diagram obtained at stage 8, at this point we should cover the moment diagram of selfweight provided by the program.

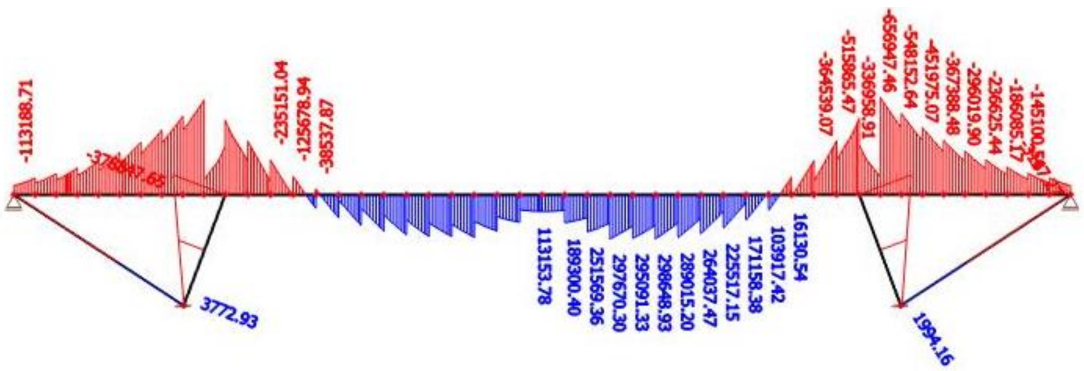


FIGURE 186: MOMENT DIAGRAM STAGE 8 4G-19T

as we can see we have tensions still on some members of the superstructure. The basic principle of the prestress establishes that we will add external forces to remove the loading effects, which in this specific case the loading effect being analyze is the selfweight. This is a first indicator that the amounts of tendons proposed are not enough.

Also, we need to focus on the fact that the strut element is absorbing the effects needed, this is due to the high stiffness the element has. However, I will try to increase the area of prestress to see how the structure will act.

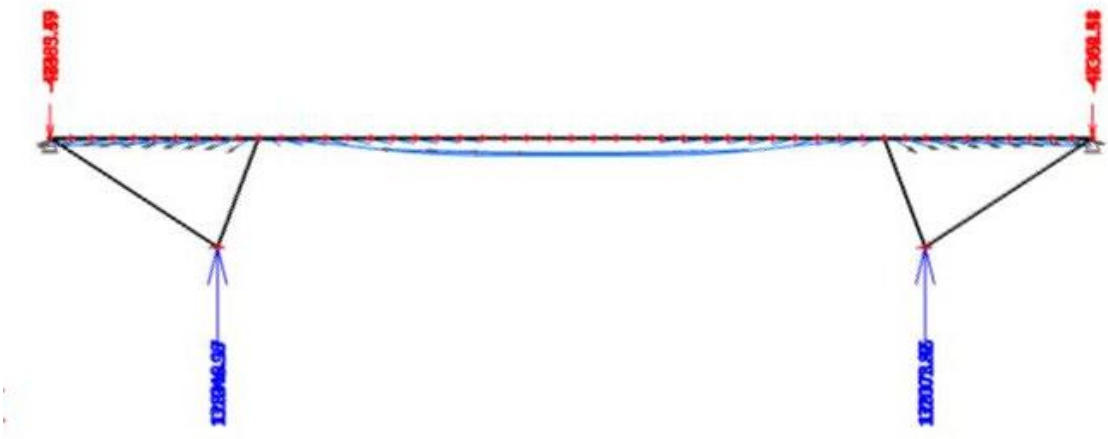


FIGURE 187: REACTIONS

At figure 187 we can see the reactions, for the design of the bridge the bearings on section 0 and 60 need to be able to hold 48.30 MN, as expected the reactions at section 20 and 40 are bigger since it distributes all the loading of the superstructure, the footings should be design for these values.

Iteration results

I will use the same method previously used on the project to find a solution, I will change the amount of prestress by iterations to see if the design proposal is correct and can provide a suitable solution for the service stages.

First iteration

At this iteration I have incremented the area of prestress from 8 groups to a total of 20 groups, where each group will have 40 tendons instead of 19.

Moment diagrams analysis

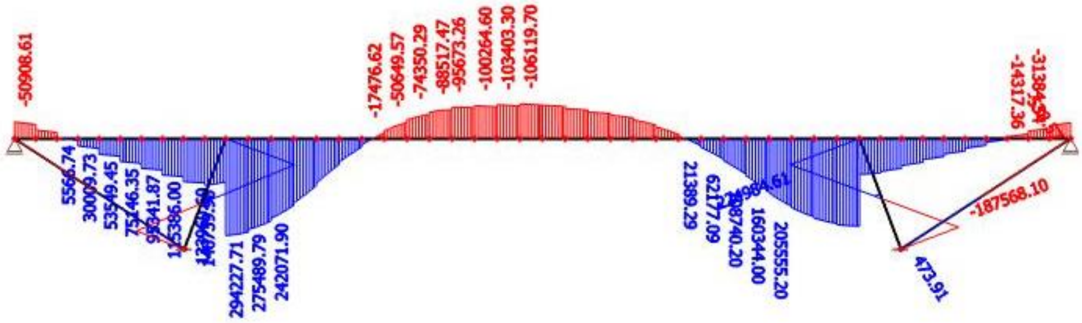


FIGURE 188: MOMENT DIAGRAM DUE TO PRESTRESS 20G-40T

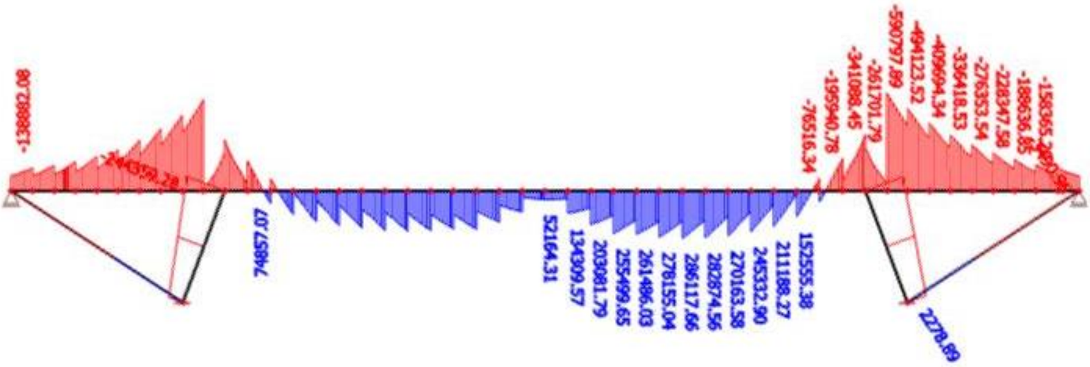


FIGURE 189: MOMENT DIAGRAM STAGE 8 20G-40T

The first two figures are introduced to show us the effects the amount of prestress has on the structure, figure 188 shows us that the prestress works and keeps the shape, however the values we have only by this are not enough to cover the selfweight moment diagram. This shows us this is not a solution for our bridge. However, is important to notice that the values on the strut have incremented showing us that the strut element still holds most of the effects needed on the superstructure. If we analyze why this effect is done we can see that the primary forces on figure 175 are mainly focus on the area, considering that the cable layout proposal is based on a 45-degree angle to obtain the curvature point of the tendons these effects are facing the strut element, since it's not a bearing point but a fixed part of the structure, the effects provided are translated to the strut.

If we compare the values on the center span of the superstructure on section 30 at figure 189, we can see that they have decrease by 54%, however we can still see that we have tension on the inner span of the superstructure. This has confirmed that the tendon is not a suitable solution.

