

EU-Russia Regulatory Dialogue: Construction Sector Subgroup

Seminar ' Bridge Design with Eurocodes'

JRC-Ispra, 1-2 October 2012

Organized and supported by

European Commission

DG Joint Research Centre
DG Enterprise and Industry

Russian Federation

Federal Highway Agency, Ministry of Transport

European Committee for Standardization

TC250 Structural Eurocodes

Design of concrete bridges

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Sintecna Ltd - Italy

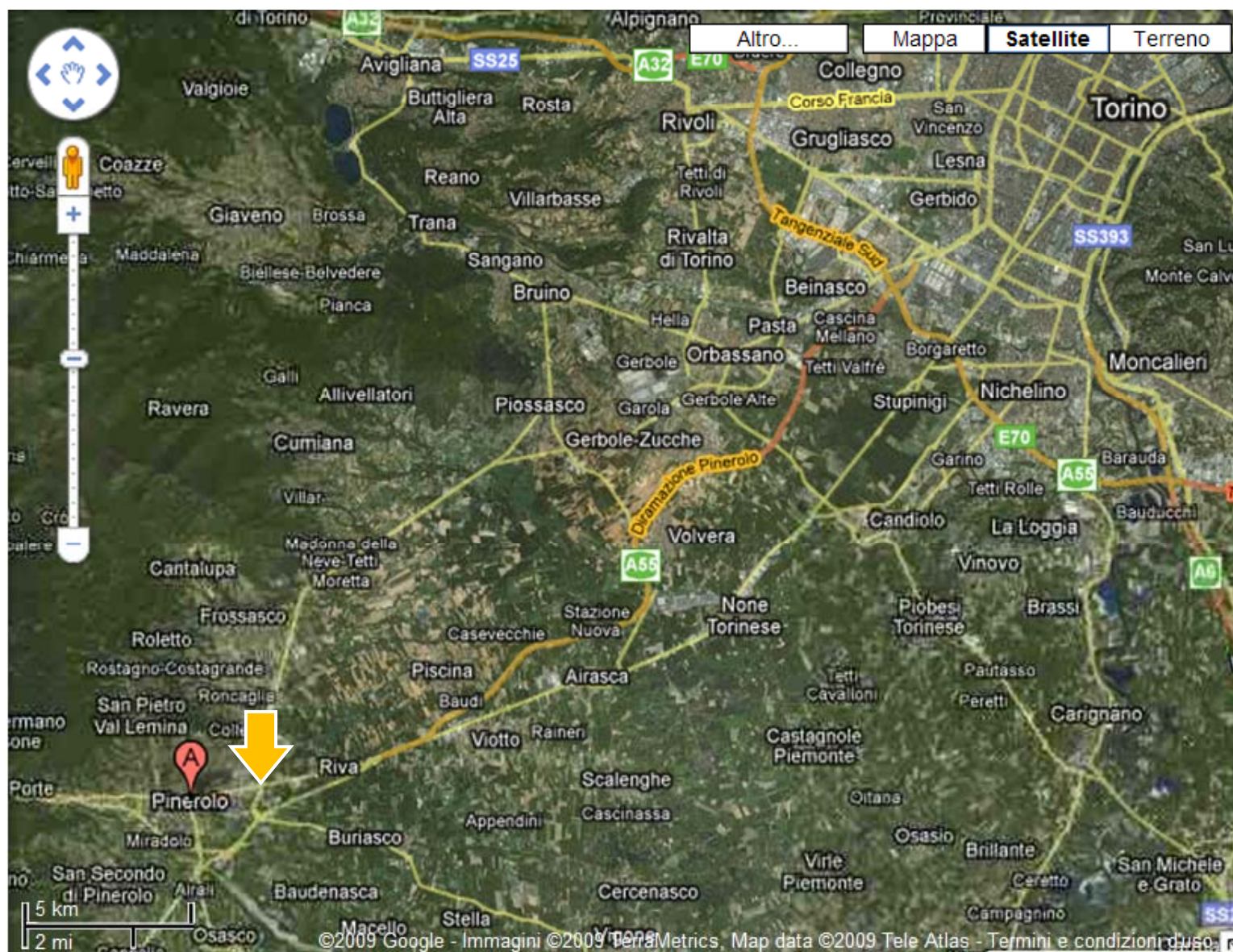
Pinerolo Bridge (Turin)

Moving scaffolding continuous beam

PINEROLO BRIDGE

Geographical positioning





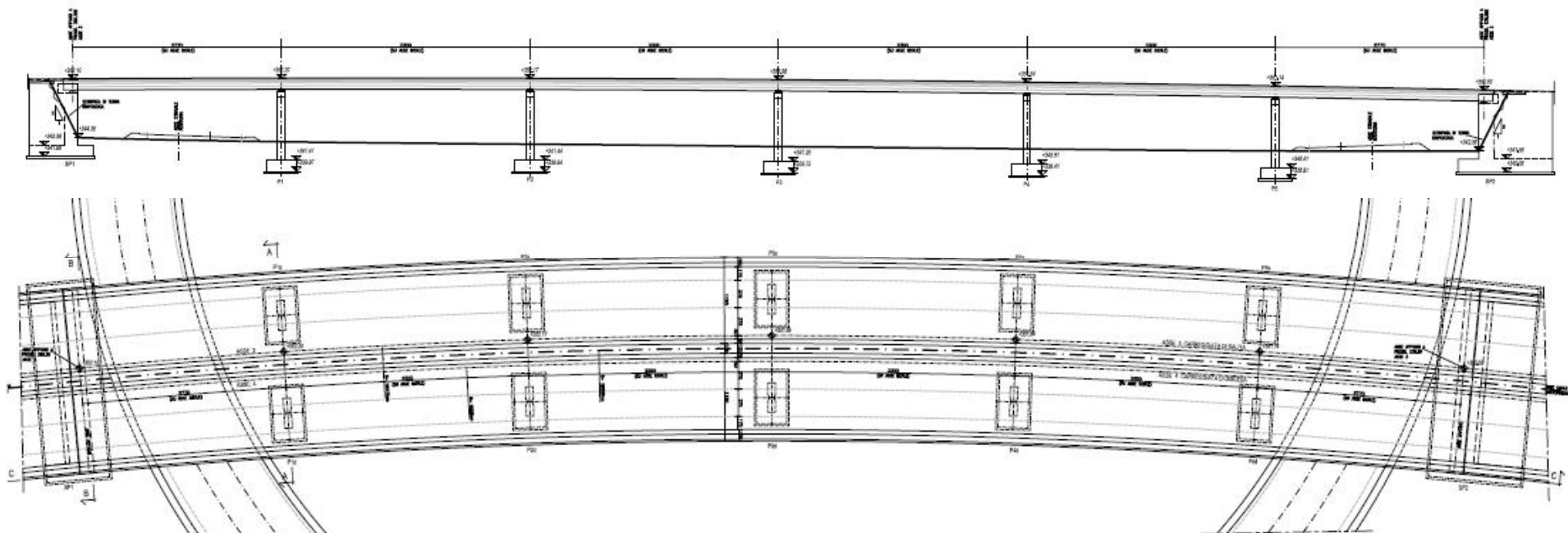
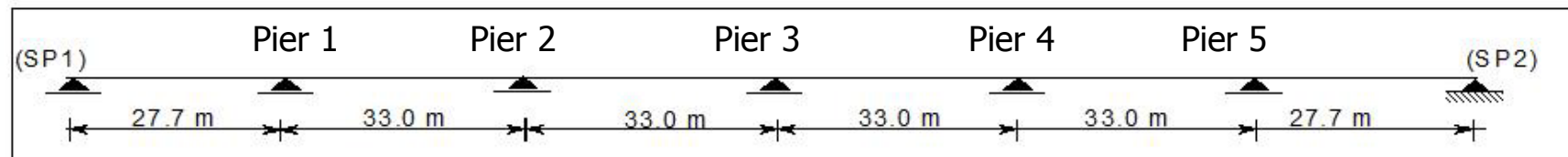


Static scheme

General dimensions

Free
abutment

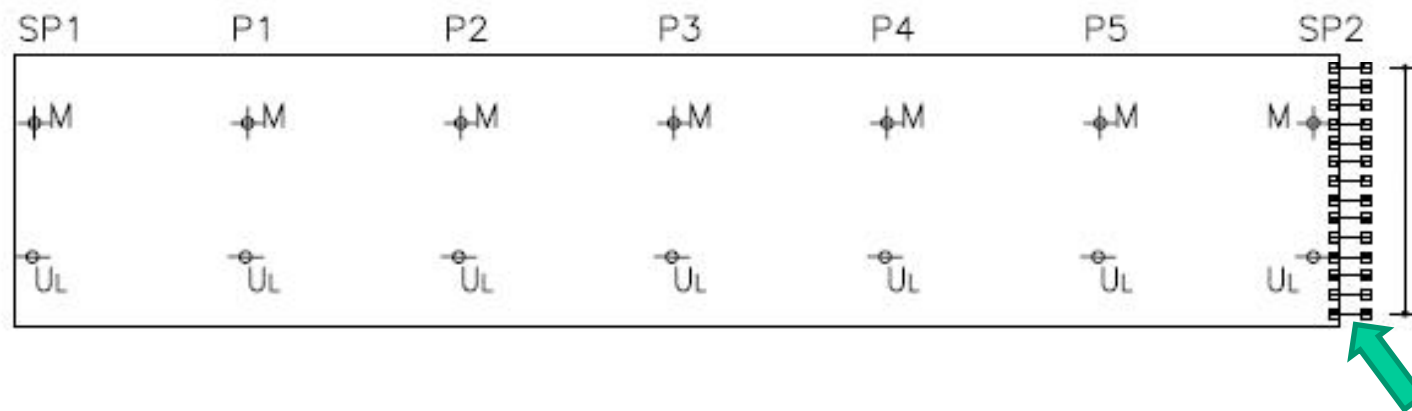
Fixed
abutment



Static scheme: Bearings

Rubber expansion joint with
320 mm excursion

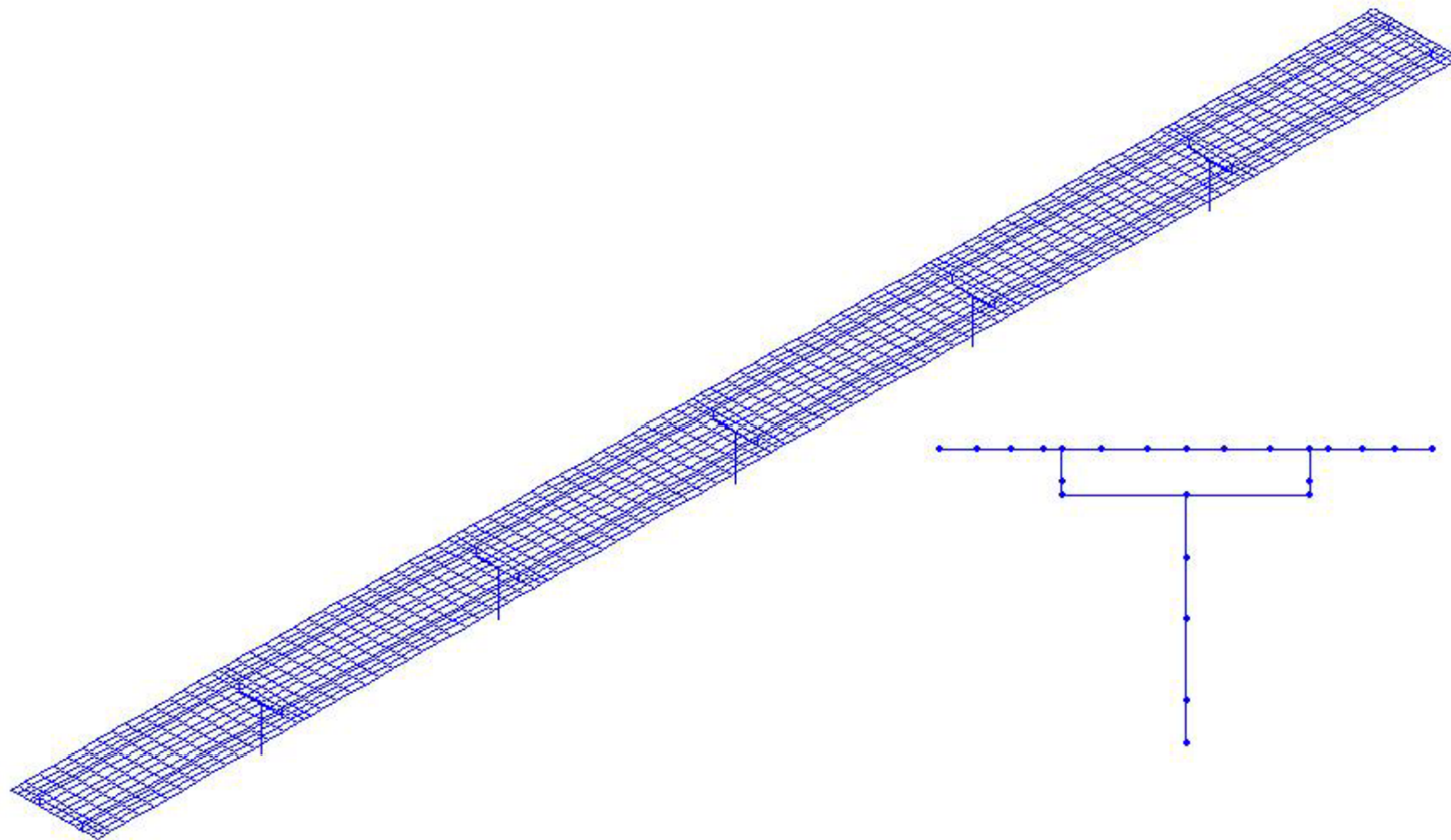
Rubber expansion joint with
50 mm excursion



M free in both directions
U_L fixed in transverse direction

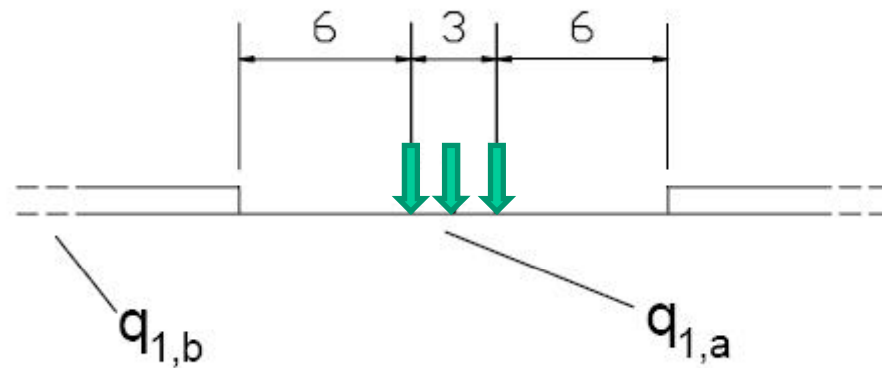
Restrain in longitudinal direction
14 bars $\phi=70\text{mm}$ $i=65\text{cm}$

Finite element model



Live loads

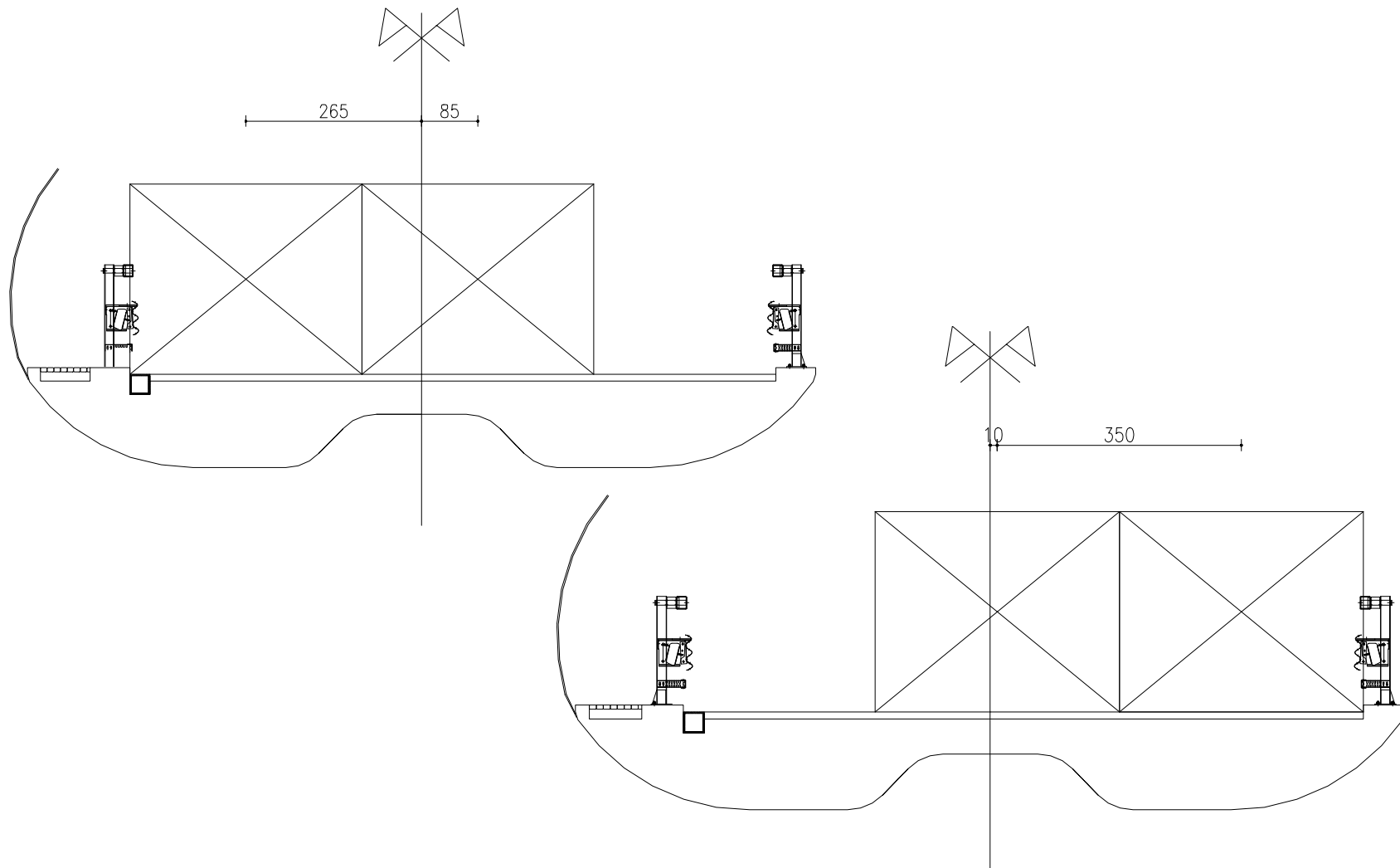
2 notional lanes in transverse direction
Each lane is 3m wide in transverse direction



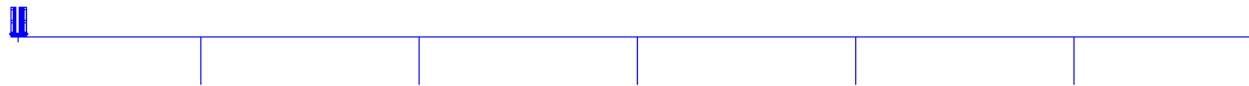
$$q_{1,a} = 3 \text{ couples of concentrated loads } 150\text{kN each} = 3 \times 2 \times 150 = 600 \text{ kN}$$

$$q_{1,b} = \text{uniformly distributed load of } 3\text{KN/m}^2$$

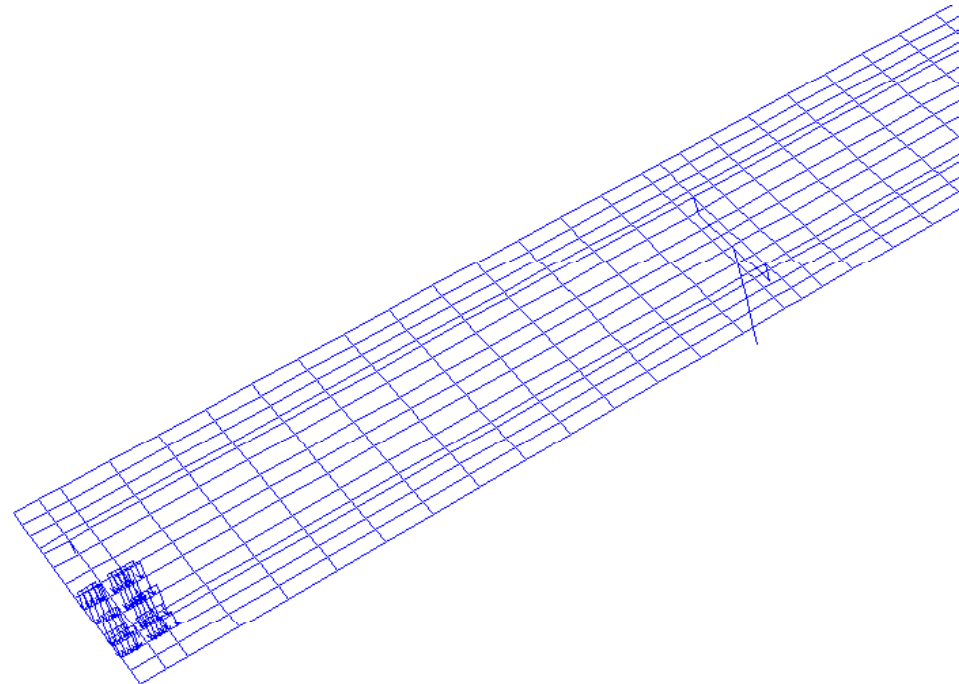
Live loads lanes transverse position



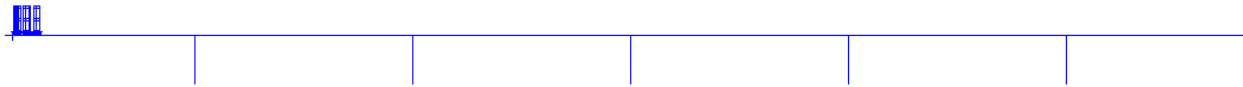
$q_{1,a}$ has been placed 64 times in different longitudinal positions on the girder model with stepping of 3 m
($64 \times 3 = 192\text{m} \cong \text{length of the bridge } 189$)



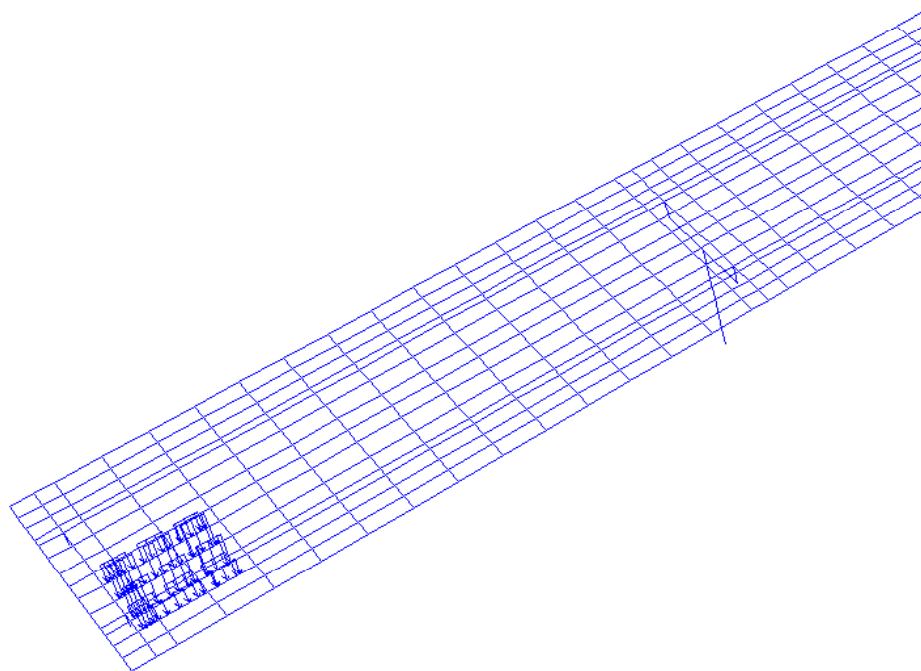
$q_{1,a}$ Loads
corresponding to
the outermost
notional lane



$q_{1,b}$ has been divided into 3x3m squared areas and placed 64 times in different longitudinal positions on the girder for each notional lane



**$q_{1,a}$ Loads
corresponding to
the outermost
notional lane**



Materials

CONCRETE:	deck:	$R_{ck} \geq 40 \text{ Mpa}$
	piers:	$R_{ck} \geq 35 \text{ Mpa}$
	abutments and foundations	$R_{ck} \geq 30 \text{ Mpa}$

PRESTRESSING STEEL: 0.6" strands

$f_{ptk} = 1860$	MPa
$f_{p(1)k} = 1670$	MPa
$E_s = 200000$	MPa

ORDINARY STEEL: Fe B 44 k

$f_{yk} \geq 430$	Mpa
$E_s = 200000$	Mpa
$f_{yd} = 374$	MPa

PINEROLO BRIDGE

Pictures taken during construction

Completed bridge



Completed bridge



Completed bridge



Reinforcement cage of the pier



Detail of reinforcement cage at the foot of the pier



Scaffolding realization



Moving scaffolding



Scaffolding near bearing



Reinforcement just before concreting



Construction joint between casting i and $i+1$ before concreting



Construction joint between casting i and i+1 after concreting



Tensioning tendons at the beginning of the deck



Cutting tendons strands after tensioning in the coupler



Bearing detail



Bars connecting the deck to the earth-containment wall



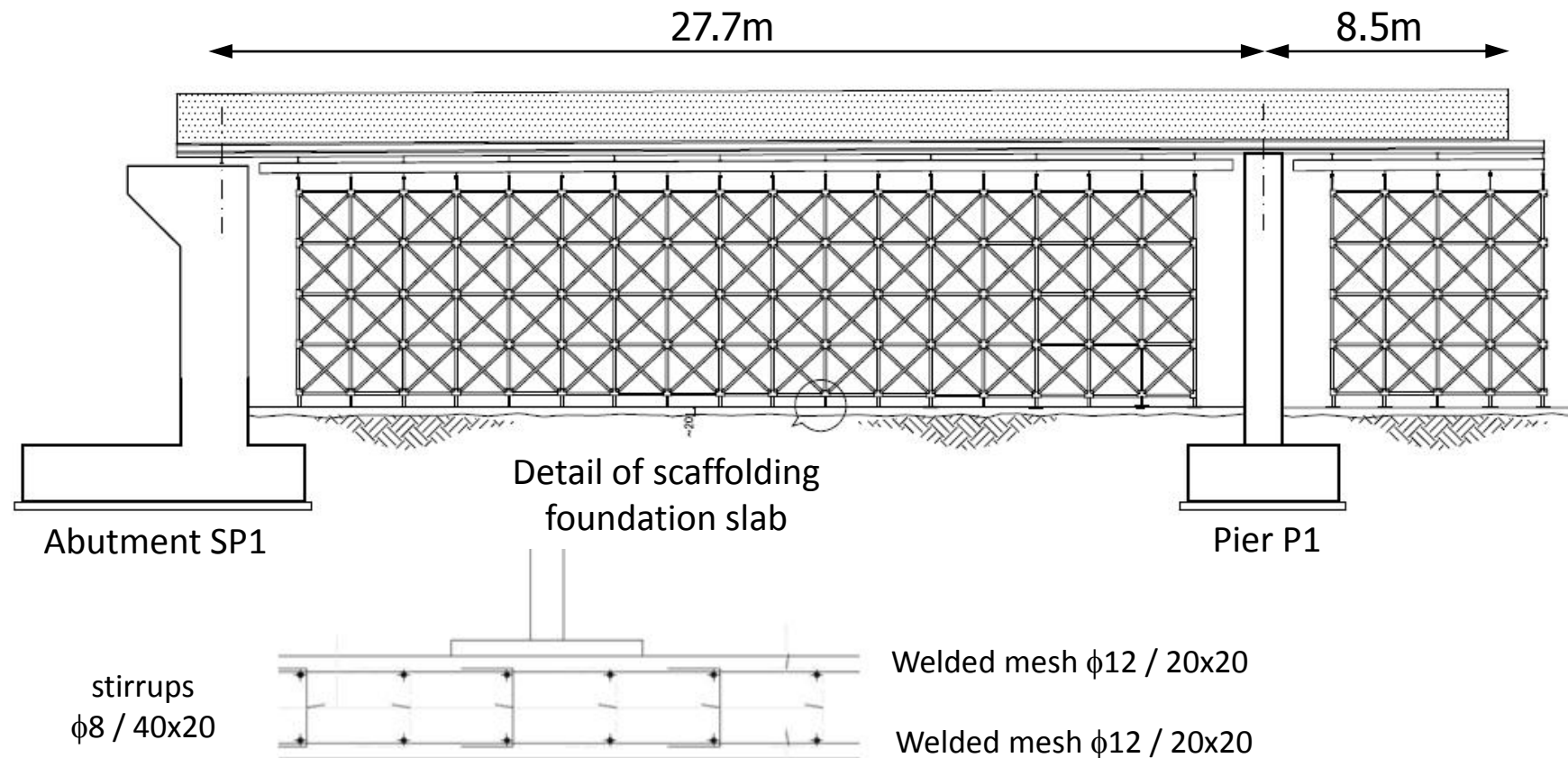
PINEROLO BRIDGE

Construction phases

Phase 1 & 2:

Day 1 - Concreting of span SP1 – P1

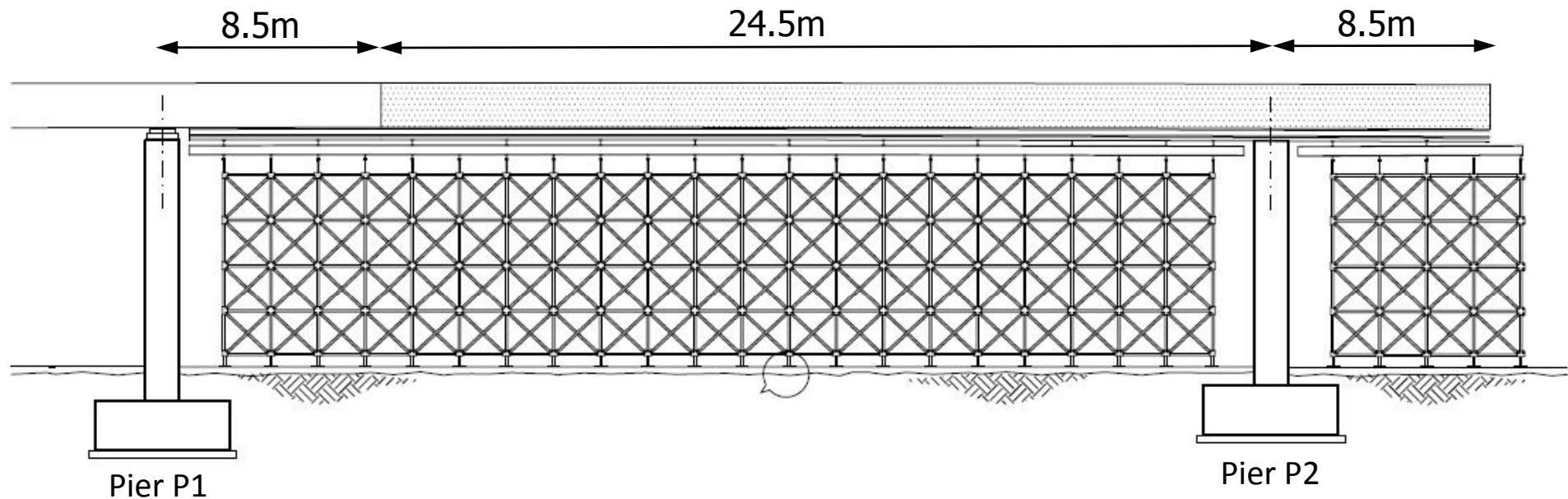
Day 14 – tensioning of tendons “I” and removal of scaffolding



Phase 4:

Day 45 - Concreting of span P1 – P2

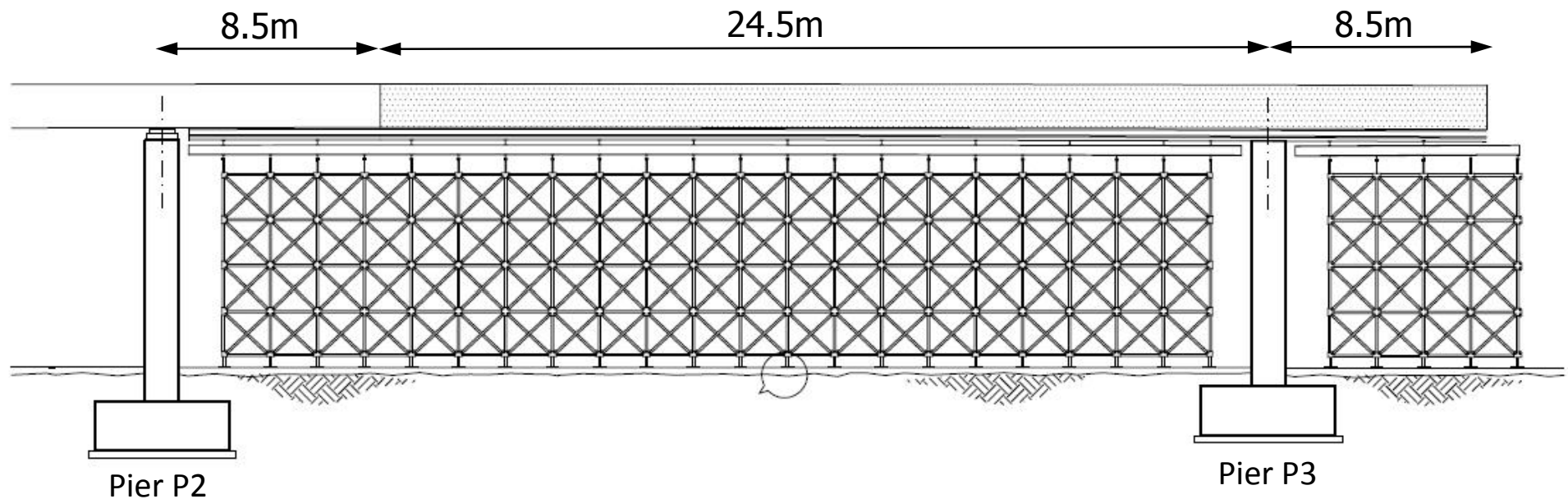
Day 58 - tensioning of tendons "I" and removal of scaffolding



Phase 10:

Day 89 - Concreting of span P2 – P3

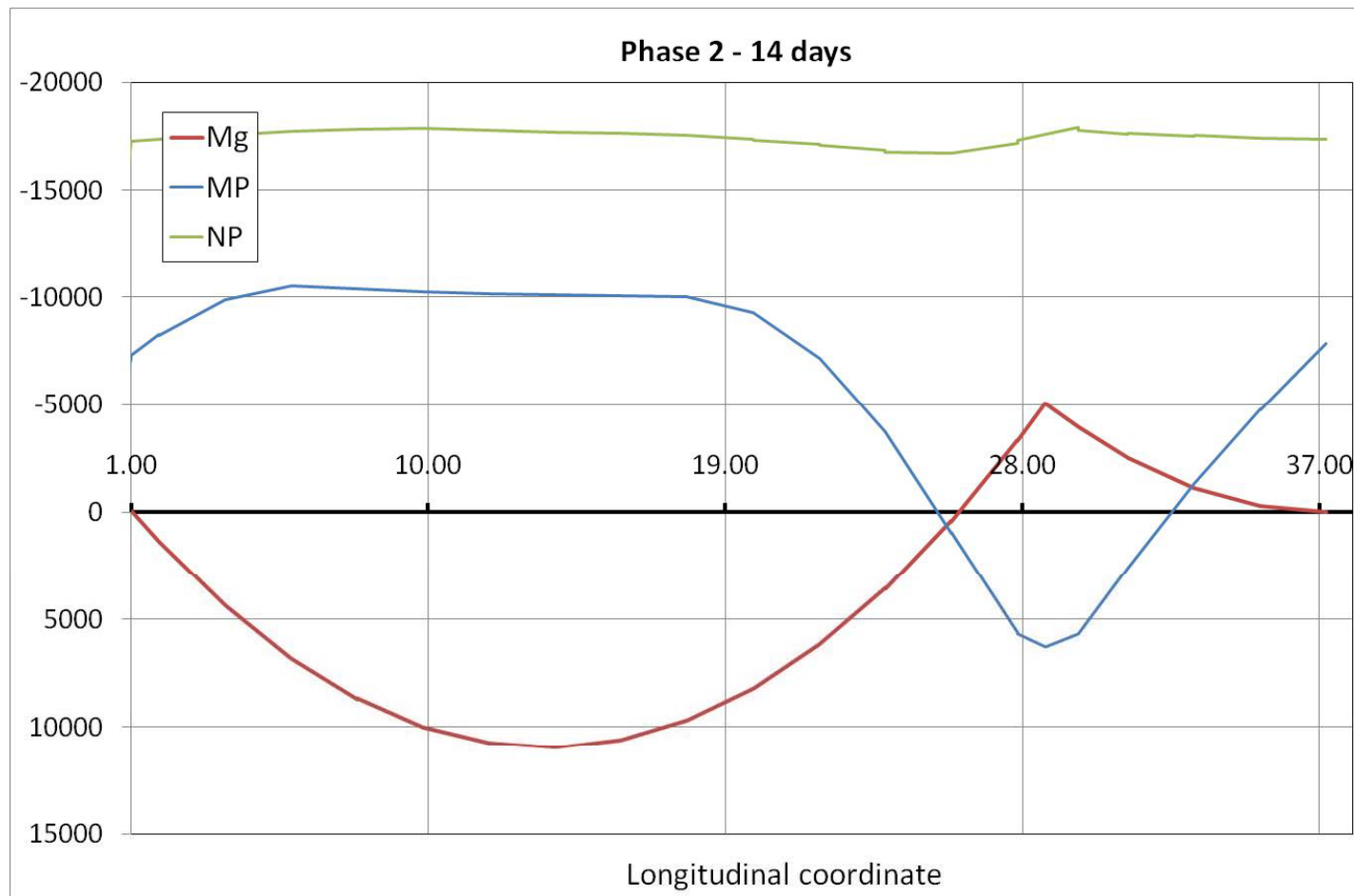
Day 102 - tensioning of tendons "I" and removal of scaffolding



Phase 1 & 2:

Day 1 - Concreting of span SP1 – P1

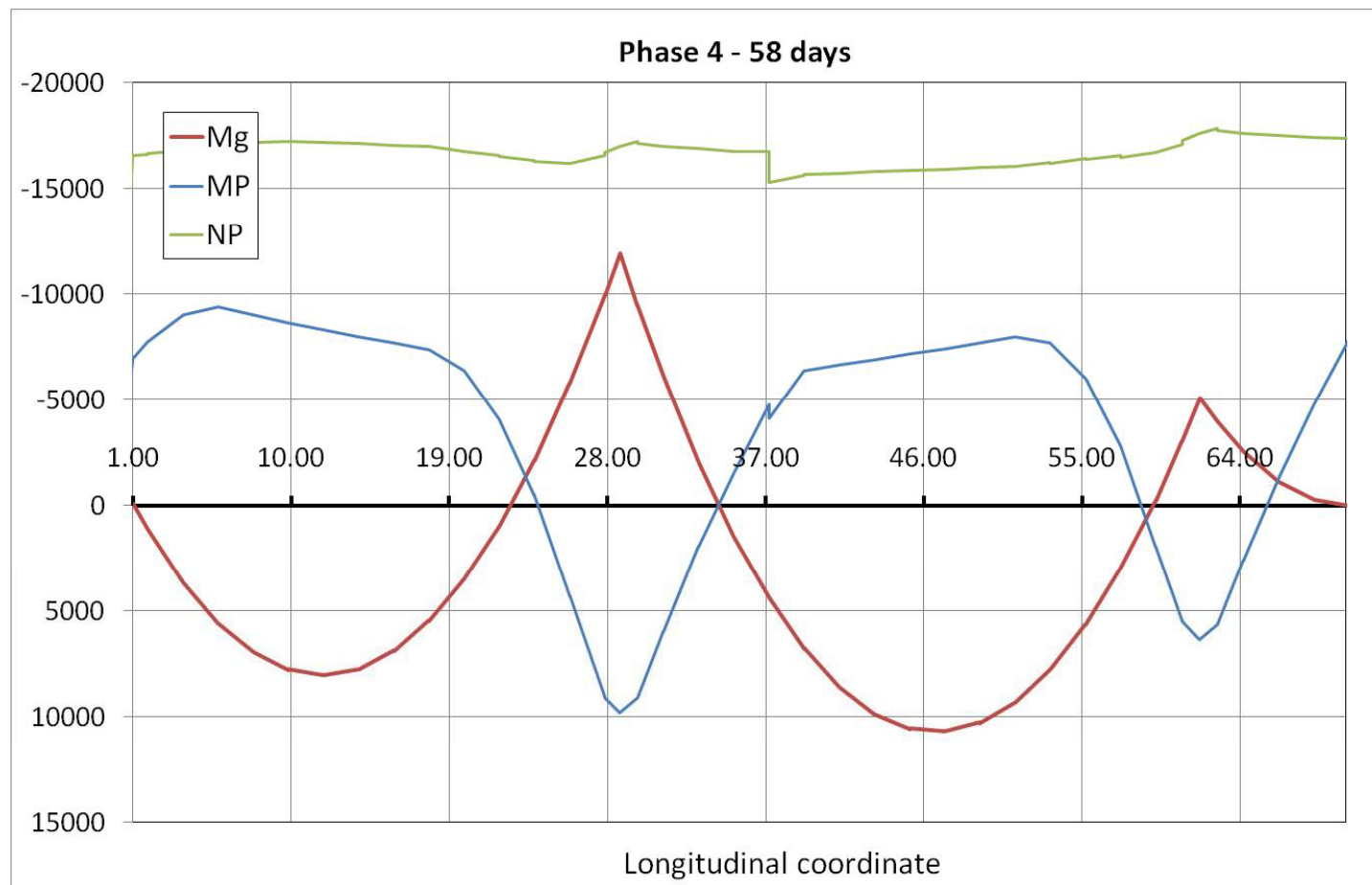
Day 14 – tensioning of tendons “I” and removal of scaffolding



Phase 4:

Day 45 - Concreting of span P1 – P2

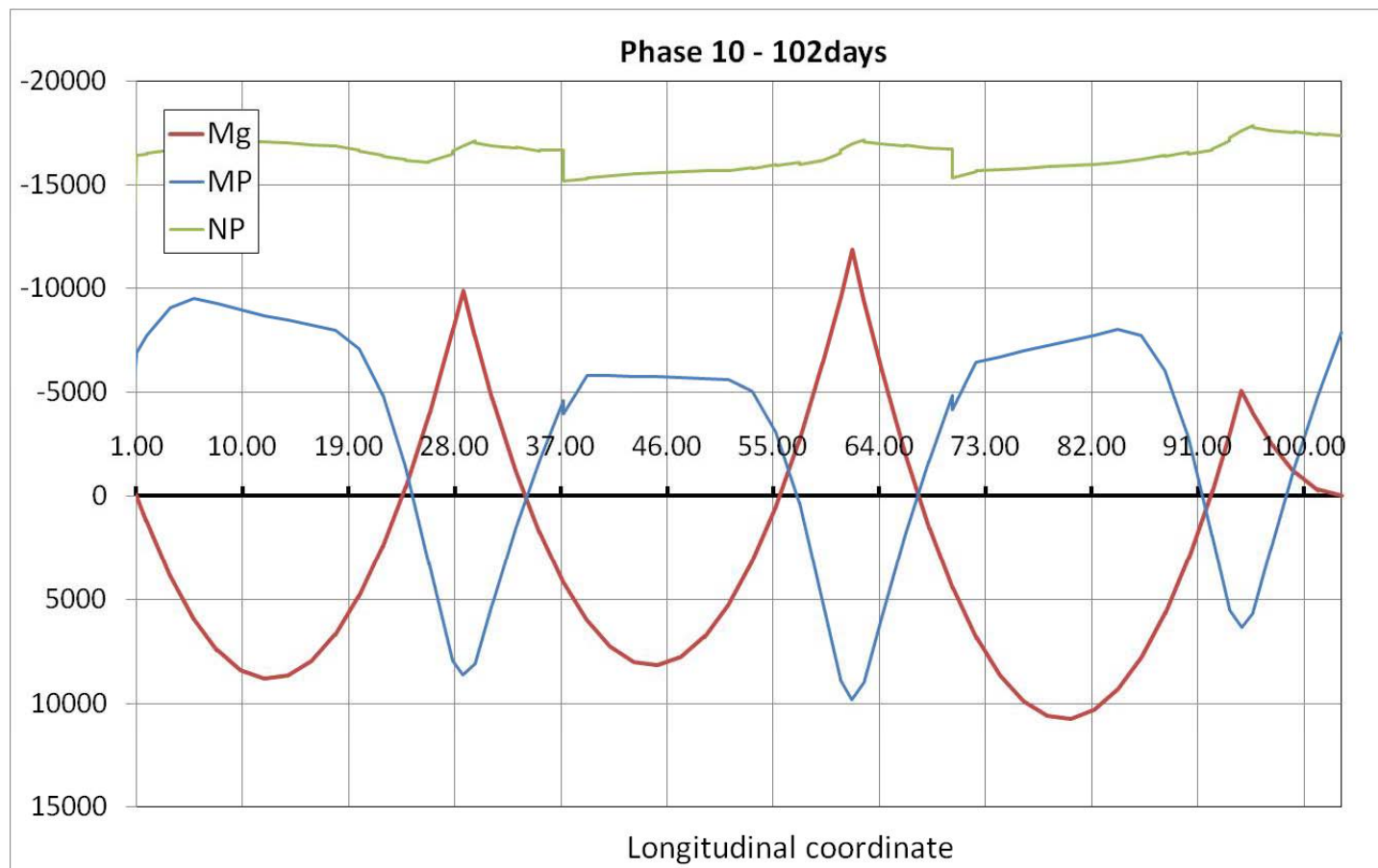
Day 58 - tensioning of tendons "I" and removal of scaffolding



Phase 10:

Day 89 - Concreting of span P2 – P3

Day 102 - tensioning of tendons "I" and removal of scaffolding



PINEROLO BRIDGE

Prestressing layout

Internal bonded tendons

19 strands Ø 0.6" tendons $A_t = 26.41 \text{ cm}^2$.

