AICAP

DESIGN OF ROAD BRIDGE WITH EXTERNAL PRESTRESSING: 3 CASE STUDIES

Autori:
Achille Devitofranceschi
Anna Chiara Salvati
Elisa Paolieri

A cura di AICAP
Promosso da AITEC

Si ringraziano CSPFEA e MAPEI per il contributo dato alla realizzazione di questo Quaderno

INDEX

INTRODUCTION

Scope of the work

This document analyzes the performance of three different bridges with external non-bonded tendons.

For numerical modelling and structural analysis MIDAS Civil 2017 has been used.

External prestressing

The bridges are equipped with external precompression system and they don't have neither rebar crossing the joints nor internal prestressing tendons within the concrete construction. Tendons are made of strands which are bare and set inside of a PE tube. Every tendon is grouted with mortar cement.

These post-tensioning details allow for replacement of the external tendons should this be required in the future. Below the advantages and disadvantages of segmental bridges with external prestressing, compared to traditional technique of prestressing are listed.

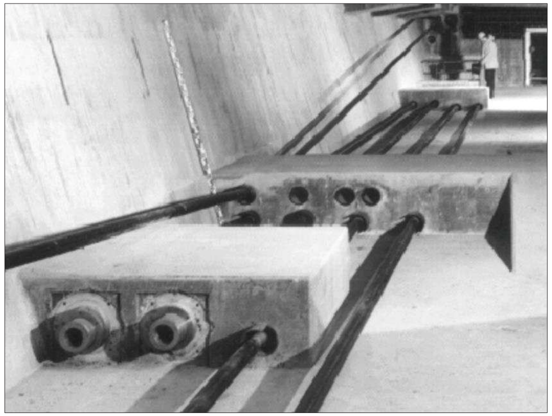


Figure 1: External prestressing tendons in a box-girder, deviation and anchor blocks along the span

<u>*Advantages:*</u> the post-tensioning concrete bridges with external unbonded tendons have simplifications in design, construction, control and maintenance. Furthermore, it is possible to replace tendons. The execution of the box-girder is easier using external tendons, for various reasons: the absence of internal ducts facilitates the placement and the vibration of the concrete, resulting in an improved quality of material; and decreases the thickness of

CASE 1: SEGMENTAL PREFABRICATED BOX-GIRDER BRIDGE L_{MAX}=90.4M

In section 1 the main characteristics of this type of bridge are described. The following sections include load analysis, modelling and design of prestressing systems and structural elements.

1. DESCRIPTION OF THE BRIDGE

The viaduct has a total length of 288.2 m, and it is composed of four spans: the internal spans are 90.4 m long, the external ones are 52.7 m long. The section has a parabolically variable depth, the upper slab has a constant thickness while the lower slab has a variable thickness; webs have a different thickness for the intermediate segments and for the segments next to the piers, as indicated in Figure 6.

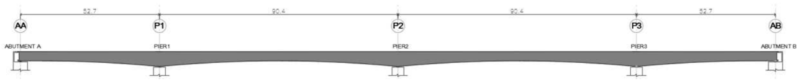


Figure 2: Longitudinal view

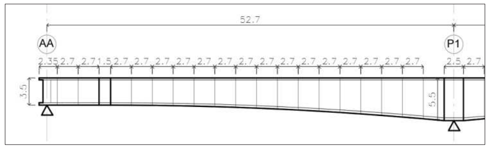


Figure 3: First span longitudinal view – L=52.7 m

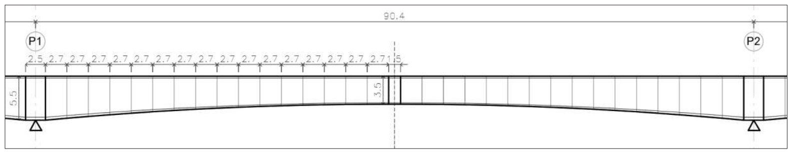


Figure 4: Intermediate span longitudinal view – L=90.4 m

1.1. Cross section

The depth of the cross section at the pier h_p should be between 1/16 and 1/18 of the length of the main span. In this case h_p is 5.50 m. The depth of the cross section at midspan h_m is

5. MODELLING

The numerical model of the bridges has been created in Midas Civil 2017. The deck is modelled using beam elements and it is composed by 114 frames which represent each segment.