SLS Check

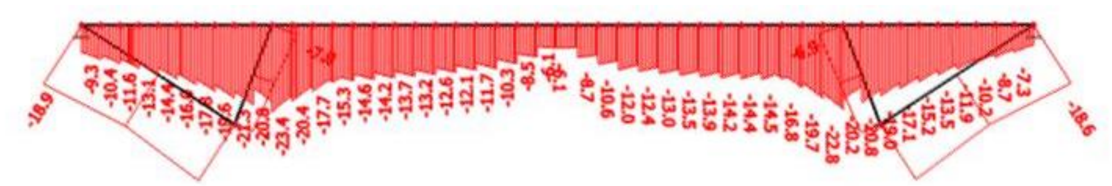


FIGURE 190: STAGE 8 STRESSES ALL FIBERS 20G-40T

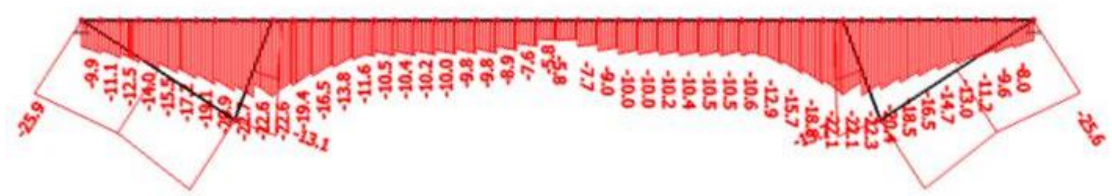


FIGURE 191: STAGE 10 STRESSES ALL FIBERS 20G-40T

Figure 190 and 191 show us the member's stresses throughout the whole structure in the two main service loads. In the SLS check the stresses should cover limit values established by the concrete strength at service life. Since we are using concrete C 60/75 our limiting conditions are:

1. $\sigma \leq 0$

   $$at\ top\ or\ bottom\ fibers\ to\ ensure\ pure\ compresion$$

2. $|\sigma| \leq 0.6\, f_{ck} = 0.6 * 60 = 36\ MPa$

   $$at\ top\ and\ bottom\ fibers\ to\ ensure\ pure\ compresion$$

From what we can see on the figures these two conditions are meet, showing us that SLS is checked, our biggest value is 23.4 in pure compression.

However, we need to notice that these graphs show us an envelope of the biggest stresses the superstructure has at each lamella. Reason why a check should be done on each fiber, figures 192-195 shows us the results for each stage and each fiber.

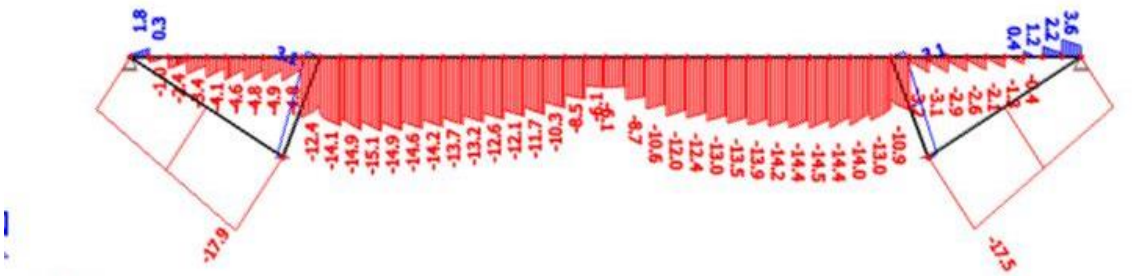


FIGURE 192: STAGE 8 TOP FIBERS STRESSES 20G-40T

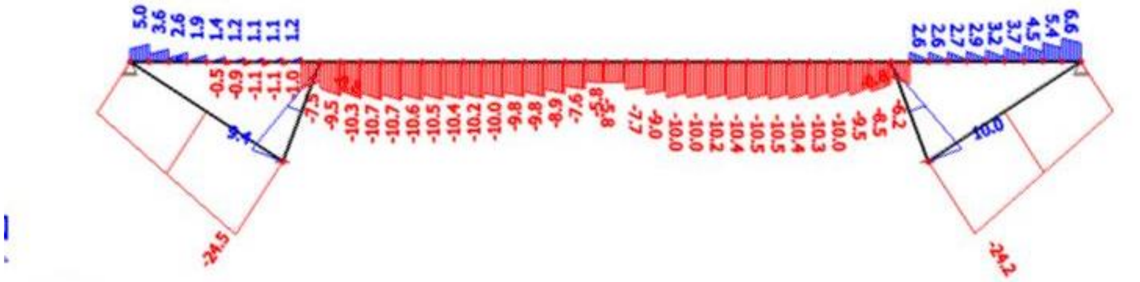


FIGURE 193: STAGE 10 TOP FIBERS STRESSES 20G-40T

If we analyze the top fibers we can see that we have a problem on the triangular frame, we have tension fibers on both stages, is important to show that the effect of creep is also present, we can see that at the end of service life the stresses on the top fibers in the tension area have increment from 3.6 to 6.6 at the most critical point, and in compression stresses from -15.1 to -10.7 in the most critical point. We can see that we are not covering the limits, so SLS check fails here two. I need to provide more prestress area at the triangular frame, or in it defect avoid the strut element to take most of the effects to redistribute them in the superstructure.

FIGURE 194: STAGE 8 BOTTOM FIBERS STRESSES 20G-40T

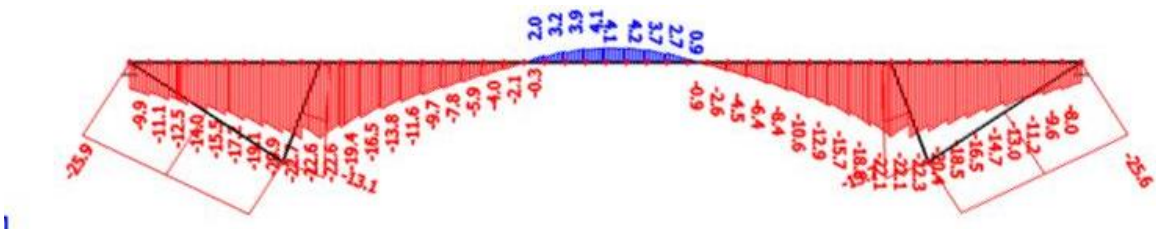


FIGURE 195: STAGE 10 BOTTOM FIBERS STRESSES 20G-40T

Analyzing the bottom stages, we can see that we have the same problem of tension stresses, however at this point they are present in the inner span. We can see the creep effects here too since the values at stage 8 are negative, meaning compression, however at the end of service life they increment to 4.1 in tension, showing the solution provided is not enough. In case we were allowed to have a limited tension, these values should be lower than the concrete tensile strength.

Analysis first iteration

As we have seen on the results the solution provided is not enough to work with. It's important to notice that I have doubled the amount of prestress and yet I haven't been able to cover the limits for SLS and the tension moments that are still present in the structure, this will cause cracking on the concrete, which is one of the main principles of prestress, eliminating this effect mention get us able to have smaller cross sections since the elements will be stiffer, also it will prevent external agents to attack the steel.

New continuity tendon layout

It's important to take in consideration the fact that I have analyze the section with a bigger number of tendons, this difficult the location of them in the cross-section with the design I provide, considering the minimum cover and distance between them, the center of gravity of the location of the tendons and the actual location in reality will differ, not providing the values we expect that the program gives us. We need to remember that all tendons have a minimal and a maximal limit where they provide the effect. Reason why my suggestion is to add not bounded tendons in the inner span on the bottom fibers, this way I will try to eliminate the tension on the area, which will also redistribute the stresses at the end of the service life on the bottom fibers. I will still use the continuity cable proposal I introduce previously, since the shape has shown its effects on the structure. The new cables will start from the center of gravity of the lamella where it will be introduced. The new tendons will be presented on figure 196.