Prestressing stress:

$$\sigma_{spi} = 0.85 \times f_{p(1)k} = 0.85 \times 1670 = 1420 \text{ MPa}$$

Maximum prestressing force in each tendon:

$$T_{\max} = 1419.5 \text{ N/mm}^2 \cdot 26.41 \text{ mm}^2 = 3749 \text{ kN}$$

Construction phases prestressing

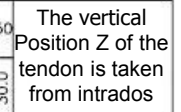
10 Tendons I1 coupled in each construction joint

End of construction prestressing

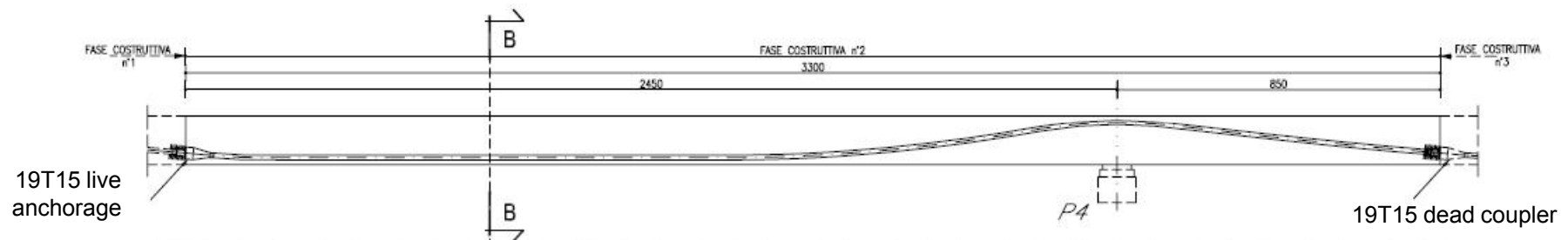
8 tendons F1 for positive and negative moments

6 baricentric tendons F2

Sec. A-A

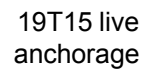


Sec. B-B



I2	X (cm) horizontal		50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	The vertical Position Z of the tendon is taken from intrados	
	Z (cm) vertical	30.0	25.6	18.7	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.1	19.9	23.8	30.1	38.4	49.2	61.9	77.1	94.1	107.1	111.8	107.4	96.4	84.5	73.2	62.6	52.6		43.2

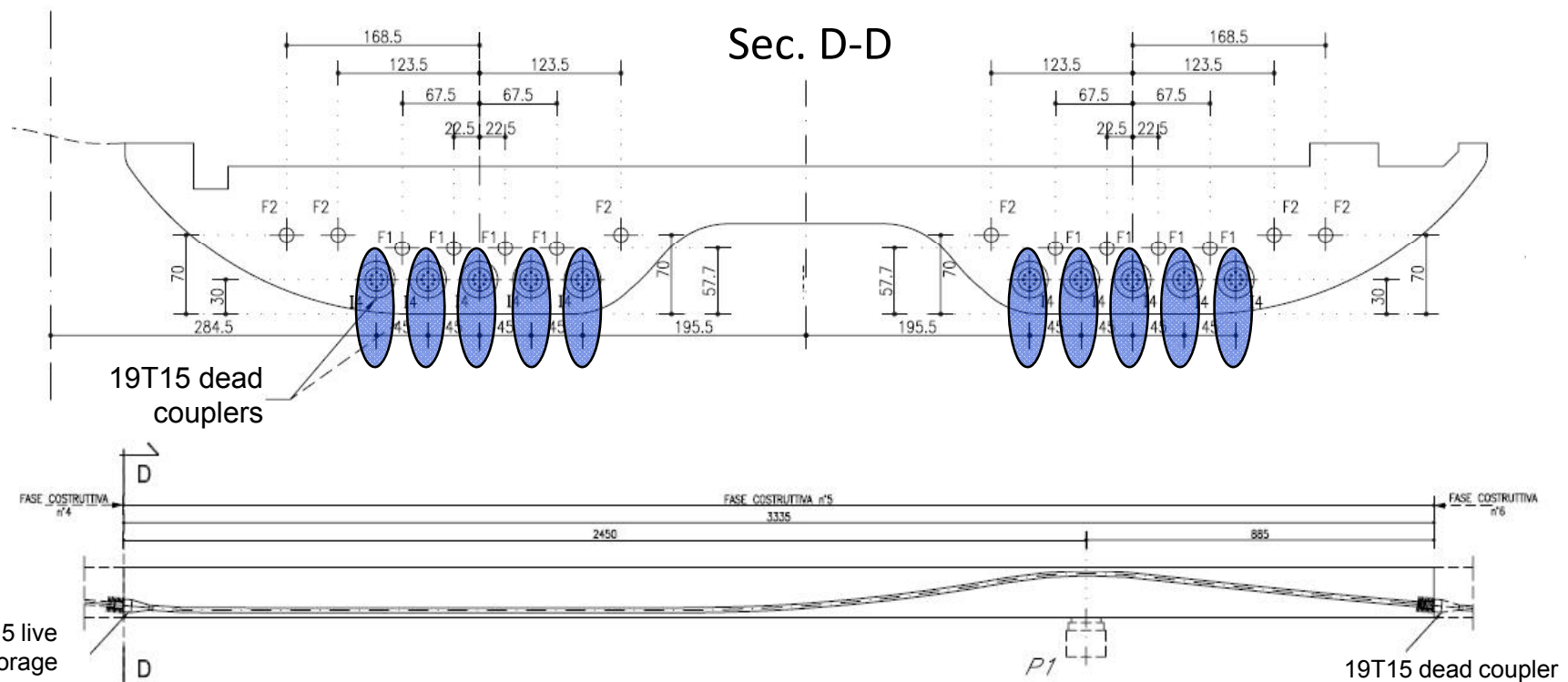
Sec. C-C



I3	X (cm) horizontal		50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	The vertical Position Z of the tendon is taken from intrados
	Z (cm) vertical	30.0	25.6	18.7	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.1	19.9	23.8	30.1	38.4	49.2	61.9	77.1	94.1	107.1	111.8	107.4	96.4	84.5	73.2	62.6	52.6	43.2	34.3	30.0	

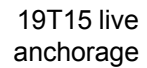
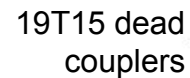
The vertical Position Z of the tendon is taken from intrados

Phase 4: tendons I4



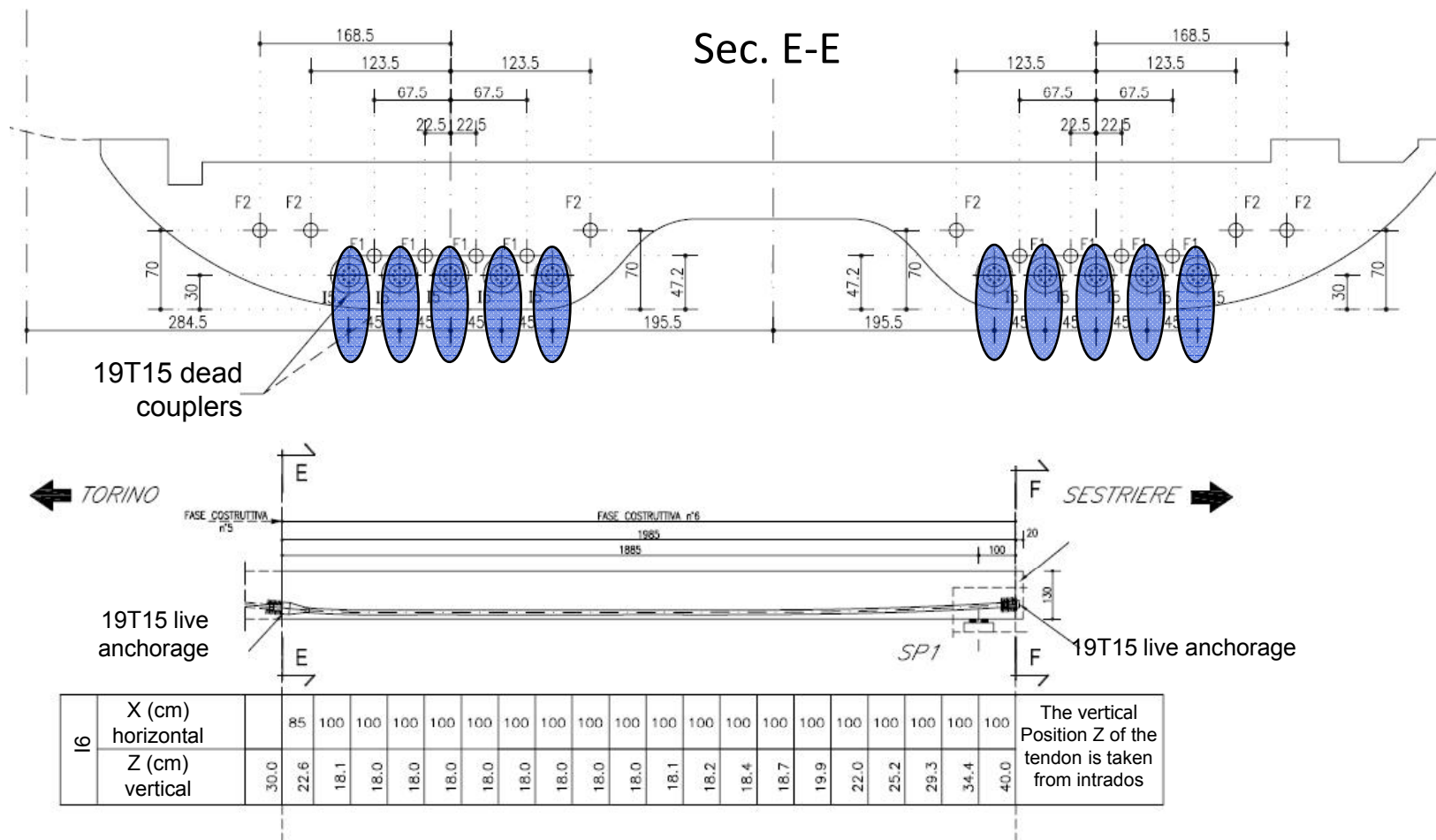
I4	X (cm) horizontal		50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	85	The vertical Position Z of the tendon is taken from intrados
	Z (cm) vertical	30.0	25.6	18.7	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.1	19.9	23.9	30.1	38.5	49.1	62.0	77.1	94.1	107.2	111.6	107.9	97.8	86.6	75.8	65.5	55.7	46.3	37.4	30.0	

Sec. D-D



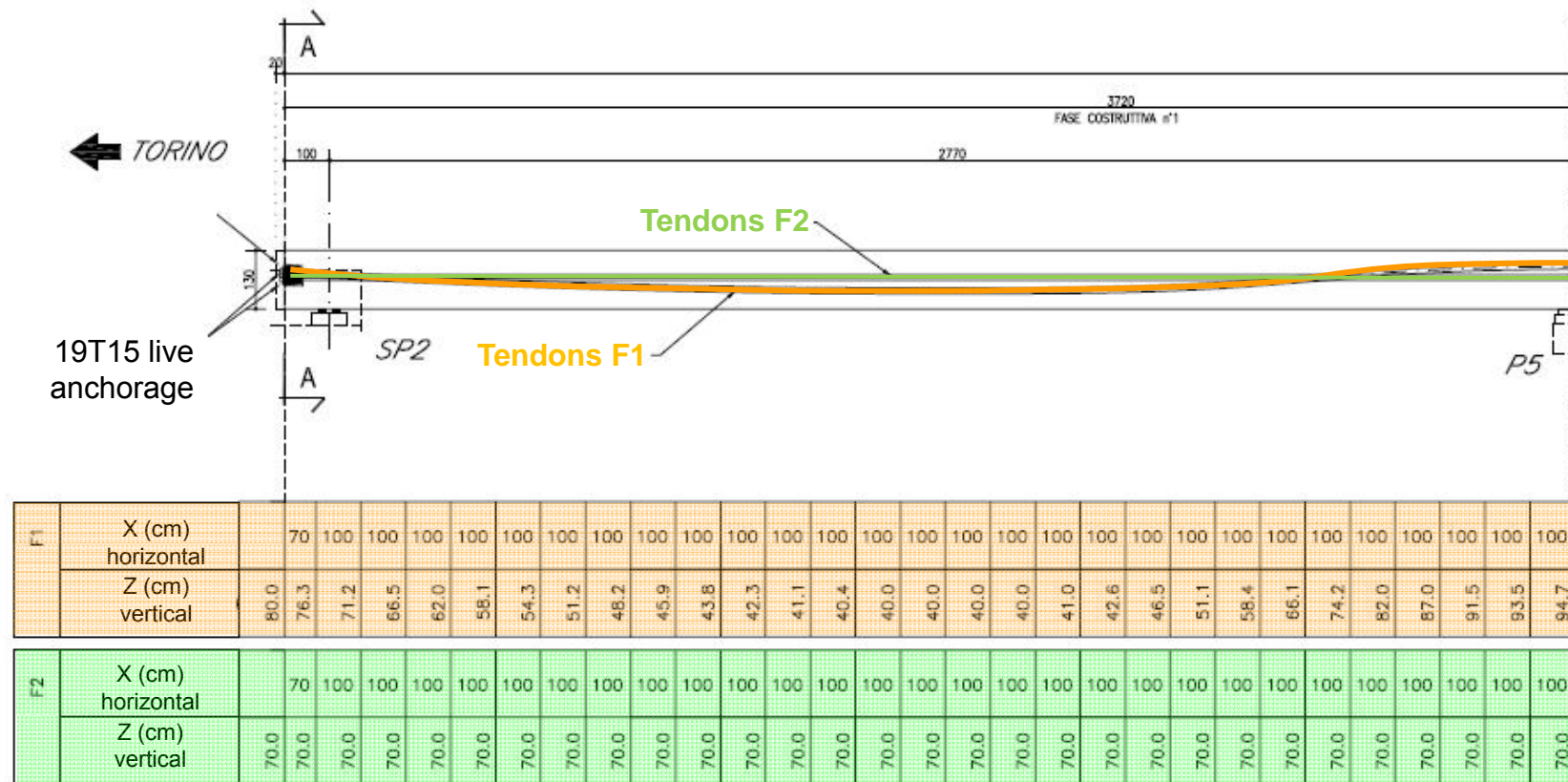
The vertical Position Z of the tendon is taken from intrados

Phase 6: tendons I6



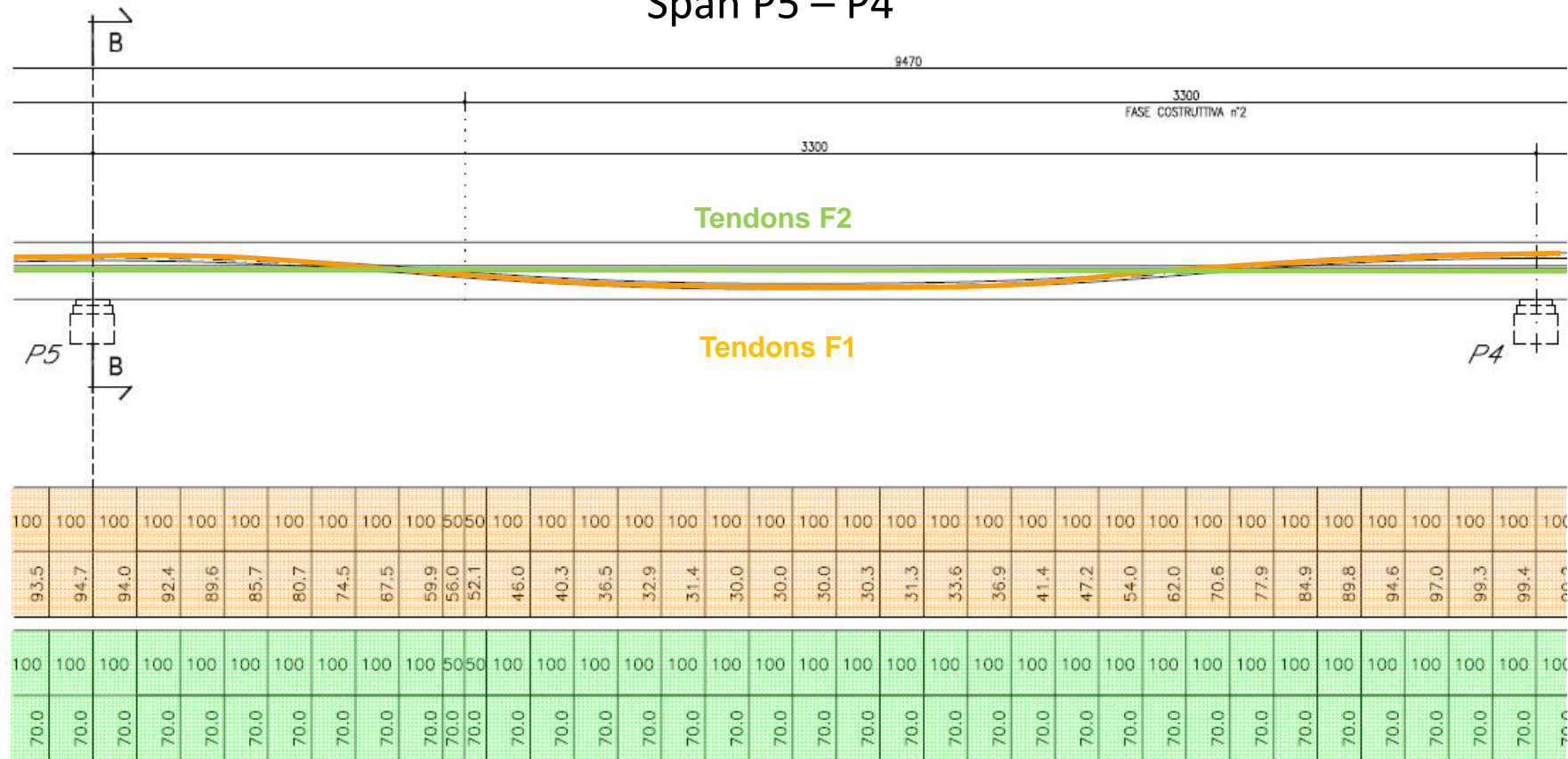
End of construction: tendons F1 & F2

Span SP2 – P5

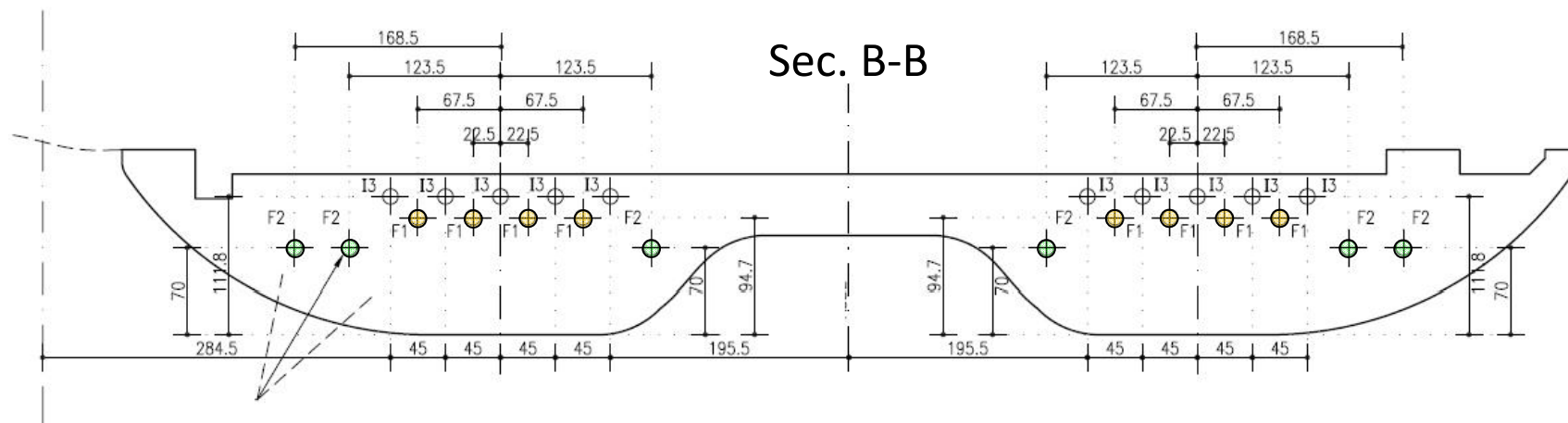
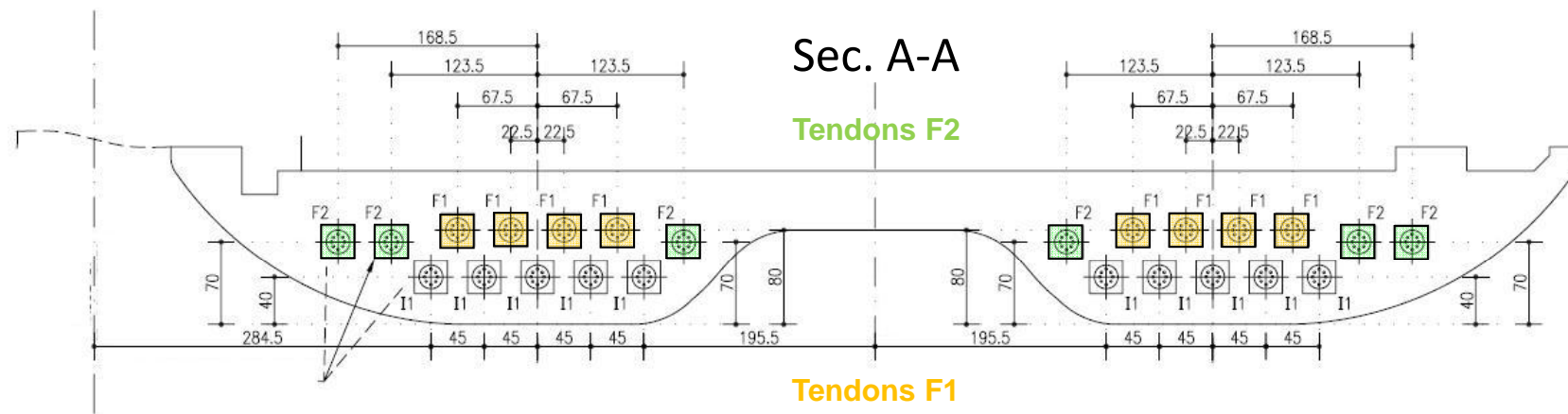


End of construction: tendons F1 & F2

Span P5 – P4



End of construction: tendons F1 & F2



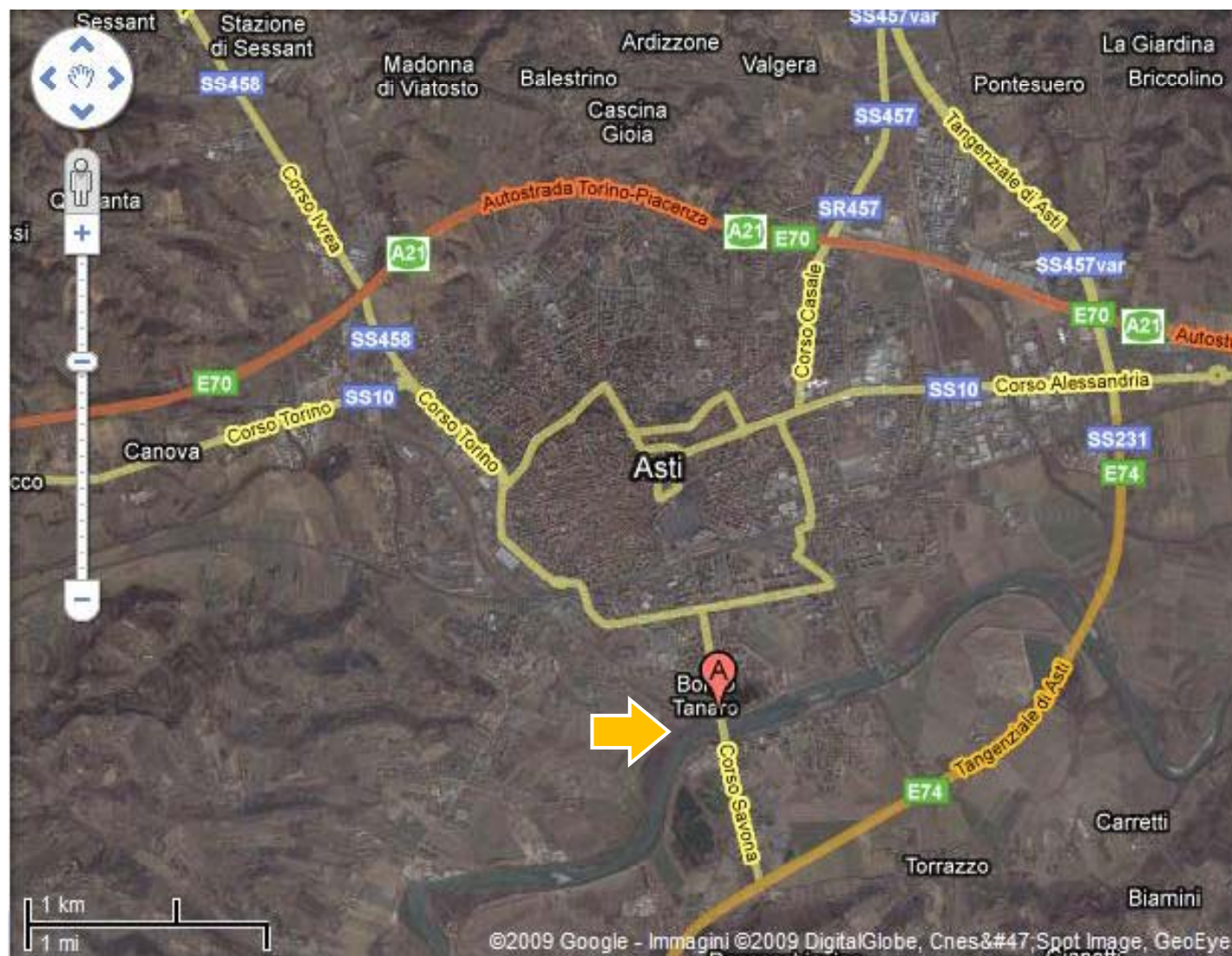
SECONDINO VENTURA BRIDGE (ASTI)

Incremental launching continuous beam

SECONDINO VENTURA BRIDGE


Geographical positioning








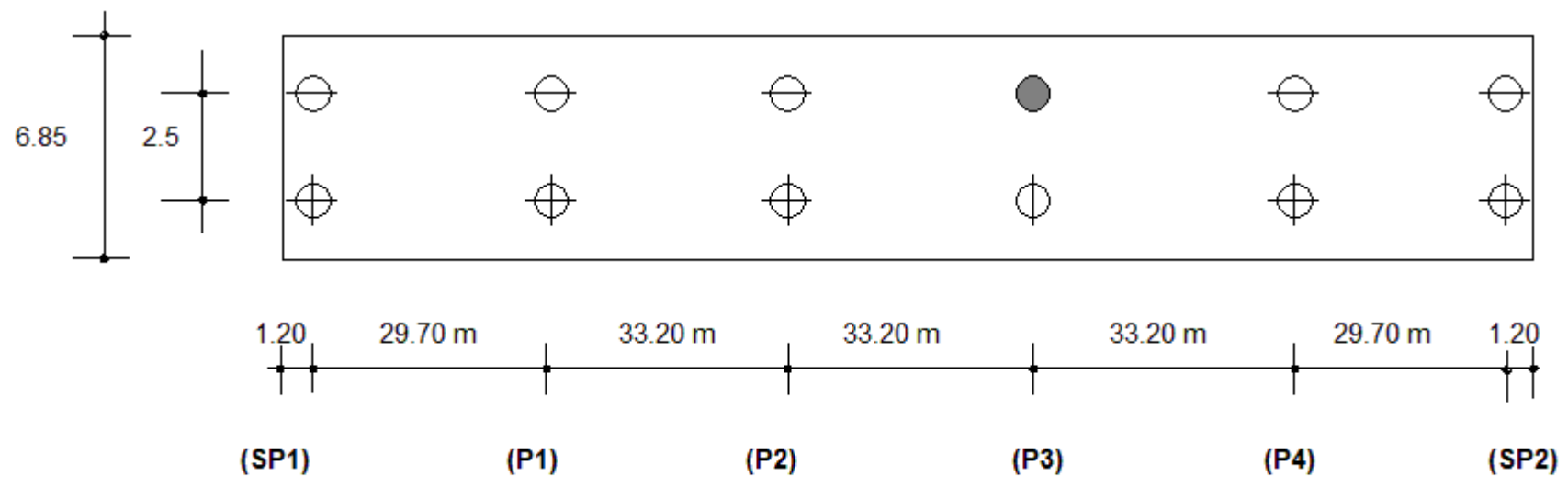
BEARINGS

Free = 

Fixed = 

Long. Free / Transv. fixed = 

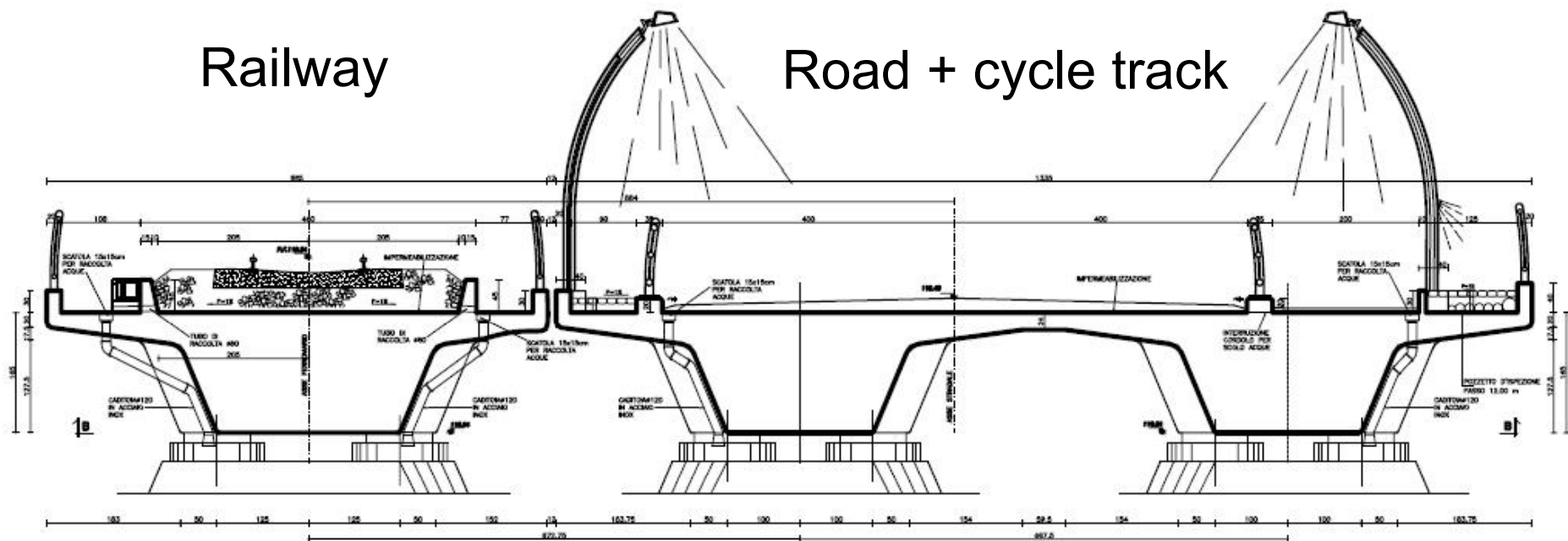
Long. fixed / Transv. free = 



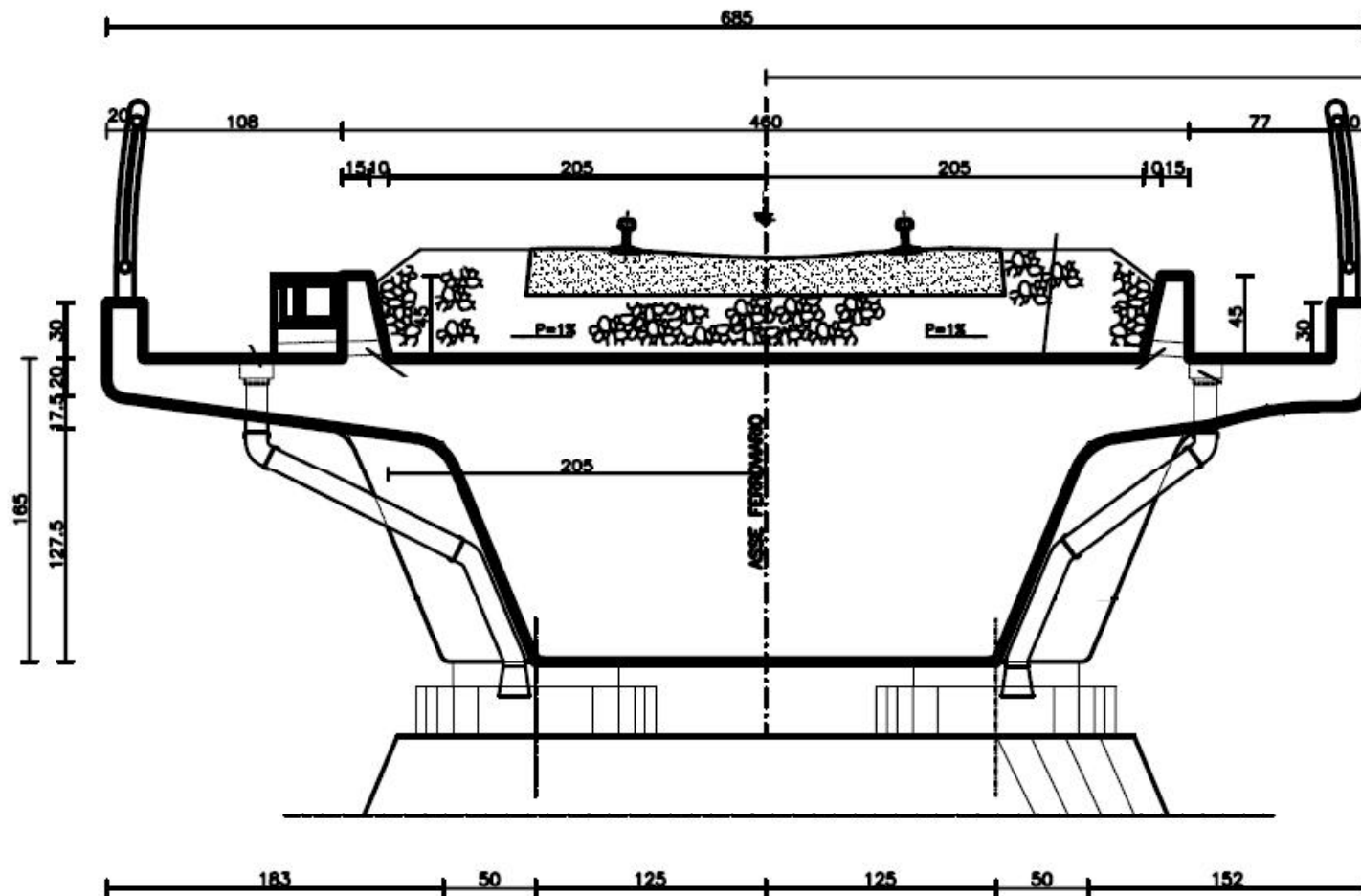
Cross section of the two independent decks

Railway

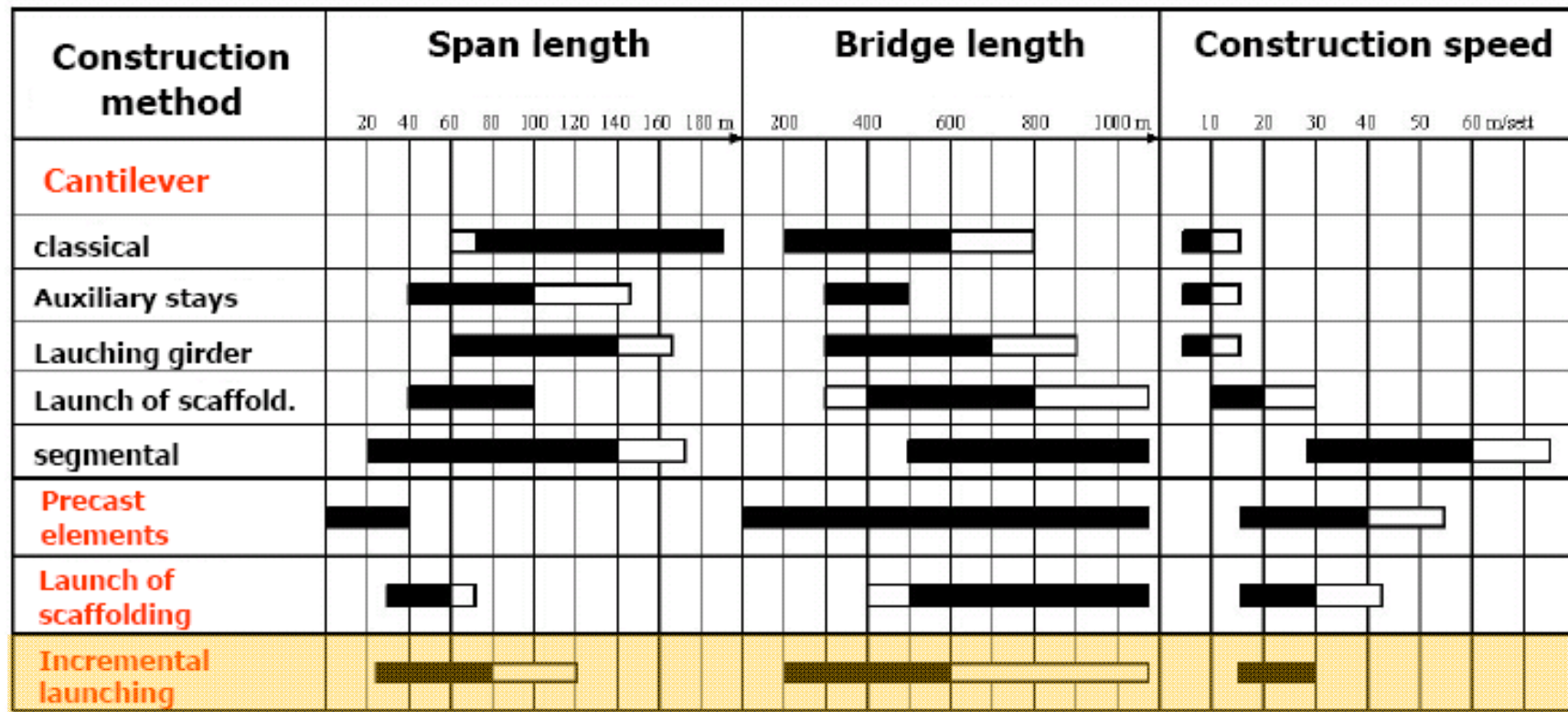
Road + cycle track



Cross section of the railway deck



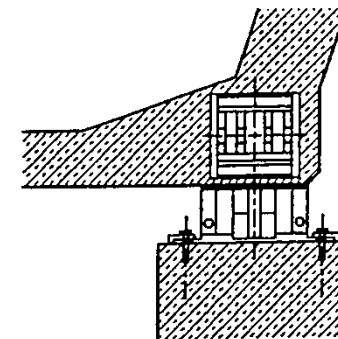
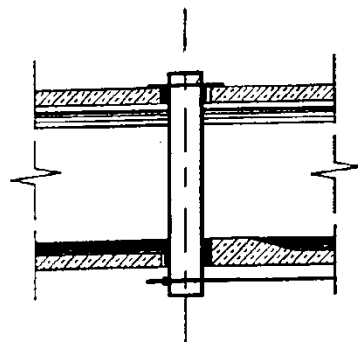
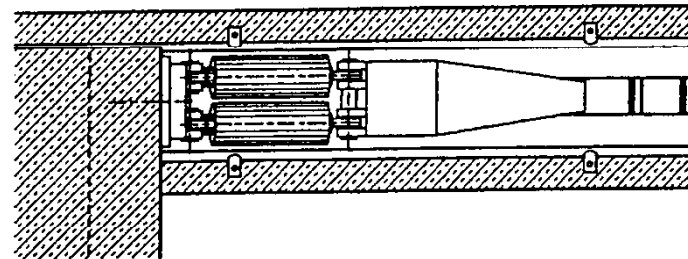
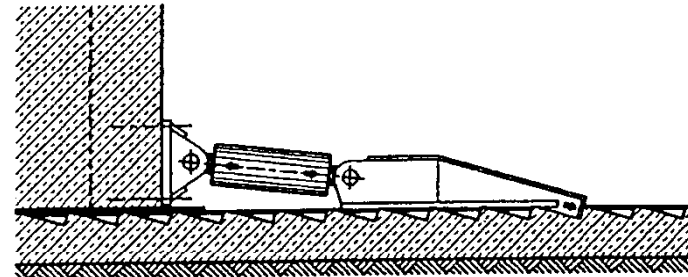
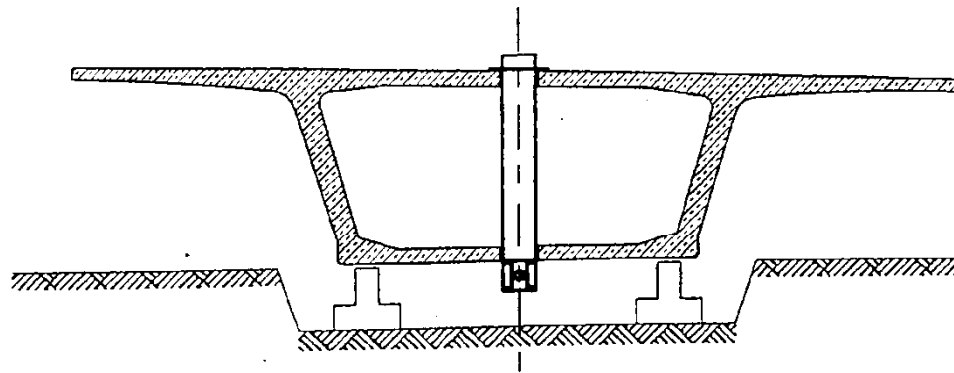
Comparison between construction techniques