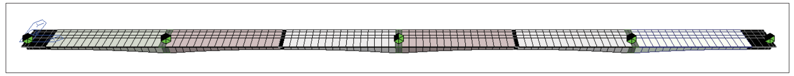


Figure 33: Longitudinal prospect of the bridge L=288.2m

Figure 34: Frontal view of the bridge L=288.2m

The modeling of the construction stages, sections geometry, materials property, external tendons and loads are described in the following paragraphs. First of all, the modeling of the construction stages is introduced.

5.1. Construction stages

A relevant aspect for this bridge is the definition of the construction method. The erection method chosen is balanced cantilever, the progress of the construction takes place by lifting symmetrically from each side of the pier. Midas Civil software allows to specify construction stages, specifing their compositions in detail in order to reflect the exact erection sequence of a bridge. The main construction phases are then explained:

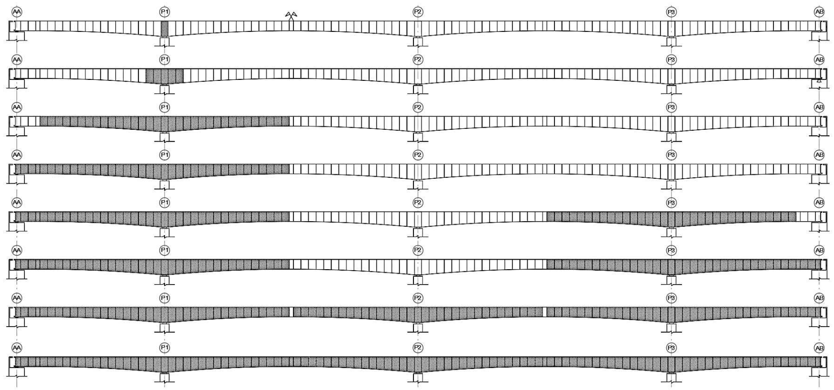


Figure 35: Construction phases

The modelling of the Construction Stage in Midas Civil consists of the definition of the following steps:

- Duration of the construction stage;
- Element, Boundary and Load characterizing the stage;
- Age (segment age at the time of erection);

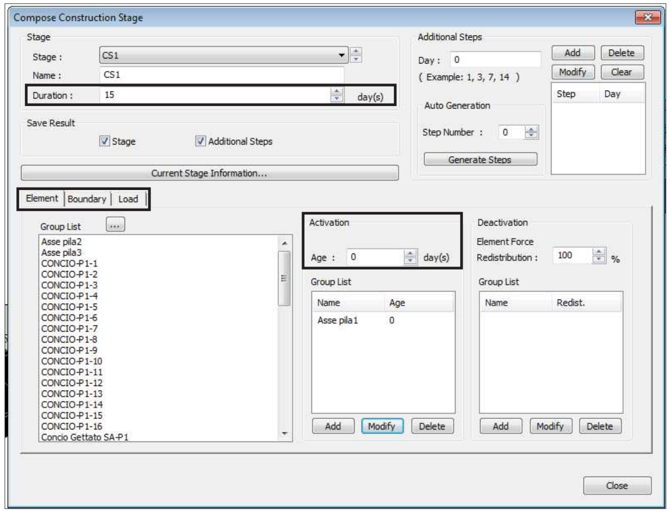


Figure 36: Construction Stage window in Midas Civil

The result of each stage is applied at the following construction stage. The precast segments are 30 days old when they are erected. The speed of construction is 4 segments per day; consequently, two segments for each side of the pier are lifted. The main Construction Stages are then reported:

<u>*Fist Construction Stage:*</u>

- Duration of the stage = 15 days;
- Element Section Group = Asse pila 1;
- Segment Age at the time of activation = 30 days;
- Boundary conditions = fix-support;
- Load = Self-weight;

The erection cycle starts with the construction of the cast in situ diaphragm at pier. The stage duration is 15 days to allow the hardening of the pier diaphragm.