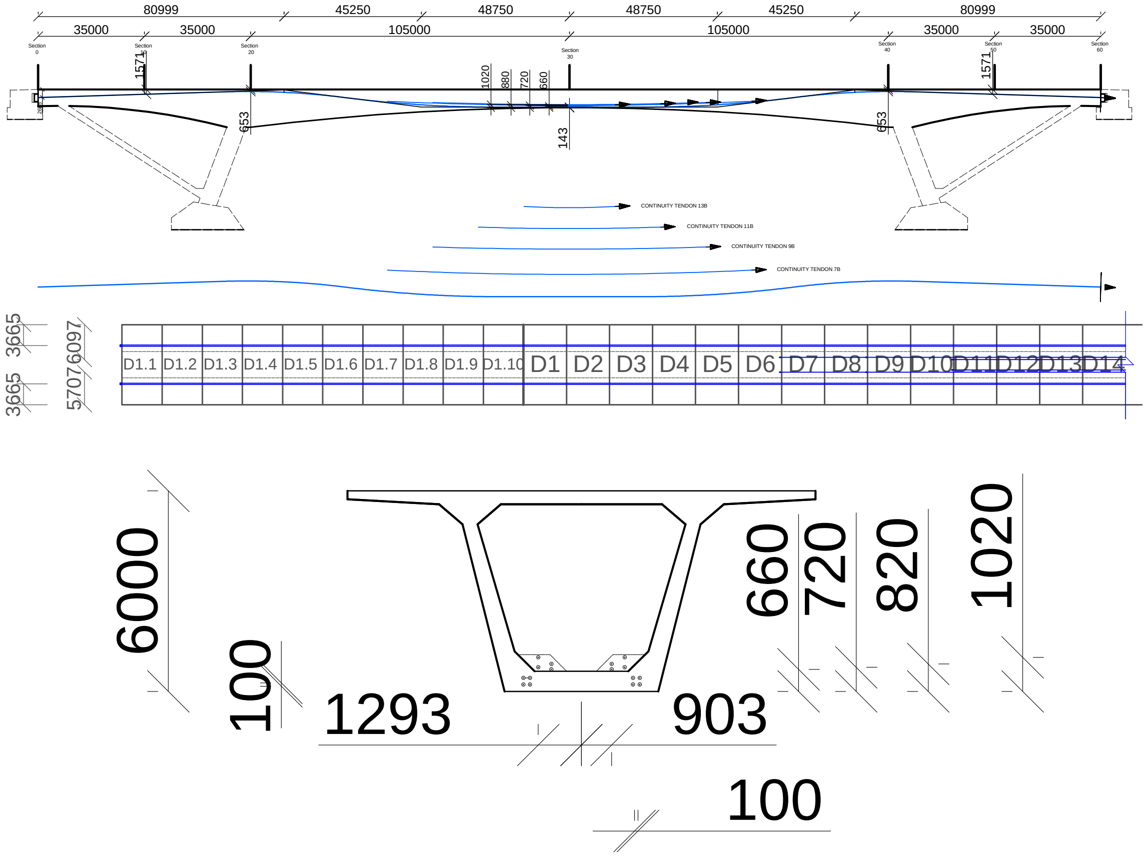


FIGURE 191: TENDON PROPOSAL 2

Results

I have provided as a comparison some results that I have obtained with the addition of 2 groups of 19 tendons each. However, for this example I have decrease the number of groups and tendons in the bonded continuity cable to 20 groups of 19 tendons each. At this point I have corrected the prestress at both ends. The final results are shown on the next figures.

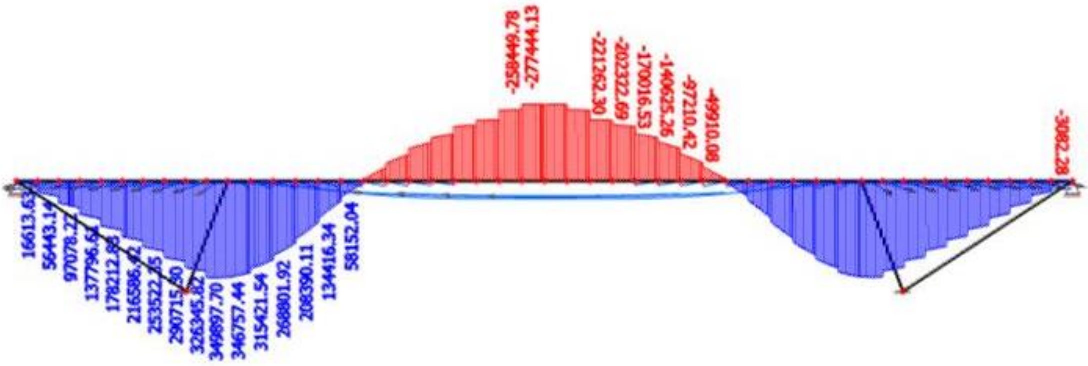


FIGURE 192: PRIMARY FORCES UNBOUNDED TENDONS

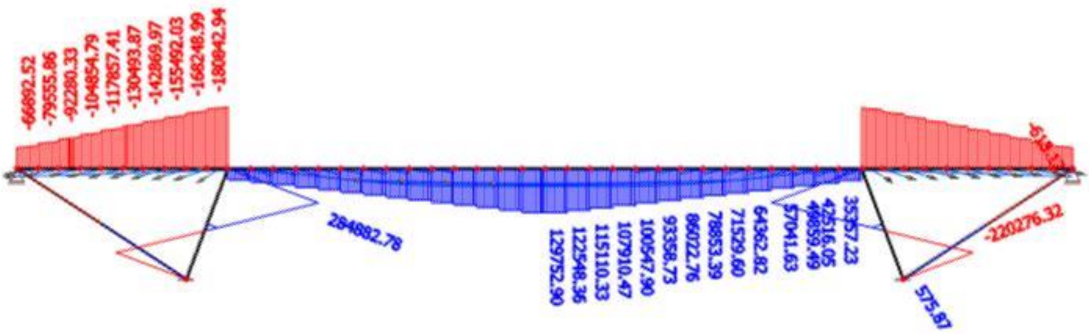


FIGURE 193: SECONDARY FORCES UNBOUNDED TENDON

The first thing we need to notice out of the primary and the secondary forces is that we can see that the losses of prestress have been corrected at the end of the beam, this is due to the fact that the prestress will be done from both end. As we see the shape still keeps the same way as the previous analysis, however, we can see that the values have increased by 3 times on the inner span, even though we have decrease the cables on the bonded continuity cable. This shows us that the effects we are looking for in the inner cable are working due to the new layout. On figure 193 we can see that the effects on the compression at section 20 have also increased to the double values, this is due to the fact that here we consider more prestress than at figure 176.