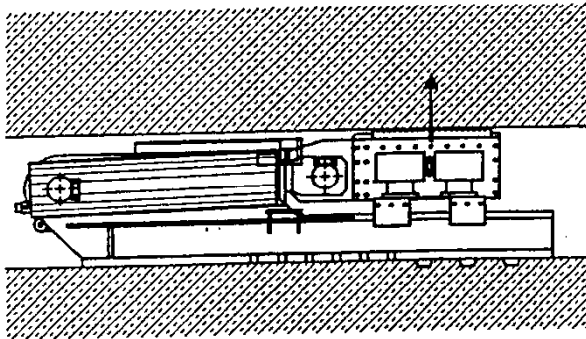
- Construction of one span (33 m) in ten days
- Launching time: 3 hours

SECONDINO VENTURA BRIDGE

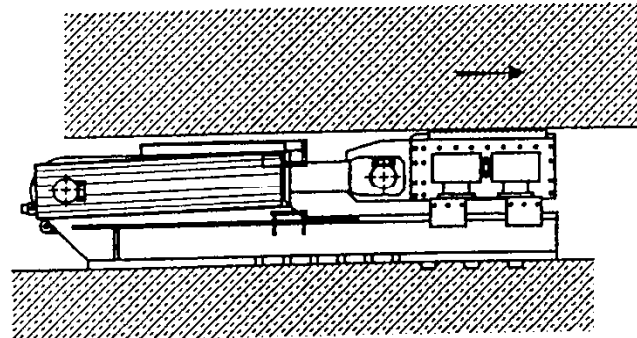
Launching technique



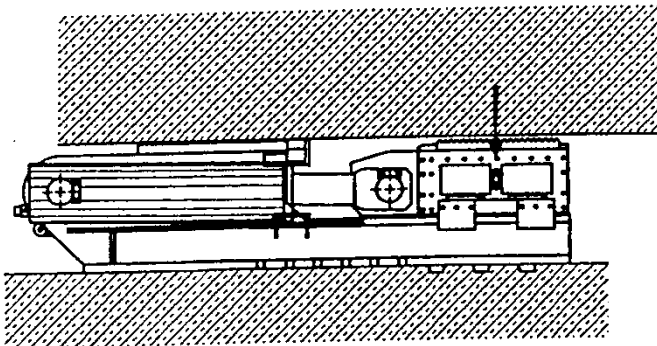
a) Uplift



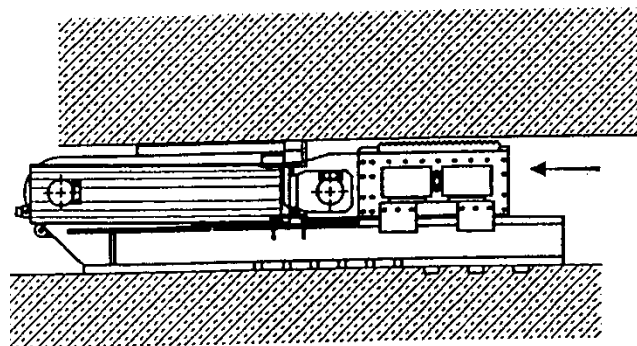
b) Trust



c) Down lift



d) Repositioning



Geometrical limitations:

In vertical plane

horizontal
circular
linear inclination
circular

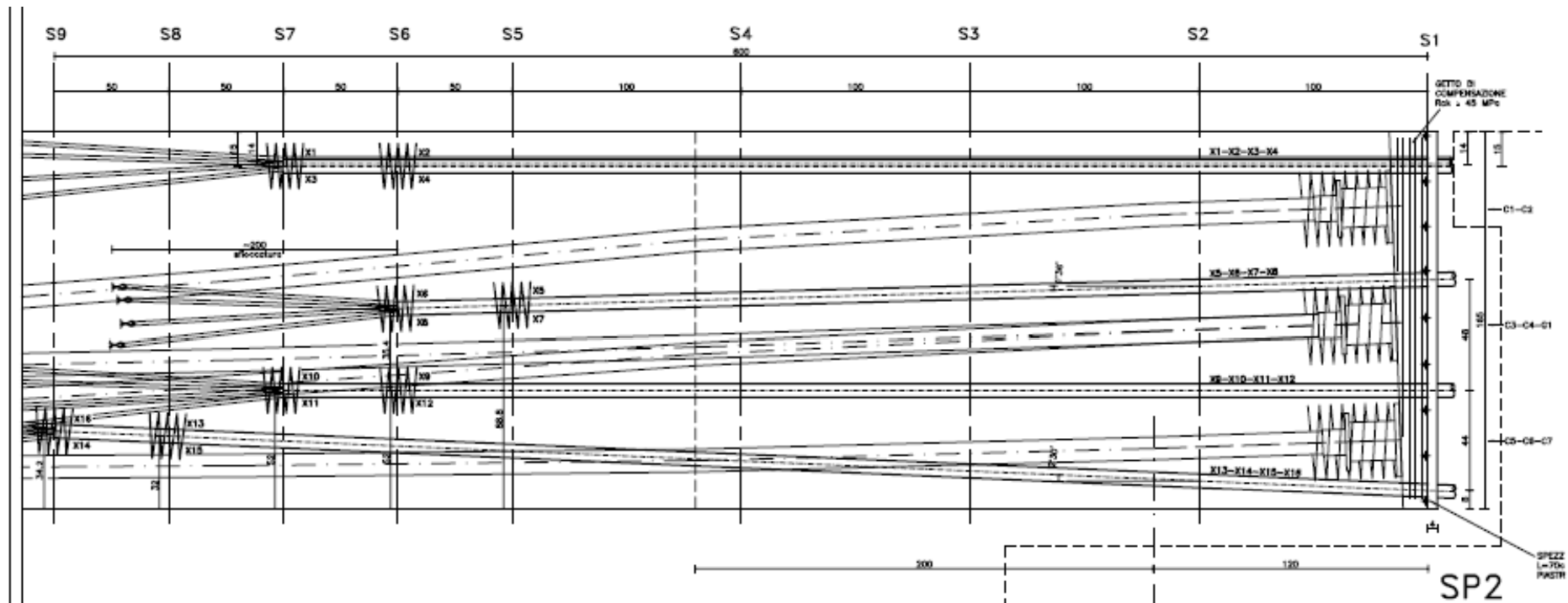
In horizontal plane

straight or circular
straight
circular
circular

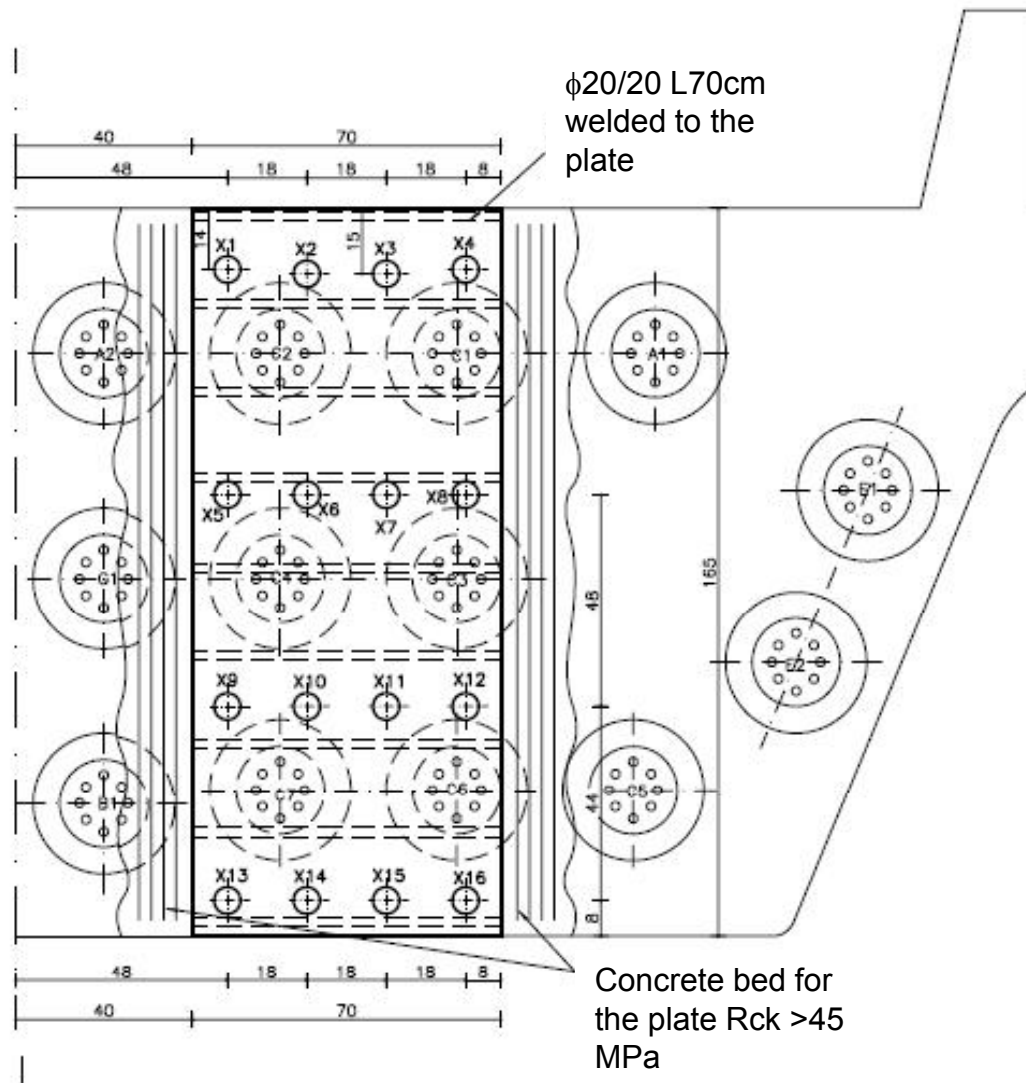
In the last two cases the projections on the horizontal plane
are ellipse circles

Launching nose anchoring system

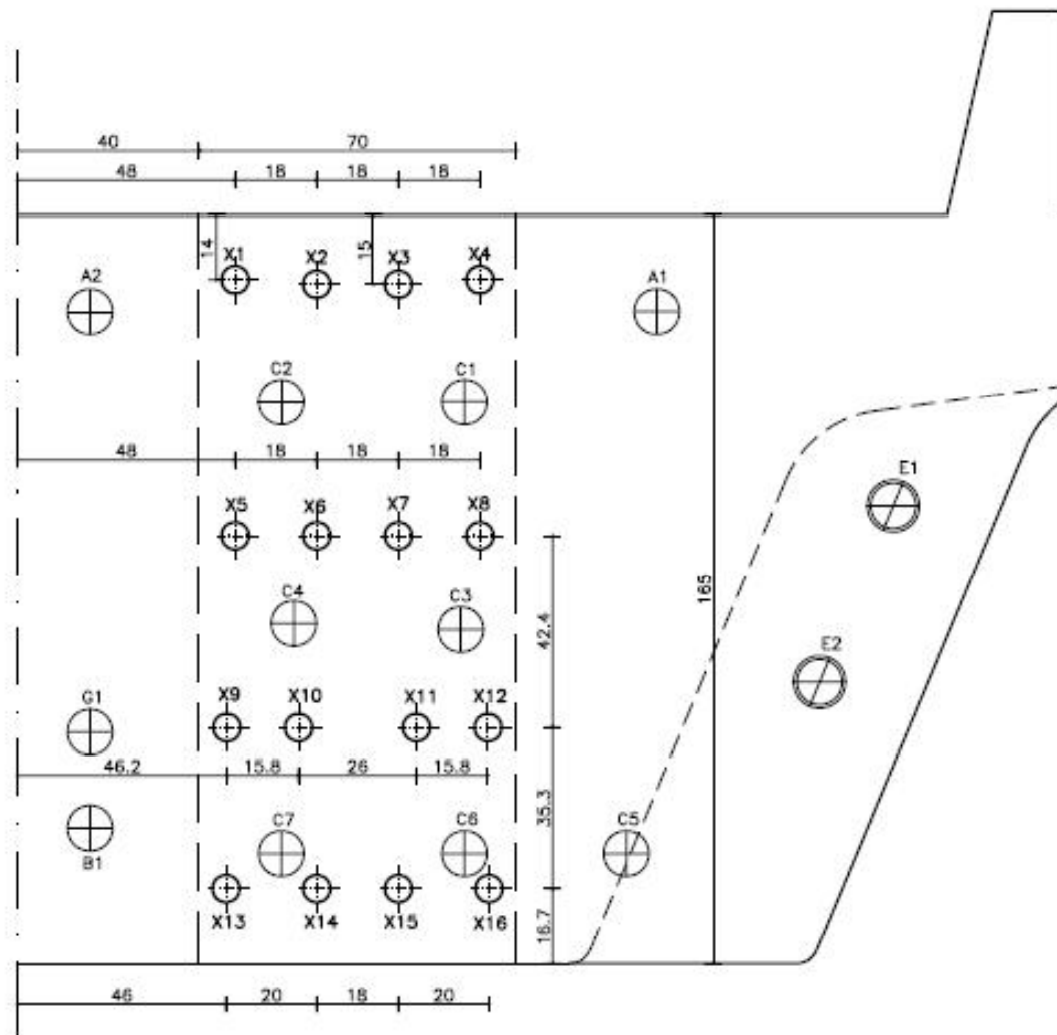
Longitudinal section



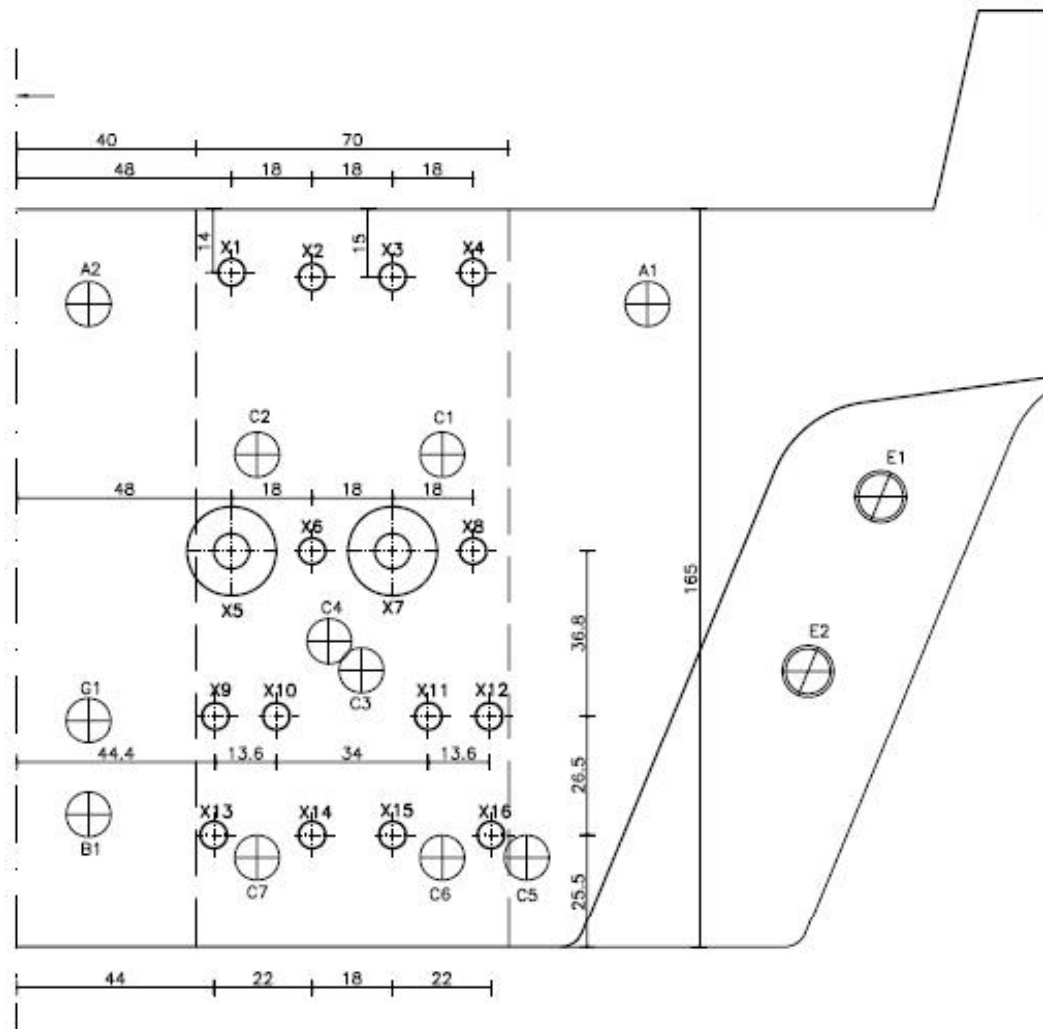
Section S1 (interface with the nose)



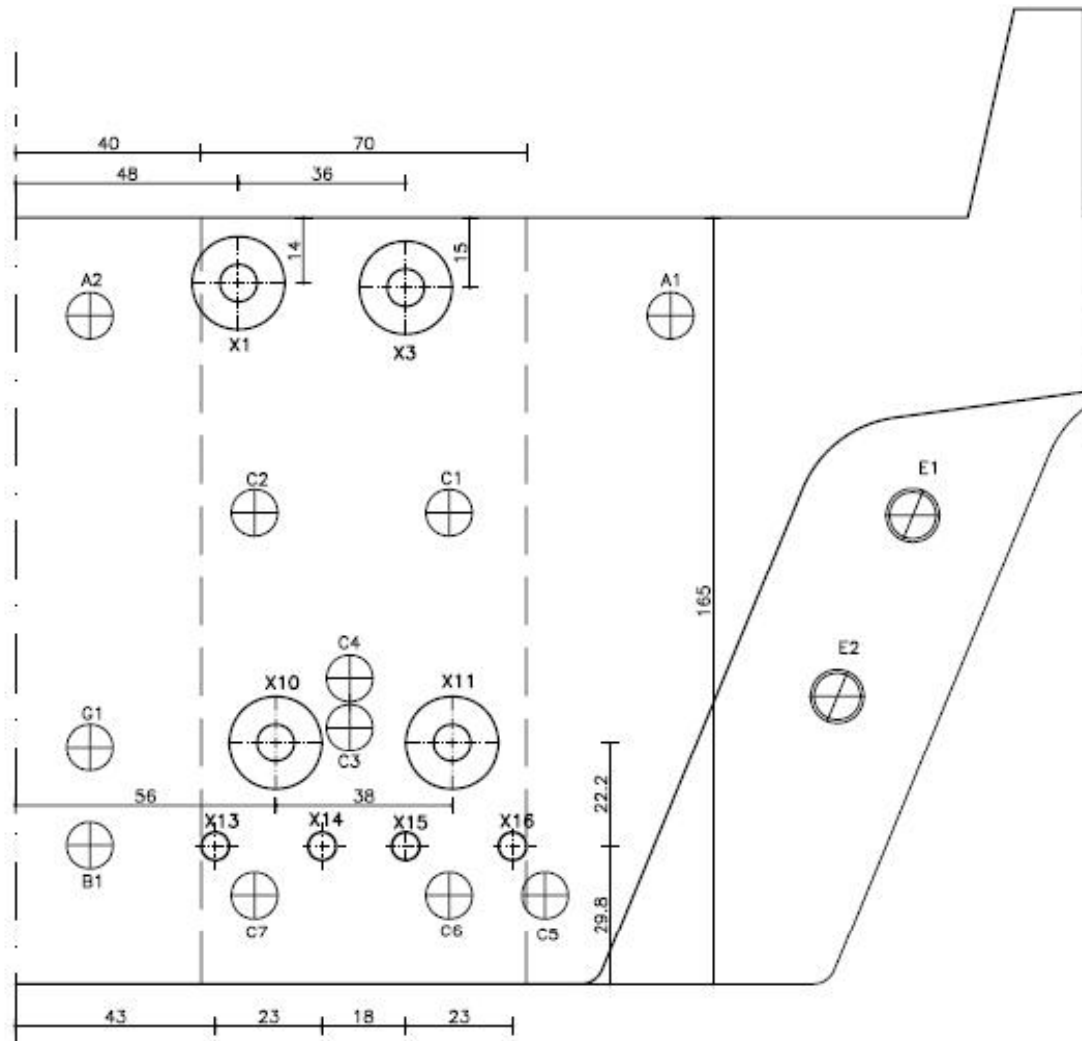
Section S3 (2m from the nose)



Section S5 (4m from the nose)



Section S7 (5m from the nose)



SECONDINO VENTURA BRIDGE

Evaluation of the internal actions during
launching and launching prestressing

INTERNAL ACTIONS DURING THE LAUNCHING: BENDING MOMENT

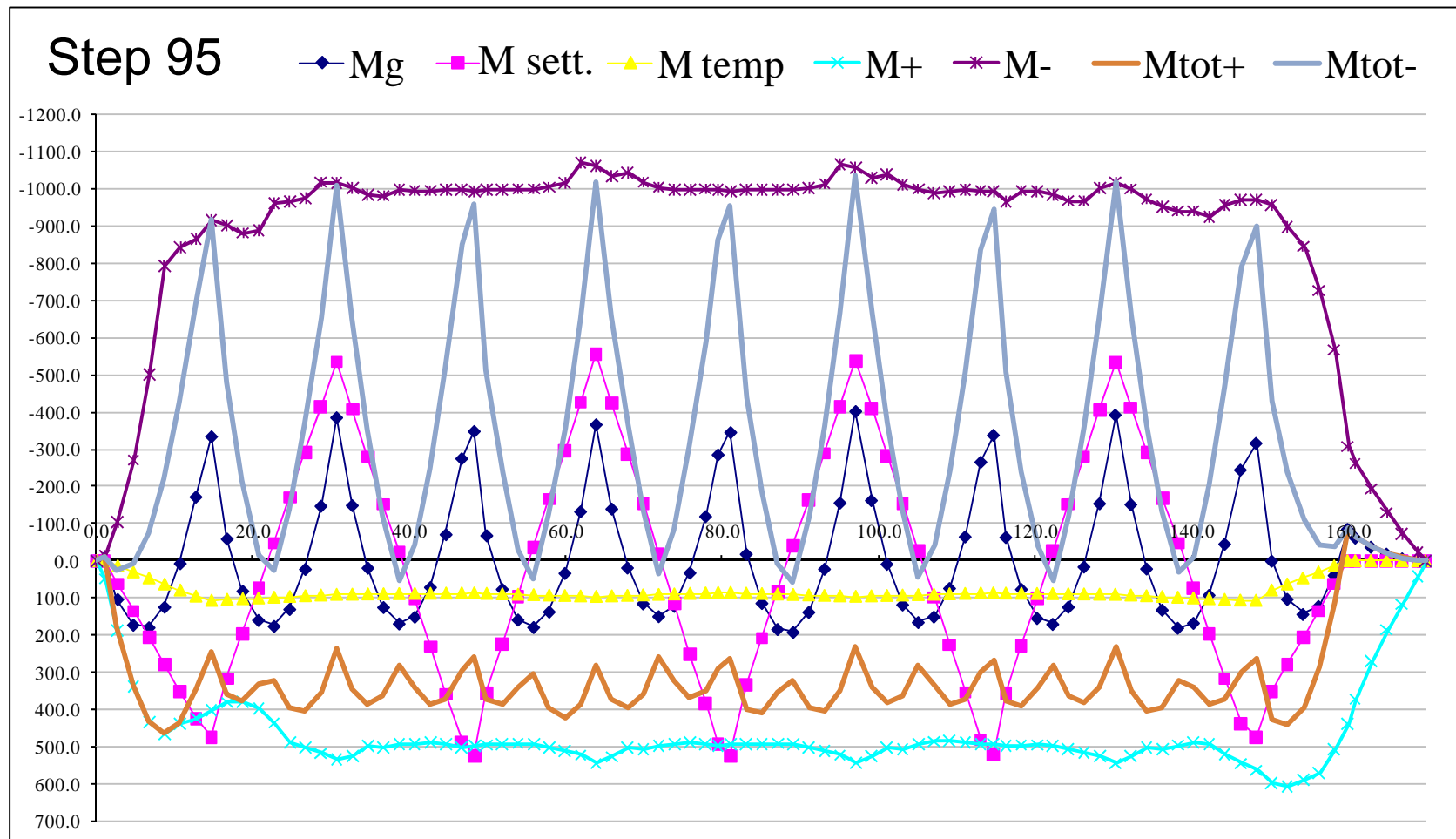
- Static scheme :



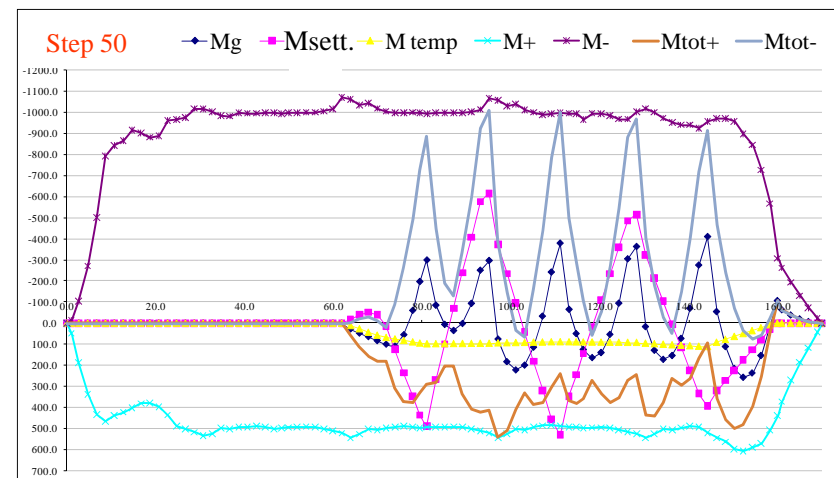
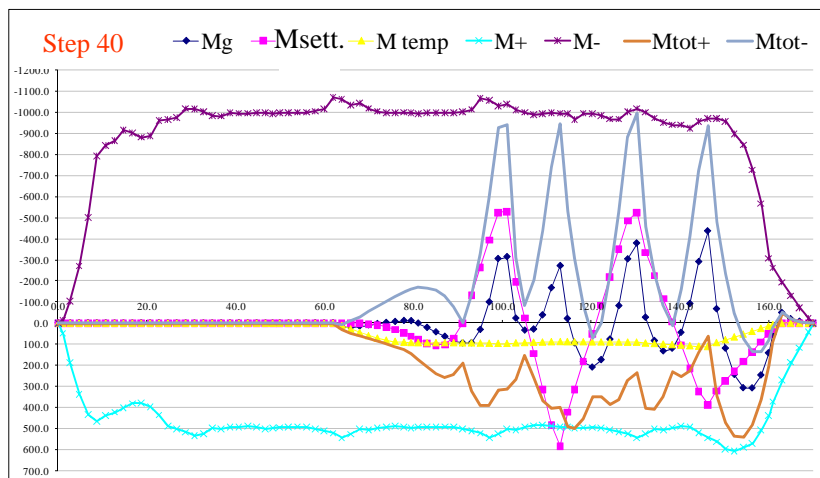
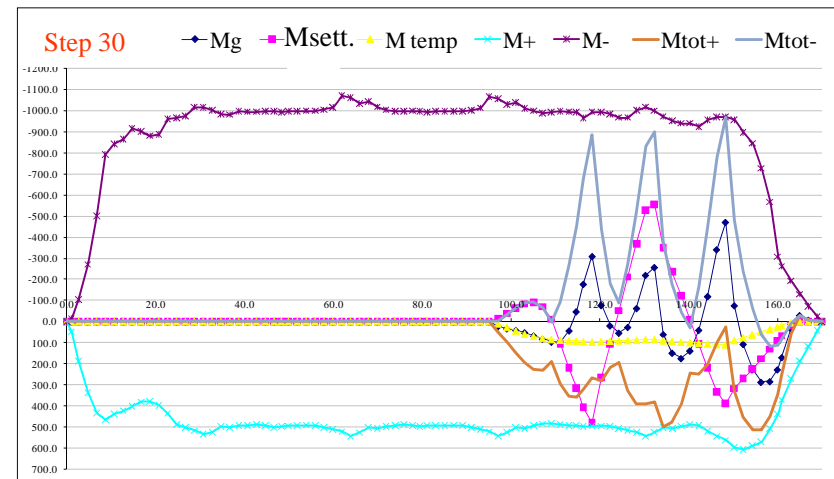
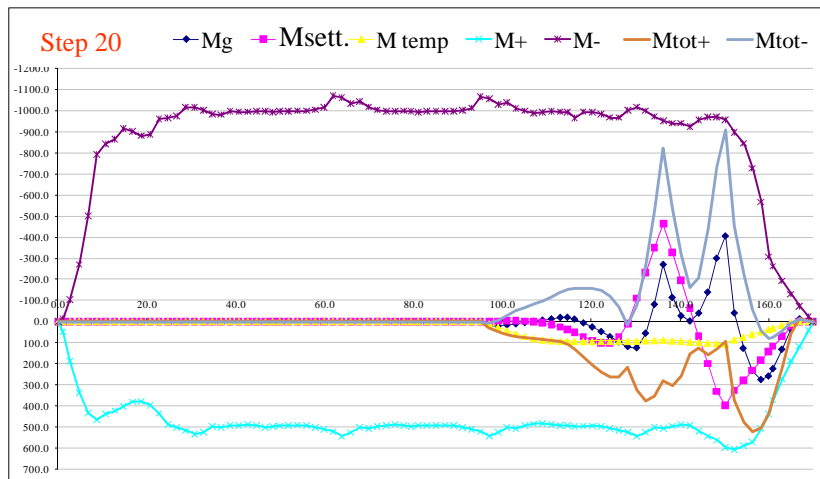
- ▲ Definitive restraint
- ▲ Temporary restraint

- Actions:
 - Self weight
 - Temperature variation between intrados and extrados of $\pm 5^\circ$
 - Maximum differential settlement between two consecutive bearings of 5 mm

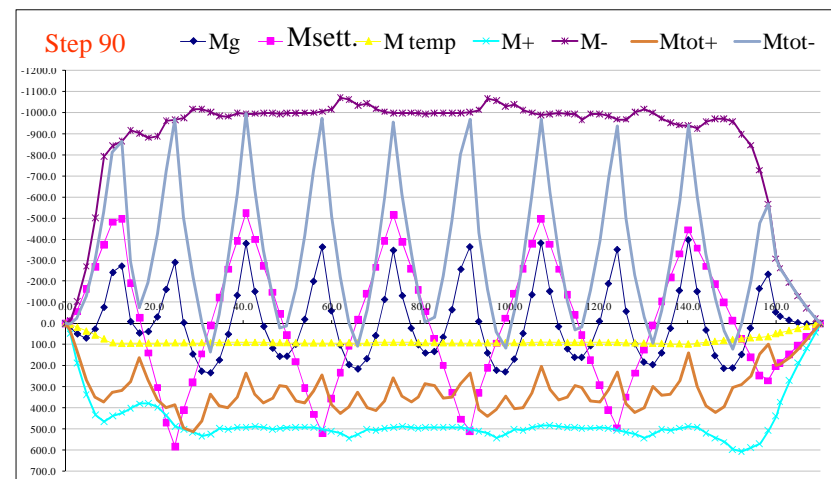
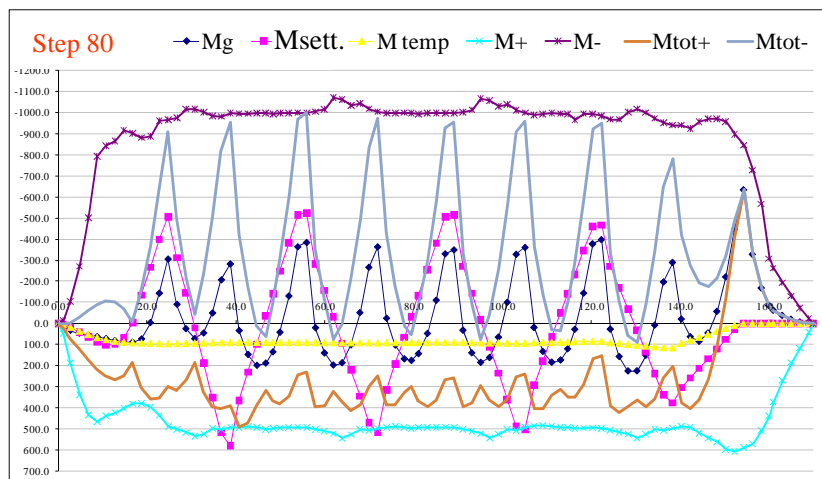
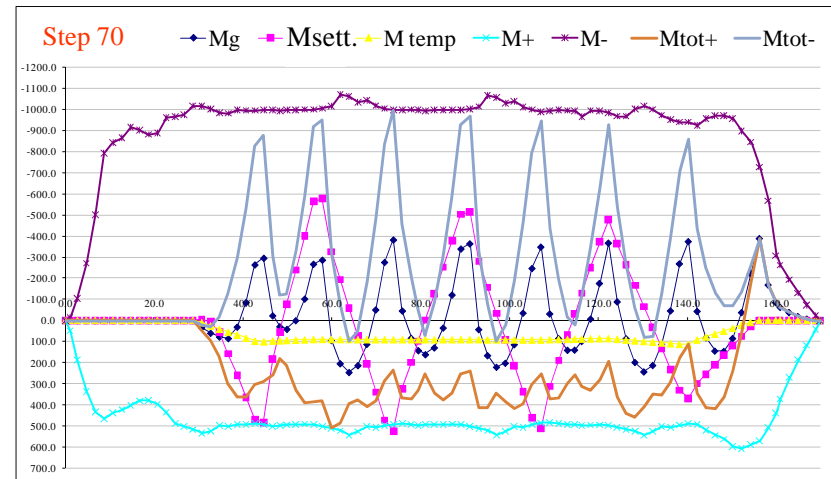
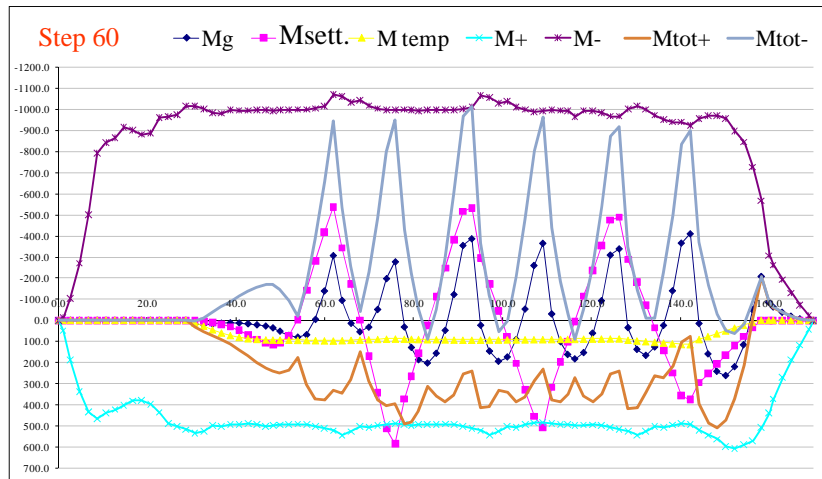
Bending moment at end of launching (values in $\text{kN} \cdot 10 \cdot \text{m}$)



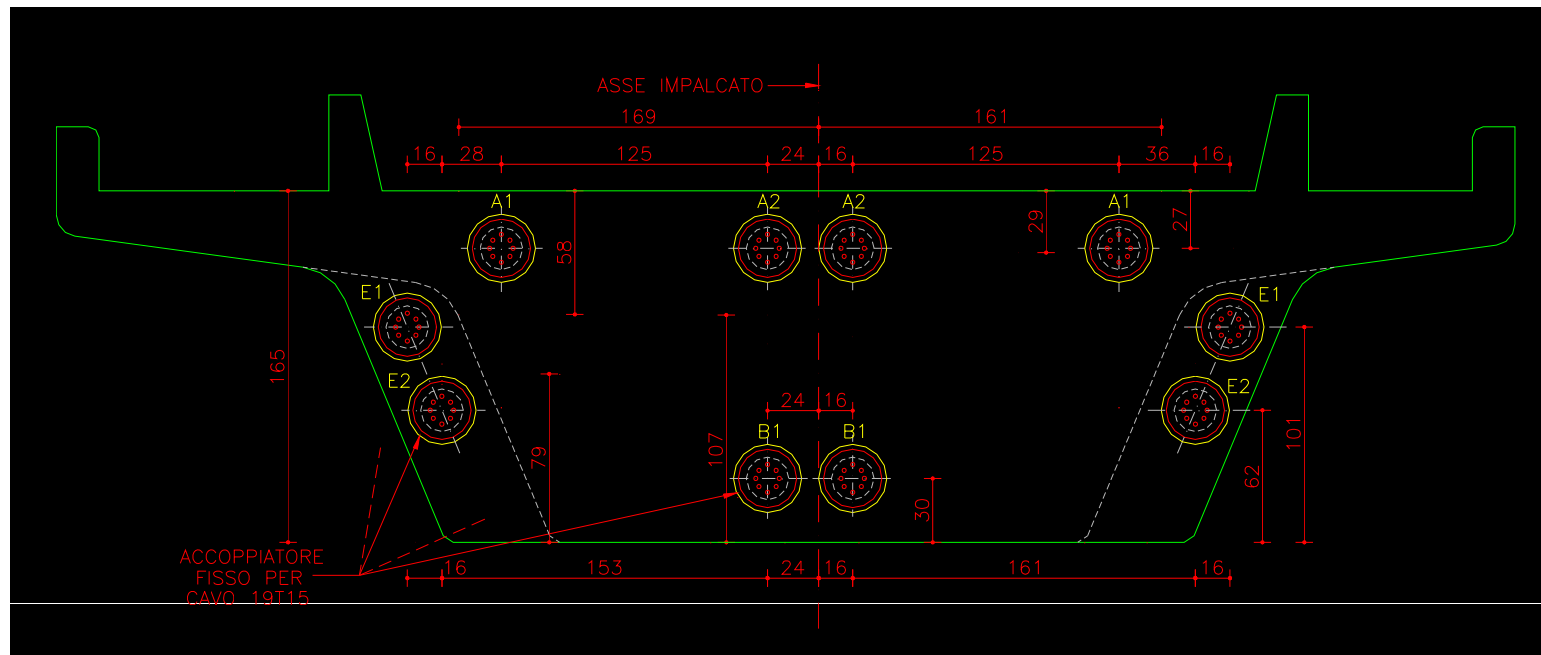
Bending moment during launching



Bending moment during launching



As the bending moments are almost constant in all the sections and the positive values are only half of the negative ones baricentric prestressing is introduced for the launching phases.