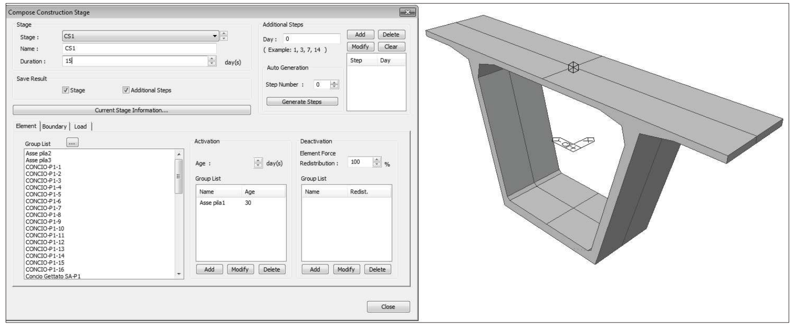


Figure 37: Construction of the Pier

The restraints at pier, during the construction, is fix-support in order to avoid lability of the structure during the balanced cantilever construction.

<u>*Second Construction Stage:*</u>

- Duration of the stage = 1 day;
- Section Group = Pier1, CONCIO P1-1, CONCIO P1-2;
- Segment Age at the time of activation = 30 days;
- Load = Self-weight, Prestressing tendons 1-1, 1-2;
- Boundary conditions = fix-support;

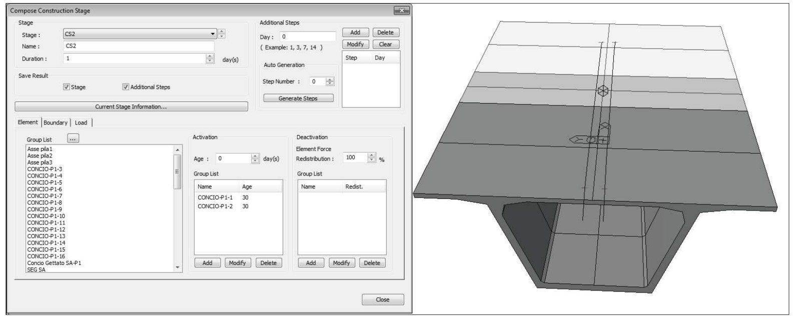


Figure 38: Second Construction Stage

<u>*Ninth Construction Stage:*</u>

- Duration of the stage = 1 day;
- Section Group = Pier1, CONCIO P1-1to16;

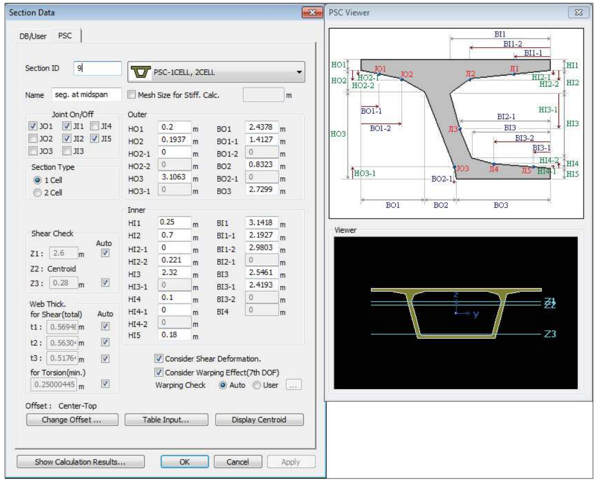


Figure 44: Geometry of the typical box-girder in midspan

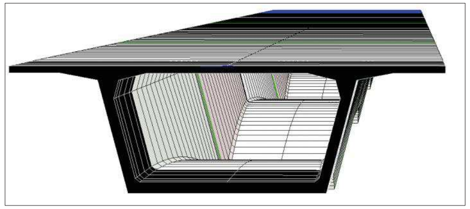


Figure 45: Prospective view of the bridge

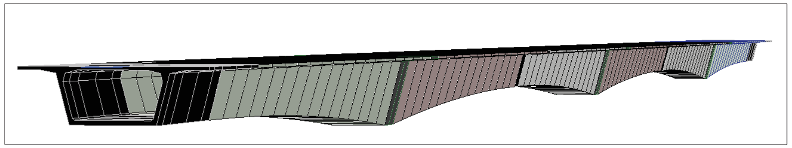


Figure 46: Lateral view of the bridge

5.3.1. *Distortional warping*

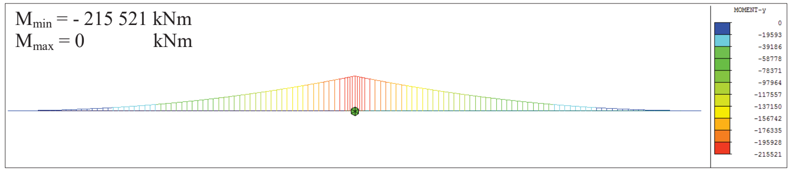
The eccentric loads acting on the section cause a *distortional warping*, which is an additional deformation of the box-girder due to the transverse deformability of the section. This deformability is based on two reasons: the former is the absence of rigid diaphragm along the span; the latter is the reduced thickness of the box-girder section members.