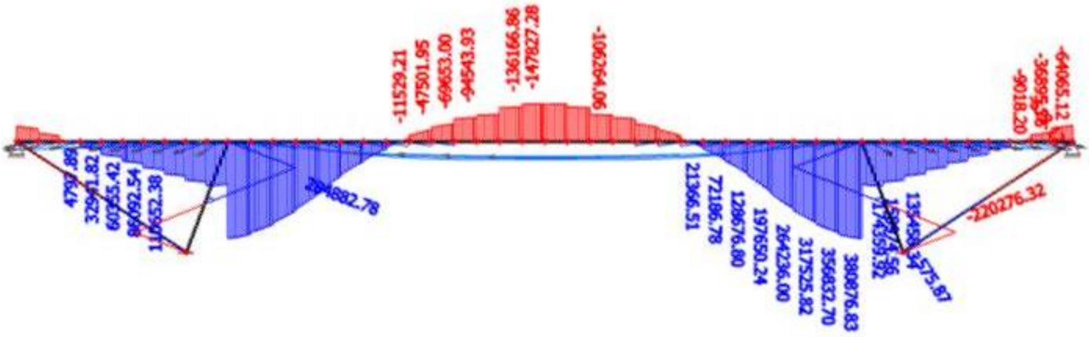


FIGURE 194: MOMENT DIAGRAM UNBOUNDED TENDONS

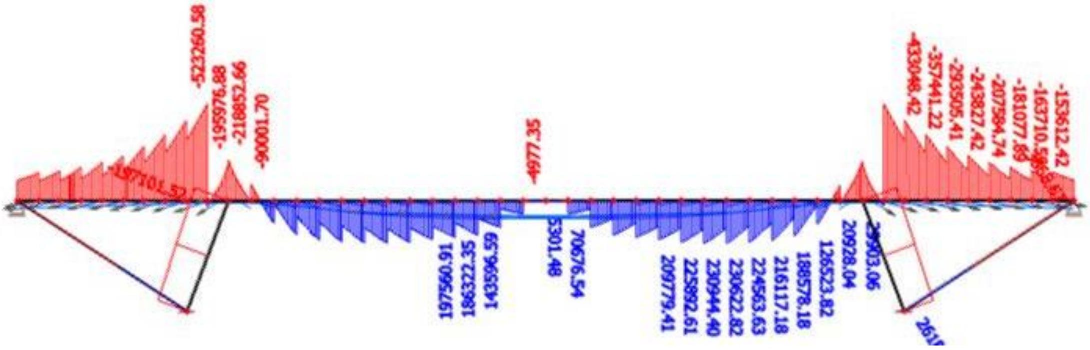


FIGURE 195: MOMENT DIAGRAM UNBOUNDED TENDONS STAGE 8

on the previous figures we can see that the values of tendon due to the prestress have increase, is important to notice that we are providing less prestress area, however we get better results. Still as we see on figure 195, tensions are present on the inner span beam, however they have been lowered, this has shown us that this is not a suitable solution since we haven't got rid of the tensions.

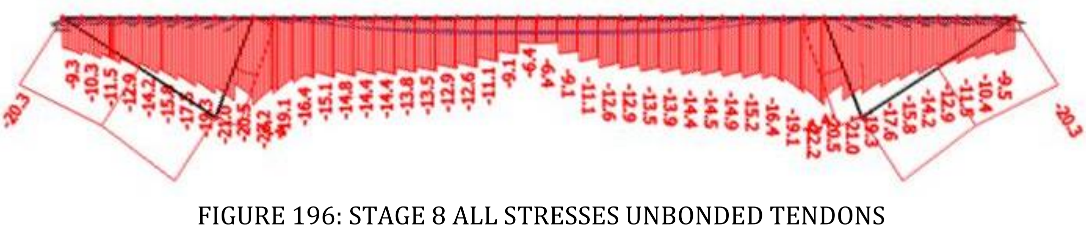


FIGURE 196: STAGE 8 ALL STRESSES UNBONDED TENDONS

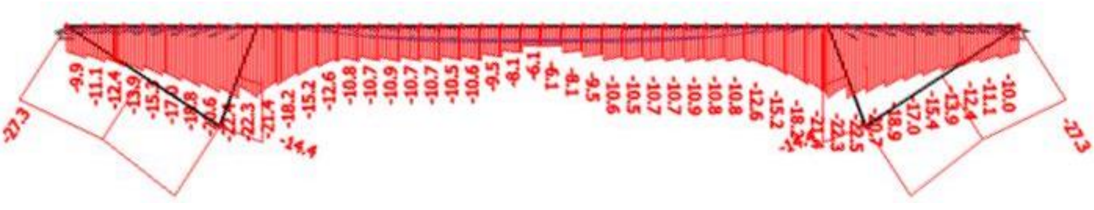


FIGURE 197: STAGE 10 ALL STRESSES UNBONDED TENDONS

The first thing we need to notice out of figures 196 and 197 is that the effects are shown in these figures due to the new tendon layout, the values have increased on the compression fibers. Also, we can see that the creep effects are the same; they change by 0.3 in the whole service stage. These effects are expected.

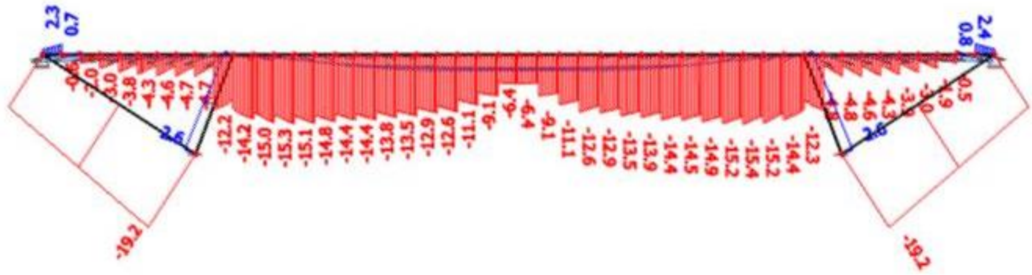


FIGURE 198: STAGE 8 TOP STRESSES UNBOUNDED TENDONS

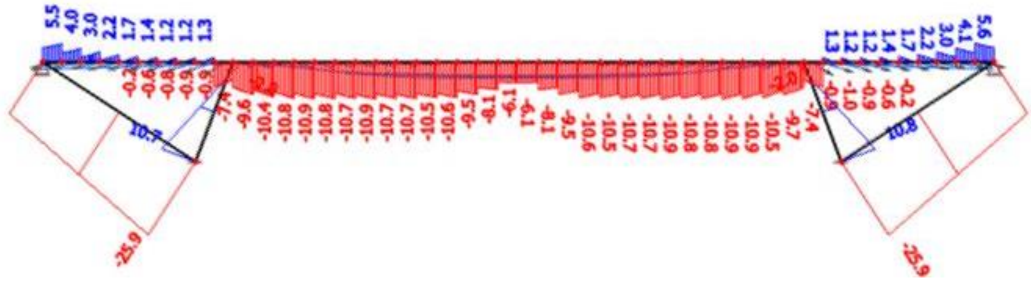


FIGURE 199: STAGE 10 TOP STRESSES UNBOUNDED TENDONS

As we can see on the figures above introduced, at the end of service life on the 70-meter beams we have tension present, since we are trying to keep zero values on this we cannot accept these results. However, is important to notice they have keep the same values, this is due to the fact that the effects of the new tendons redistribute the forces in the bonded continuity tendon, reason why having less tendons in these cables have the same effect, also as previously stated we can see that the values are similar in both ends, this is a difference from the previous figures since the tension is applied from both ends.

FIGURE 200: STAGE 8 BOTTOM STRESSES UNBOUNDED TENDONS

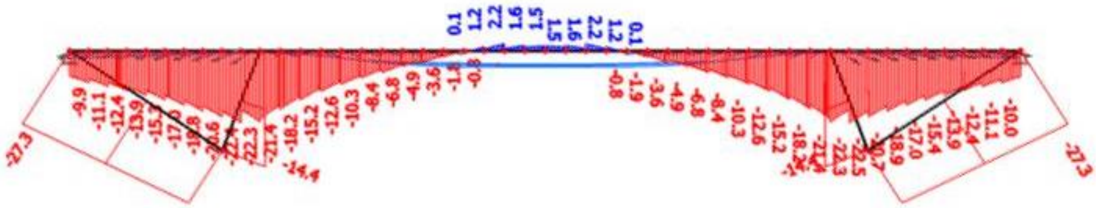


FIGURE 201: STAGE 10 BOTTOM STRESSES UNBONDED TENDONDS

This last two figures show us the effects on the bottom fibers, we still have some tension present, however they have been lowered considerably, the effects of the new tendon layout is clear here.

Final Analysis

From the results shown on this new layout I can assume that this is a good solution to be following, however my suggestion can be adding a new tendon on the top fibers on the 70-meters beam. This will correct the tension on this part, also redistributing the forces of the bonded continuity tendon. Also, I consider this can be optimized to have lower tendons. As you can see on the annexes I haven't include this second tendon layout since I haven't been able to find the appropriate optimization. If this is reached with the new suggestions we can lower the number of tendons on the continuity cable, my suggestion will be 8 groups of 19 tendons each, this way the tendons will keep between the limits of the cross section and will still have positive effects.