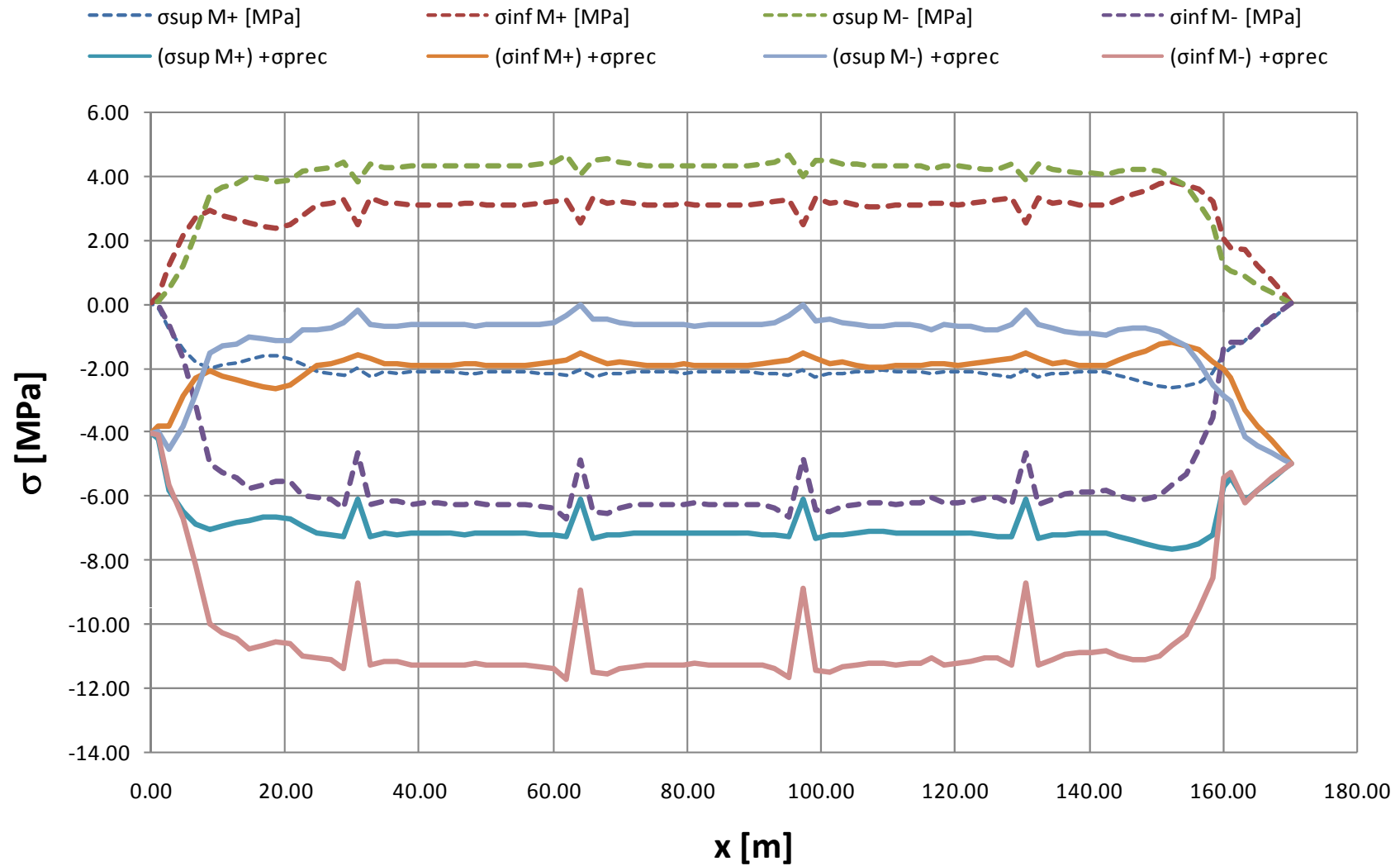
Enlarged section

A	$W_{sx,sup}$	$W_{dx,sup}$	$W_{sx,inf}$	$W_{dx,inf}$
[m ²]	[m ³]	[m ³]	[m ³]	[m ³]
7.897	-2.828	-2.631	2.171	2.237

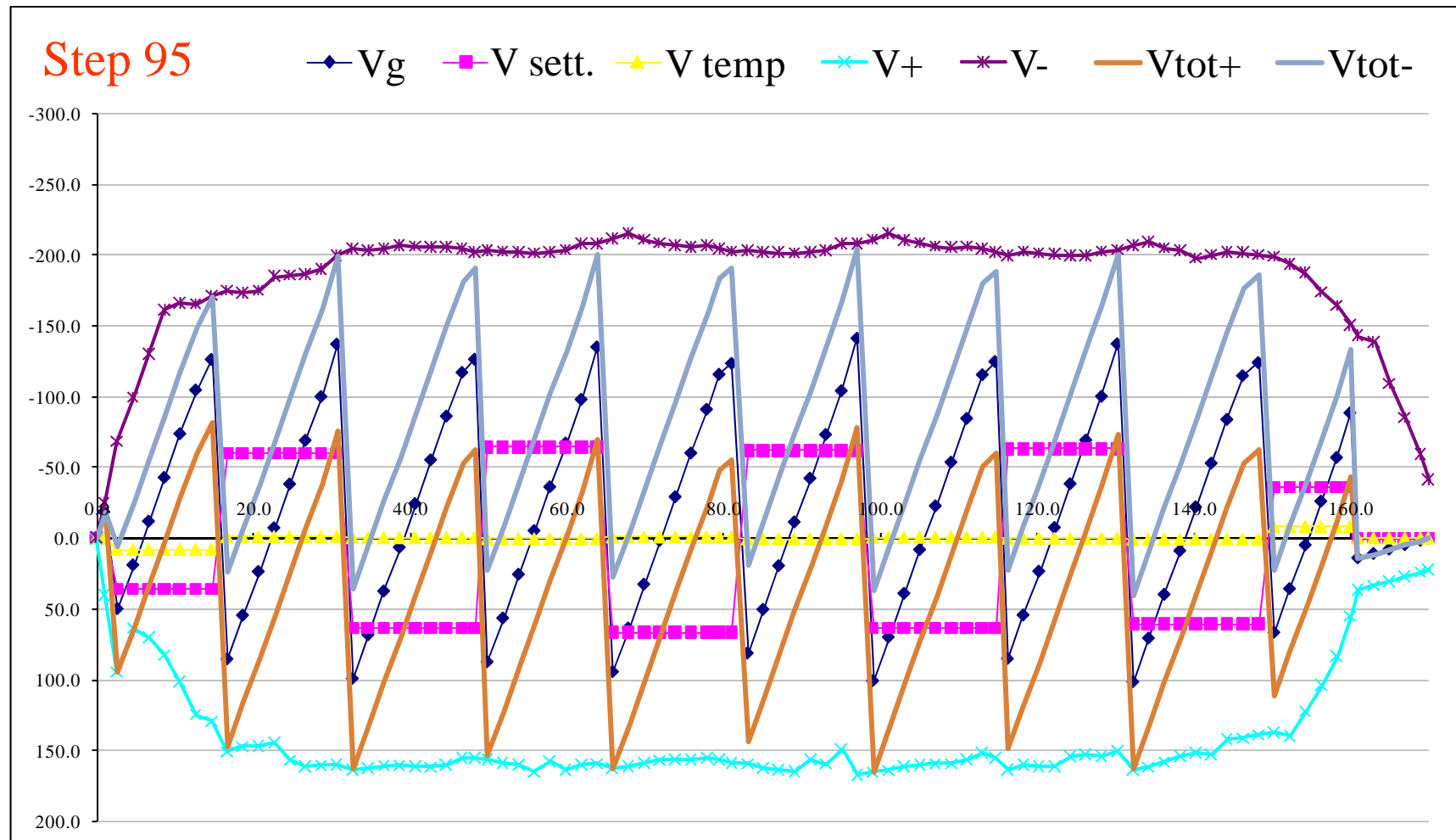
Current section

A	$W_{sx,sup}$	$W_{dx,sup}$	$W_{sx,inf}$	$W_{dx,inf}$
[m ²]	[m ³]	[m ³]	[m ³]	[m ³]
6.458	-2.498	-2.290	1.590	1.629

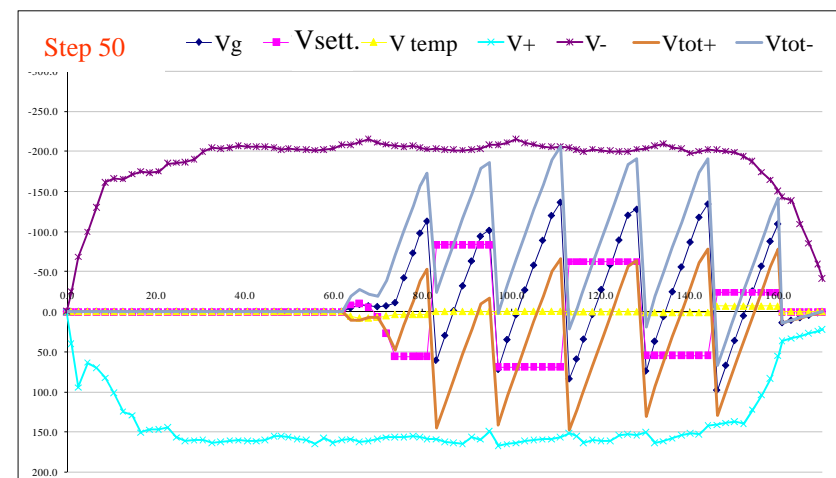
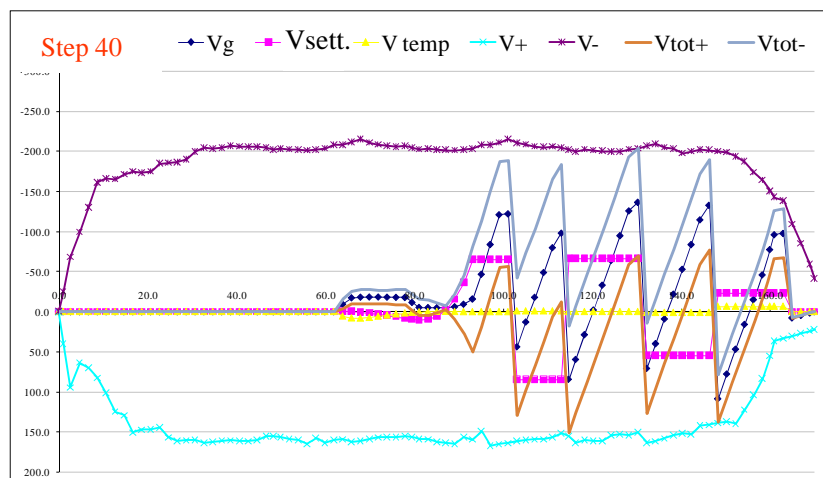
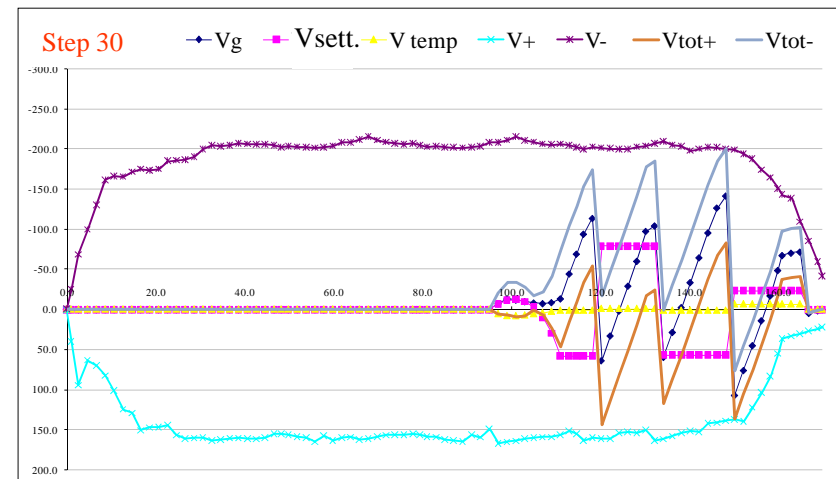
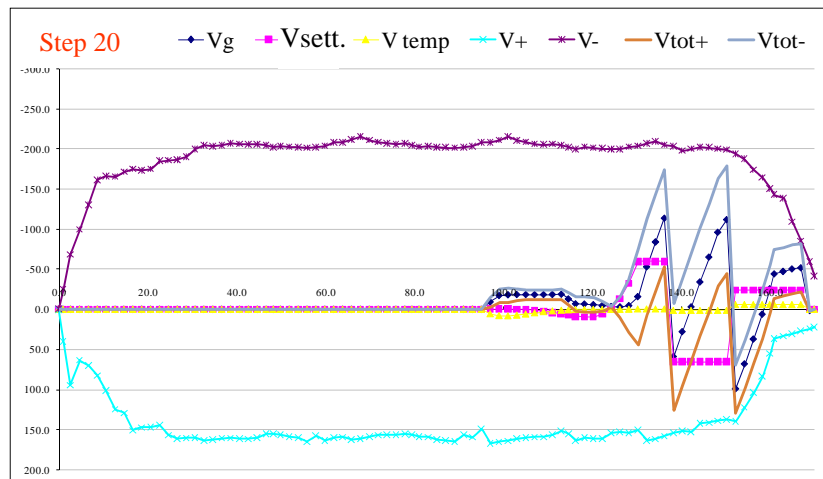
Longitudinal stresses during launching



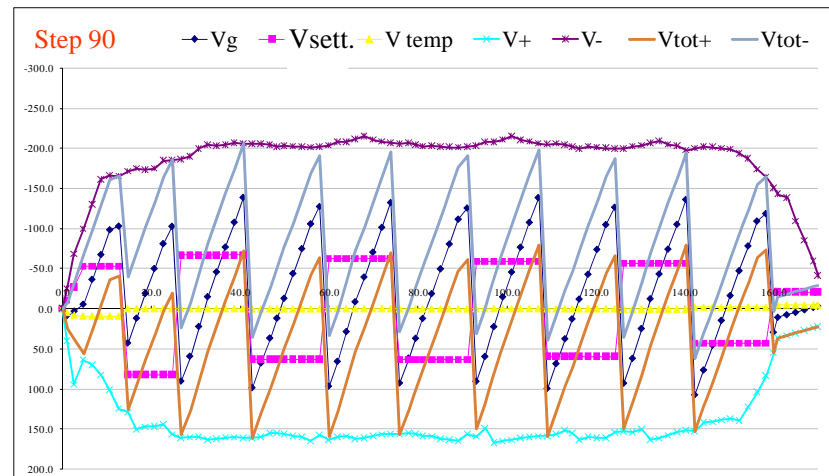
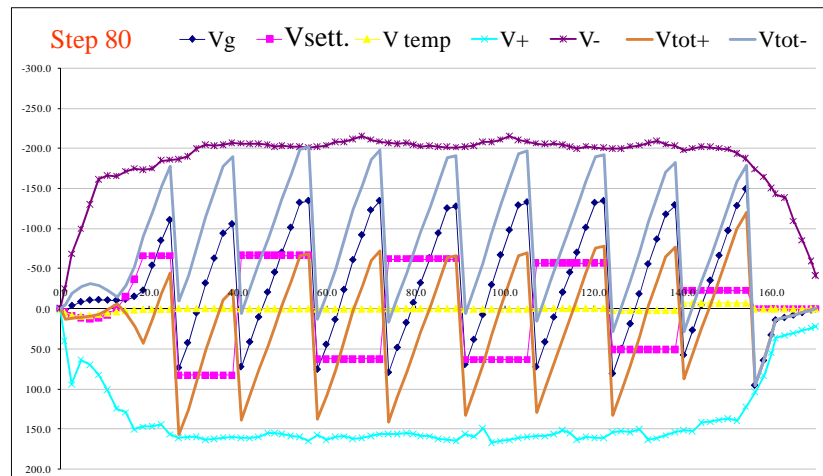
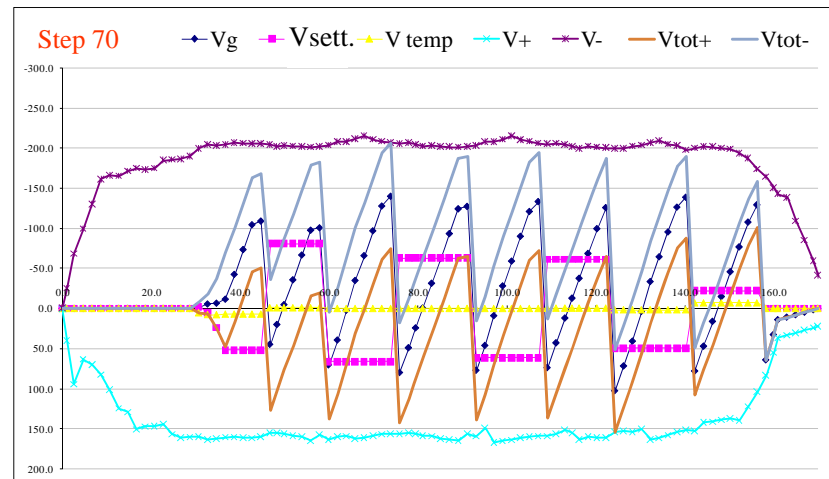
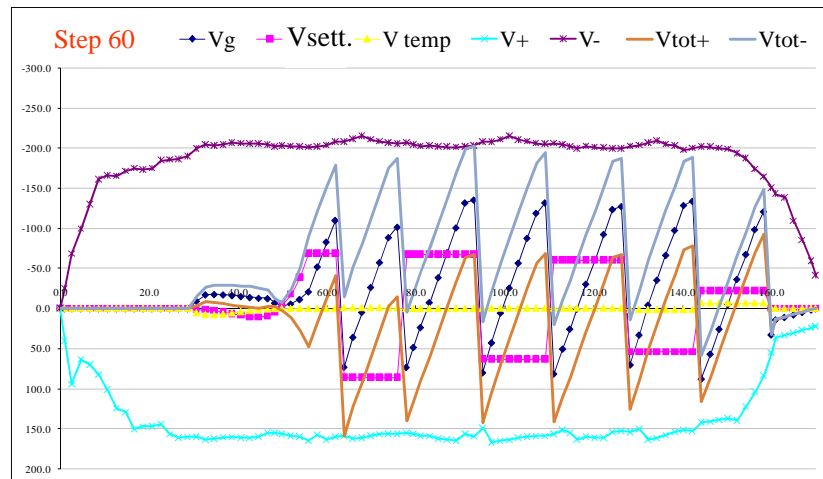
Shear at end of launching (values in $\text{kN} \cdot 10 \cdot \text{m}$)