5.7. **Elementary loads Outputs**

The following paragraphs show the value of bending moment, axial forces and stresses along the structure.

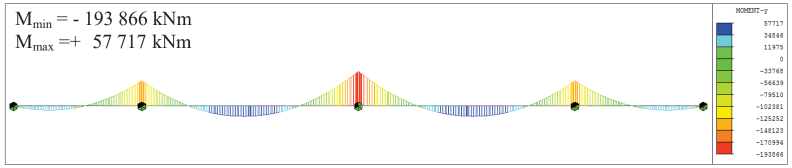
5.7.1. *Self-weight at the end of construction of the first cantilever*

Characteristic values



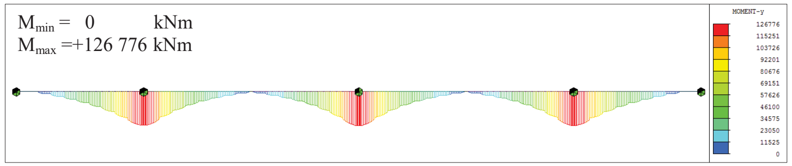
5.7.2. *Self-weight t $_{365\ 000\ days}$*

Characteristic values



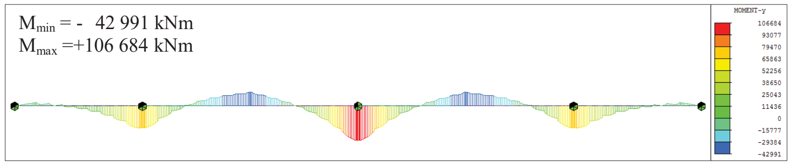
5.7.3. *Upper tendons t $_{0\ day}$ final construction stage*

Characteristic values



5.7.4. *Upper tendons t $_{365\ 000\ days}$*

Characteristic values



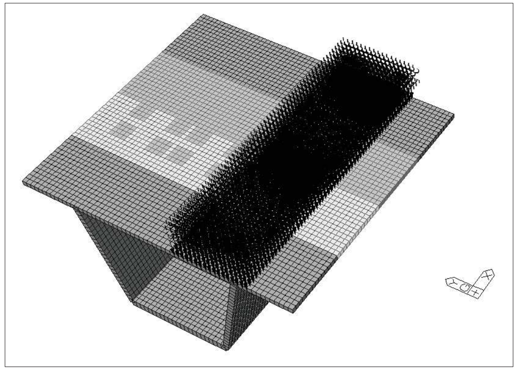


Figure 78: UDL load: scheme A, lane n°3

6.2.3. ULS verifications

This paragraph deals with the ULS verifications of the sections investigated, illustrated below:

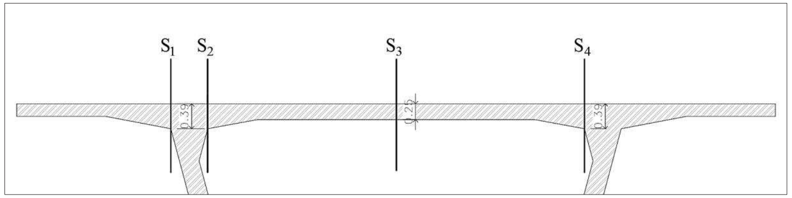


Figure 79: Section analysed

The bending moment acting on the section joint, for each scheme of live loads, is shown in the following figures:

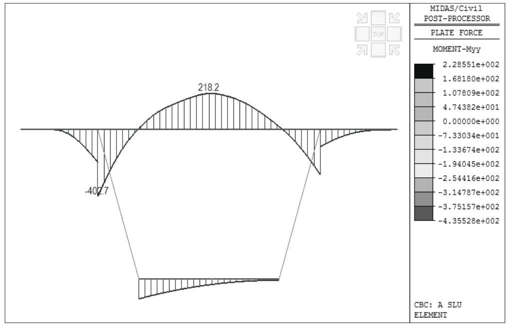


Figure 80: Myy scheme A of live loads

The design of the deviation block is carried out by a simplified model. The block is assumed like a beam hinged in the webs.