As we saw, it's possible to keep lowering the amount of cables in the cross section, however I believe is better to obtain a better cross section to have more benefits out of the continuity cables bonded or unbounded.

CONCLUSIONS

Recommendations

The first suggestion is that this project must be revised completely, this is a project developed from scratch, where suppositions have been made based on Eurocode and the Czech Republic standards, however many factors and values can be renewed with time by the authorities.

Also, is important to notice that the project haven't brought a satisfying solution to the problem faced so is better to analyze the structure again, focusing on eliminating the stresses on the superstructure. I have found many mistakes made me be in the program due to the lack of experience at the time of using it, however the process is the main factor to be followed from this project.

It is highly recommended to start the project with a smaller and more symmetrical cross-section and a different lamella casting distance in the cantilever, in these designs I used a 7.5 meters lamella where it prove to be big and not recommendable, is suggested to use a 5 meters lamella. In addition, the strut element should be less stiff to avoid the effects it has on the continuity cable design, since it has been proved that it absorbs the effect desired on the superstructure. If we are able to implement a more symmetric cross section, we will be able to provide more compression area in the structure, this way I will reduce the stresses created internally since the leaver arm will be smaller, creating less internal moments that affect the final internal forces throughout the whole structure, if this is done less prestress will need to be provided too.

If its decided to continue the project in order to optimize it based on the results obtained, its recommended to change the geometry of the cross sections of the project, the height taken in account were based on predesigns, the original bridge and the design solution presented on this project are completely different, I attempted to replicate the structural design using my own calculations for cross sections, tendons, construction stages and service loads. This project does not include the design of the abutment, the footings, passive steel at the cross section, the strut and tie elements; they were placed as a solution for the main problems faced on construction and service stages.

Another recommendation to take in account is that the center of gravity in the structural model applied on the program has a variety from what in reality is, as previously stated the center of gravity of the superstructure was placed on the top fibers of the cross section, when in reality they change on each section depending of the height of the haunch. Its suggested that the design of a structure as important as this, it should be done two different models, one where the center of gravity is in the top fibers and one where the real connection of the nodes are made, this way it can be compared the values until obtaining the real results. This was a 2D model with many limitations, my results have varied due to this problem, however, I consider this was the best approach taken since we try to replicate the real bridge.

Conclusions.

Different from what it seems, this project is not a failure, even thou the project didn't brought a solution to the problem faced initially, this has been a path for me to learn from my mistakes, projects like this require expertise on the area, where I didn't had enough, my background on bridge design where a few classes mainly focus on steel bridges, however on my intentions to improve my knowledge I decide to experiment with prestress bridges, where it prove to be most demanding, however I manage to expand my knowledge on this field and know I consider myself more prepared for future problems I might face on the area.

I am well aware that the decisions made throughout the project might seem like not suitable solutions, however is important to notice that out of the many problems I faced, I was able to find solutions for them. This structure selected at the beginning of the project brought many complications due to the complexity of it, the first decisions made by me, where a mix of solutions out of the preliminary investigation I did, I thought I was having the best previous design to start off, however, it was completely different. At the end of this project I can see that the main problem faced was in the cross section of the structure, it was to rigid, it had such a stiffness in every element of it that the solutions where not the most efficient, as we can see on the results obtained and previously discussed.

This project required more time than the available time scale, is important to notice that a project of this size usually is calculated by a team of engineers and it takes more than 5 months to have a suitable solution for approval of the authorities, I believe that if I would have had more time I would be able to find better solutions for the bridge design.

The bridge project has been divided in two main parts, construction stages and service stages as previously stated. They are a compliment, where a solution has to be found for both of them I was able to find a solution for construction stages, based on iterations, investigations and application of theory learned on classes and in the process of this design, however I consider it can be improved if the recommendations made are taken in consideration, if we are able to have a better solution for the constructions stages it will reflect on better solutions for the service stage.

REFERENCES AND BIBLIOGRAPHY

Armado, NEC-SE-HM Estructura de Hormigón. «Norma Ecuatoriana de la Construcción.» 2014. http://www.normaconstruccion.ec/capitulos_nec_2015/NEC_SE_HM_(hormigon_armado).pdf (accessed 3 de Nov de 2015).

Bridge, What is an Arch. «innovateus.» 2013. http://www.innovateus.net/innopedia/what-arch-bridge (accessed 20 de 03 de 2017).

Bridges, Classification of. «Bridge Engineering.» 2017. http://civildigital.com/bridge-engineering-components-classification-bridges/ (accessed 30 de 03 de 2017).

Chiche, Puente de. «Grupo puentes.» *Grupo Puentes.* 2015. http://www.grupopuentes.com/es/proyectos-destacados/puente-de-chiche (accessed 07 de 03 de 2017).

Cimentaciones, NEC-SE-CM Geotécnia y. «Norma Ecuatoriana de la Construcción.» 2014. http://www.normaconstruccion.ec/capitulos_nec_2015/NEC_SE_CM_(Geotecnia_y_Cimentaciones).pdf (accessed 3 de Nov de 2015).

Civil, Reglamento a la Ley del Ejercicio Profesional de la Ingeniería. 2004. http://www.cici.org.ec/vademecum/creglamleyejercicioprof.htm (accessed 22 de Oct de 2015).

debate, Trazado de la ruta VIVA aprobada en segundo. «Quito Alcaldia.» *epmmop.* 24 de jun de 2011. http://www.epmmop.gob.ec/epmmop/index.php?option=com_k2&view=item&id=158 (accessed 06 de 03 de 2017).

Dlouhy, Ing. Lukas. *training, Prestress concrete, construction stages, prestress check.* Edited by SCIA engineering. 2010.

Ecuador, Vulnerabilidad Sismica del. «CAMICON.» 2016. http://www.camicon.ec/wp-content/uploads/2015/11/VULNERABILIDAD-SISMICA-DEL-ECUADOR.pdf (accessed 07 de 03 de 2017).

EN 1990 eurocode, Basis for structural design. *European Comitte for Standarization.* december de 2002.

EN-1991 2, Eurocode 1. «Action on Structures.» *Part 2: Traffic loads on bridges.* European Comitte for Standarization. November de 2003.

EN-1992 2, Eurocode 2. «design of concrete structures, concrete bridges, design and detailing rules.» *European Comitte for Standarization.* november de 2005.

II, Pliegos Ruta Viva Fase. «EPMMOP.» 31 de jul de 2012. http://www.epmmop.gob.ec/epmmop/comprimidos/PLIEGOS%20RUTA%20VIVA%20FASE%20II-%20PUENTES.pdf (accessed 07 de 03 de 2017).

luz, tipologías y procesos constructivos versus. «estructurando.» *estructurando blogspot.* 27 de mar de 2012. http://estructurando.net/2012/03/27/una-de-puentes-tipologias-y-procesos-constructivos-versus-luz/ (accessed 2017 de 03 de 2017).