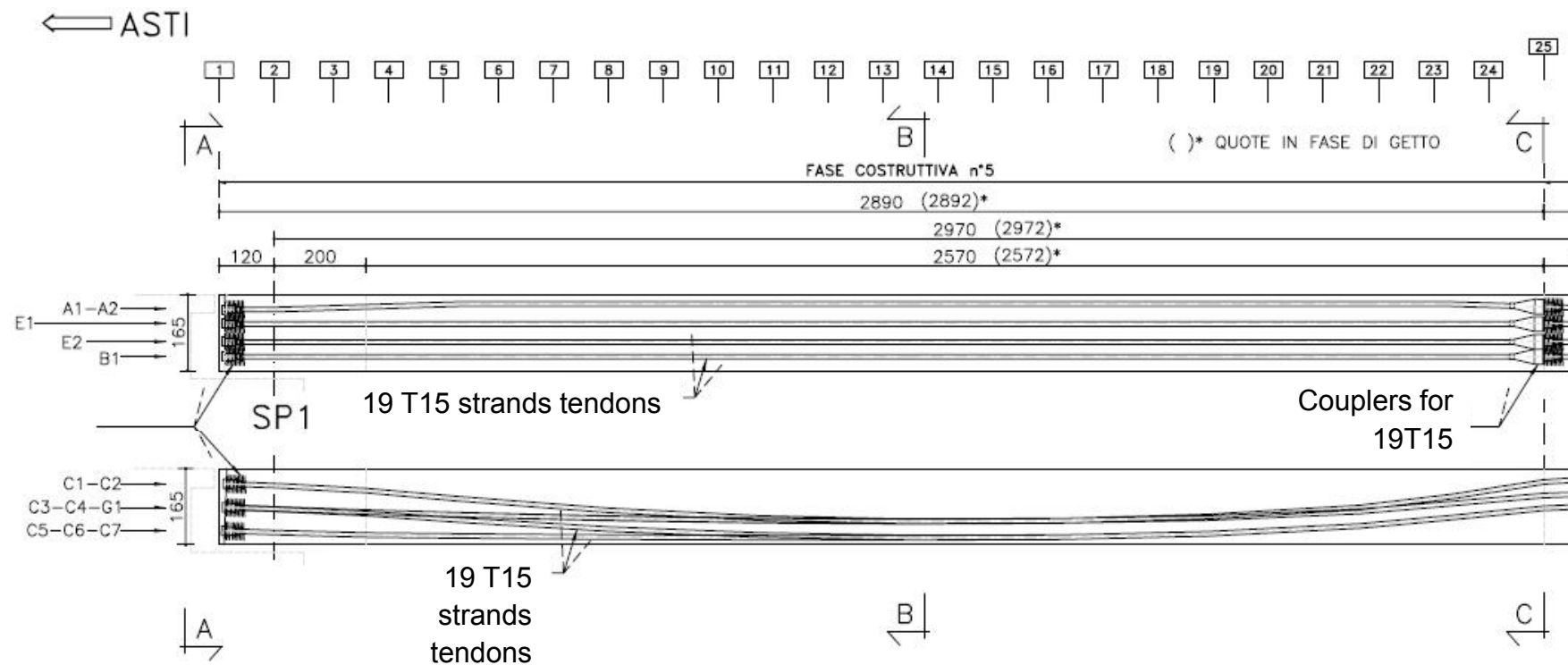
Shear during launching



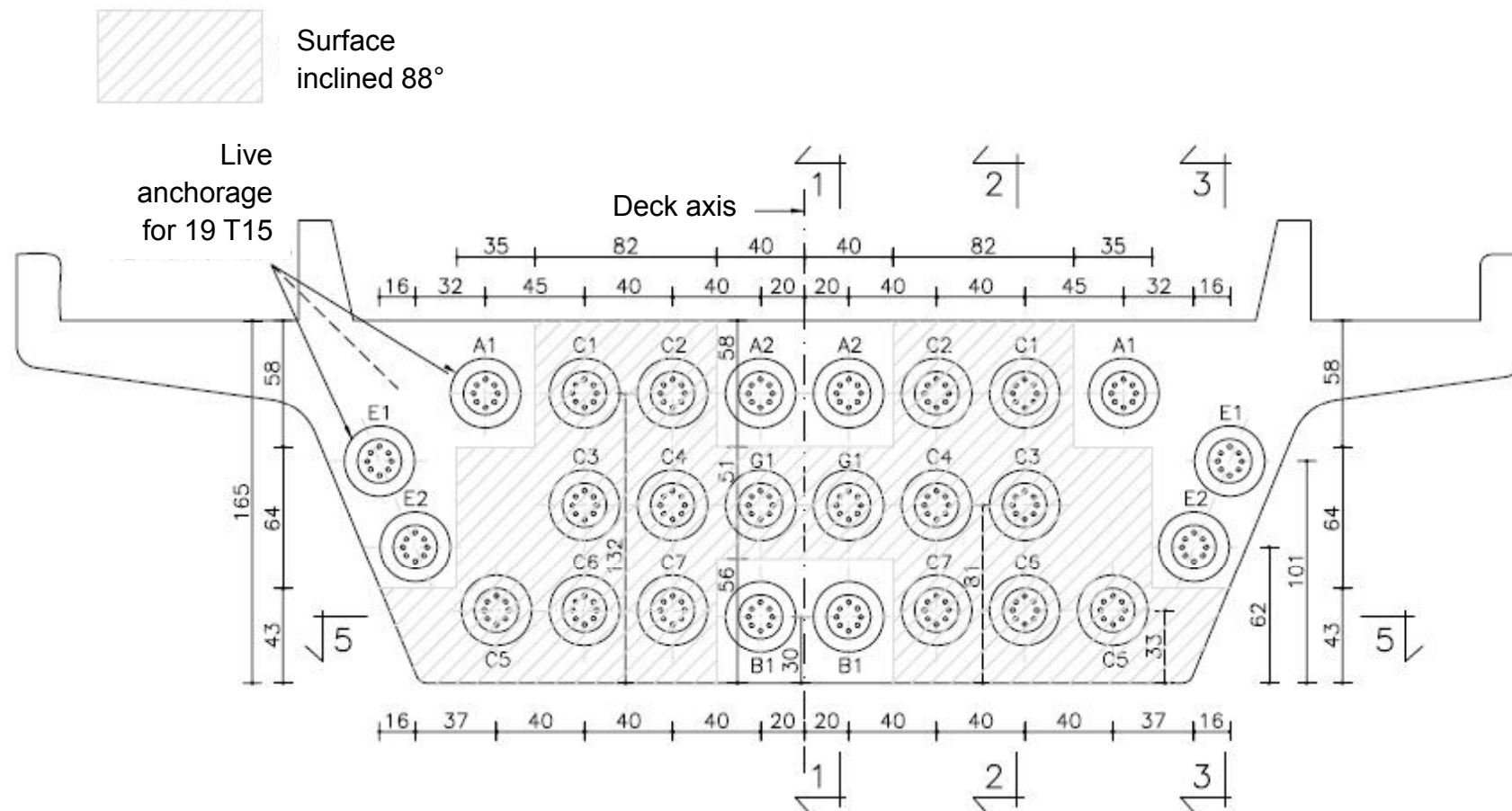
Shear during launching



Prestressing layout – 1st span

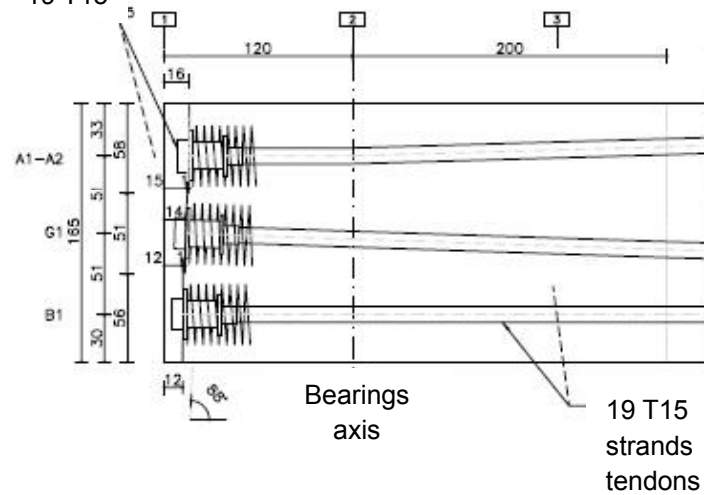


Prestressing layout – section AA



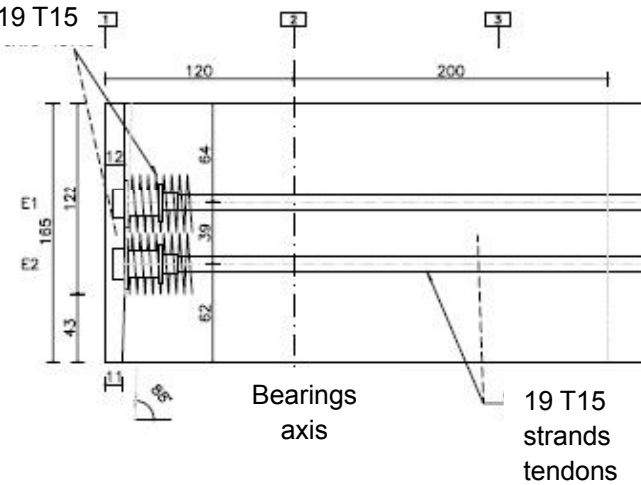
Live
anchorage for
19 T15

section 11



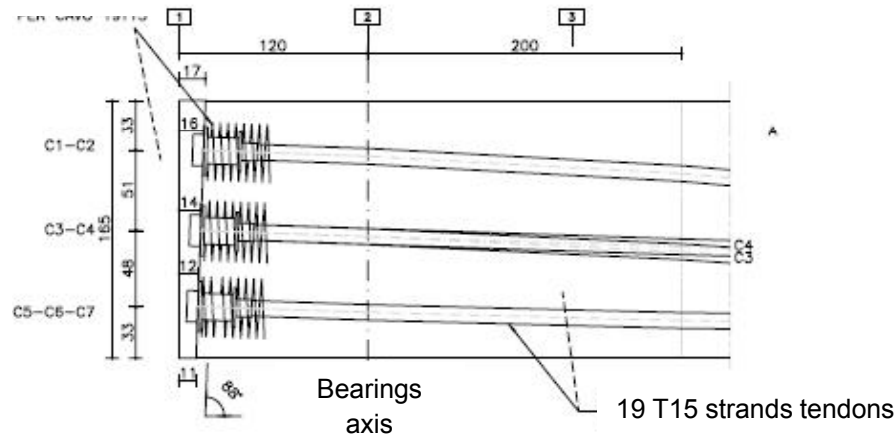
Live
anchorage for
19 T15

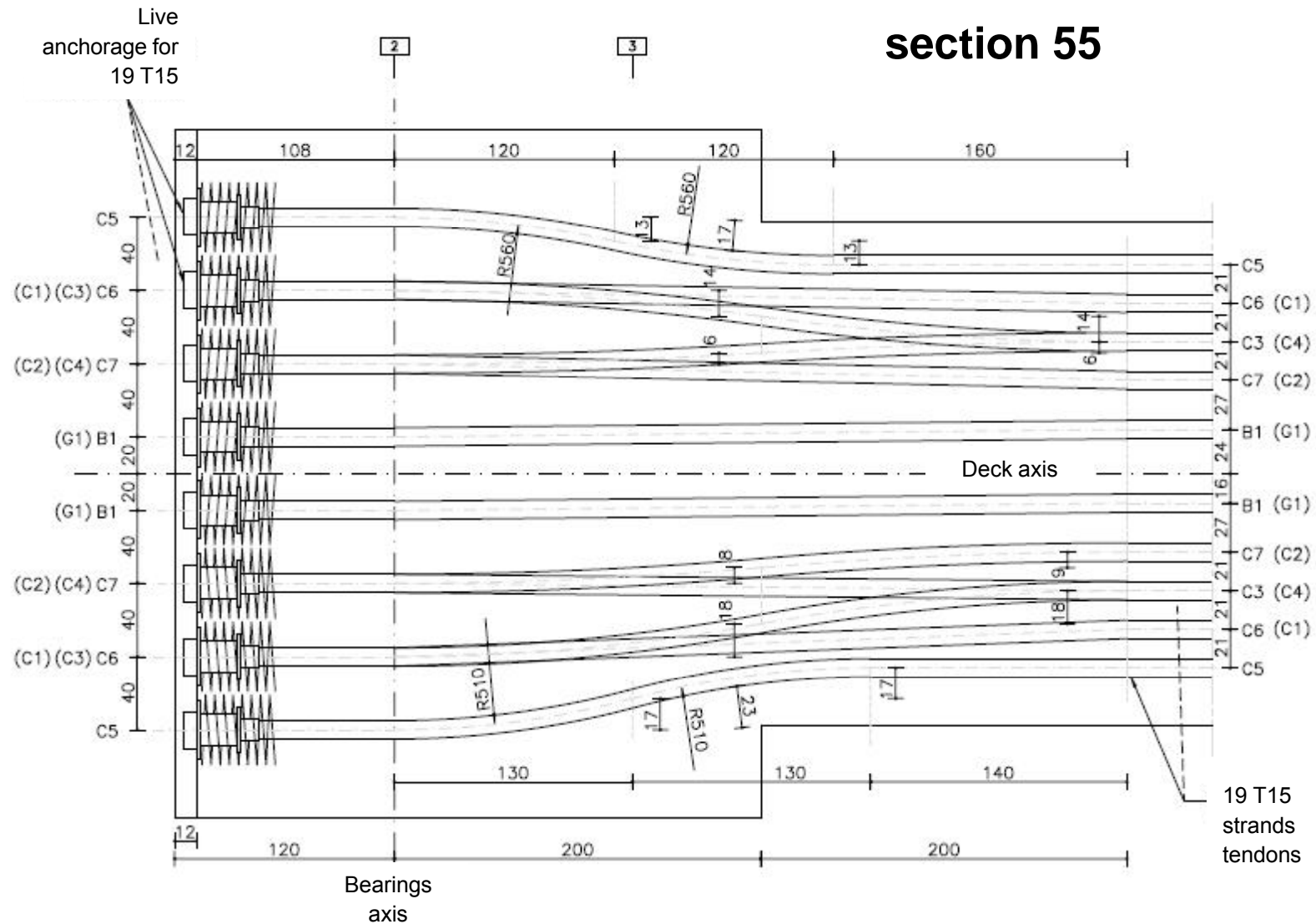
section 33



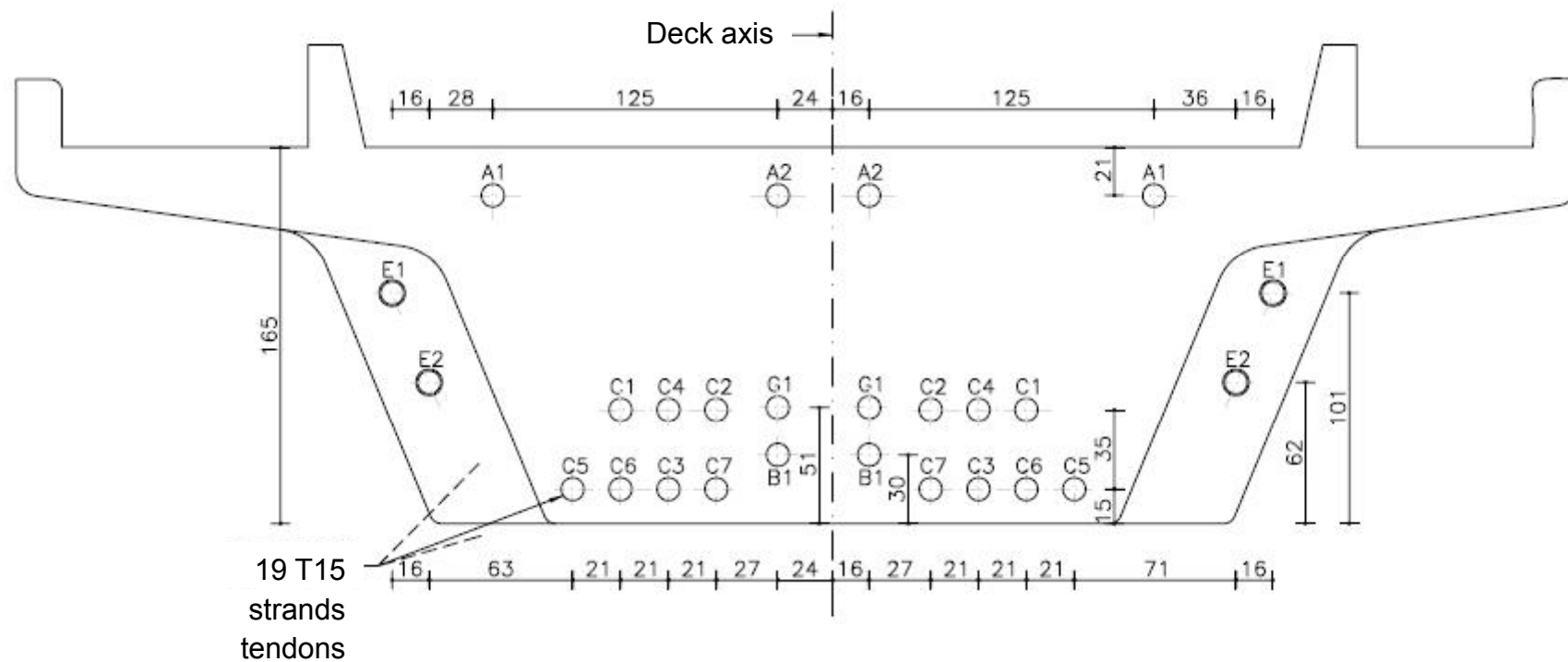
Live
anchorage for
19 T15

section 22

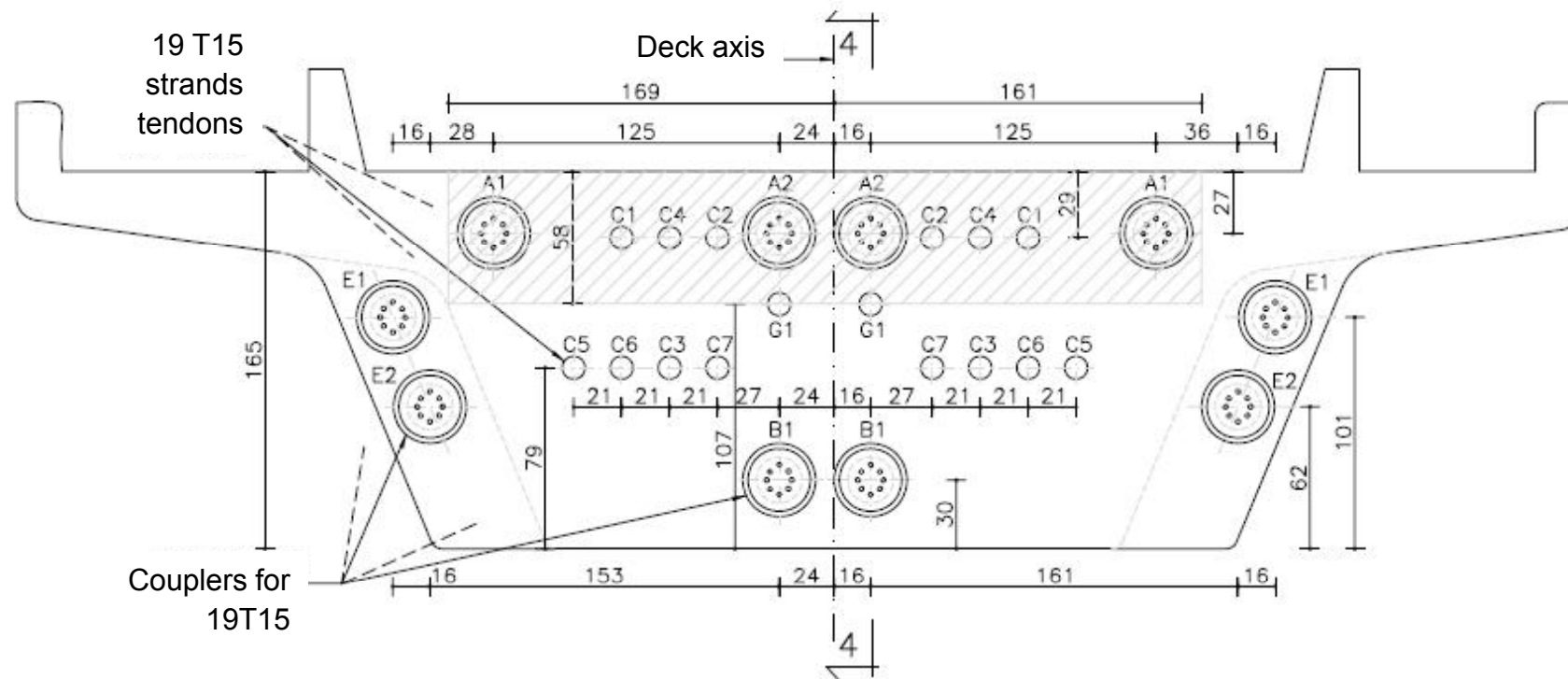




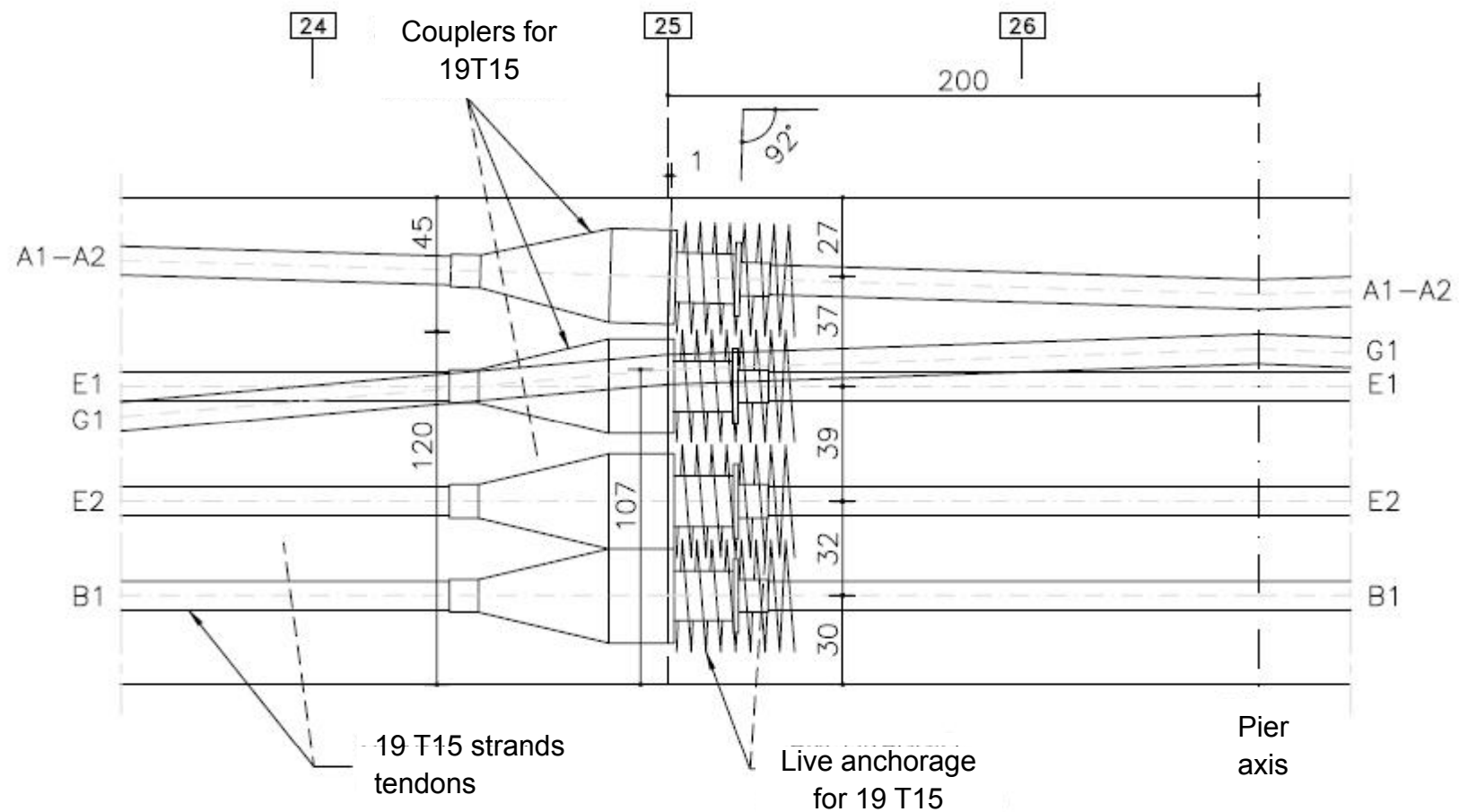
Prestressing layout – section BB



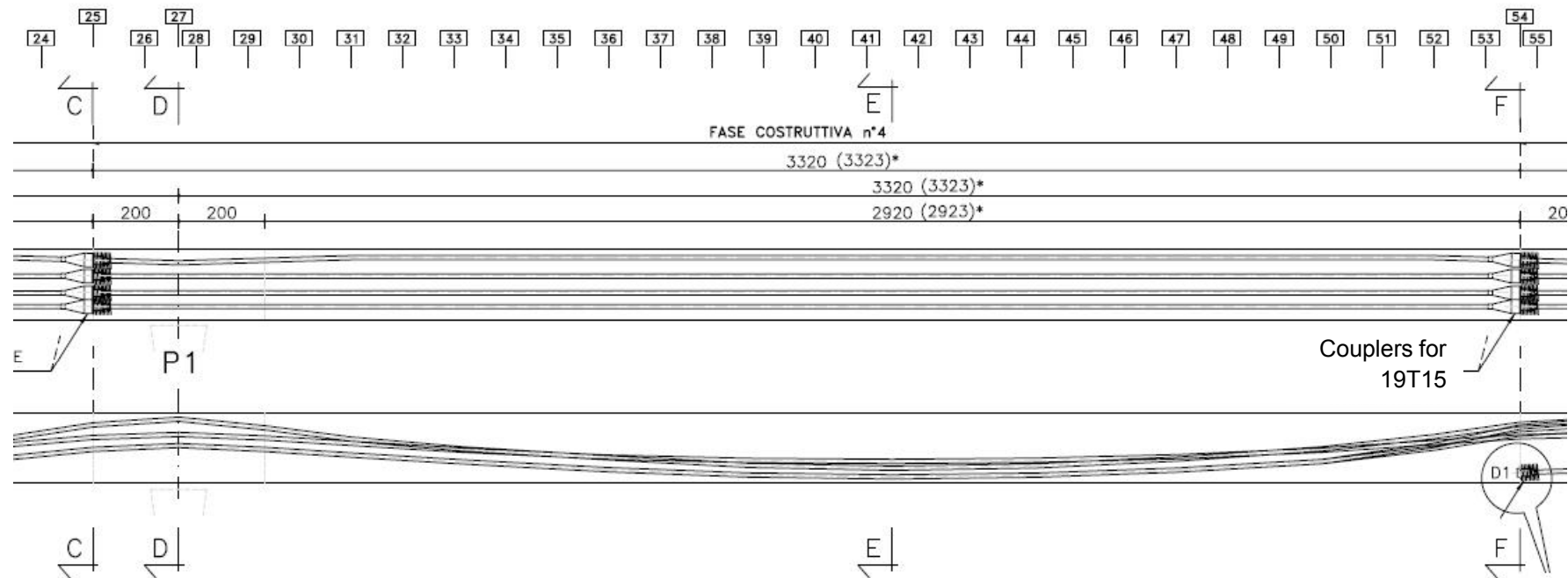
Prestressing layout – section CC



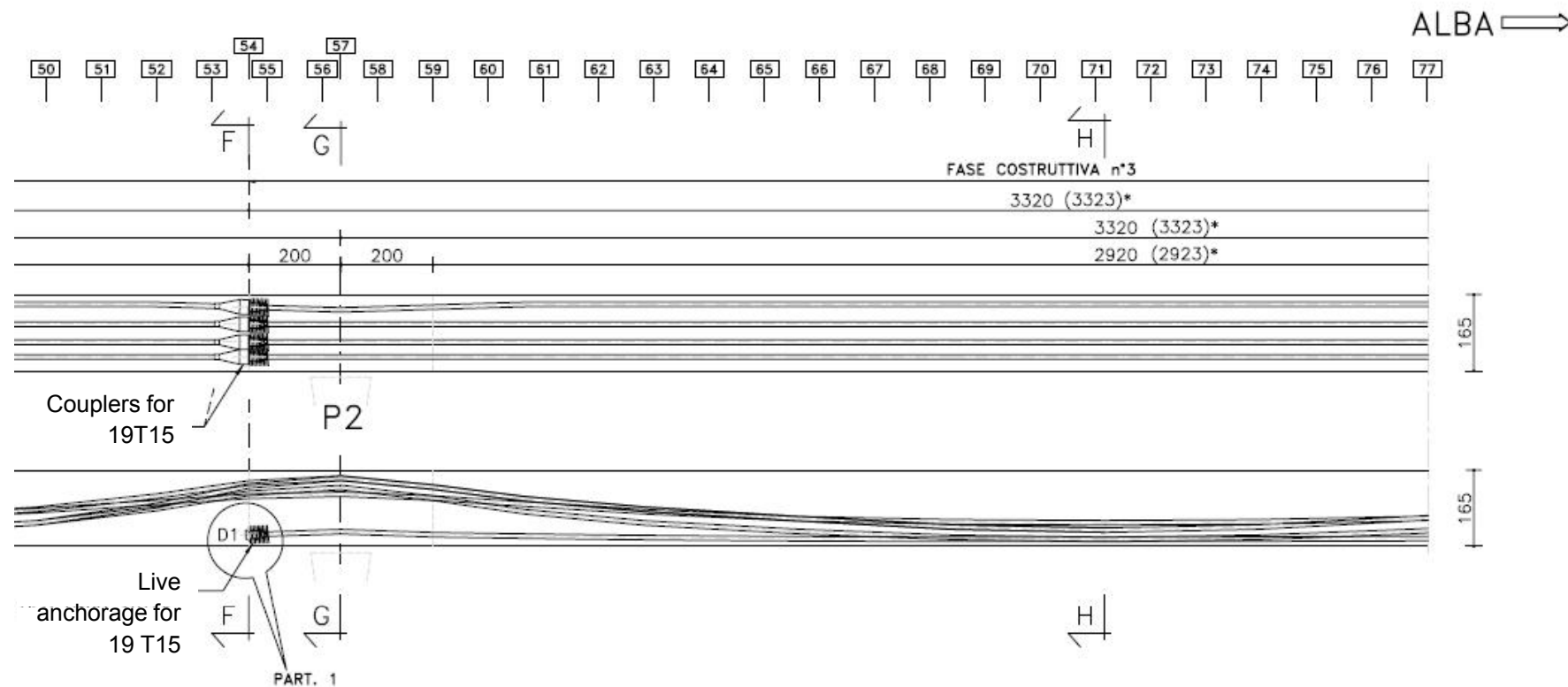
section 44



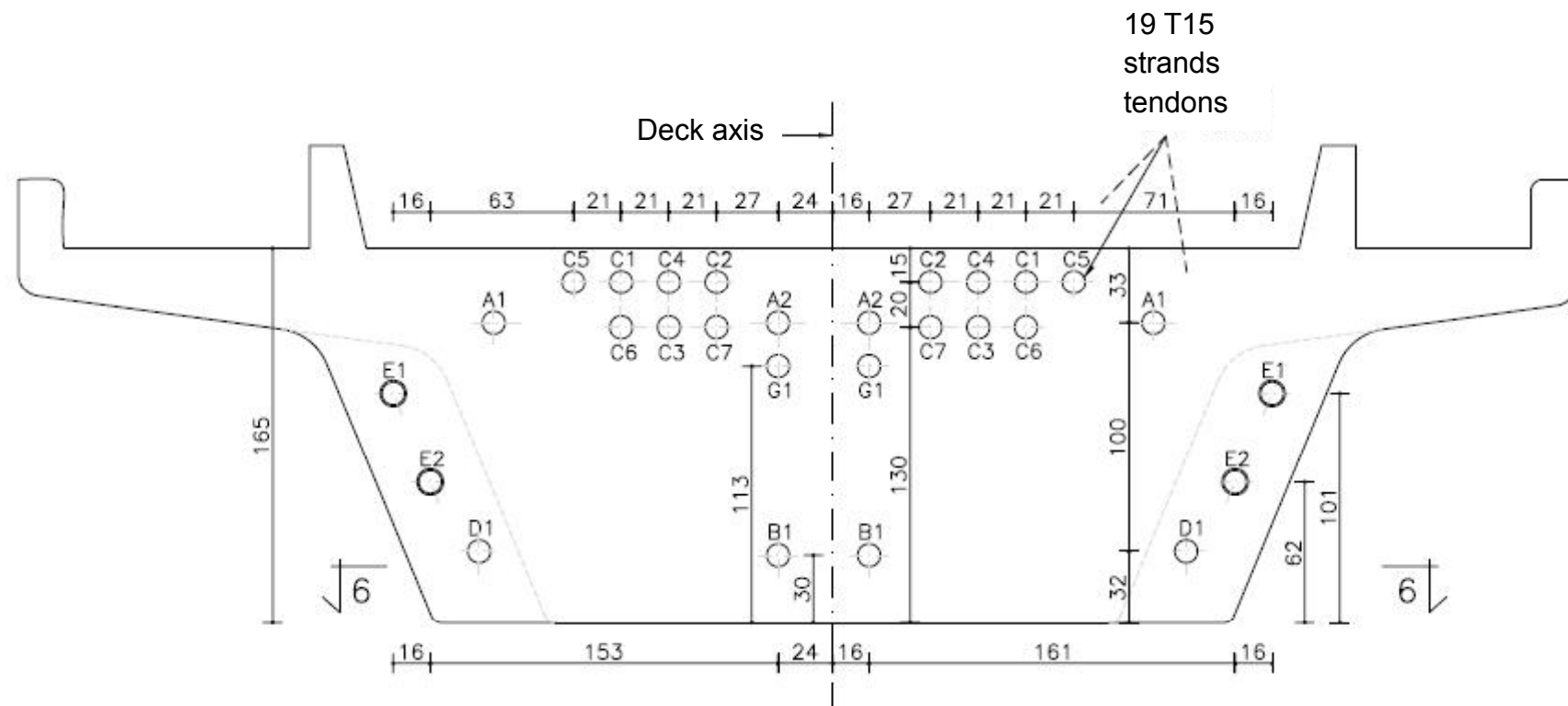
Prestressing layout – 2nd span



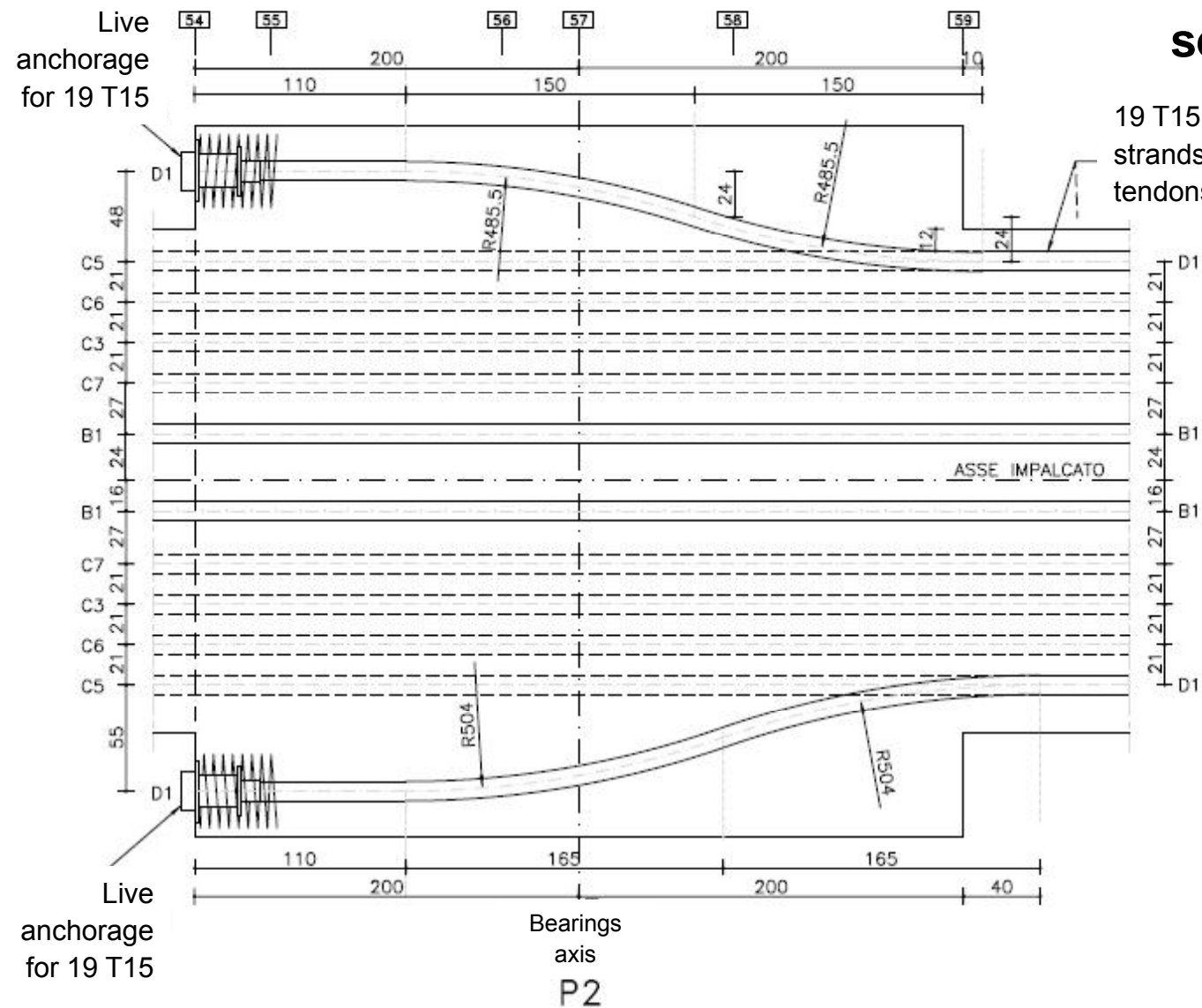
Prestressing layout – 3rd span



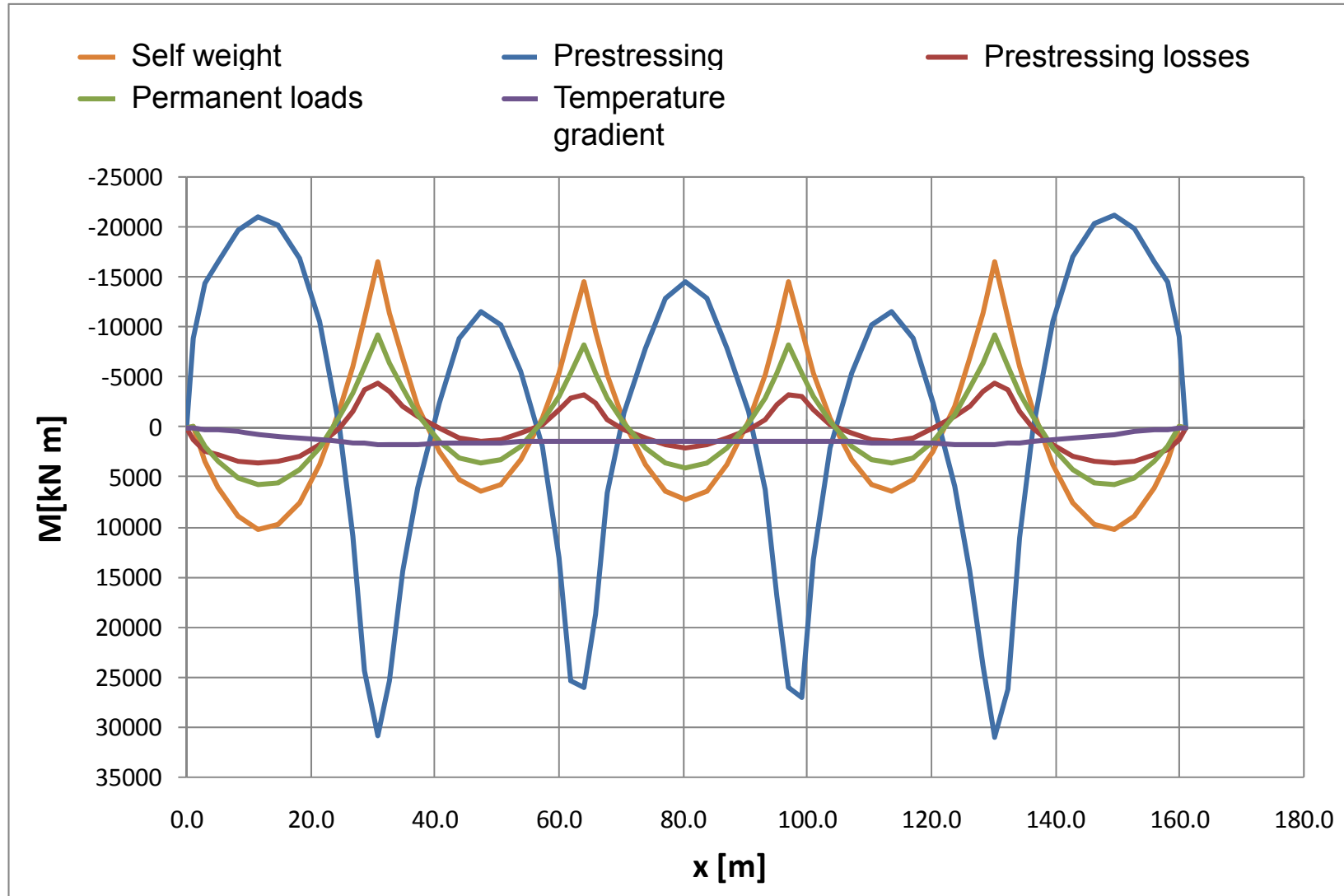
Prestressing layout – section GG



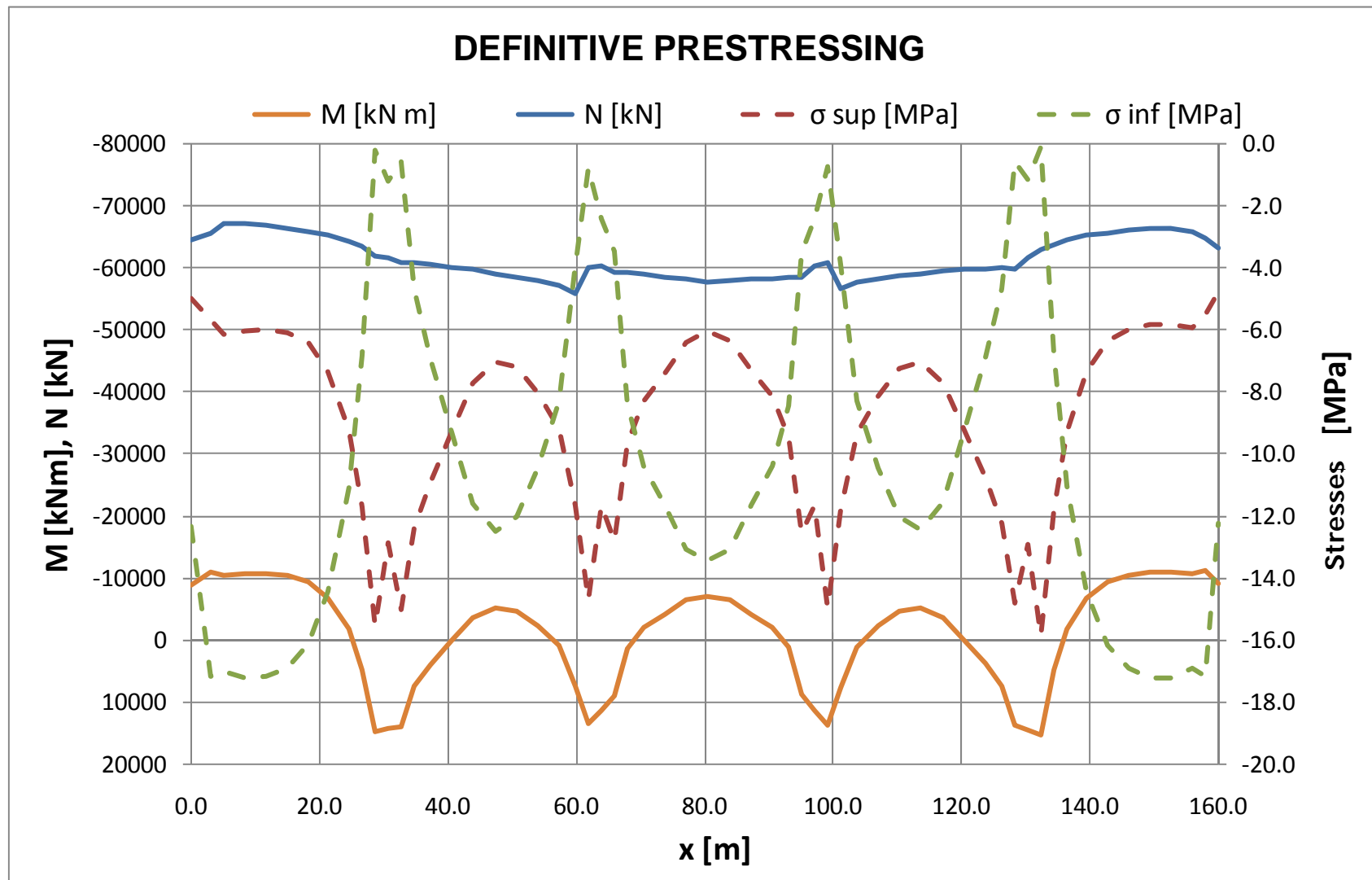
19 T15
strands
tendons



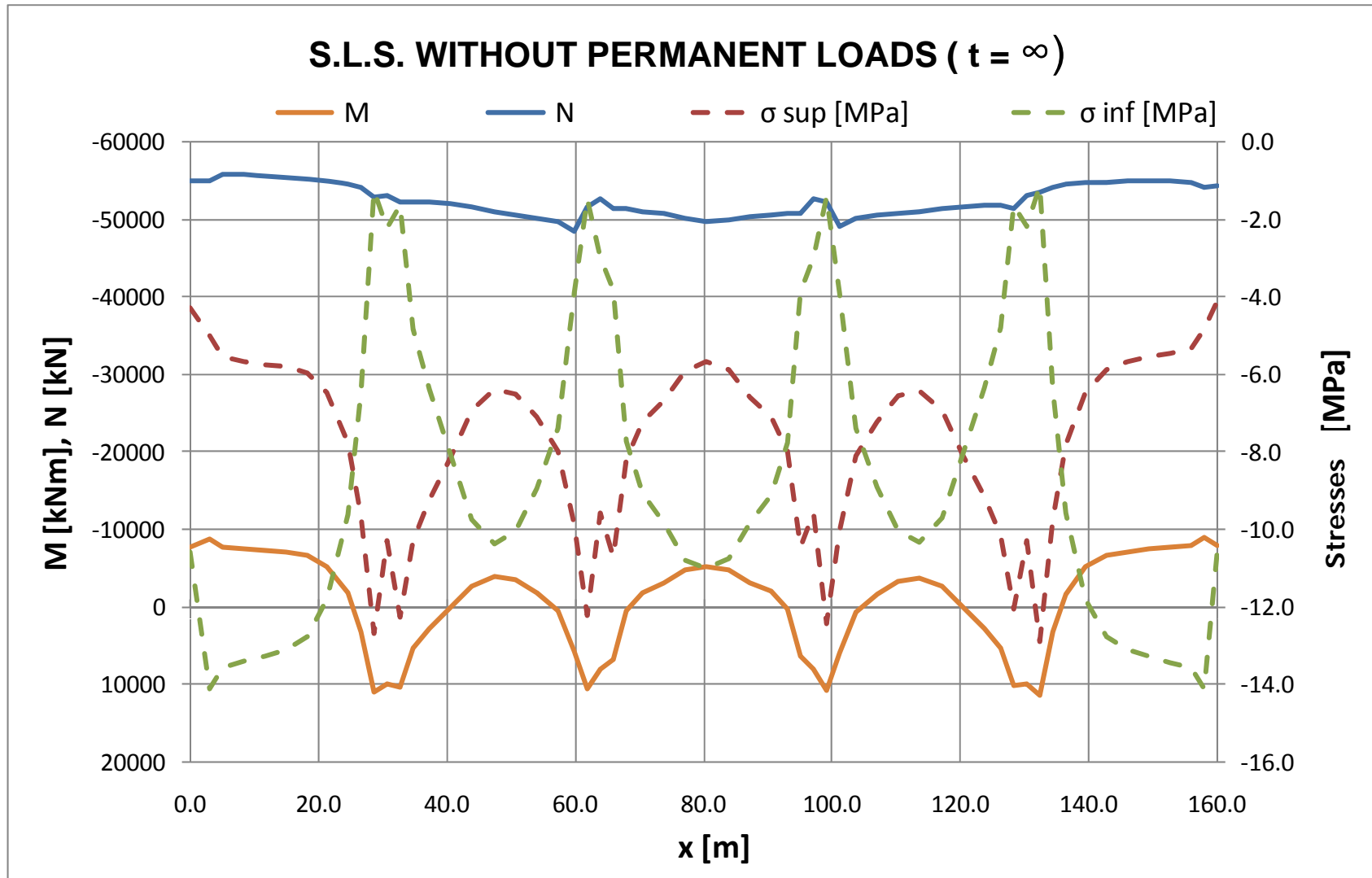
Bending moment



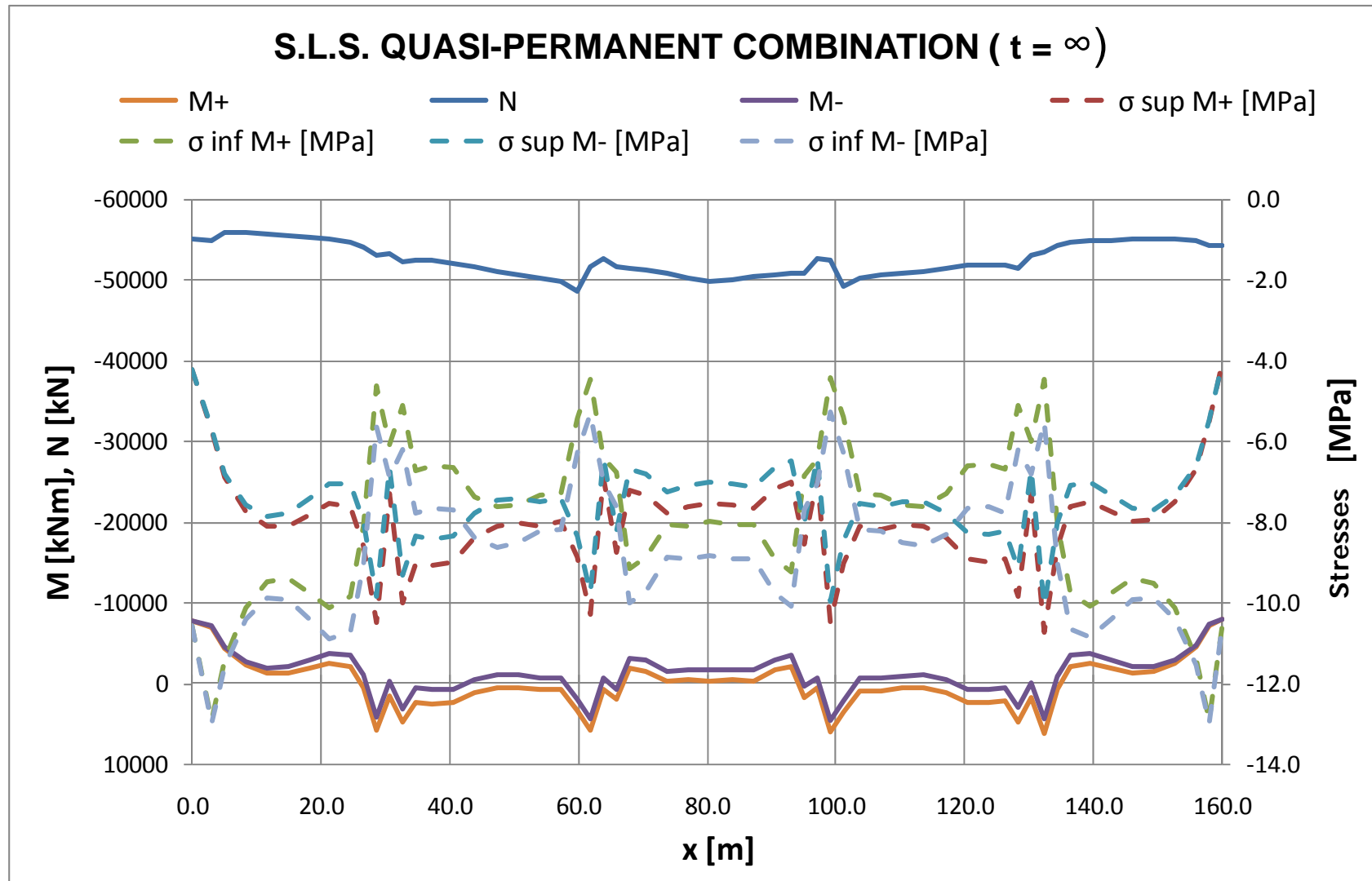
Internal actions (M,N) and relative stresses



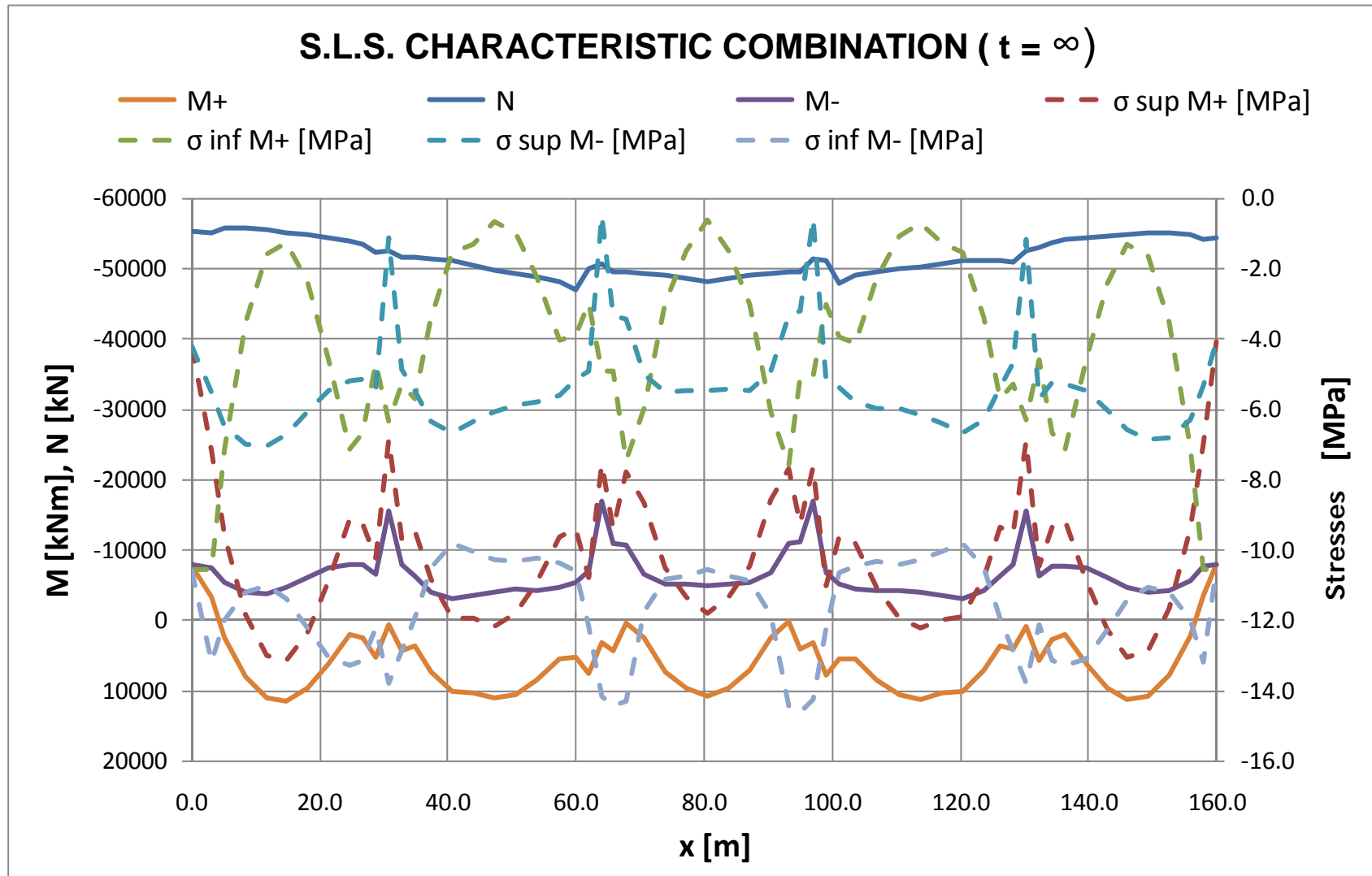
Internal actions (M,N) and relative stresses



Internal actions (M,N) and relative stresses



Internal actions (M,N) and relative stresses



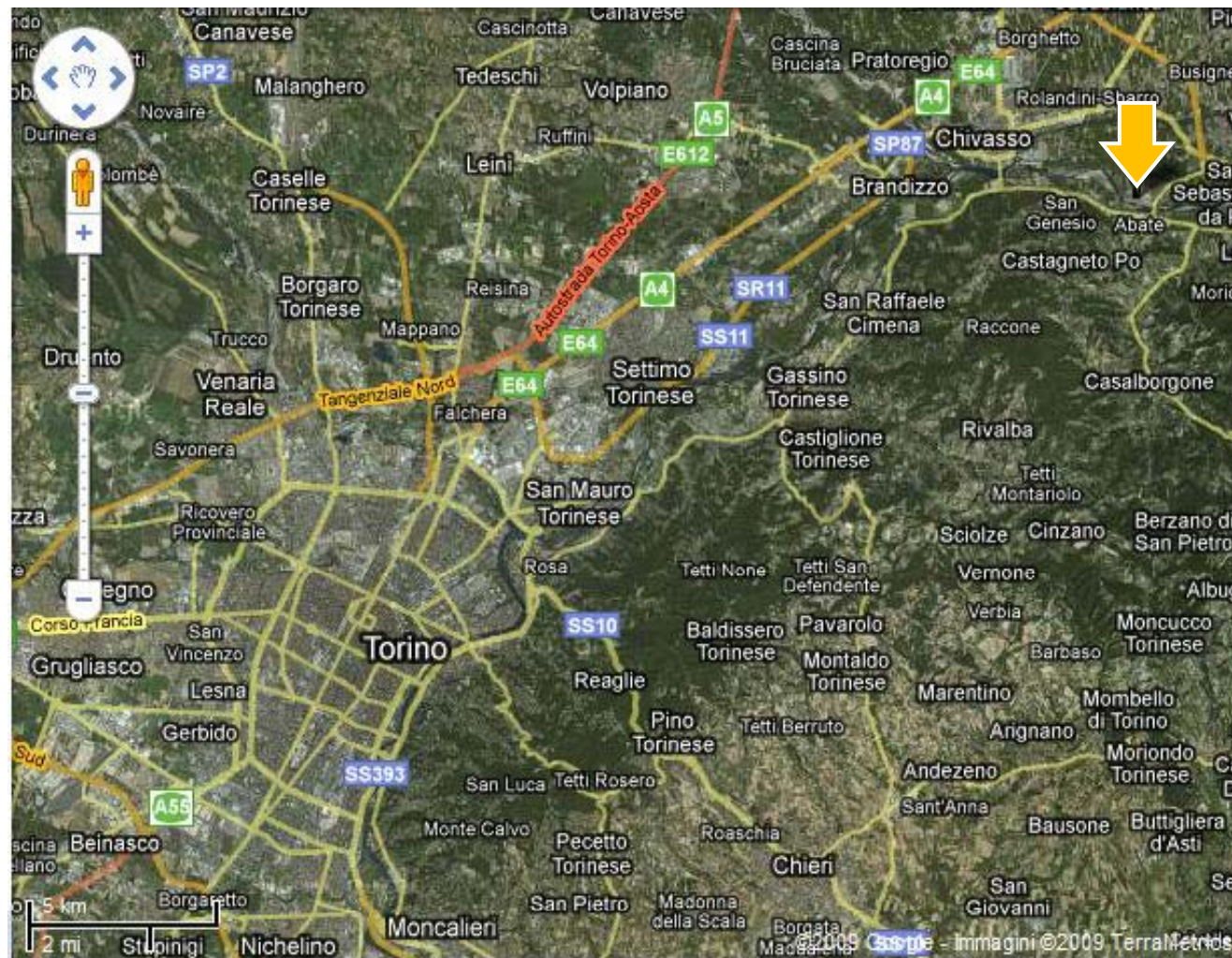
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Precast continuous beam

VEROLENGO BRIDGE

Geographical positioning





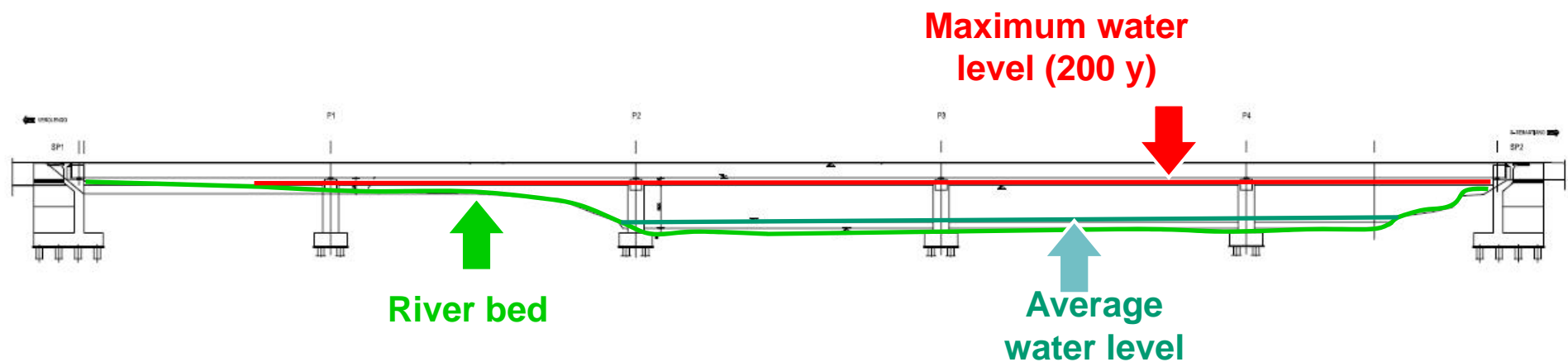
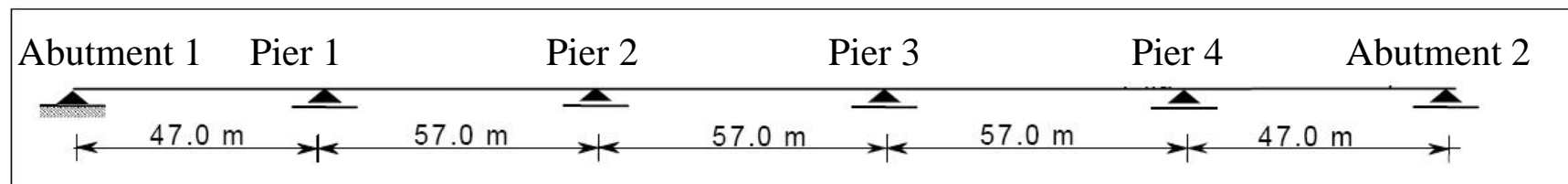


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General overview

Static scheme

General dimensions

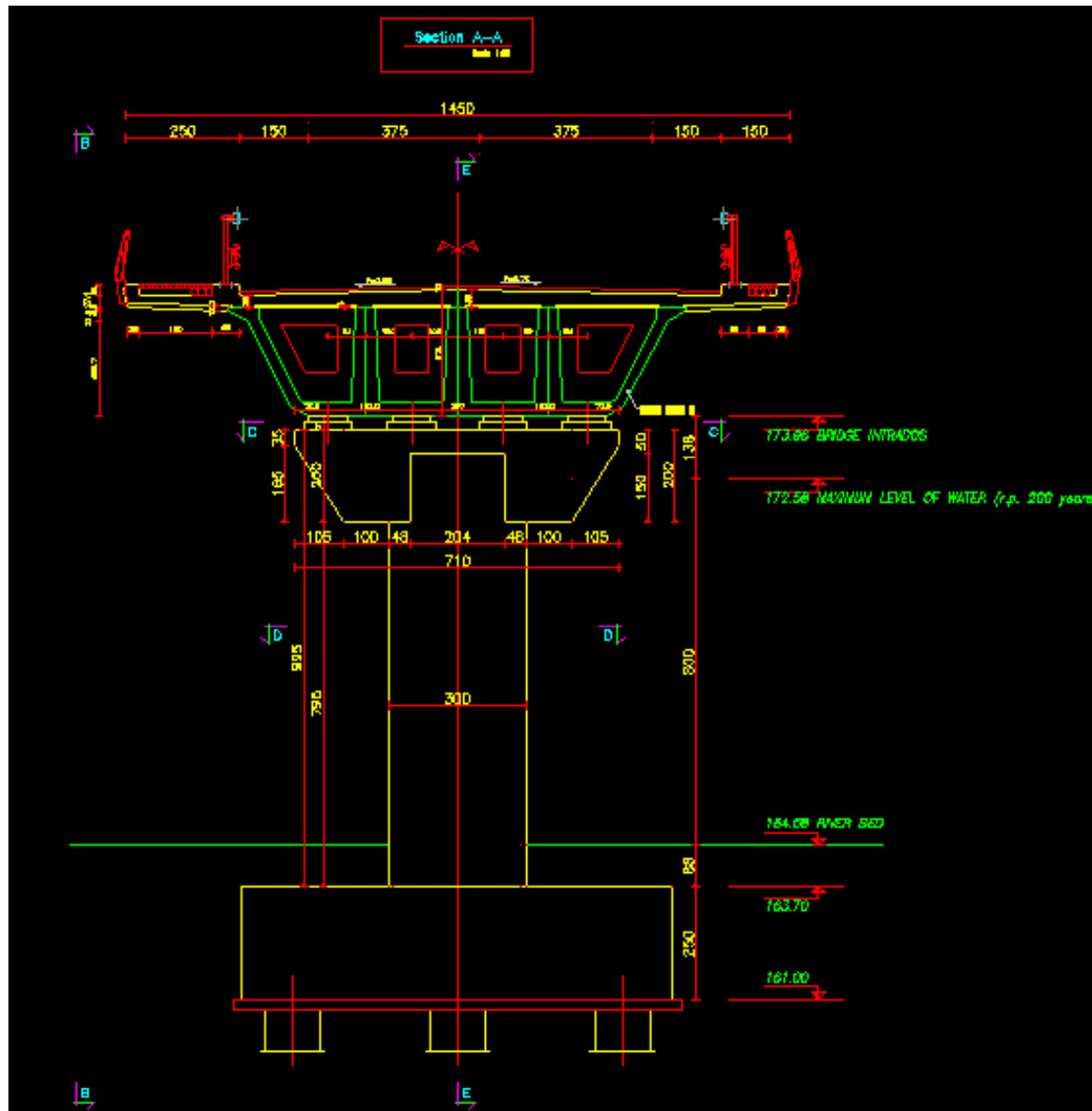


Static scheme: Bearings

	SP1	P1	P2	P3	P4	SP2
M		 M	 M	 M	 M	 M
F		 UL	 UL	 UL	 UL	 UL
UT		 M	 M	 M	 M	 M
M		 M	 M	 M	 M	 M

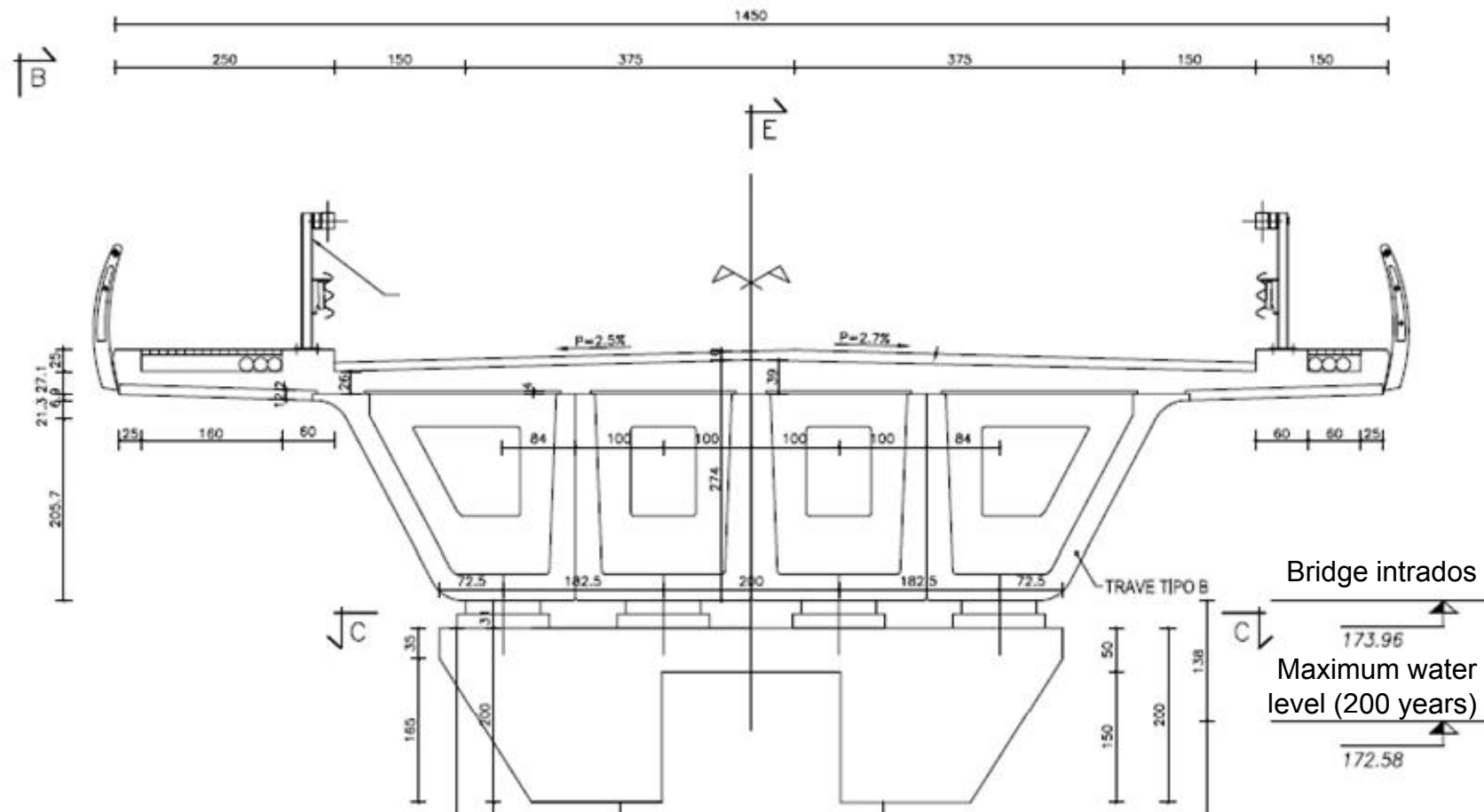
- M free in both directions
- UL fixed in transverse direction
- UT fixed in longitudinal direction
- F fixed in both directions