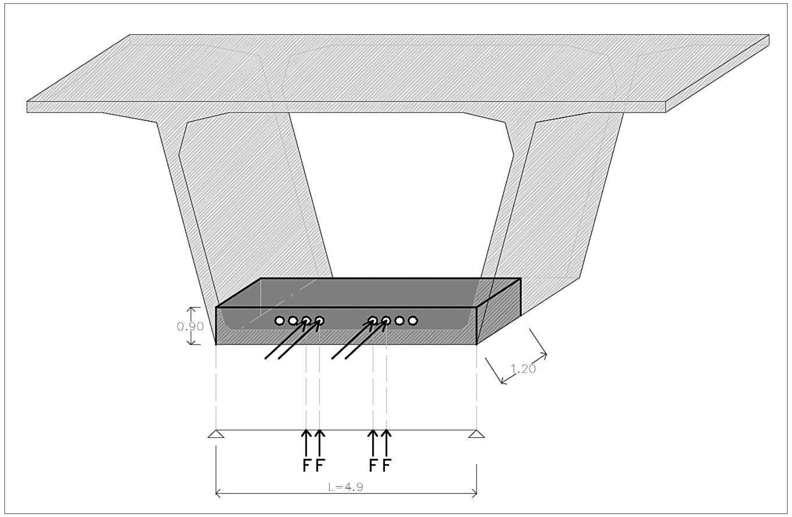


Figure 114: Simplified model of the Deviator1's actions

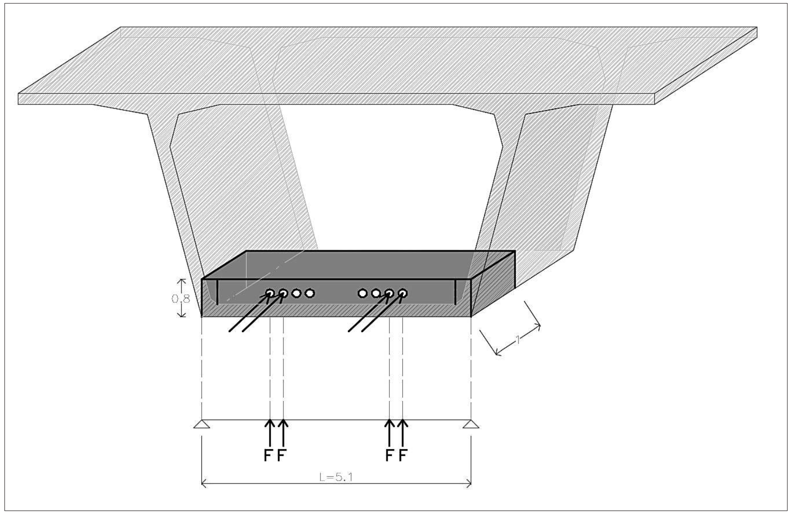


Figure 115: Simplified model of the Deviator2's actions

8. ALTERNATIVE DESIGN WITH FIBER REINFORCED CONCRETE (FRC)

An alternative design is analysed replacing the ordinary reinforced concrete elements. The geometry of the alternative proposal is the same of the reinforced concrete one. The only variation consists of using of Fiber Reinforced Concrete, which leads to minor quantities of ordinary reinforcements and, therefore, a minor quantities of hand craft.

8.1. Reference Codes

The analysis and verification phases of the structure have been conducted according to the following Codes:

[S10] *Model Code 2010 - First complete draft - Volume 1.* In the following paragraph indicated as MC10;

[S11] Istruzioni per la Progettazione, l'Esecuzione ed il Controllo di Strutture di Calcestruzzo Fibrorinforzato, Consiglio Nazionale delle Ricerche, CNR-DT 204/2006-rev. 4 Febbraio 2008. In the following paragraph indicated as CNR-DT 204.

8.2. Materials

Specific durability requirements in relation to material properties, concrete cover and corrosion protection are indicated in the following table.