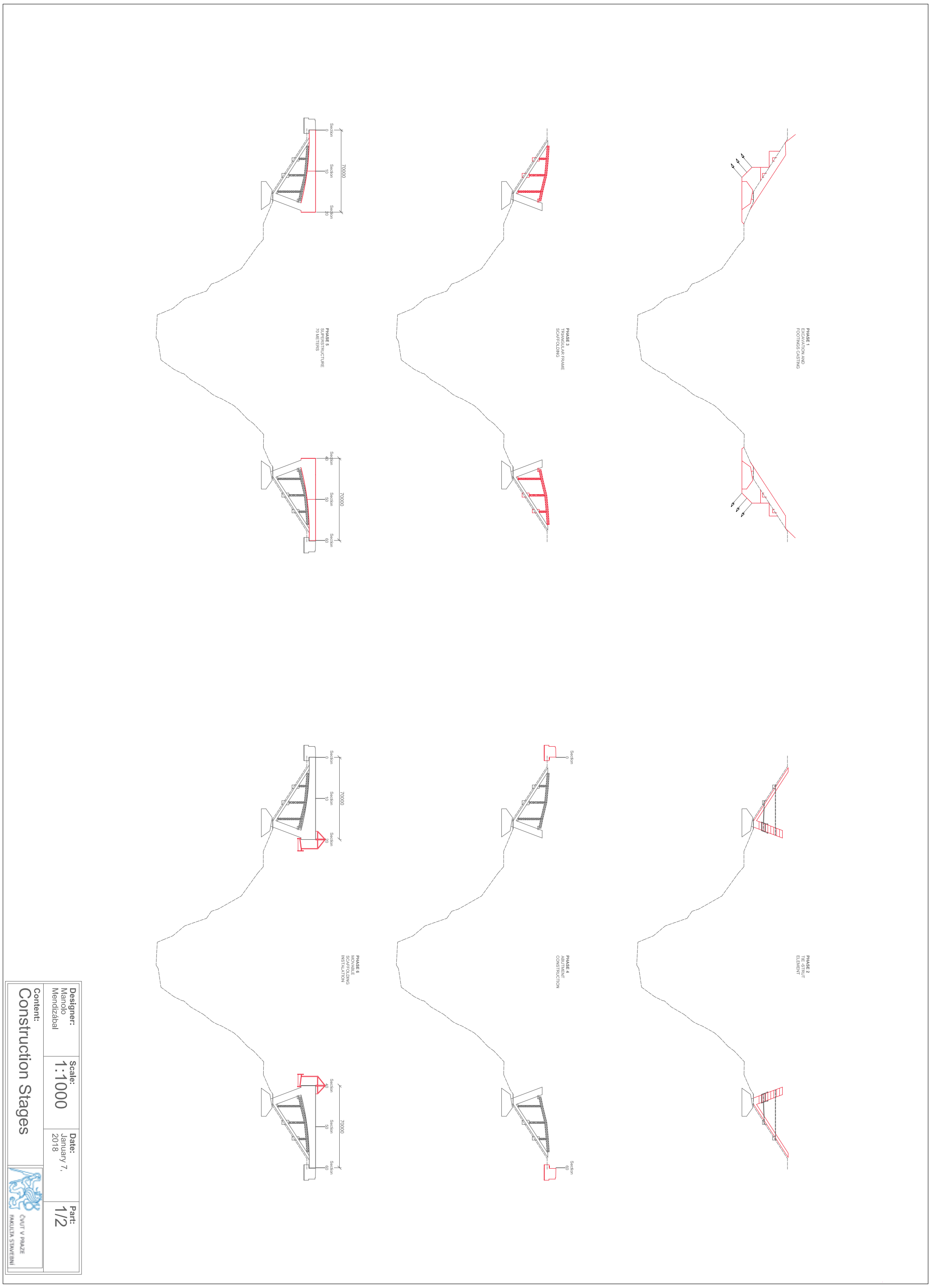
personas, Crece la poblacion en Ecuador en 117.363. «Expansion.» *DatosMacro.* 2015. http://www.datosmacro.com/demografia/poblacion/ecuador (accessed 06 de 03 de 2017).

Quito, 50000 automotores nuevos circulan en las vias de. «El Comercio.» *El Comercio.* 27 de dic de 2014. http://www.elcomercio.com/actualidad/50000-autos-nuevos-trafico-quito.html (accessed 06 de 03 de 2017).

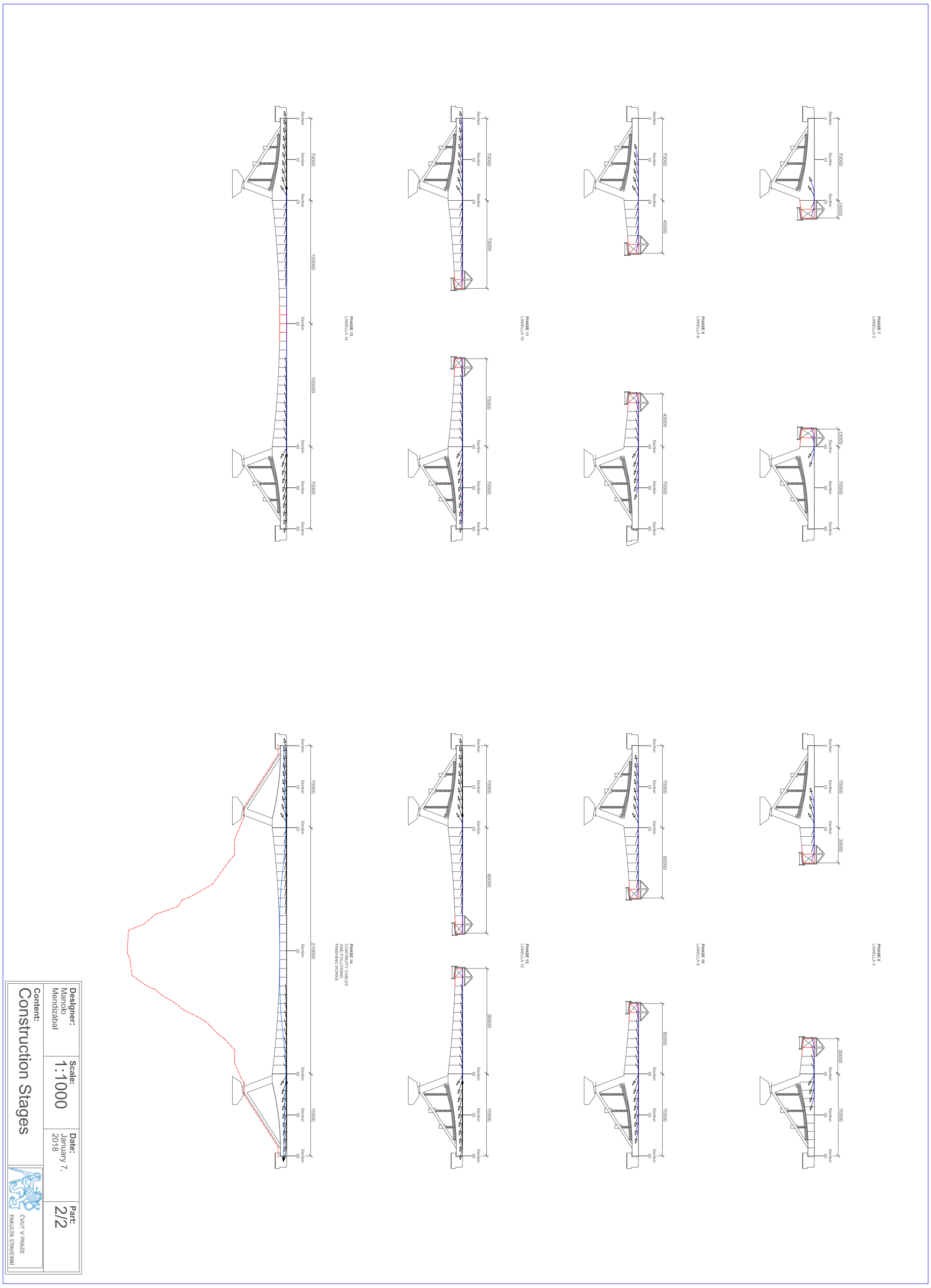
Safar, Ing. Roman. *Concrete Bridges.* Prague, Prague: Ceske Vysoke Uceni Technicke V Praze, Fakulta Stavební, 2015.

SCIA. *Advance expert training-Construction Stages.* 2010.
SCIA. *Advance expert training-Post-Tensioning.* 2015.
SCIA. *tutorial-Post-tension concrete modeling & analysis.* 2016.
Sismoresistente, NEC-SE-DS peligro Sísmico Diseño. «Norma Ecuatoriana de la Construcción.» 2014. http://www.normaconstruccion.ec/capitulos_nec_2015/NEC_SE_DS_(peligro%20sismico).pdf (accessed 3 de Noviembre de 2015).