Rubber expansion joints with
350 mm excursion

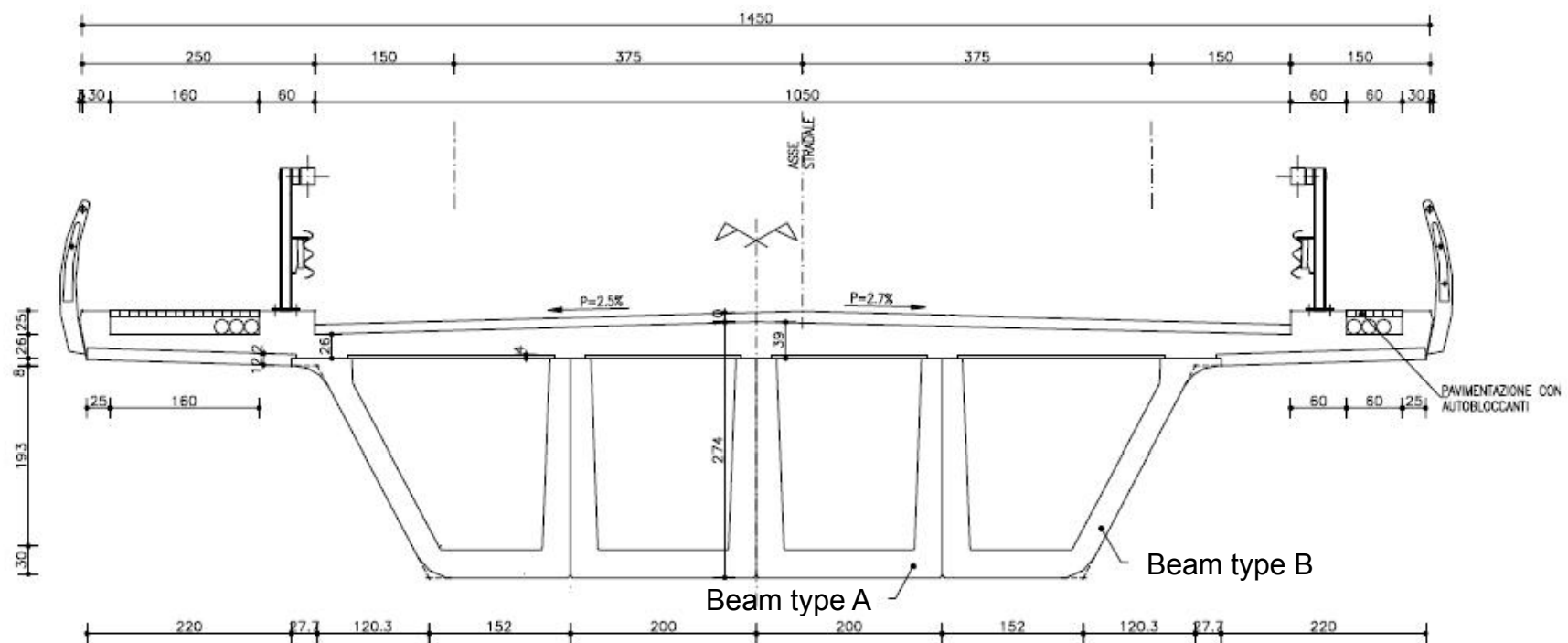


Typical cross
section on a
pier

Deck and upper part of the pier



Deck cross section



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Pictures taken during construction

Reinforcement cage of abutment n°1



Pier n°1 and old pier



Old and new piers within the river bed



Positioning of the beams on temporary piers



Beams on temporary piers



Inflection of 1st span after the removal of its 2 temporary piers



External tendons within the beams



Cast in situ transverse beam just before concreting



Anchorage of transverse beams prestressing



Reinforcement of deck slab before concreting



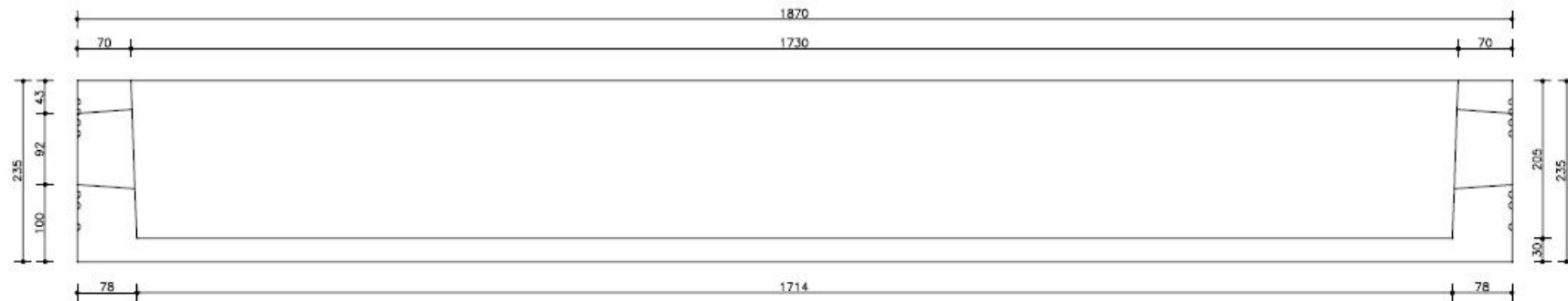
Completed bridge



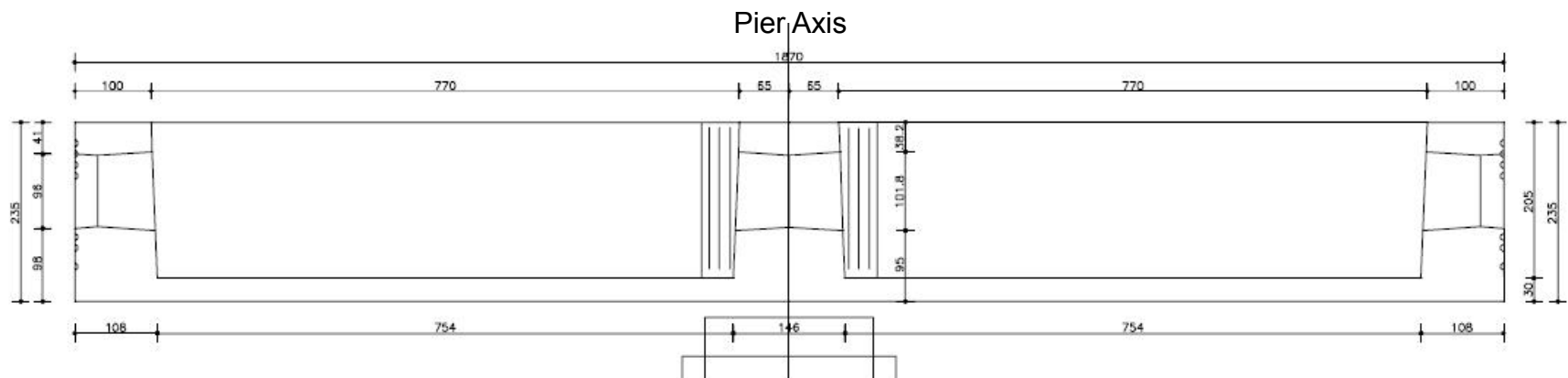
VEROLENGO BRIDGE

Beams geometry and prestressing layout

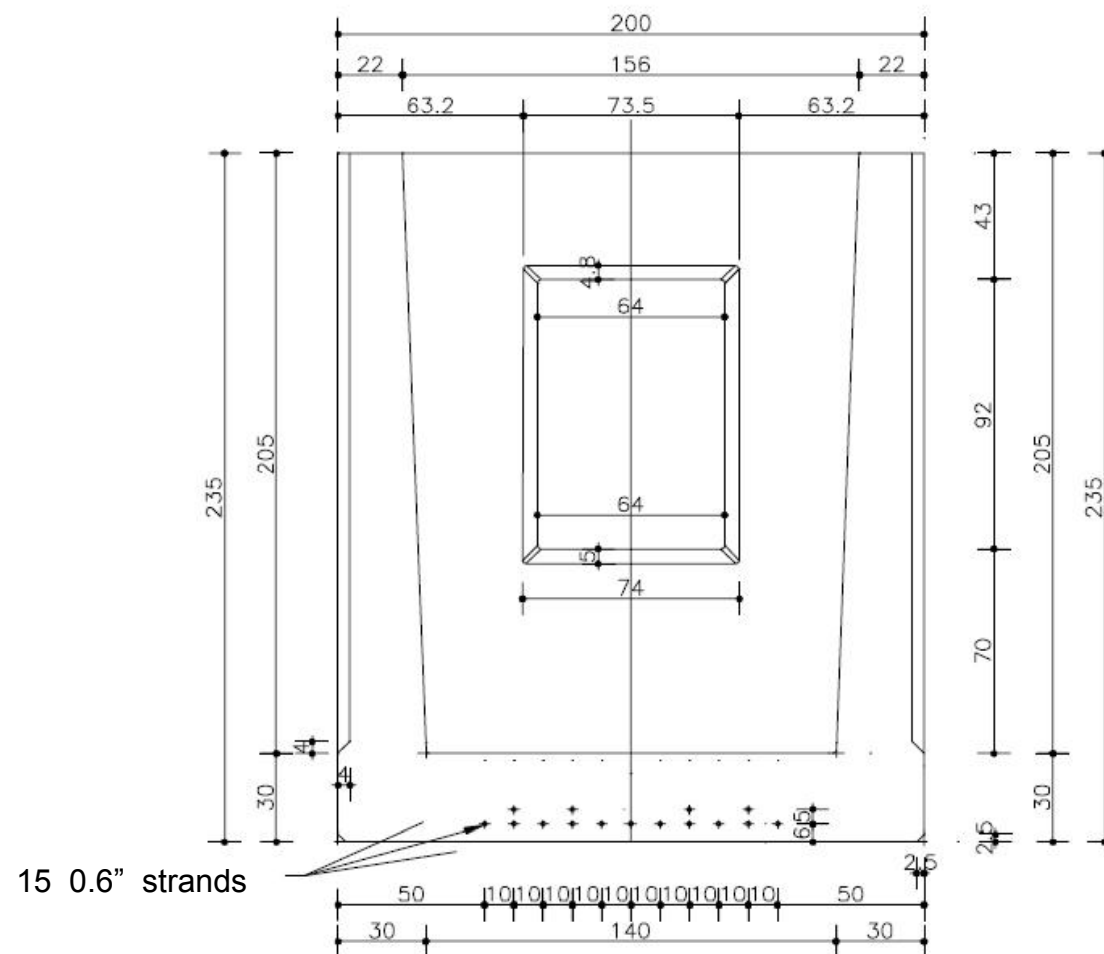
Span element
Longitudinal section



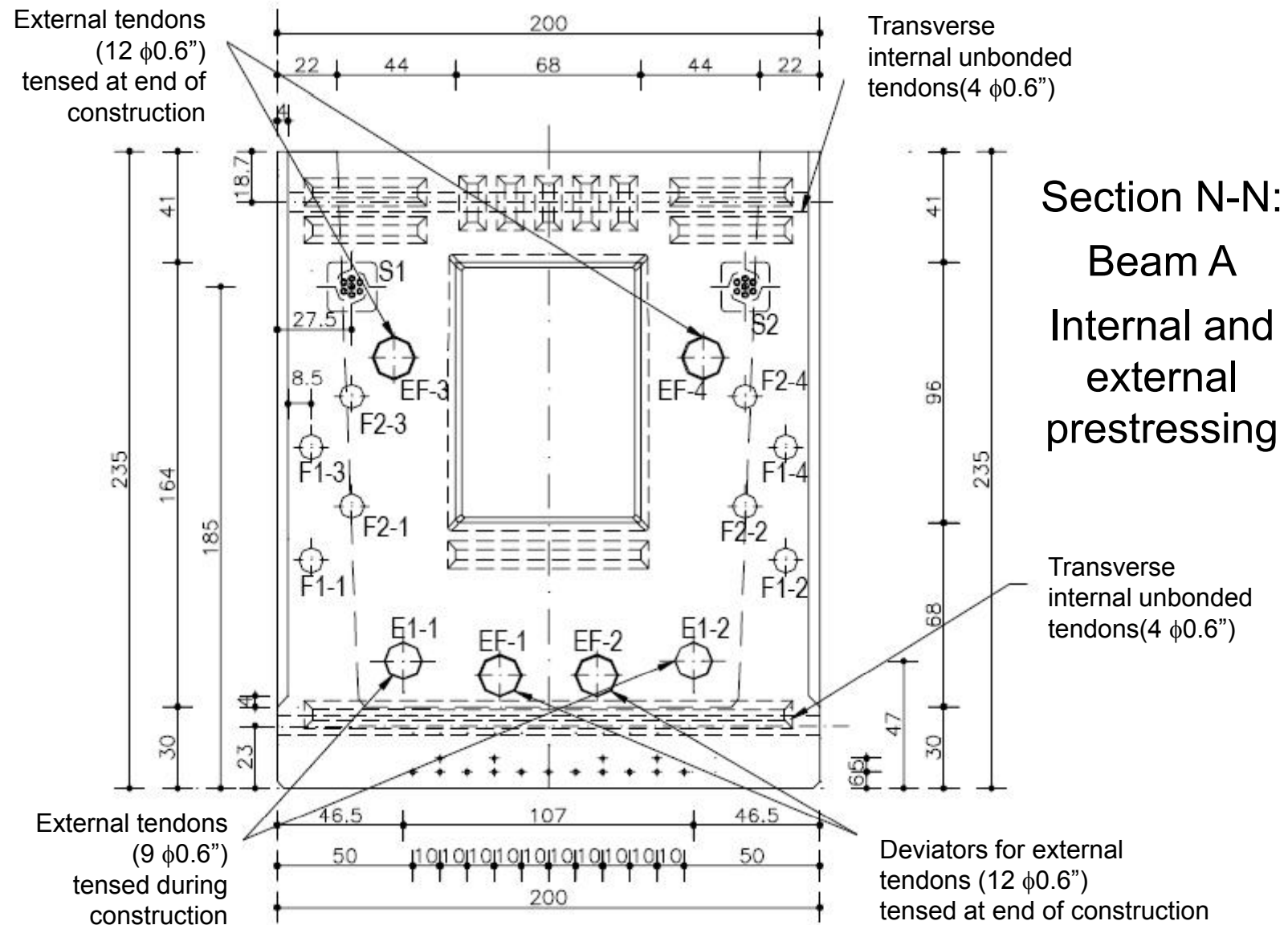
Pier element
Longitudinal section



Beam A Cross section

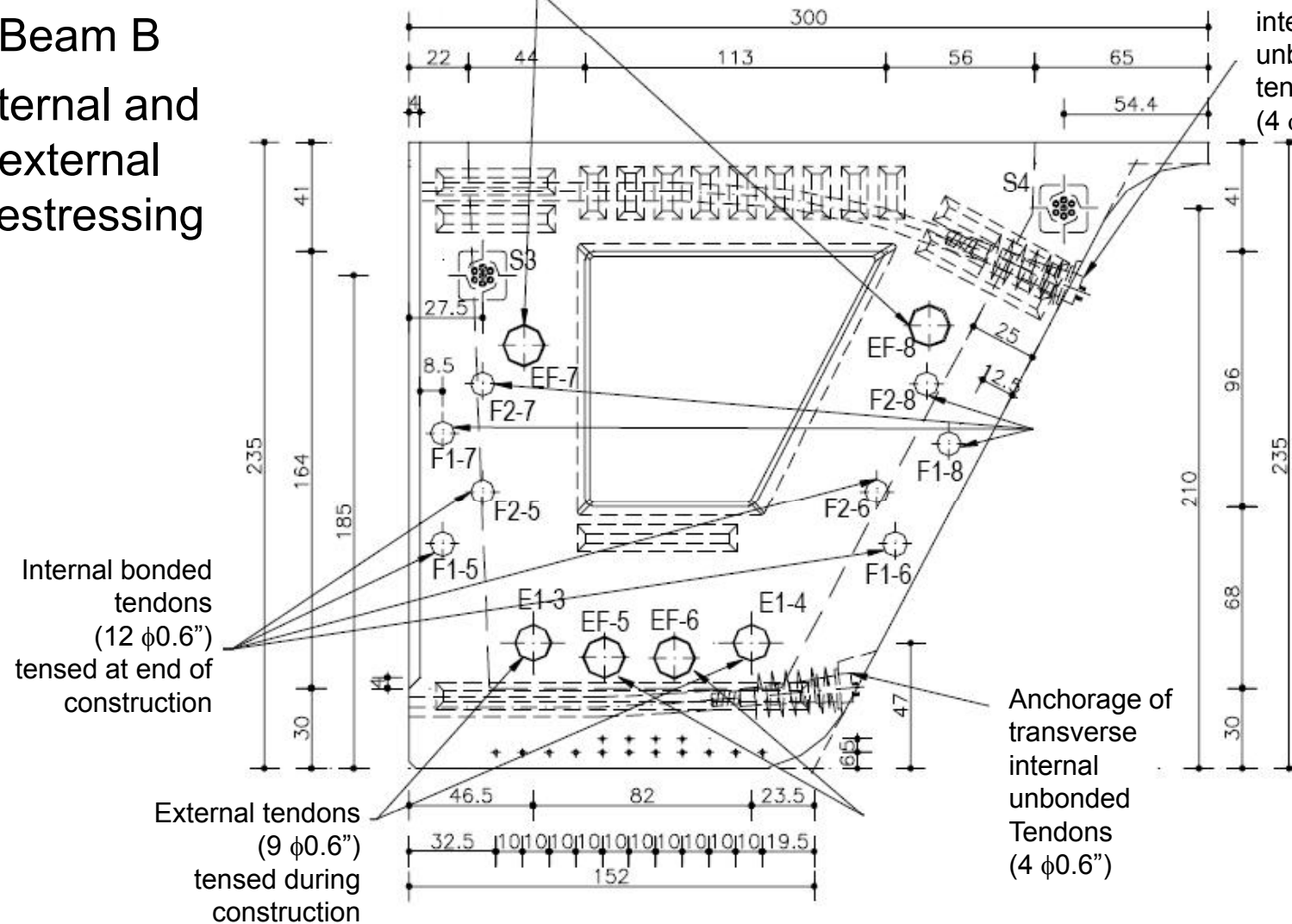


[illegible]

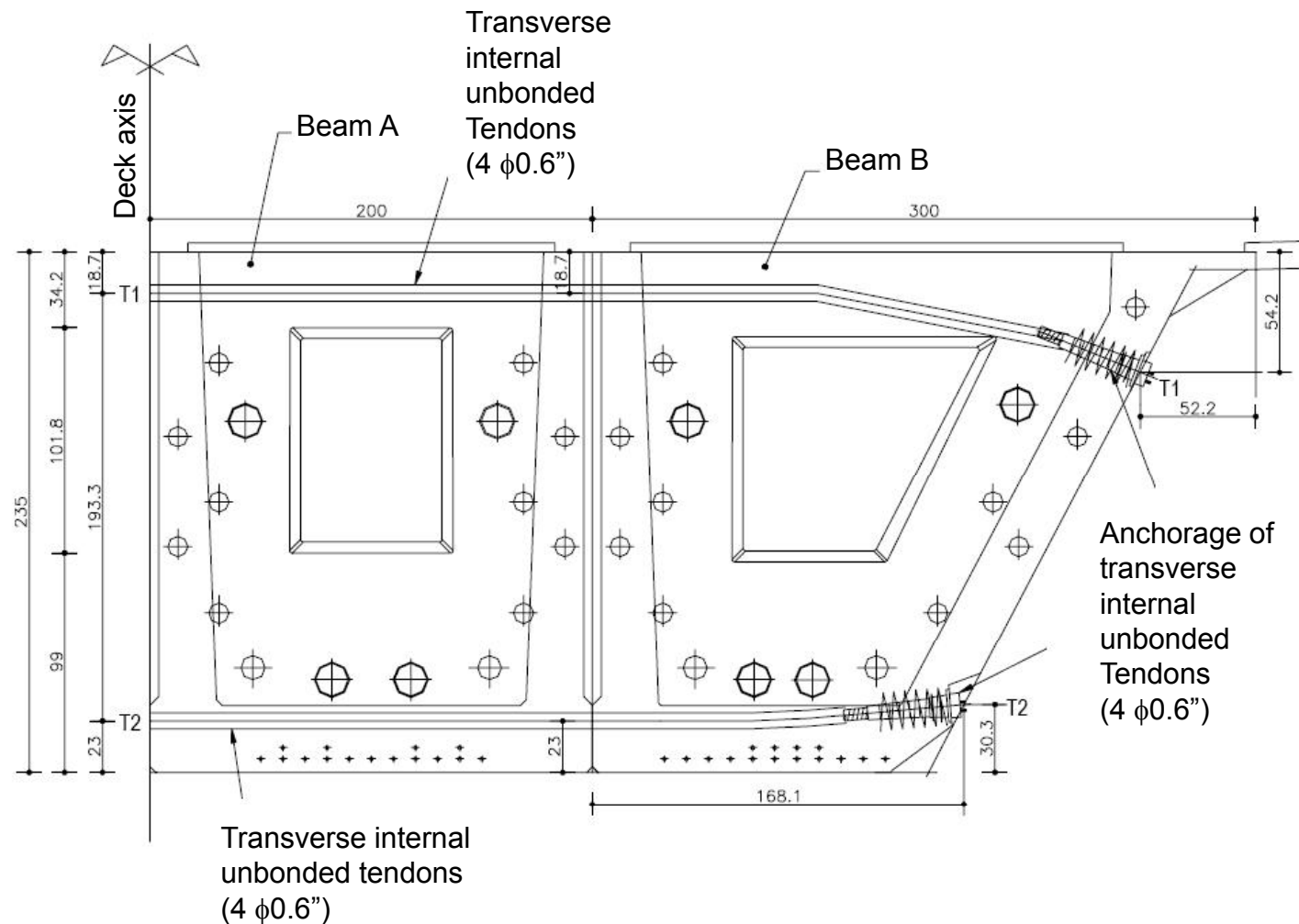


External tendons (12 ϕ 0.6") tensed at end of construction

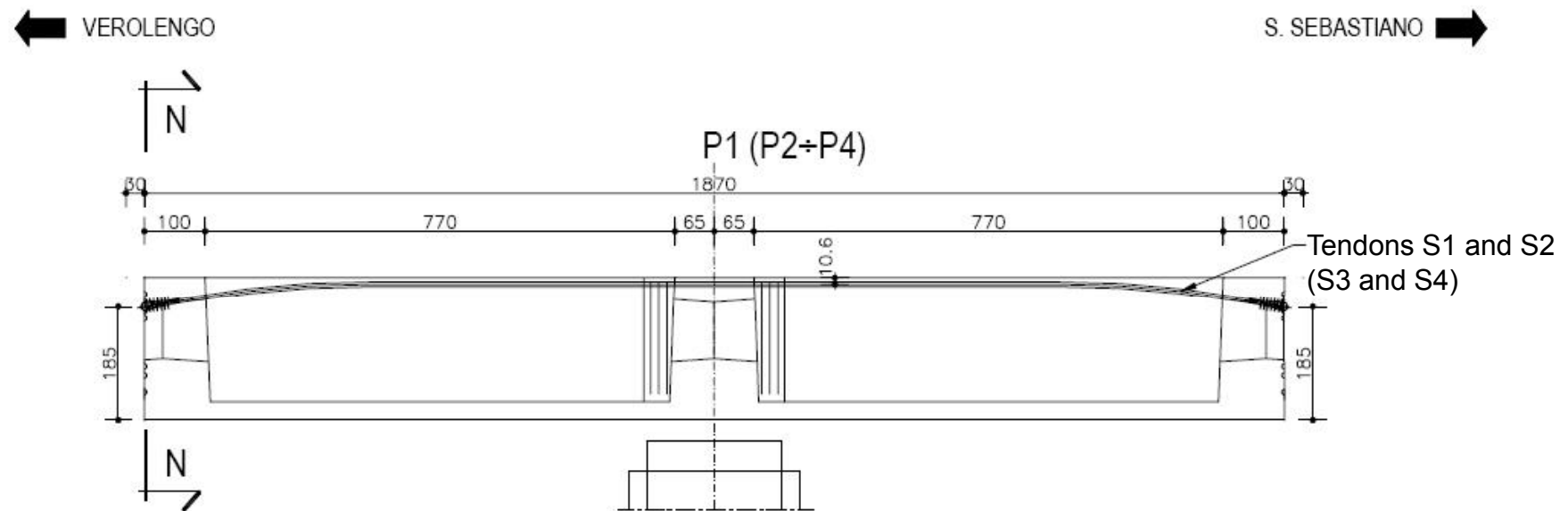
Anchorage of
transverse
internal
unbonded
tendons
(4 $\phi 0.6''$)



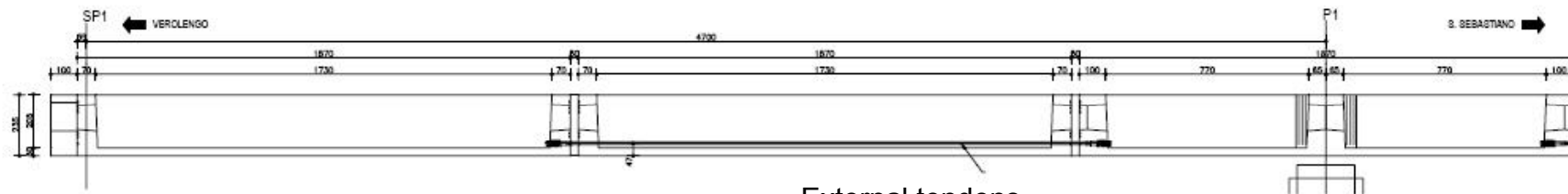
Typical transverse beam section



Internal bonded prestressing of pier elements

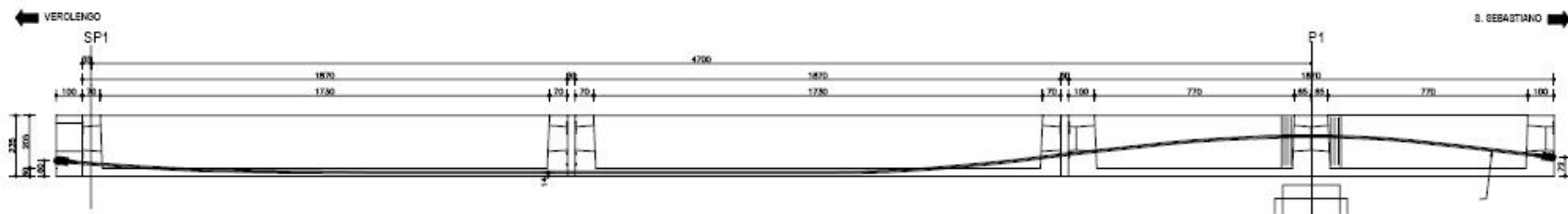


External prestressing of abutments spans (span1 and 5)



External tendons
E1-1 to E1-4 (9 f0.6")
tensed during construction

Internal prestressing of abutments spans (span1 and 5)



Internal tendons
F1-1 to F1-8 (9 f0.6")
tensed during construction

Materials

CONCRETE:	precast beams:	$R_{ck} \geq 55 \text{ Mpa}$
	cast in situ	
	(slab, transverse beams etc.)	$R_{ck} \geq 45 \text{ Mpa}$

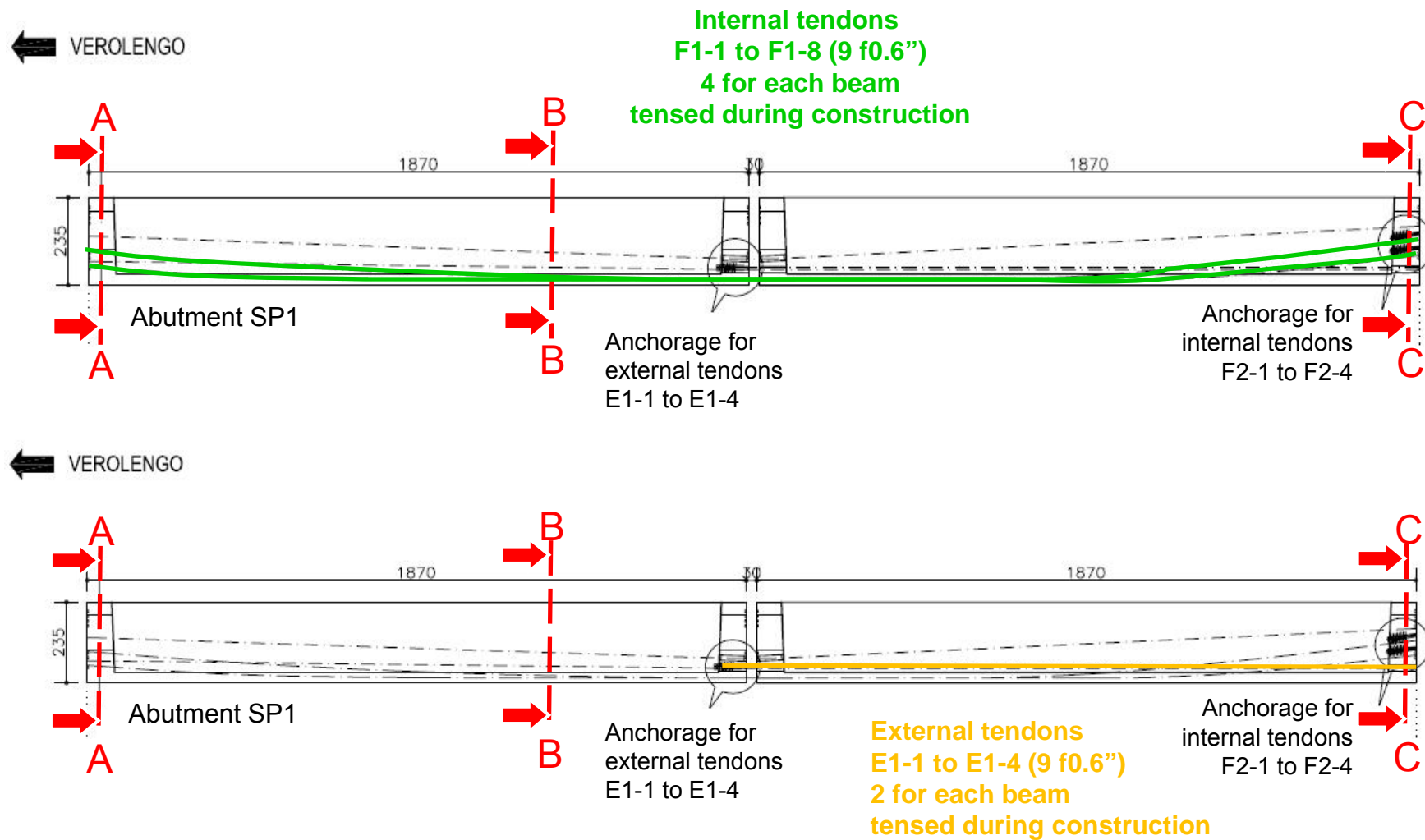
PRESTRESSING STEEL: 0.6" strands

$f_{ptk} = 1860$	MPa
$f_{p(1)k} = 1670$	MPa
$E_s = 200000$	MPa

ORDINARY STEEL: Fe B 44 k

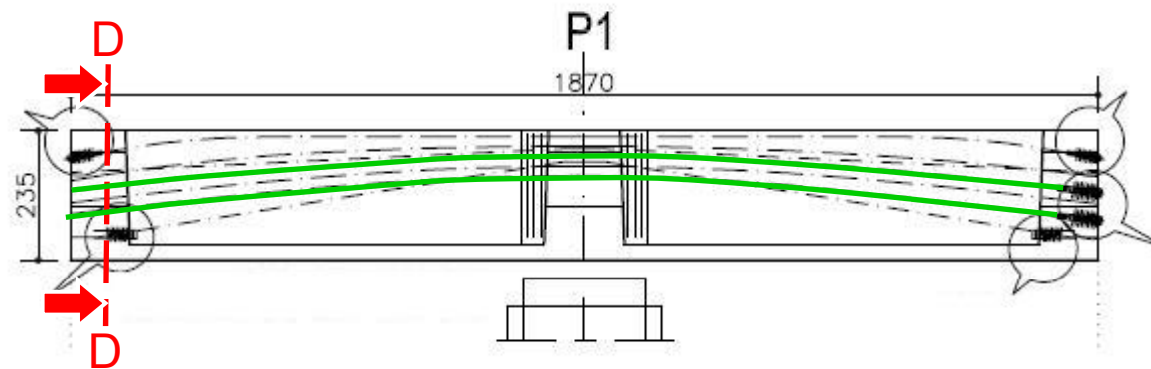
$f_{yk} \geq 430$	Mpa
$E_s = 200000$	Mpa
$f_{yd} = 374$	MPa

Prestressing of beam A: segments 1 and 2 - construction



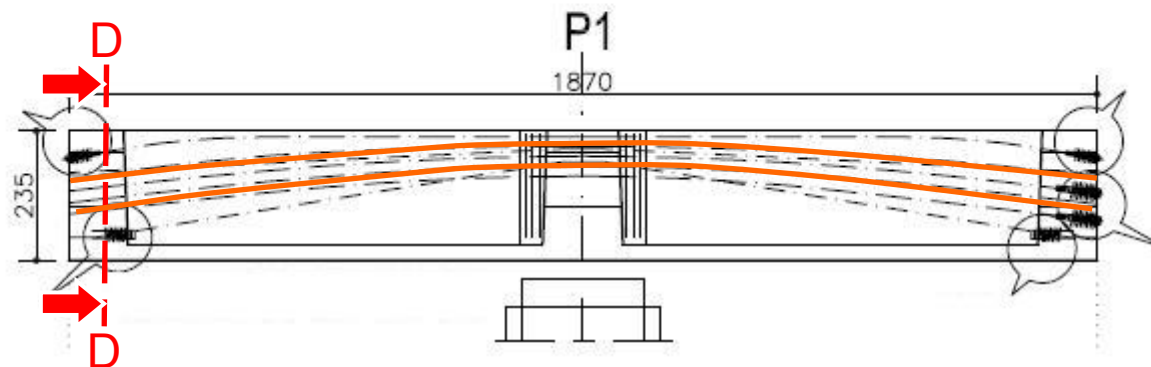
Prestressing of beam A: segment 3 - construction

← VEROLENGO



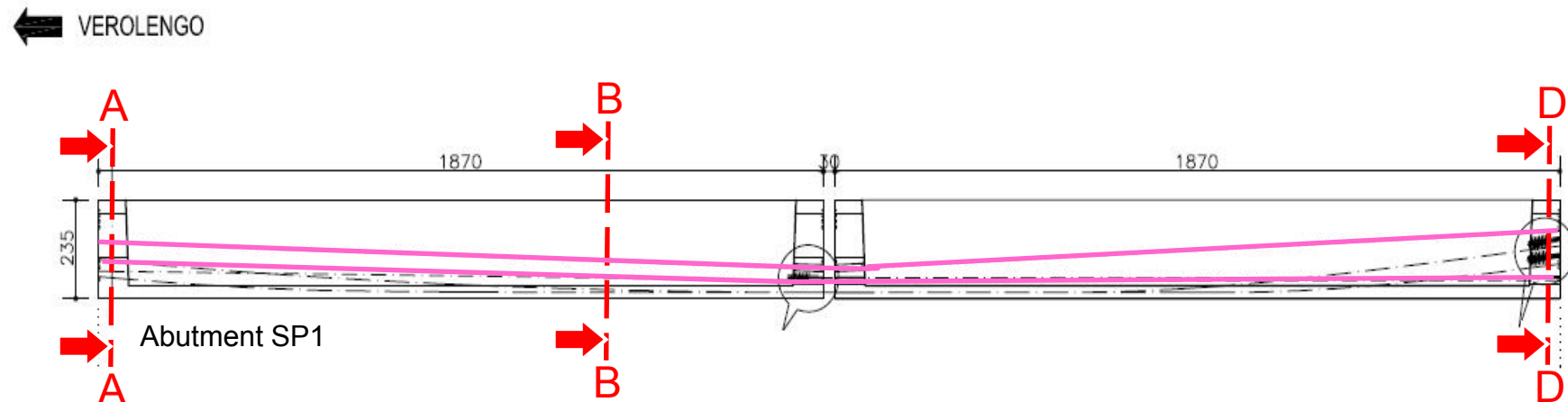
Internal tendons
F1-1 to F1-8 (9 f0.6")
1st span
4 for each beam
tensed during construction

← VEROLENGO

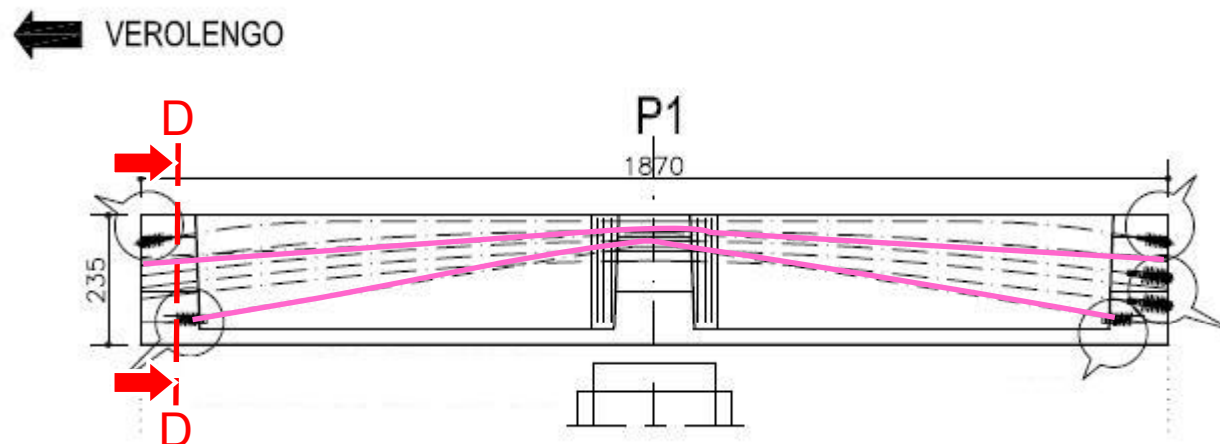


Internal tendons
F2-1 to F2-8 (9 f0.6")
2nd span
4 for each beam
tensed during construction

Prestressing of beam A: segments 1 and 2 – END of construction



Prestressing of beam A: segment 3 – END of construction



External tendons
F1-1 to F1-8 (9 f0.6")
4 for each beam
tensed at the end of
construction

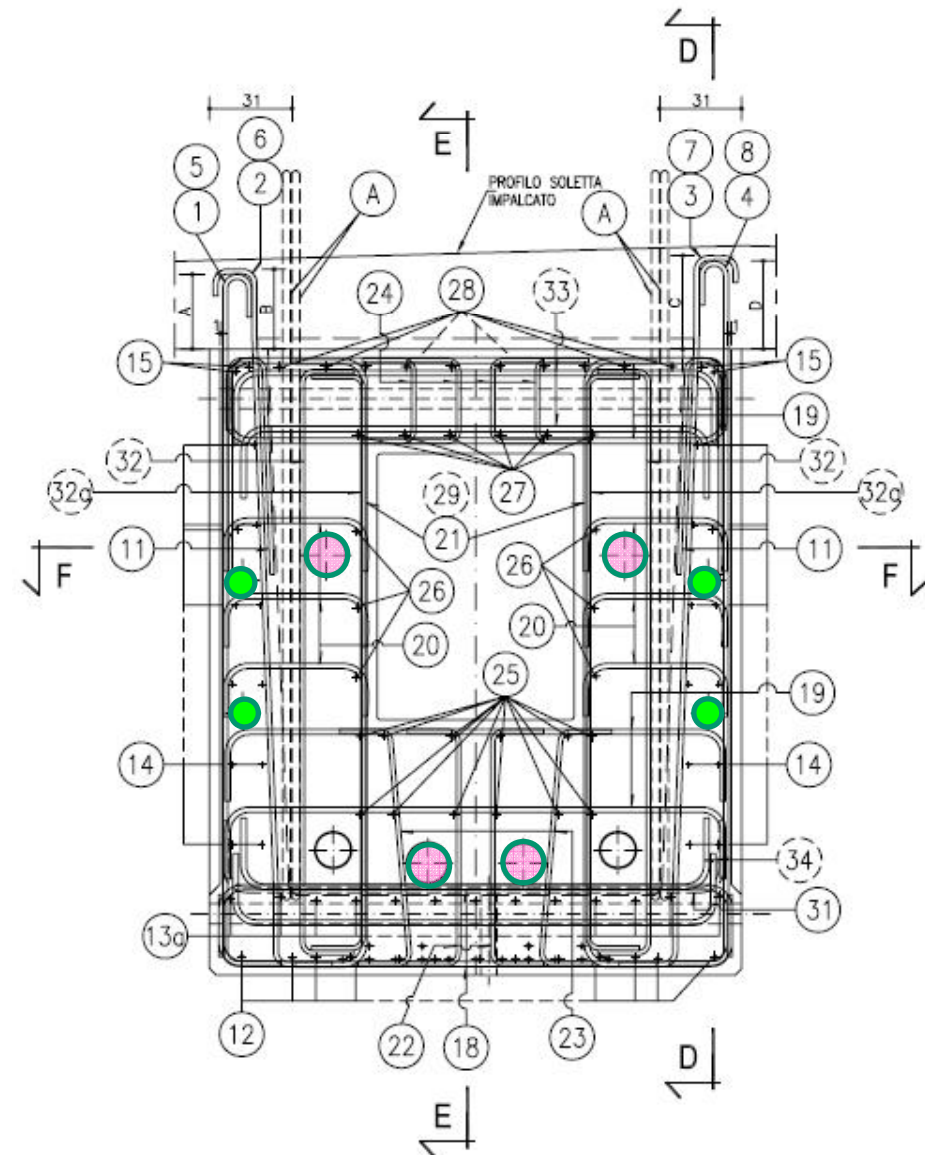
Beam A

First segment

Cross section AA

Internal tendons F ●

External tendons
tensed at the end of
construction ○




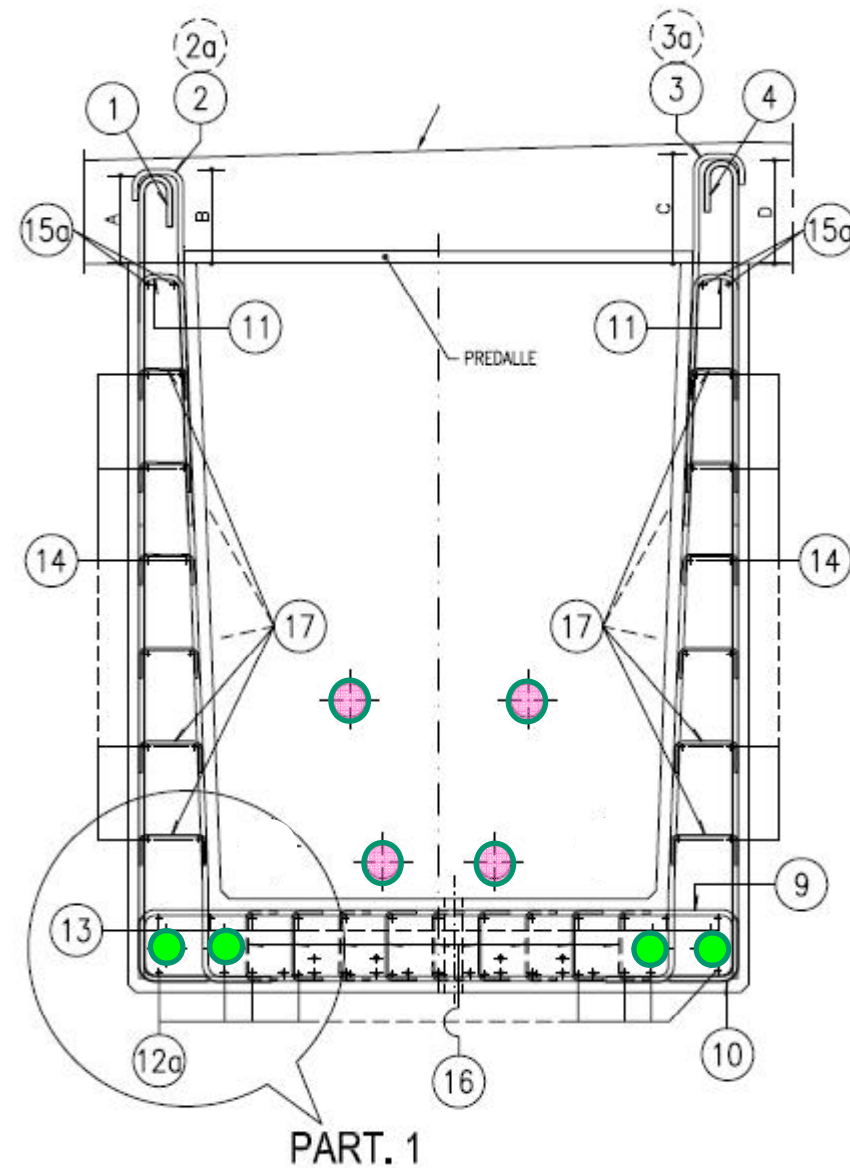
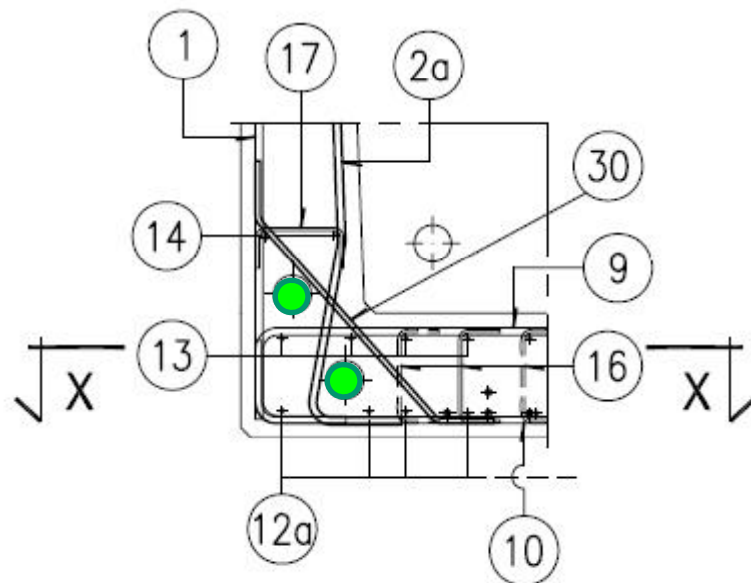
Beam A