FIBER REINFORCED CONCRETE			
Concrete class	*C50/60 6c*		
Characteristic value of cylindrical resistance	f_{ck}	50	N/mm^2
Characteristic value of cubic resistance	R_{ck}	60	N/mm^2
Characteristic residual strength for SLS conditions	f_{R1k}	6.0	N/mm^2
Characteristic residual strength for ULS conditions	f_{R3k}	5.4	N/mm^2
Partial factor for materials and actions	Υ_c	1.5	-
	α_{cc}	0.85	-
Design residual strength for SLS conditions	$f_{Fts,k}$	2.7	N/mm^2
Modulus of elasticity of concrete	E_c	37278	N/mm^2
Exposure class	XC4+XD1		
Minimum concrete cover	c	40	mm

CASE 2: SEGMENTAL PREFABRICATED BOX-GIRDER BRIDGE L_{MAX}=47.7M

In section 1 the main characteristics of this type of bridge are described. The following sections include load analysis, modelling and design of prestressing systems and structural elements.

1. DESCRIPTION OF BRIDGES

The viaduct has a total length of 155.2 m, and it is composed of four spans: the internal spans are 47.70 m long, the external ones are 28.65 m. The section has a constant depth, the upper slab, lower slab and webs have a constant thickness.

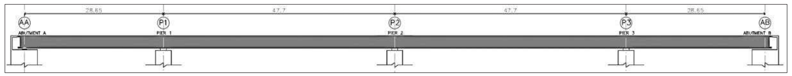


Figure 151: Longitudinal view

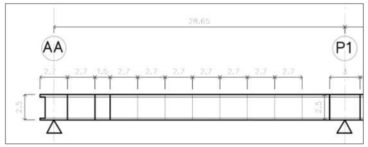


Figure 152: First span longitudinal view – L=28.65 m

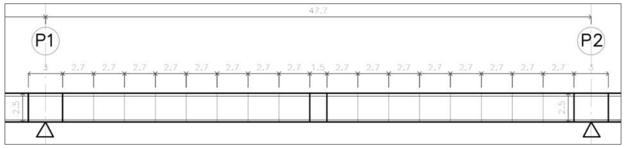


Figure 153: Intermediate span longitudinal view – L=47.70 m

1.1. Cross section

The depth of the cross section should be between 1/16 and 1/18 of the length of the main span. In this case h_p is 2.50 m.

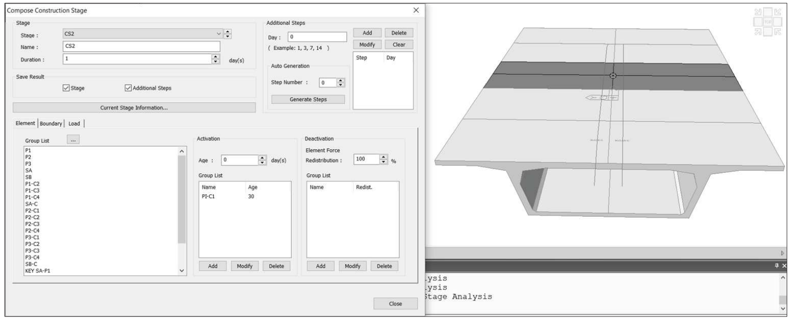


Figure 182: Second Construction Stage

<u>Ninth Construction Stage:</u>

- Duration of the stage = 1 day;
- Section Group = P1, P1-C1to4;
- Load = Self-weight, Prestressing tendons 1to8;
- Boundary conditions = fix-support;
- Segment Age at the time of activation = 30 days;

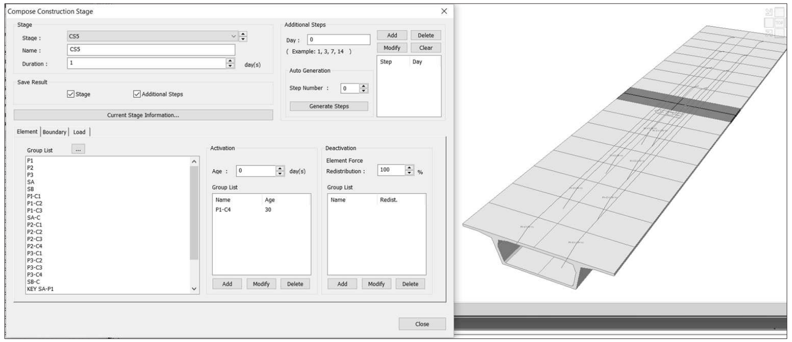


Figure 183: Ninth Construction Stage

At this stage the first cantilever is completed. All the upper tendons are installed.