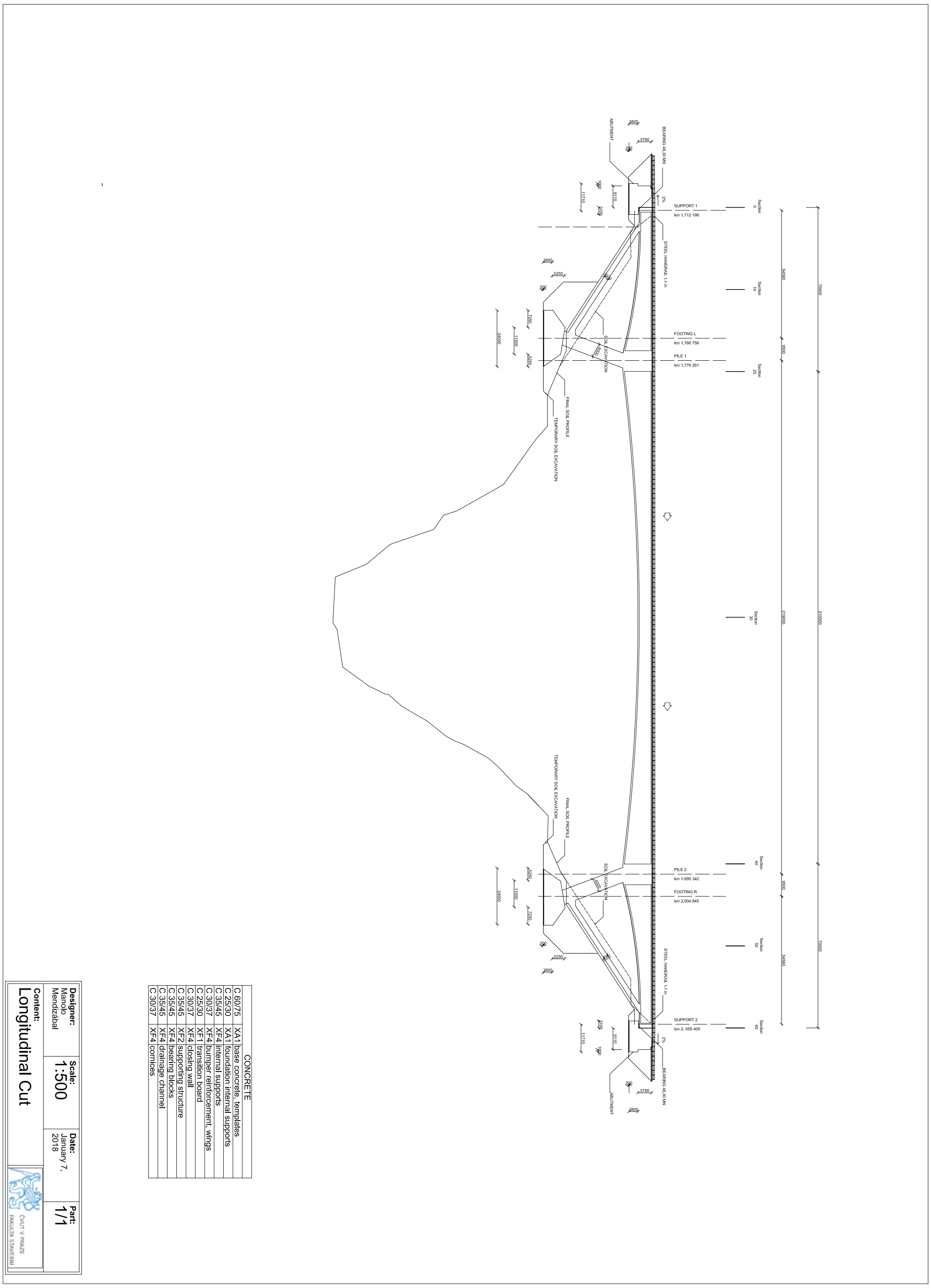
ANNEX A: CONTRUCTION STAGES 1/2



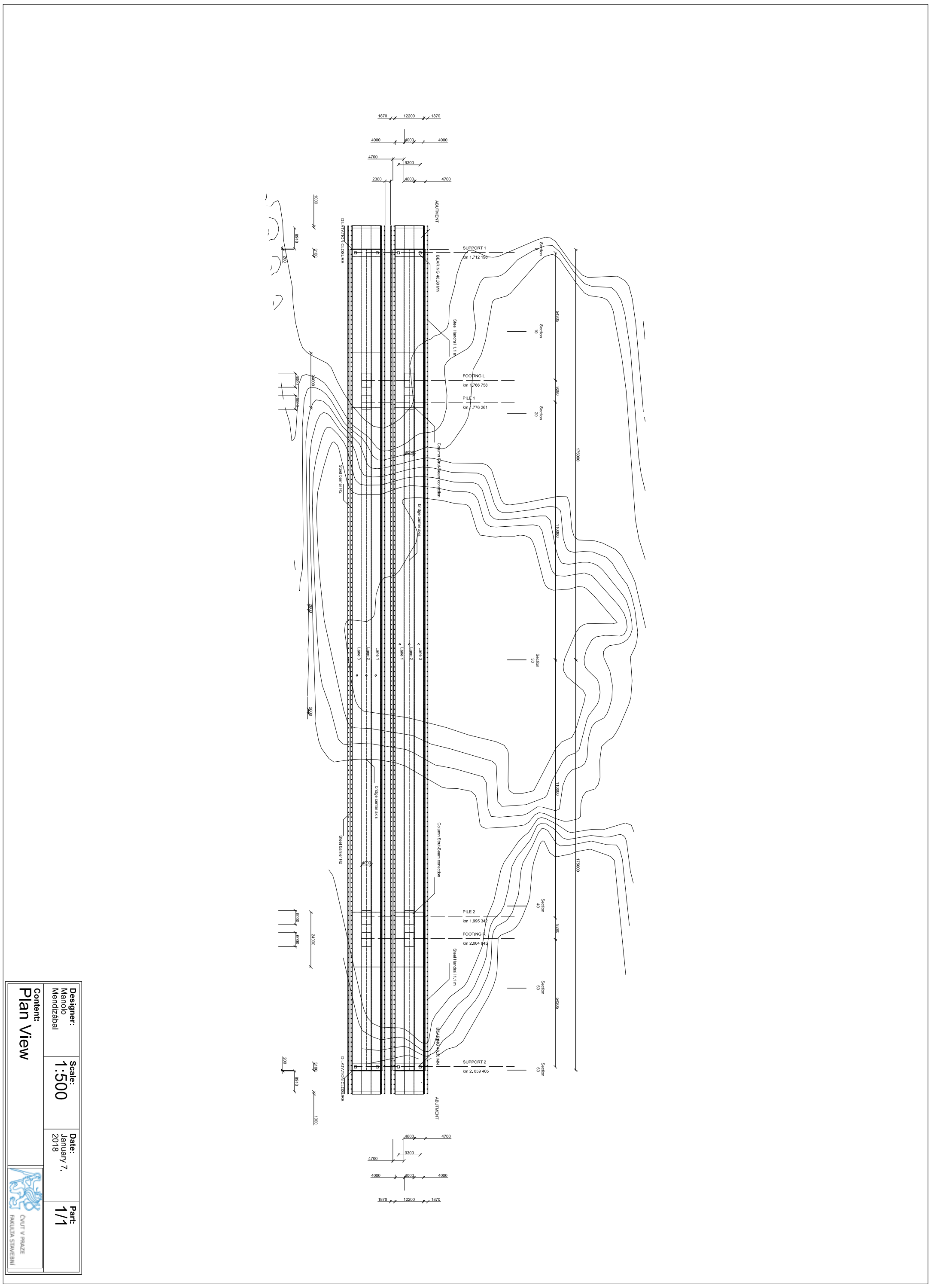
ANNEX B: CONTRUCTION STAGES 2/2



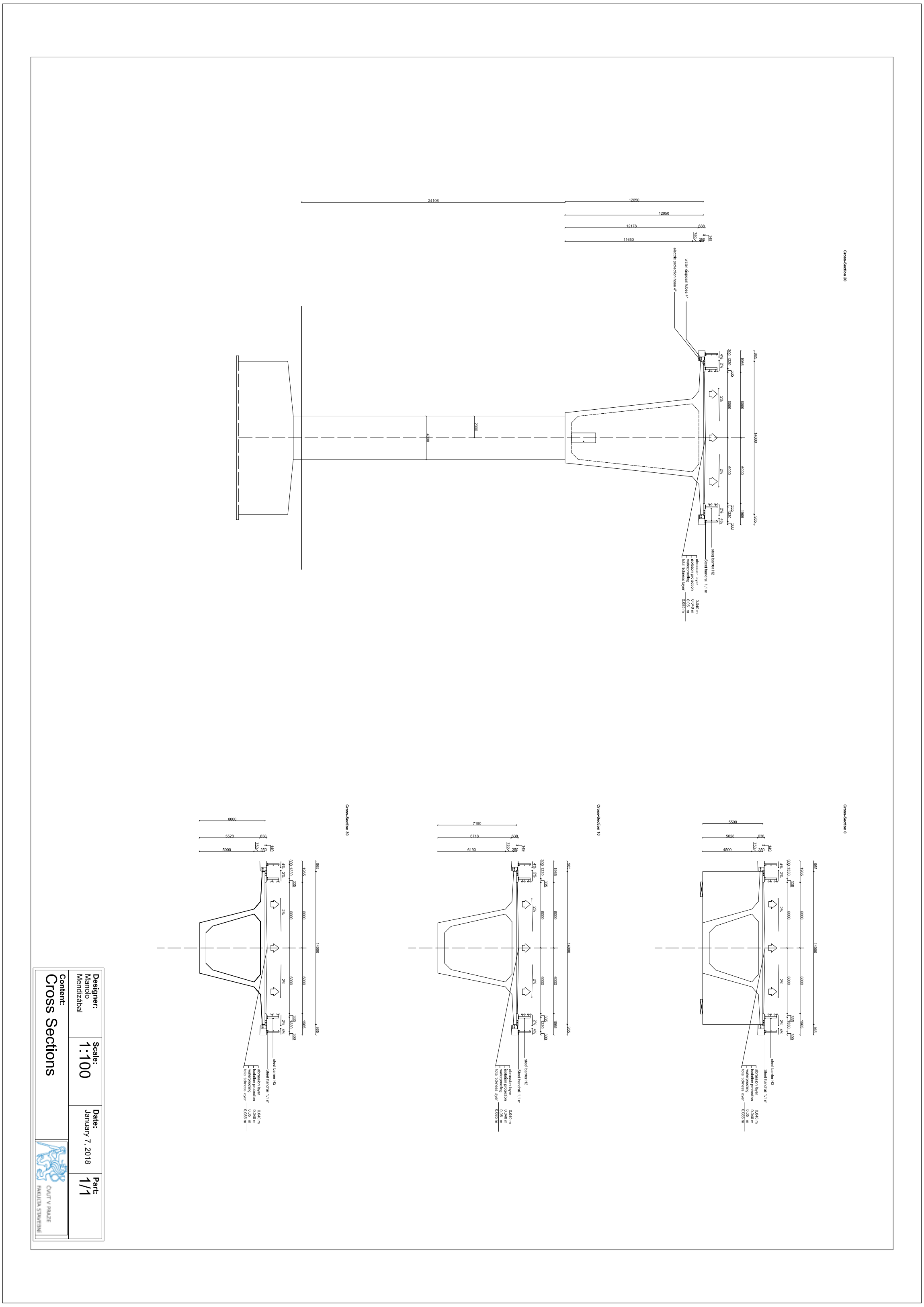