First segment

Cross section BB

PART. 1

Detail of reinforcement to be placed
when internal tendons F  change
position horizontally



Beam A

Second segment

Cross section CC

Internal tendons
F1-1 to F1-8
(1st span)



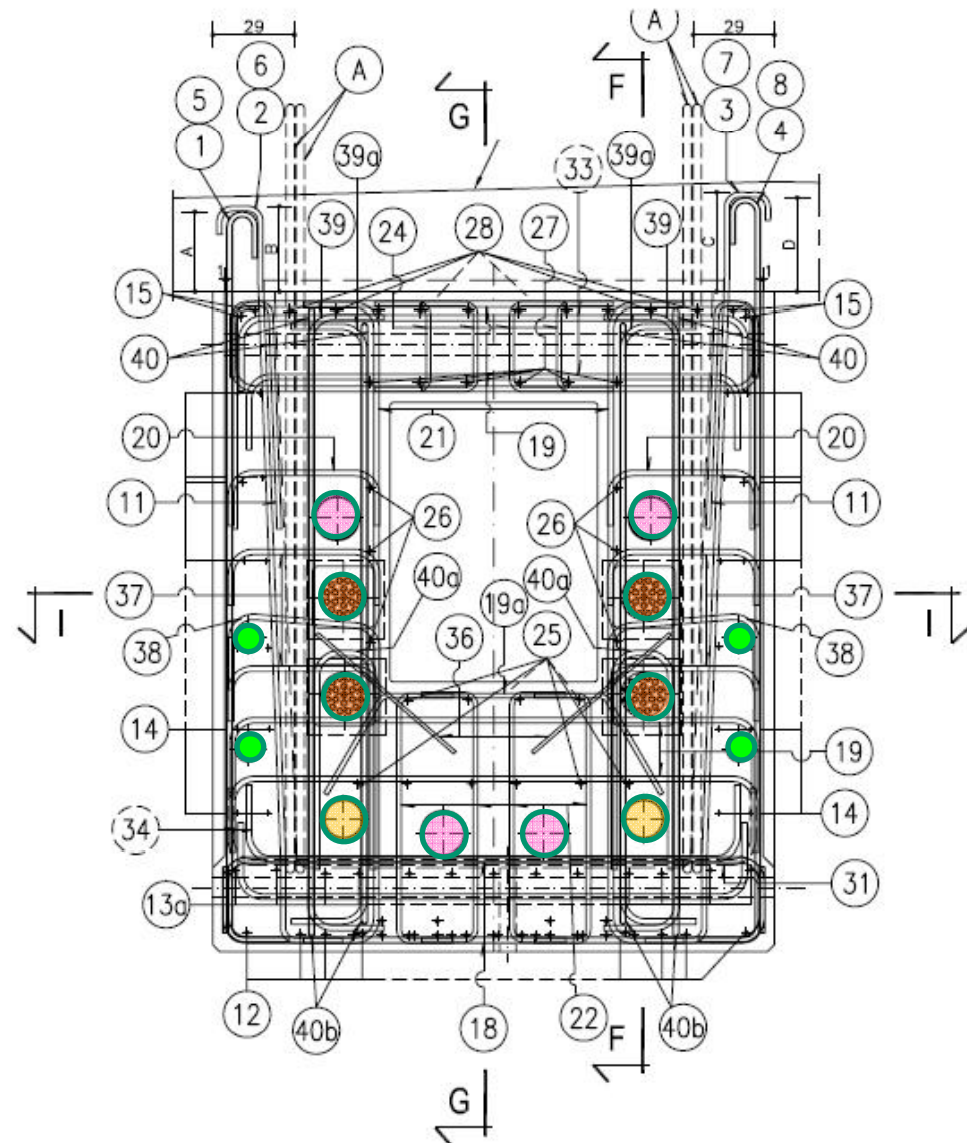
External tendons
tensed at the end of
construction



External tendons
tensed during
construction



Internal tendons
F2-1 to F2-8
(2nd span)

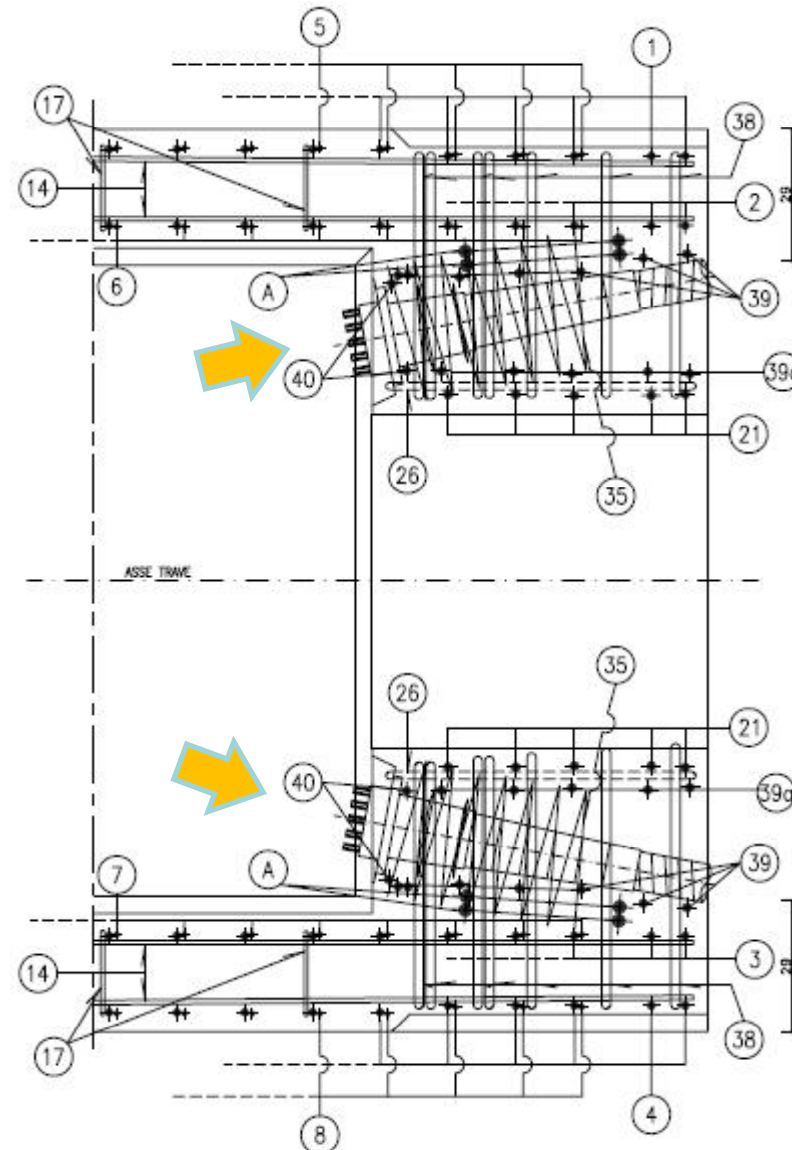


Beam A

Second segment

Horizontal section II

Anchorage of
internal tendons
F2-1 to F2-8
(2nd span)



Beam A

Third segment

Cross section DD

Internal tendons
F1-1 to F1-8
(1st span)



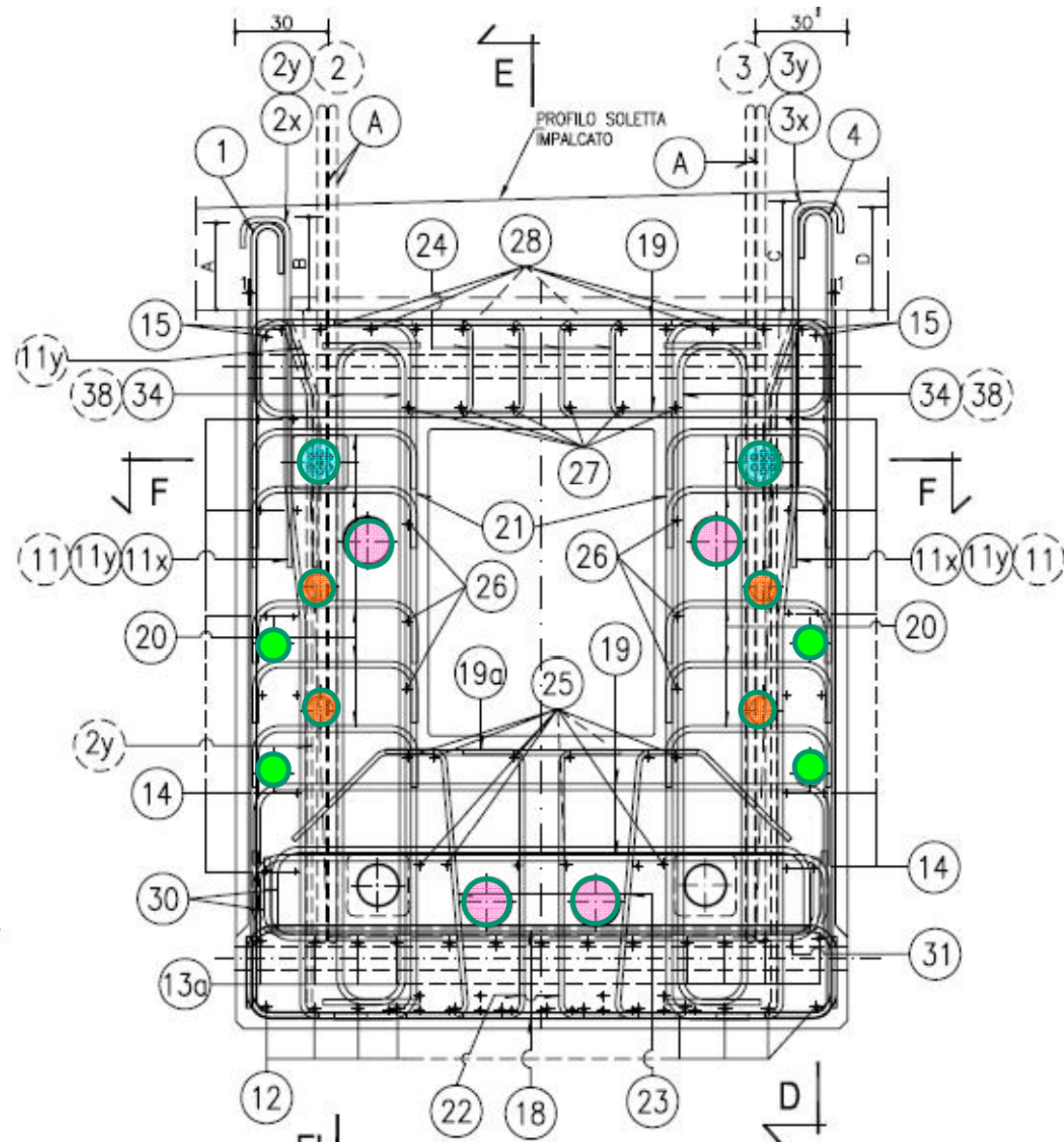
External tendons
tensed at the end of
construction



Internal tendons S1-
S4 tensed at the birth
of the element



Internal tendons
F2-1 to F2-8
(2nd span)



VEROLENGO BRIDGE

Finite element model

2 different models:

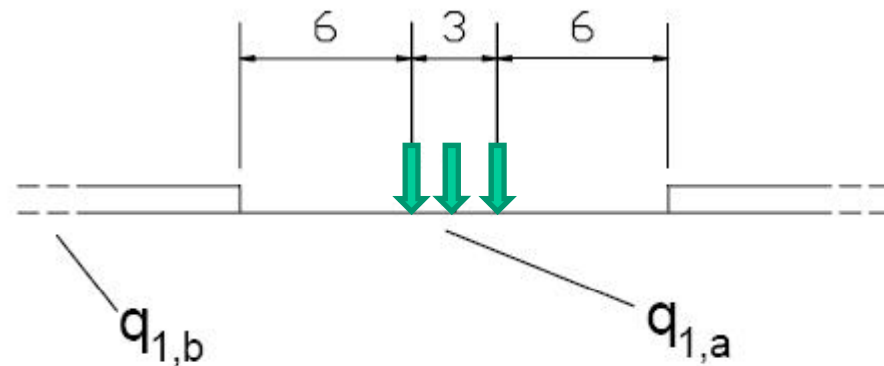
- 1 Construction phases and creep effects:
one dimension model
the deck is a single continuous straight beam
deadweight does NOT give rise to torsion

- 2 SLS and ULS with live load:
girder model:
the deck is a girder made of longitudinal and
transverse beams and slab;
live load gives rise to torsion

Live loads on model 2:

3 notional lanes in transverse direction

Each lane is 3m wide in transverse direction



$q_{1,a}$ = 3 couples of concentrated loads 150kN each =
 $3 \times 2 \times 150 = 600 \text{ kN}$

$q_{1,b}$ = uniformly distributed load of 3 kN/m^2

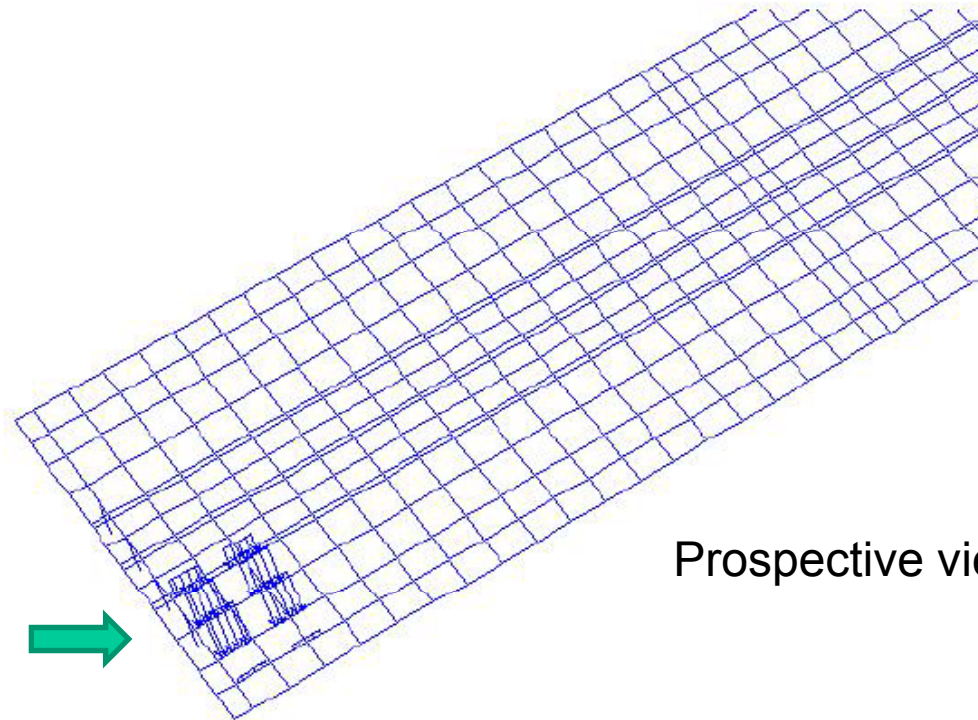
$q_{1,a}$ has been placed 89 times in different longitudinal positions on the girder model with stepping of 3 m
($89 \times 3 = 267\text{m} \cong \text{length of the bridge } 266$)



Longitudinal view

Position 1

$q_{1,a}$ Loads
corresponding to the
outermost notional
lane



Prospective view

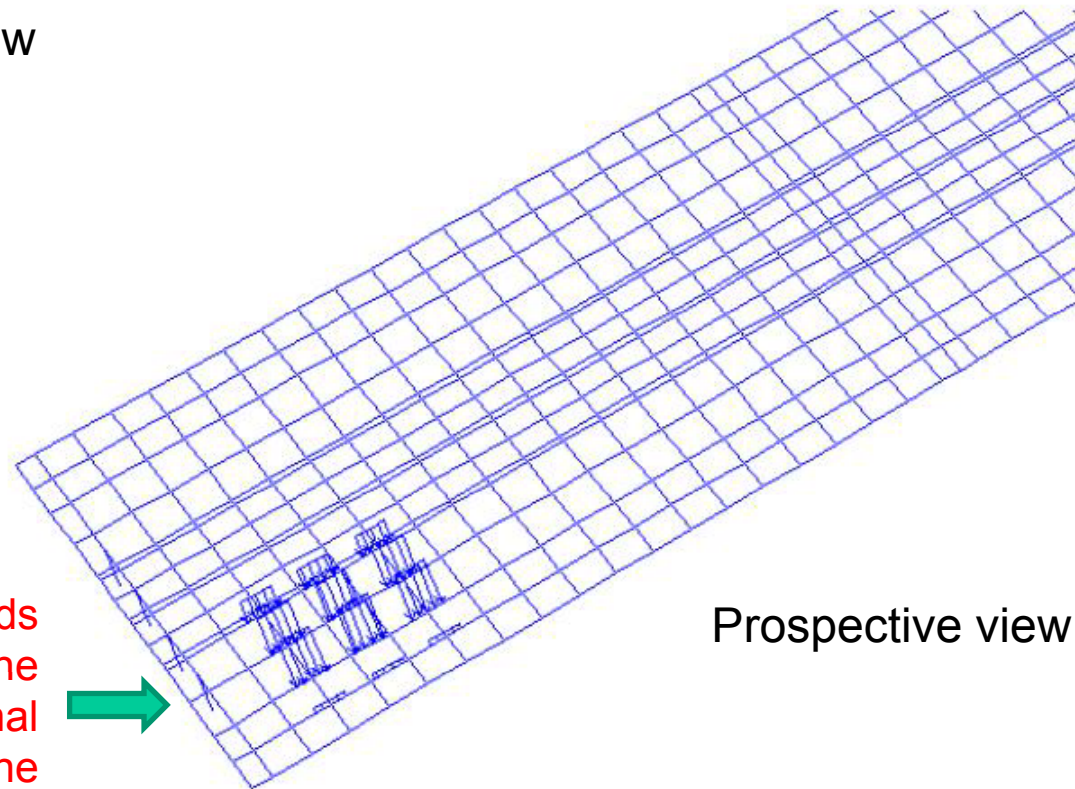
$q_{1,b}$ has been divided into 3x3m squared areas and placed 89 times in different longitudinal positions on the girder for each notional lane



Longitudinal view

Position 2

$q_{1,a}$ Loads
corresponding to the
outermost notional
lane



Prospective view

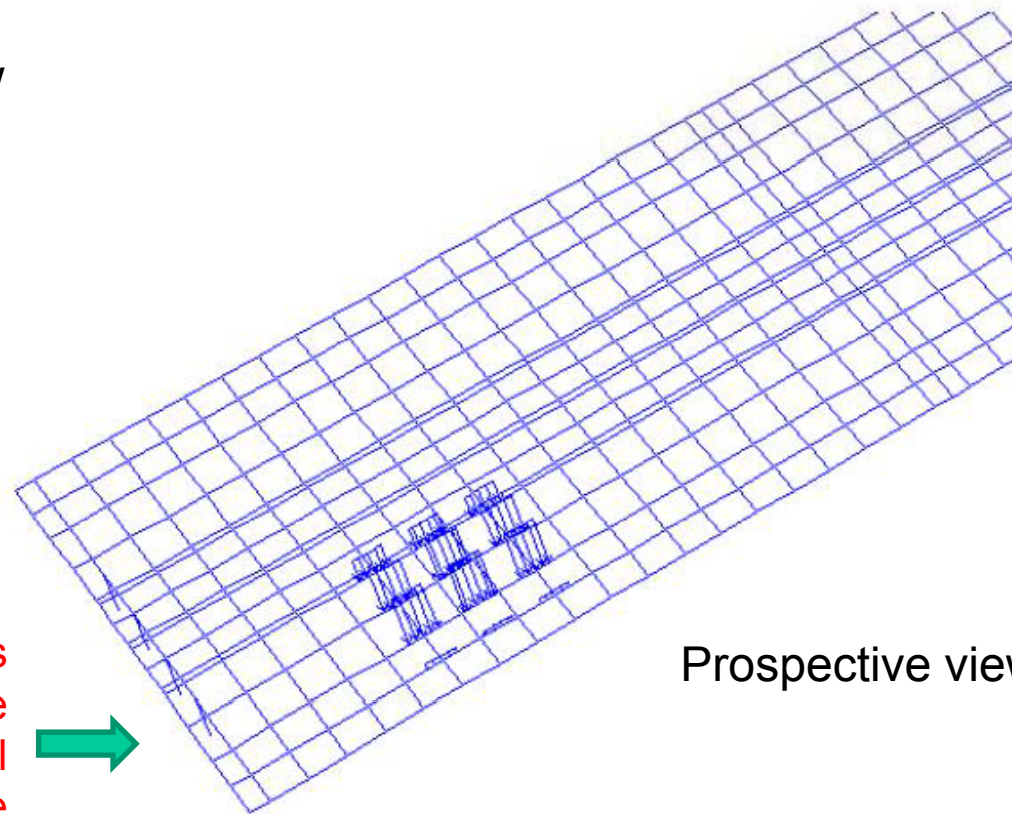
The results given by model 1 for deadweight, prestressing, creep, shrinkage, construction phases are then divided between the 8 beams corresponding to the webs of the boxes



Longitudinal view

Position 3

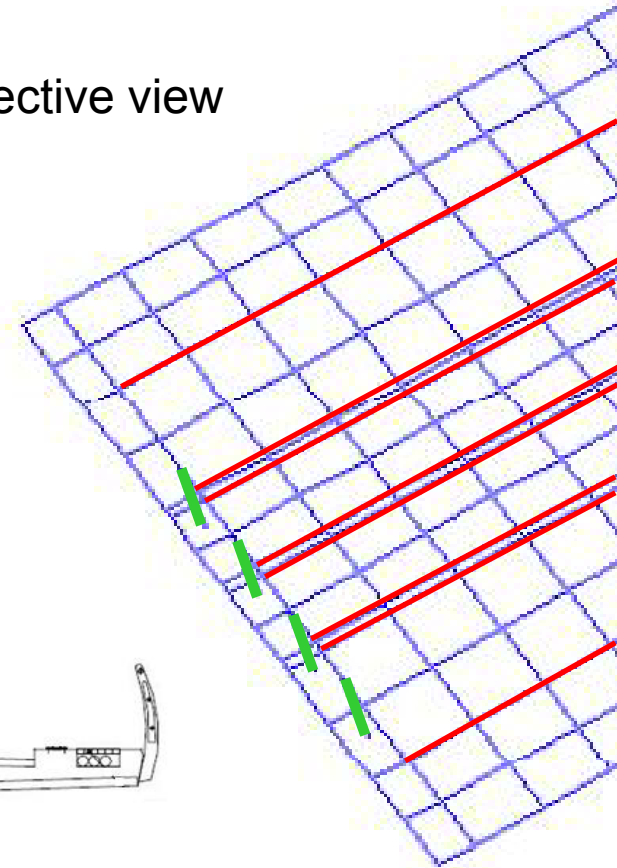
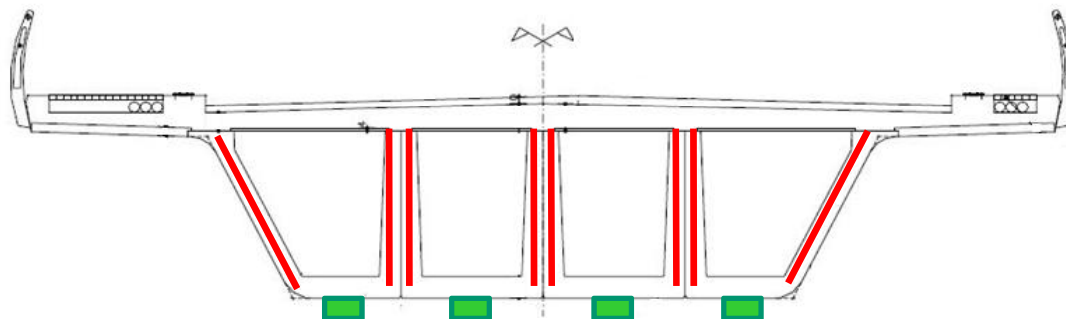
$q_{1,a}$ Loads
corresponding to the
outermost notional
lane



Prospective view

The webs are highlighted in red whereas the offset elements for the bearings are evidenced in green.

Prospective view



VEROLENGO BRIDGE

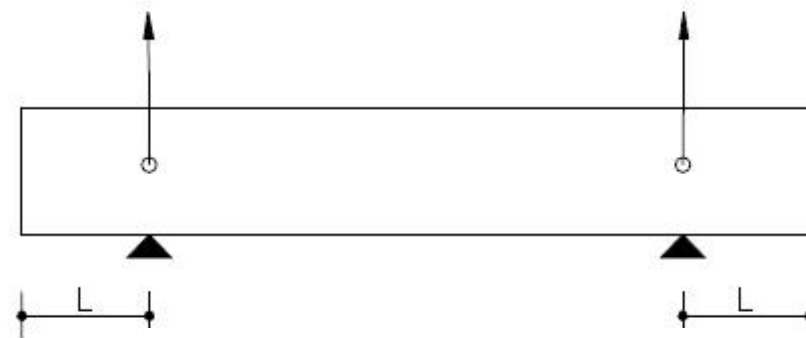
Construction phases

Phase 2:

A. prestressing strands release

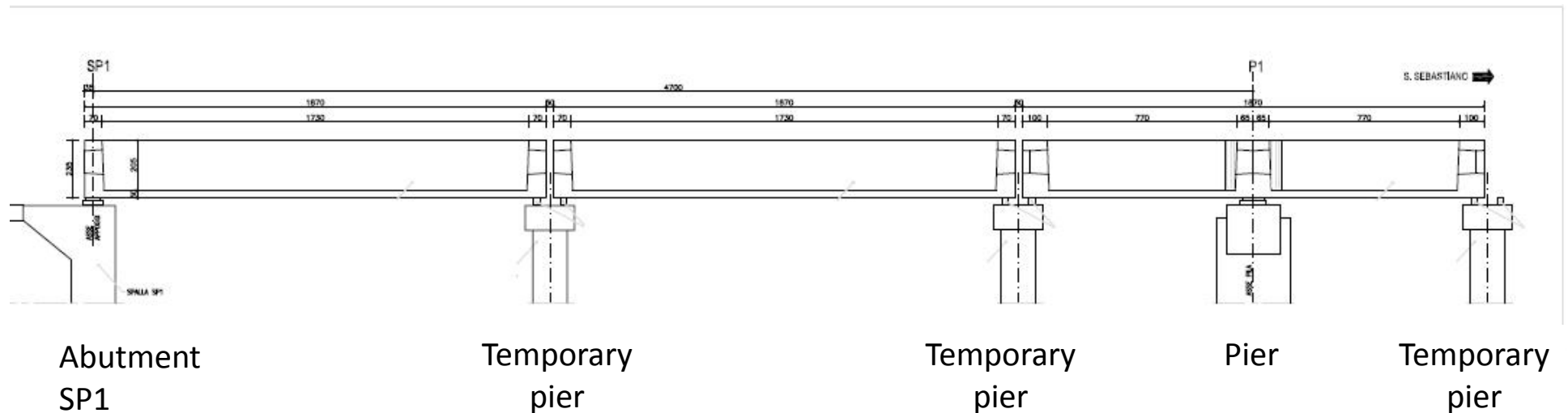
B. tensioning of tendons S1 to S4 on pier elements

Storage, lifting and
transport scheme



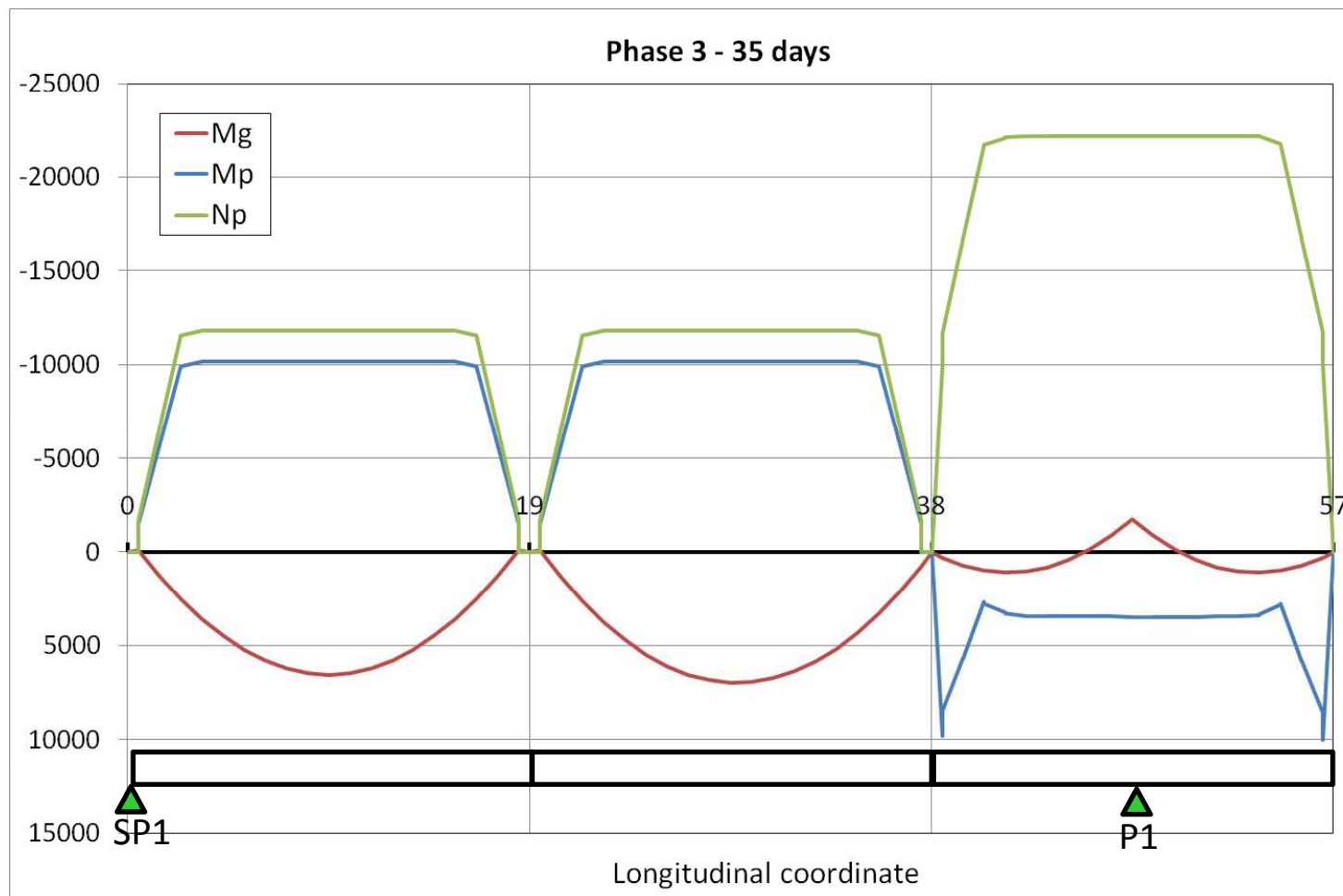
$L=0.35$ for span elements
 $L=0.50$ for pier elements

Phase 3:
Positioning of precast elements of span SP1-P1 and concreting of relative transverse beams



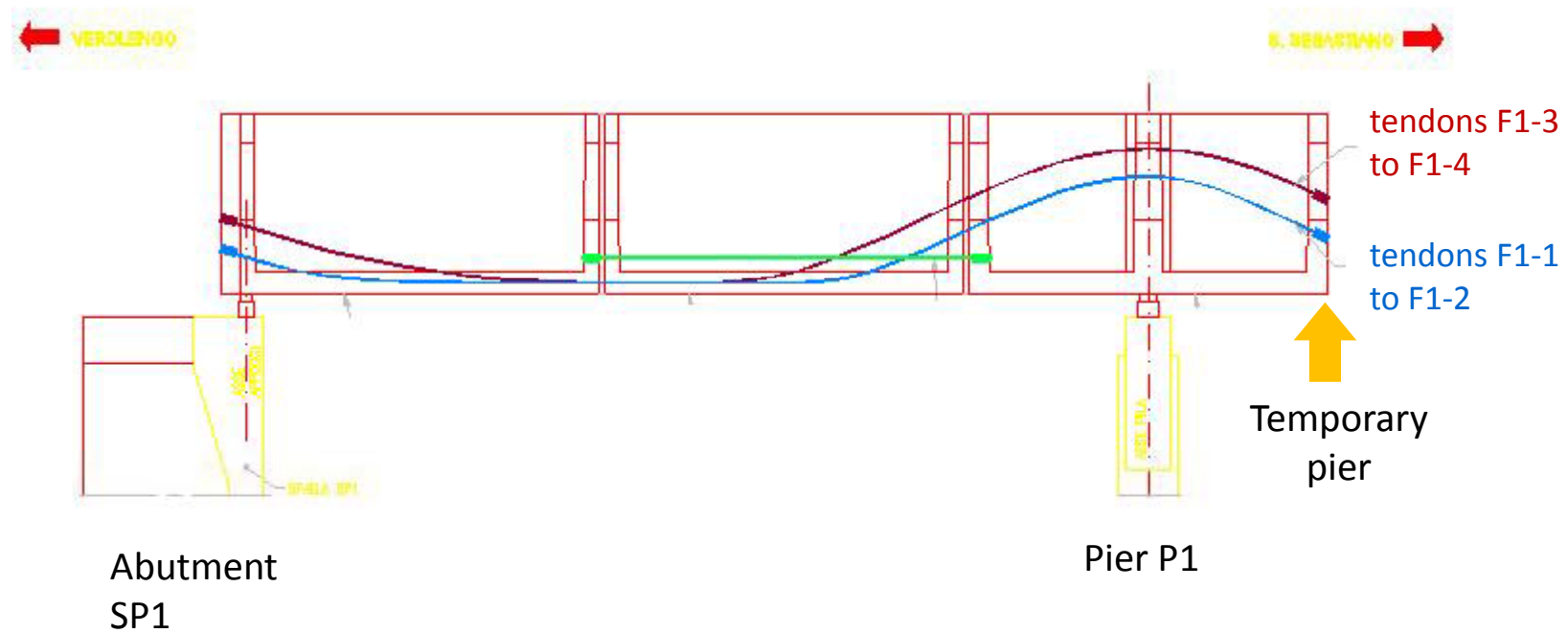
Phase 3: 35 days

Positioning of precast elements of span SP1-P1 and concreting of relative transverse beams



Phase 4:

- A. Tensioning of tendons F1-1 to F1-8
- B. Removal of temporary piers of span SP1-P1

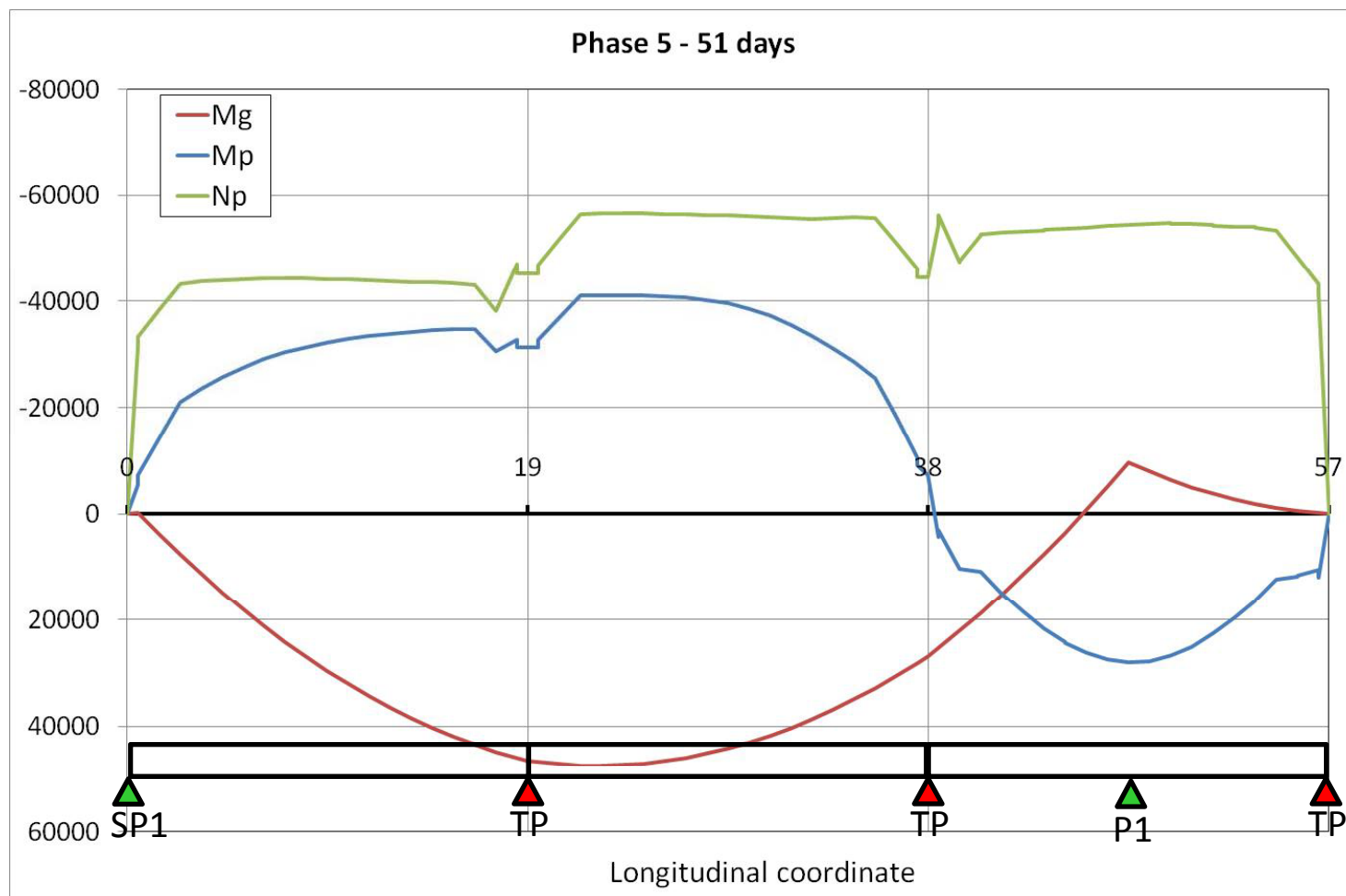


Phase 5: Tensioning of tendons E1-1 to E1-8



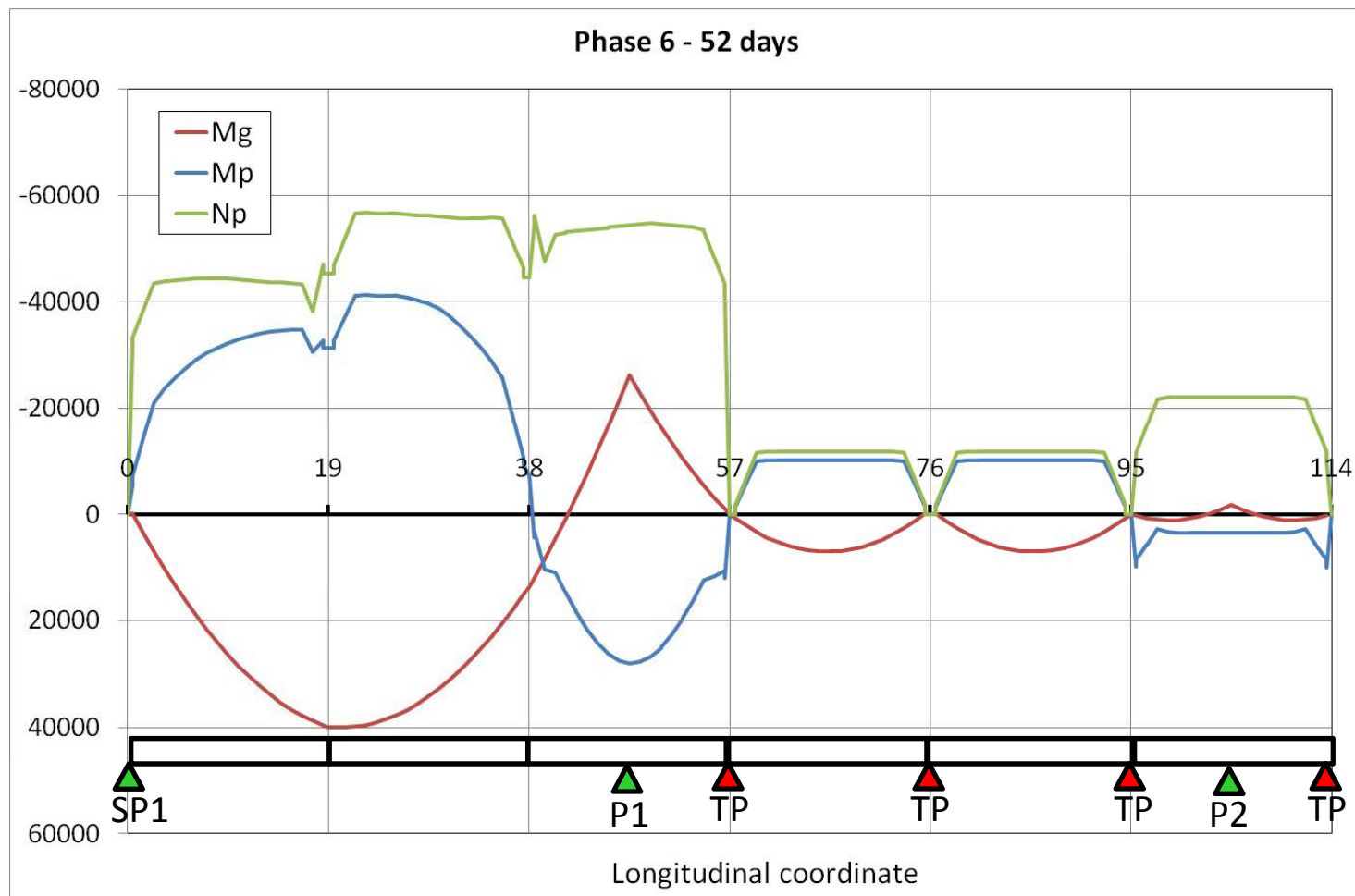
Phase 5: 51 days

Tensioning of tendons E1-1 to E1-8



Phase 6: 52 days

Positioning of precast elements of span P1-P2 and concreting of relative transverse beams