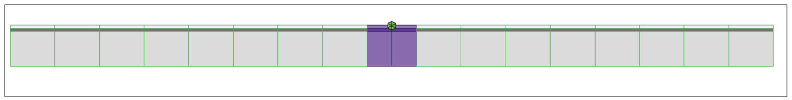


Figure 184: First Cantilever completed

The Stages proceed equally for the third and second pier. At the end of construction, when the casting key segment reaches the characteristic value of resistance f_{ckj}, the deck is

6.2.3. ULS verifications

This paragraph deals with the ULS verifications of the sections investigated, illustrated below:

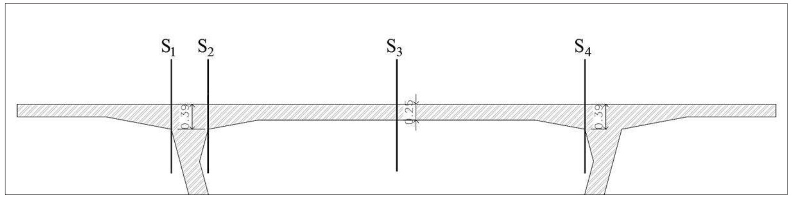


Figure 217: Section analysed

The bending moment acting on the section joint, for each scheme of live loads, is shown in the following figures:

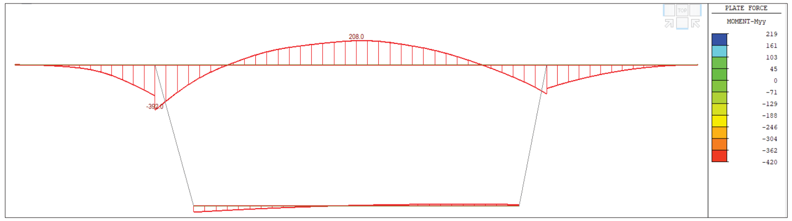


Figure 218: Myy scheme A of live loads

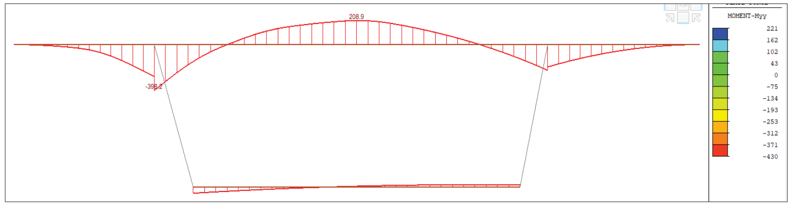


Figure 219: Myy scheme B of live loads

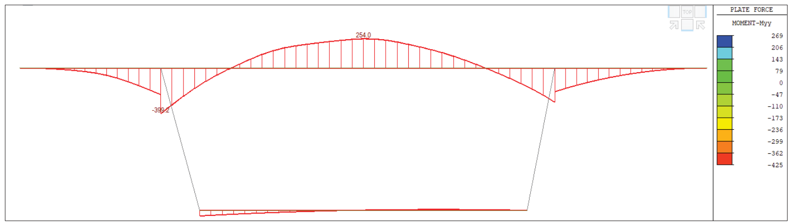


Figure 220: Myy scheme C of live loads

CASE 3: DESIGN OF GRID DECK BRIDGE L_{MAX}=45M

1. DESCRIPTION OF THE BRIDGE

The viaduct studied is 150 m long and has 4 spans: two central spans of 45 m, and two outer spans of 30 m. The bridge is made of reinforced and prestressed concrete.