ANNEX C: LONGITUDINAL CUT 1/1



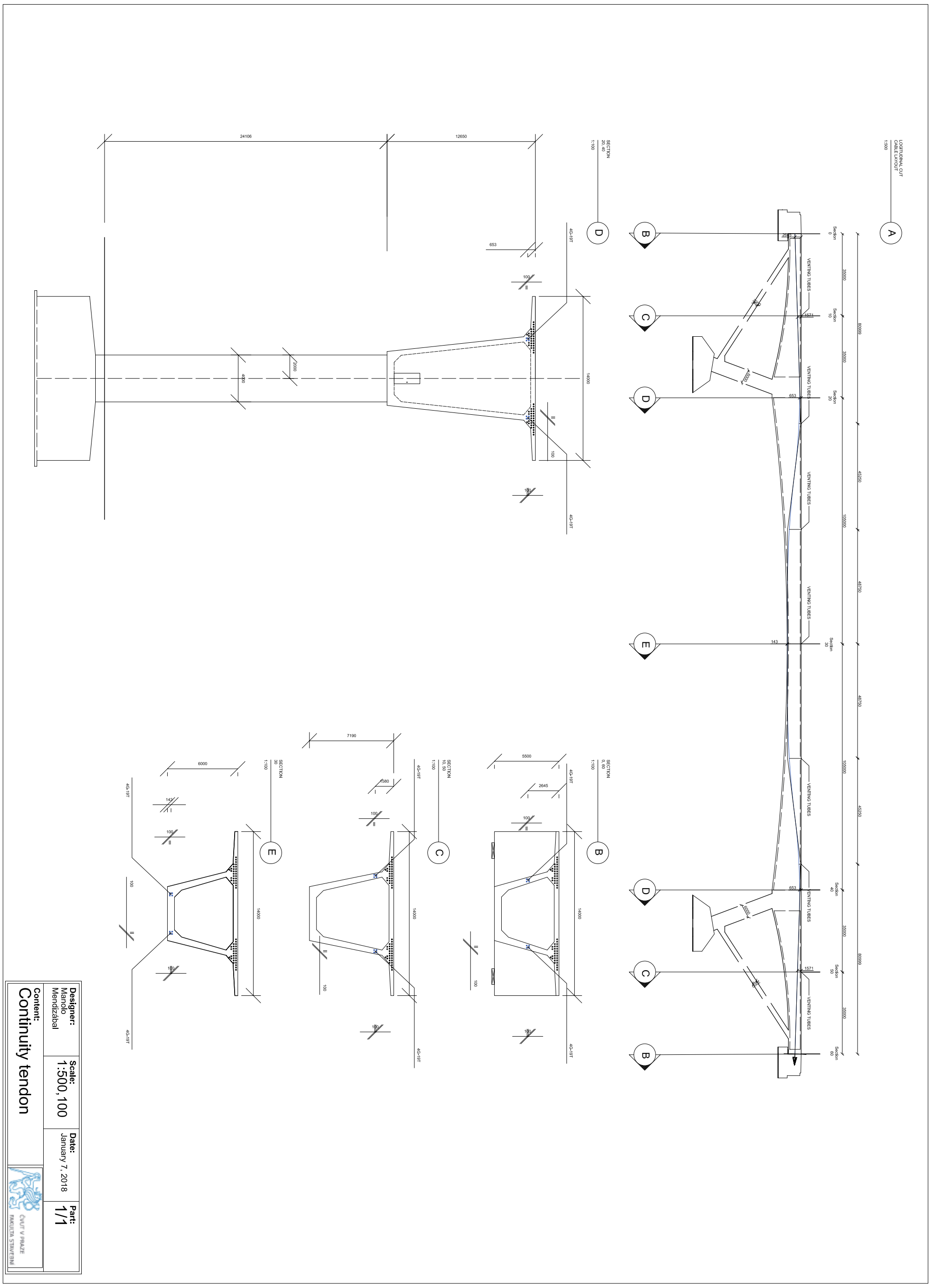
ANNEX D: PLAN VIEW 1/1



ANNEX E: CROSS-SECTION 1/1



ANNEX F: CONTINUITY TENDON LAYOUT 1/1



ANNEX G: TENDONS CONSTRUCTION STAGES 1/1