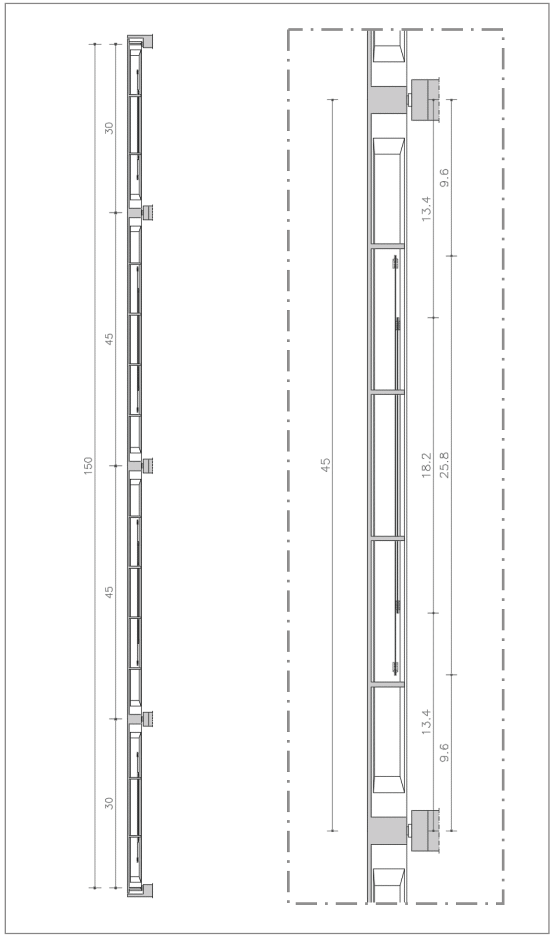


Figure 272 - Lateral view of the bridge

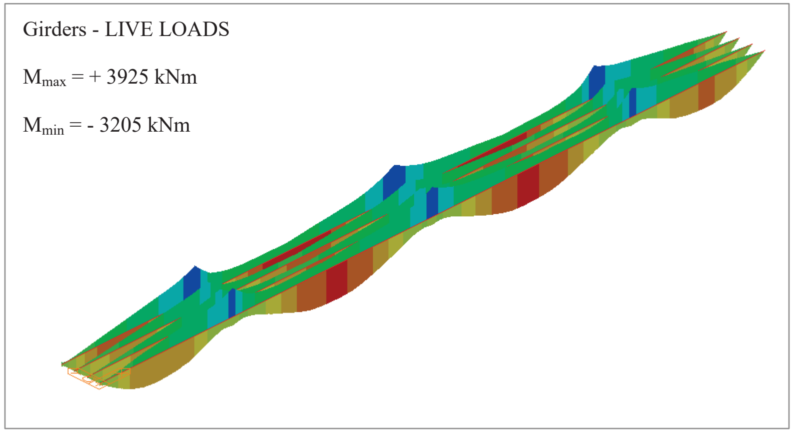


Figure 297 – Girders: bending moment for live loads

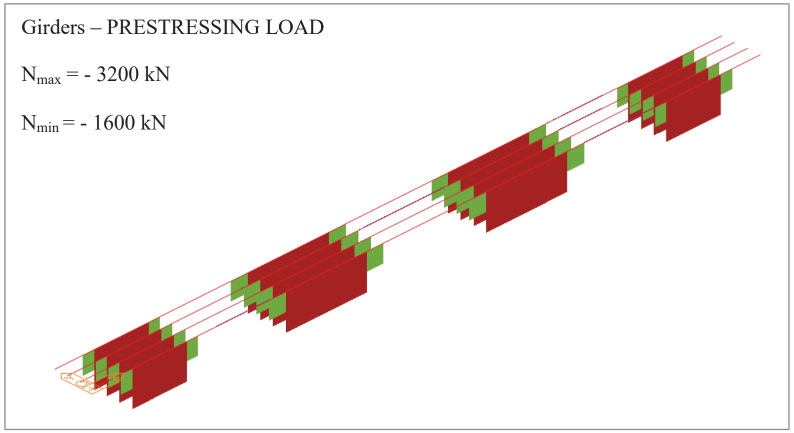


Figure 298 – Girders: axial force for prestressing load

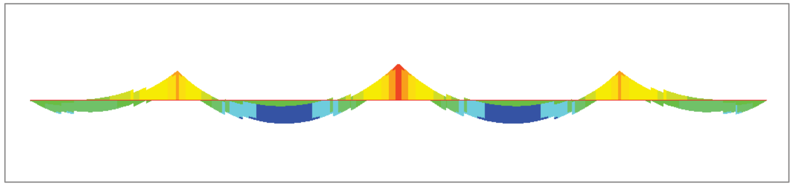


Figure 299 – Girders: bending moment ULS