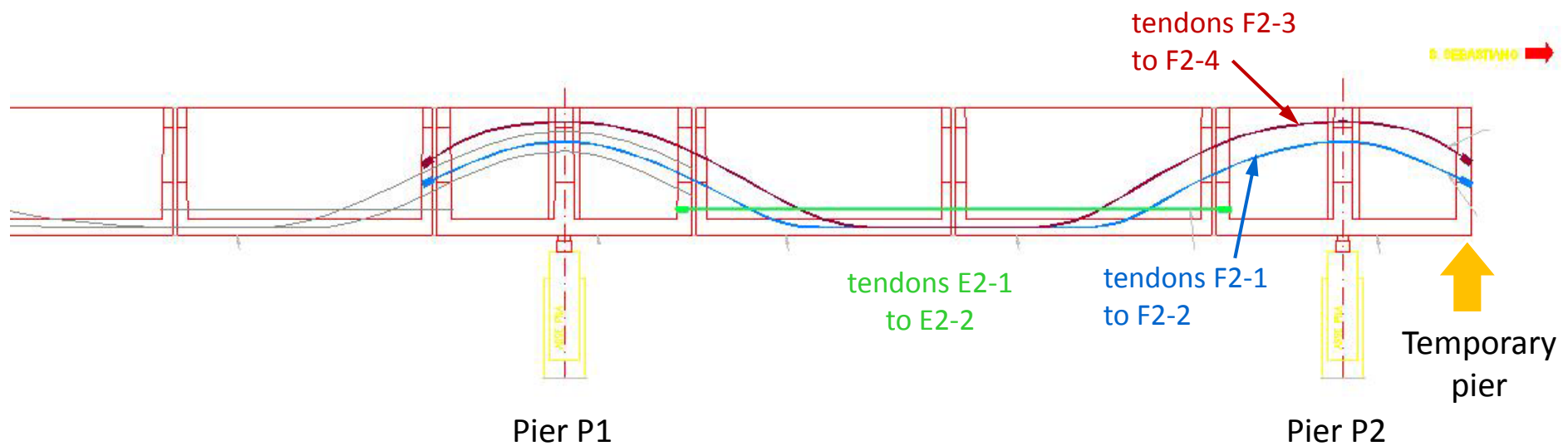


Phase 8:

A. Tensioning of tendons F2-1 to F2-8 P1-P2

B. Removal of temporary piers of span 2

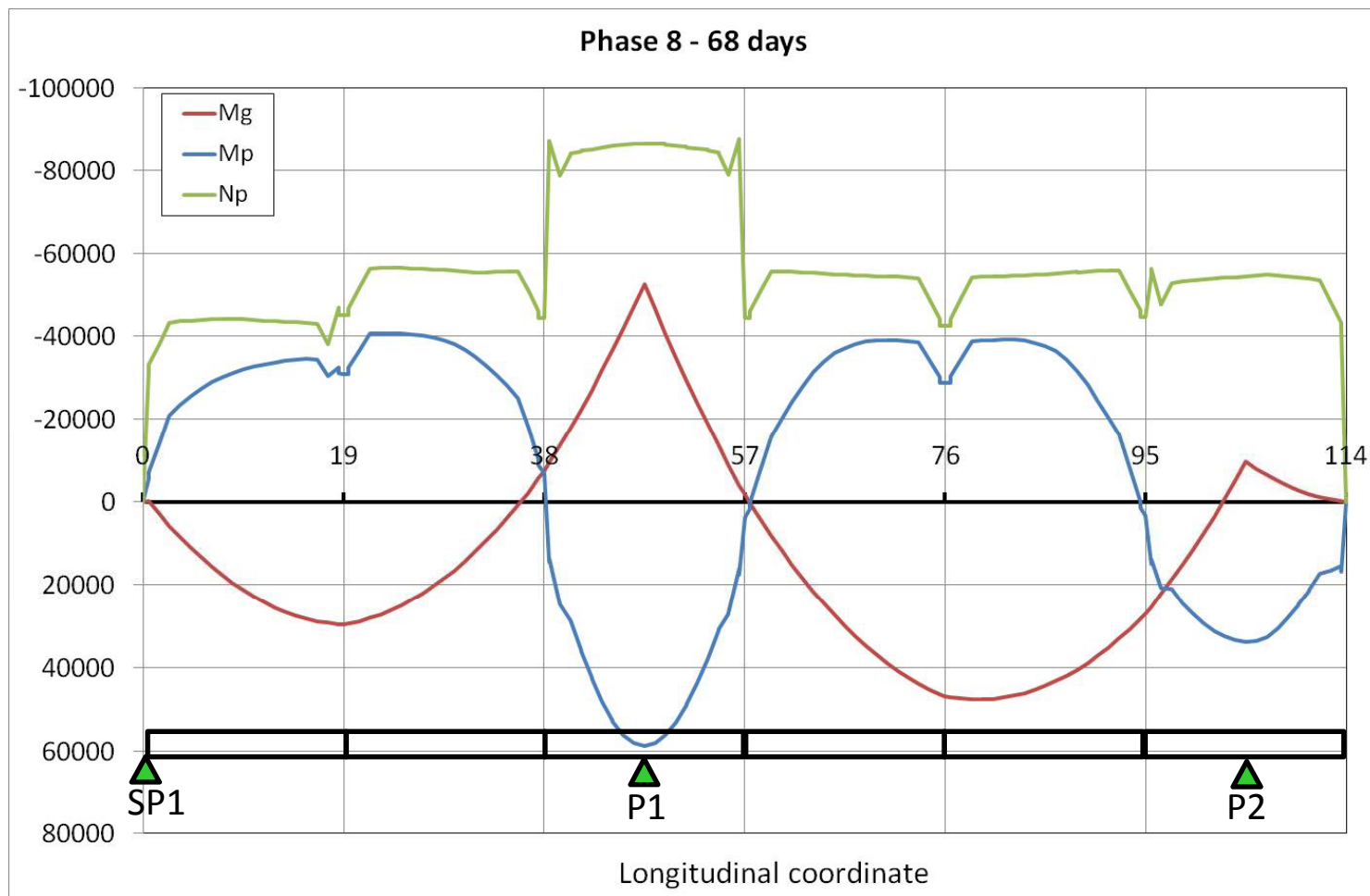
C. Tensioning tendons E2-1 to E2-8



Phase 8: 68 days

A. Tensioning of tendons F2-1 to F2-8 P1-P2

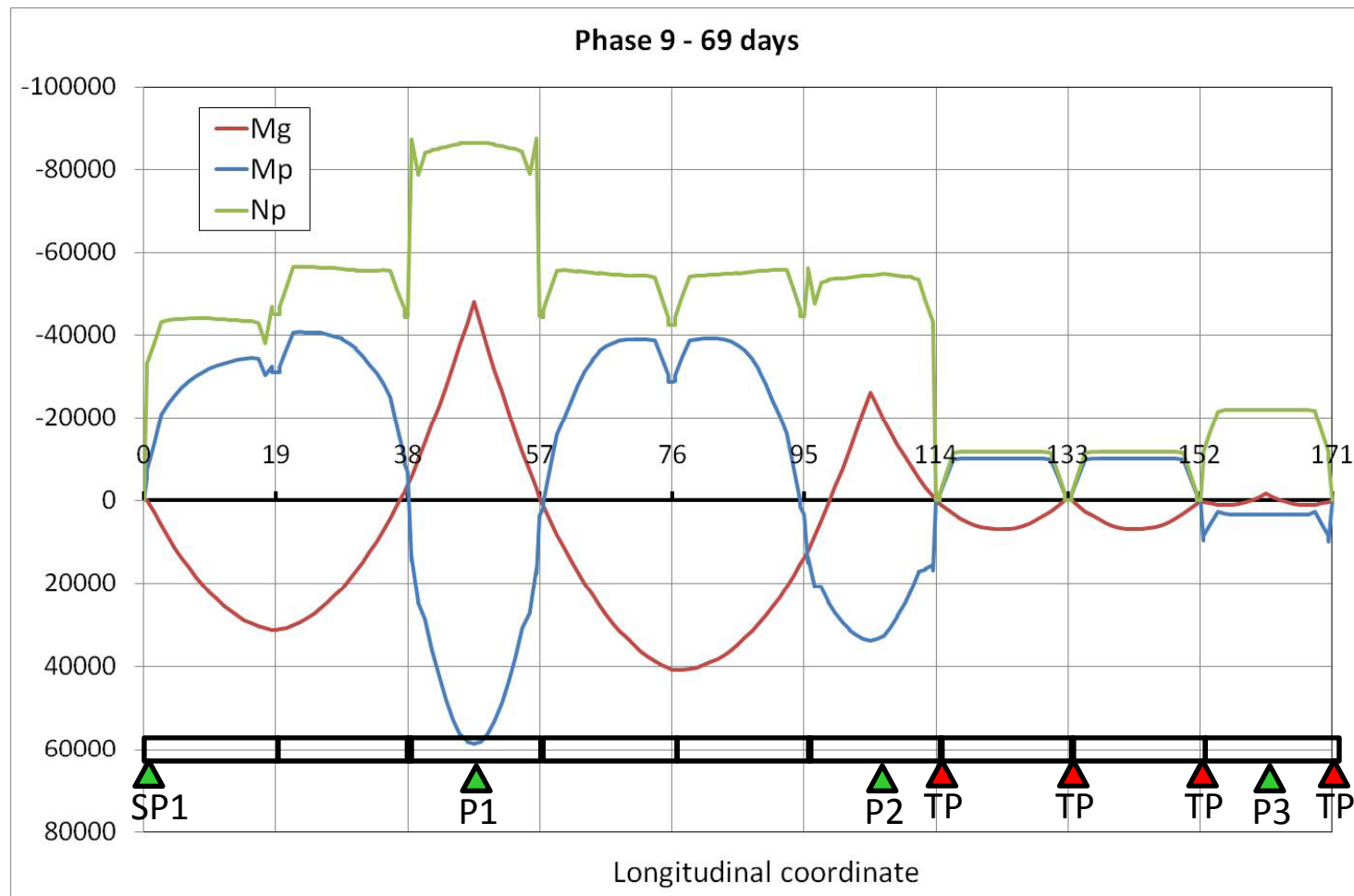
B. Removal of temporary piers of span 2 C. Tensioning tendons E2-1 to E2-8



Phase 9: 69 days

A. Tensioning of tendons F2-1 to F2-8 P1-P2

B. Removal of temporary piers of span 2

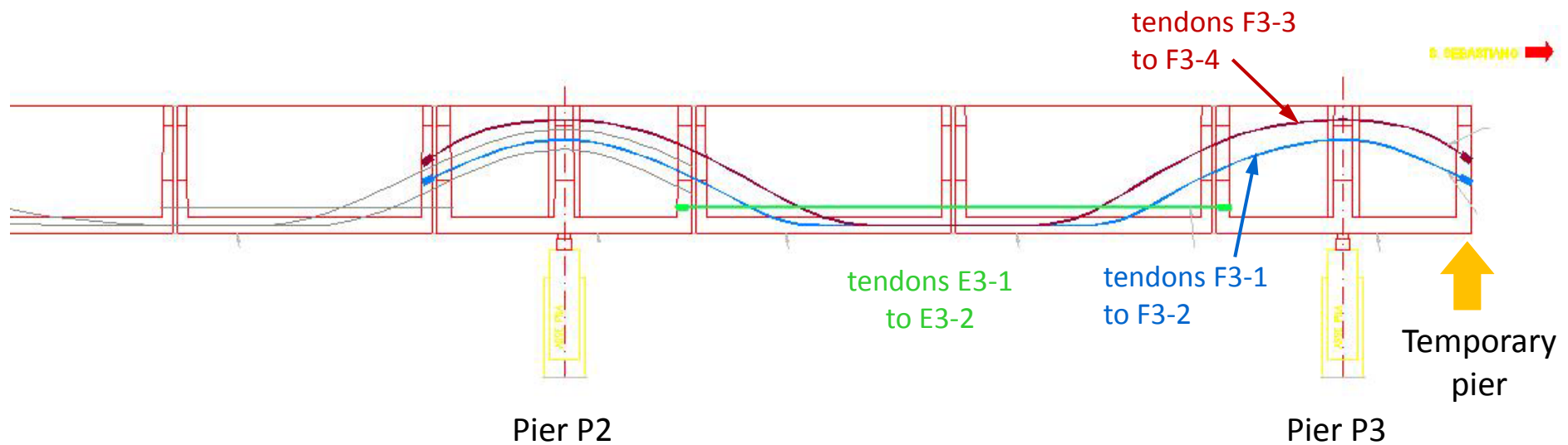


Phase 11: 85 days

A. Tensioning of tendons F3-1 to F3-8 P2-P3

B. Removal of temporary piers of span 3

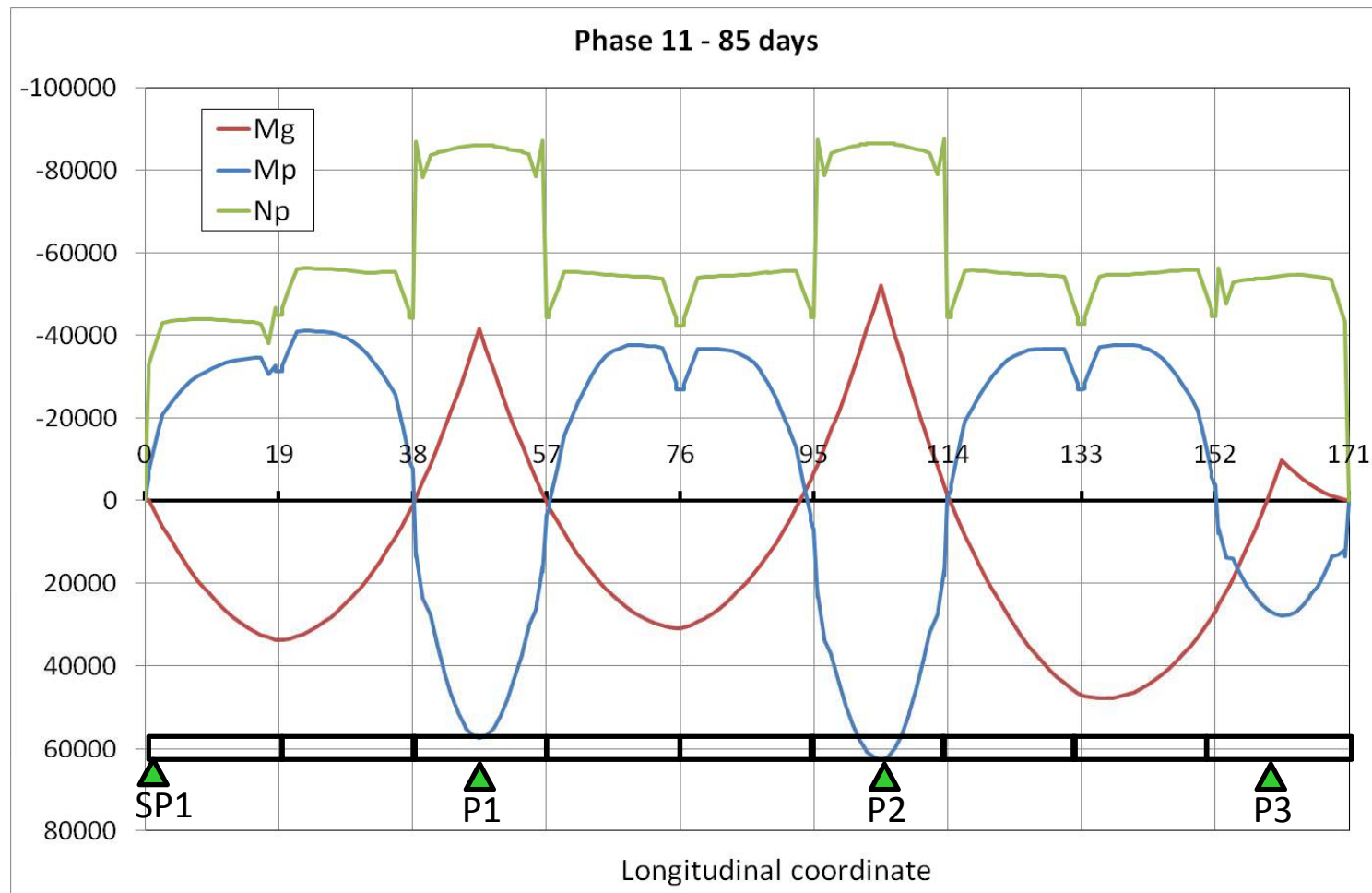
C. Tensioning tendons E3-1 to E3-8



Phase 11: 85 days

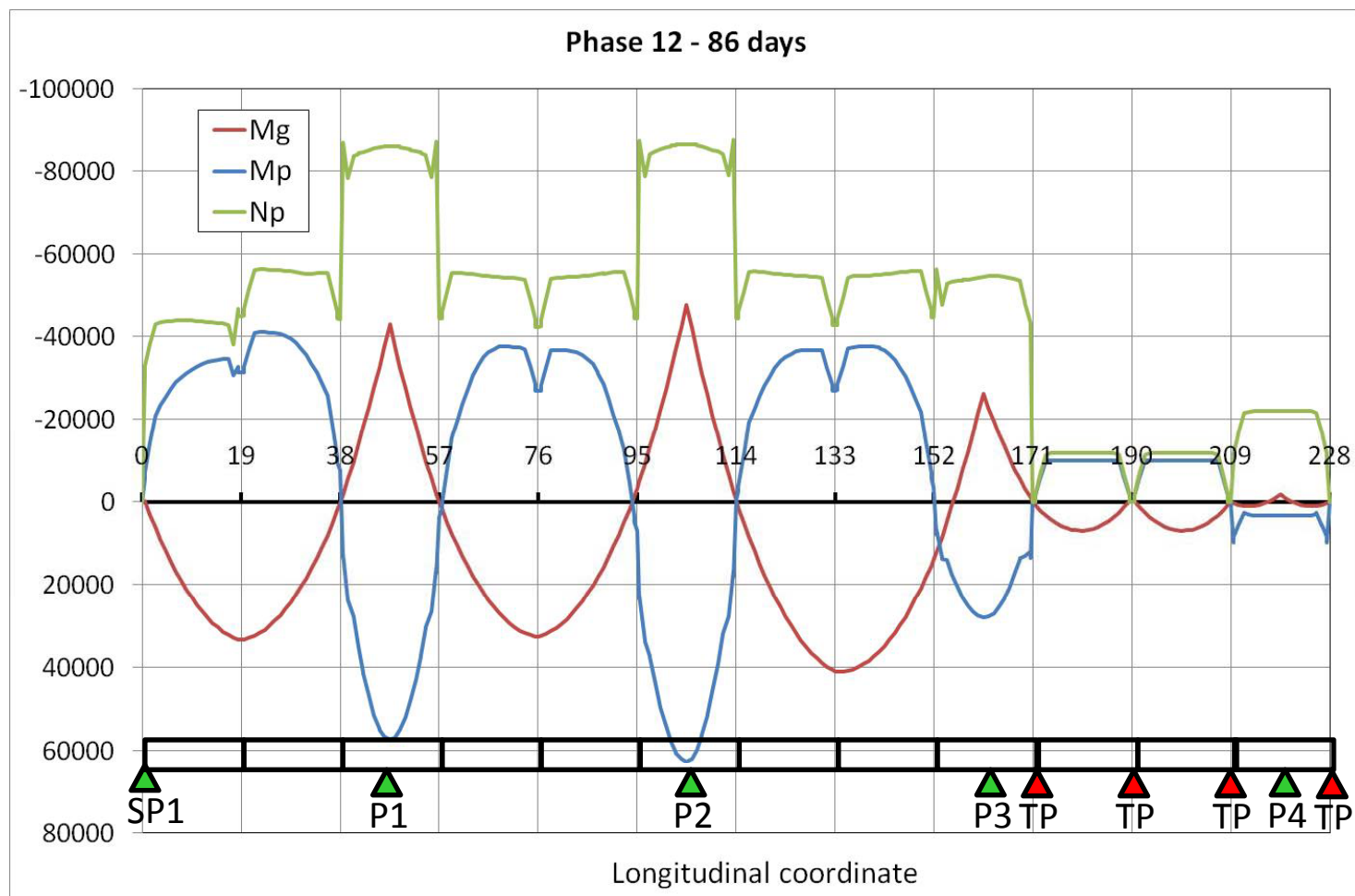
A. Tensioning of tendons F3-1 to F3-8 P2-P3

B. Removal of temporary piers of span 3 C. Tensioning tendons E3-1 to E3-8



Phase 12: 86 days

Positioning of precast elements of span P3-P4 and concreting of relative transverse beams

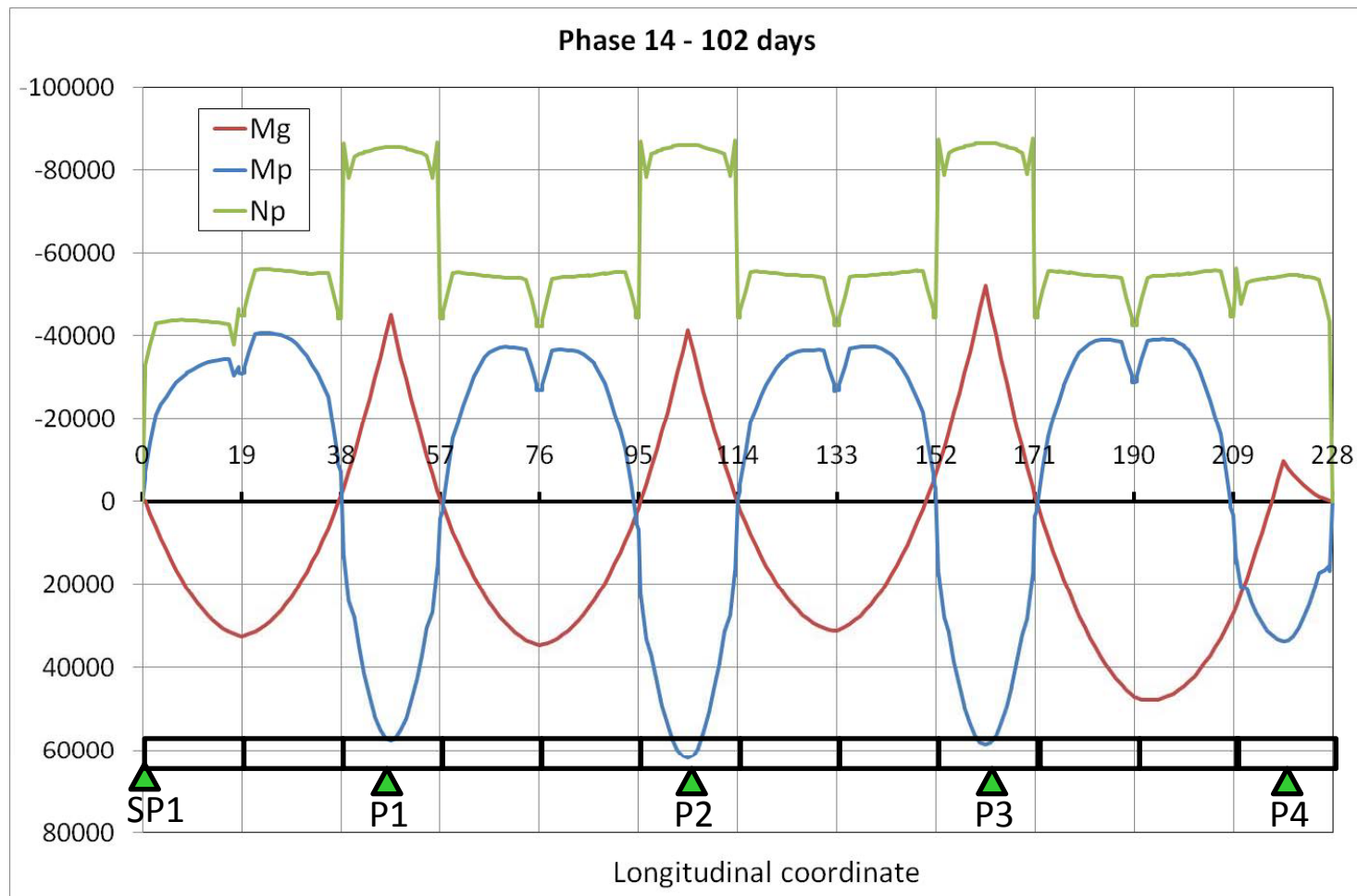


Phase 14: 102 days

A. Tensioning of tendons F4-1 to F4-8 P3-P4

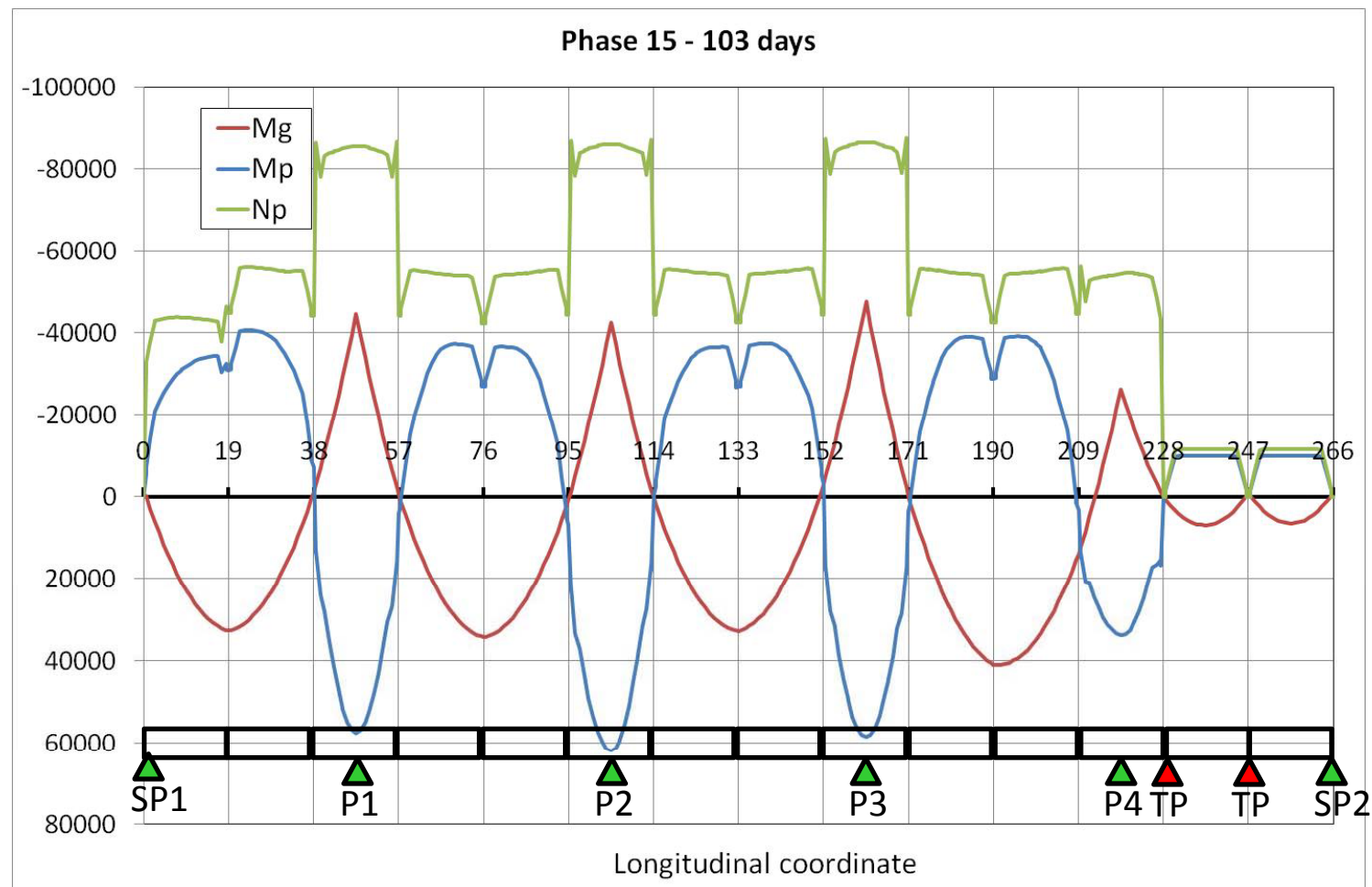
B. Removal of temporary piers of span 4

C. Tensioning tendons E4-1 to E4-8



Phase 15: 103 days

Positioning of precast elements of span P4-SP2 and concreting of relative transverse beams

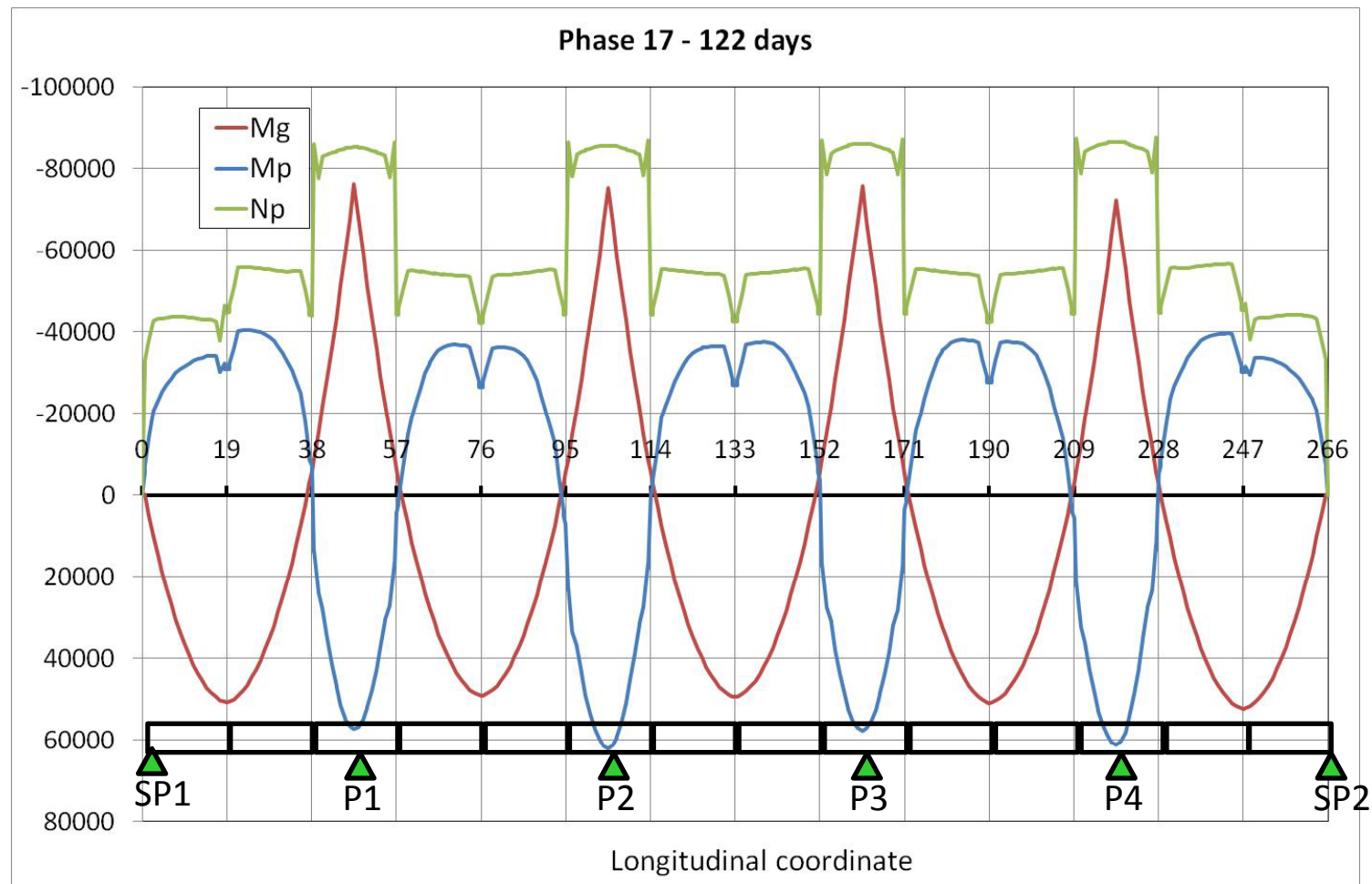


Phase 17: 122 days

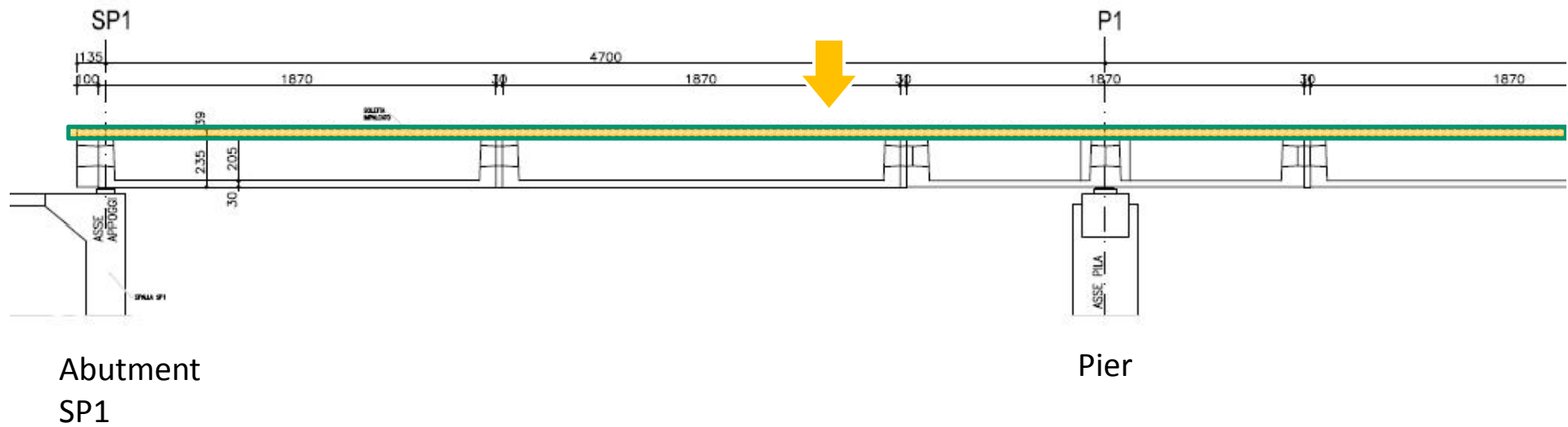
A. Tensioning of tendons F5-1 to F5-8 P4-SP2

B. Removal of temporary piers of span 5

C. Tensioning tendons E5-1 to E5-8

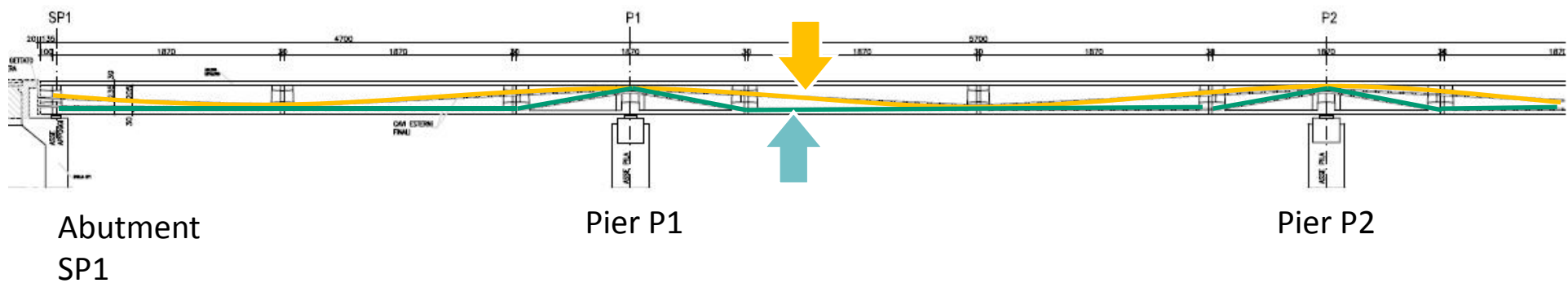


Phase 18: Slab concreting



Phase 19:

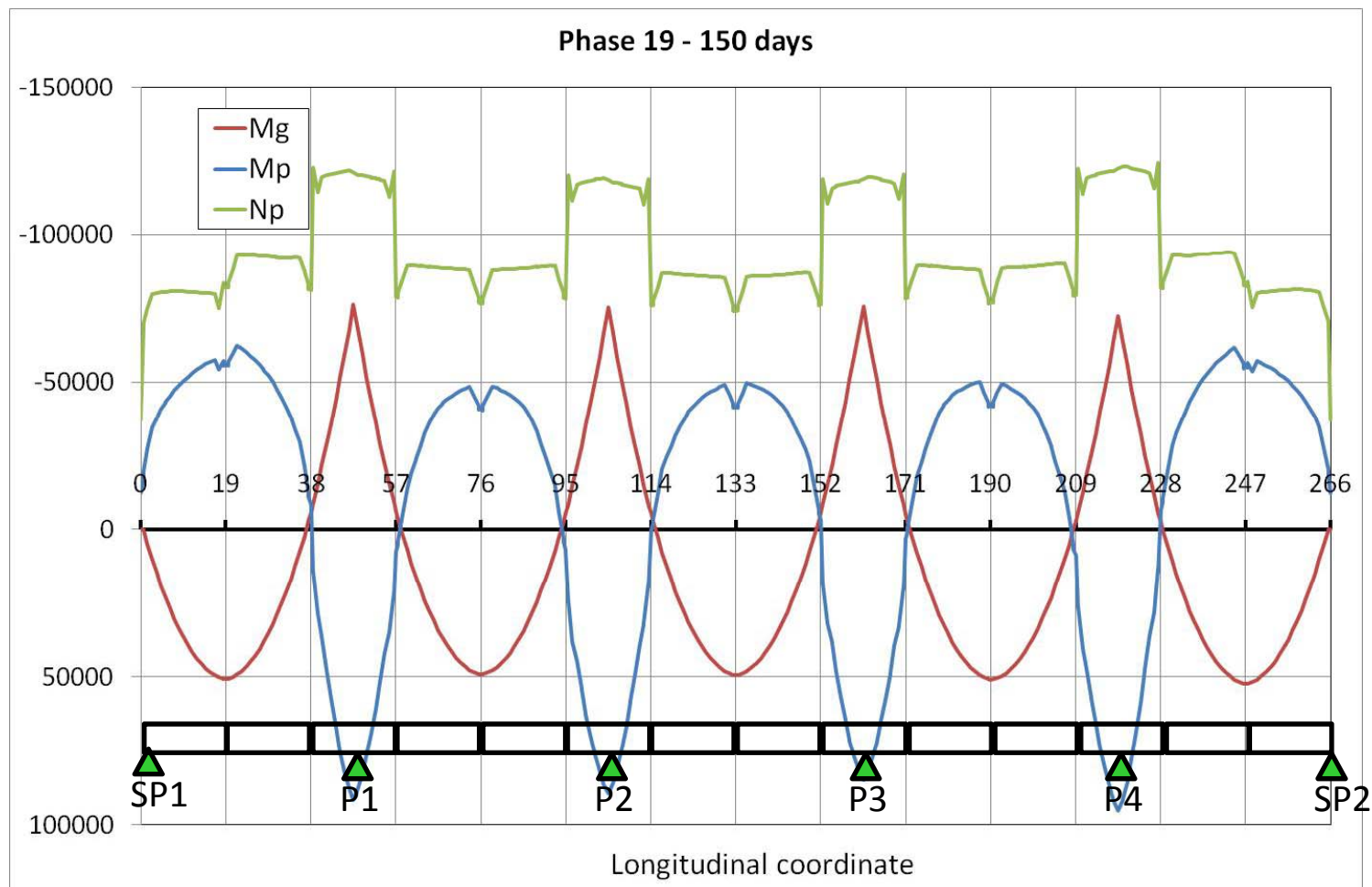
- A. End of slab hardening - change of centroid positions
- B. Tensioning of tendons EF1 to EF8



Phase 19: 150 days

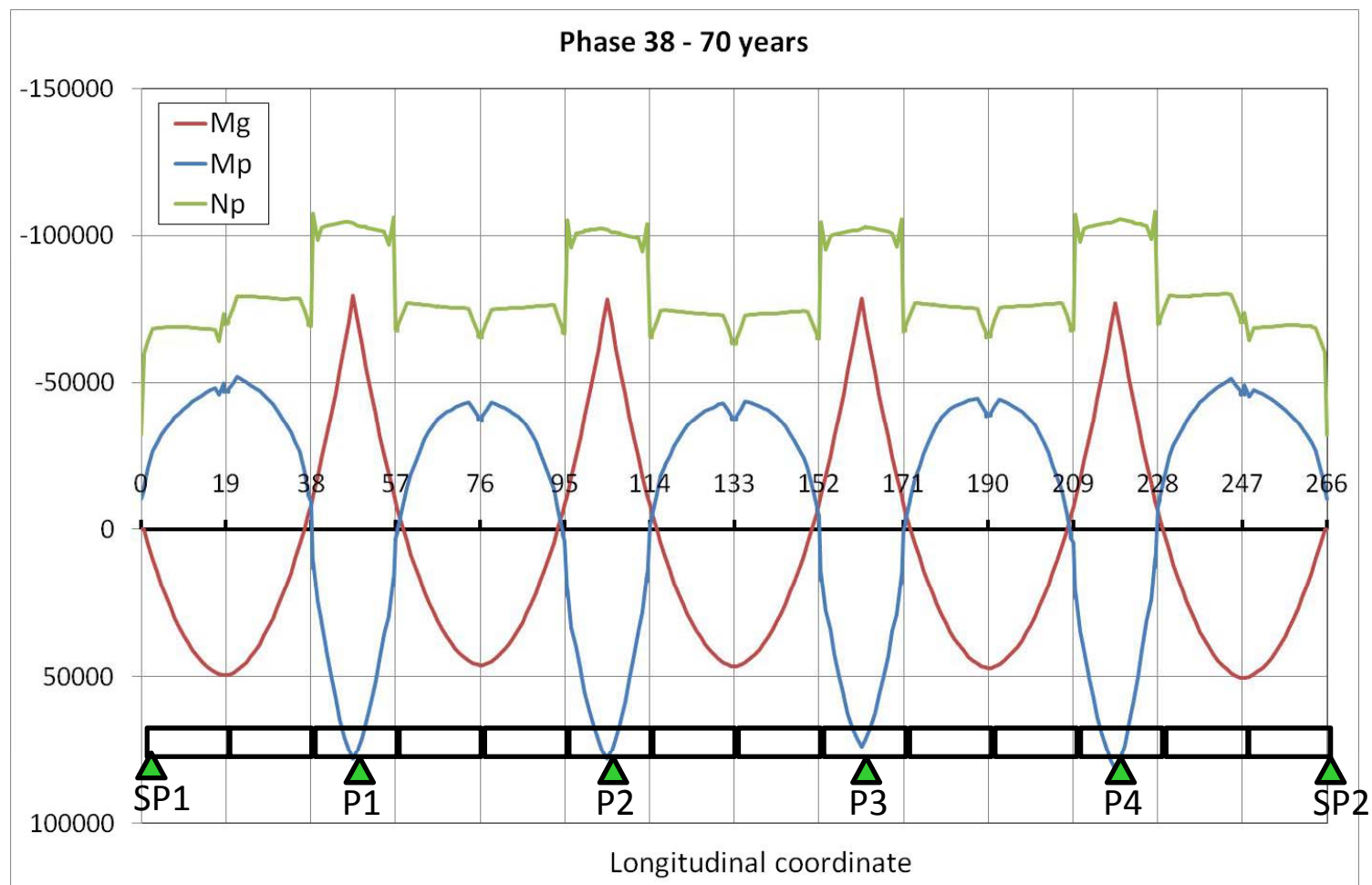
A. End of slab hardening - change of centroid positions

B. Tensioning of tendons EF1 to EF8



Phase 38: 70 years

End of analysis for time dependant behaviour



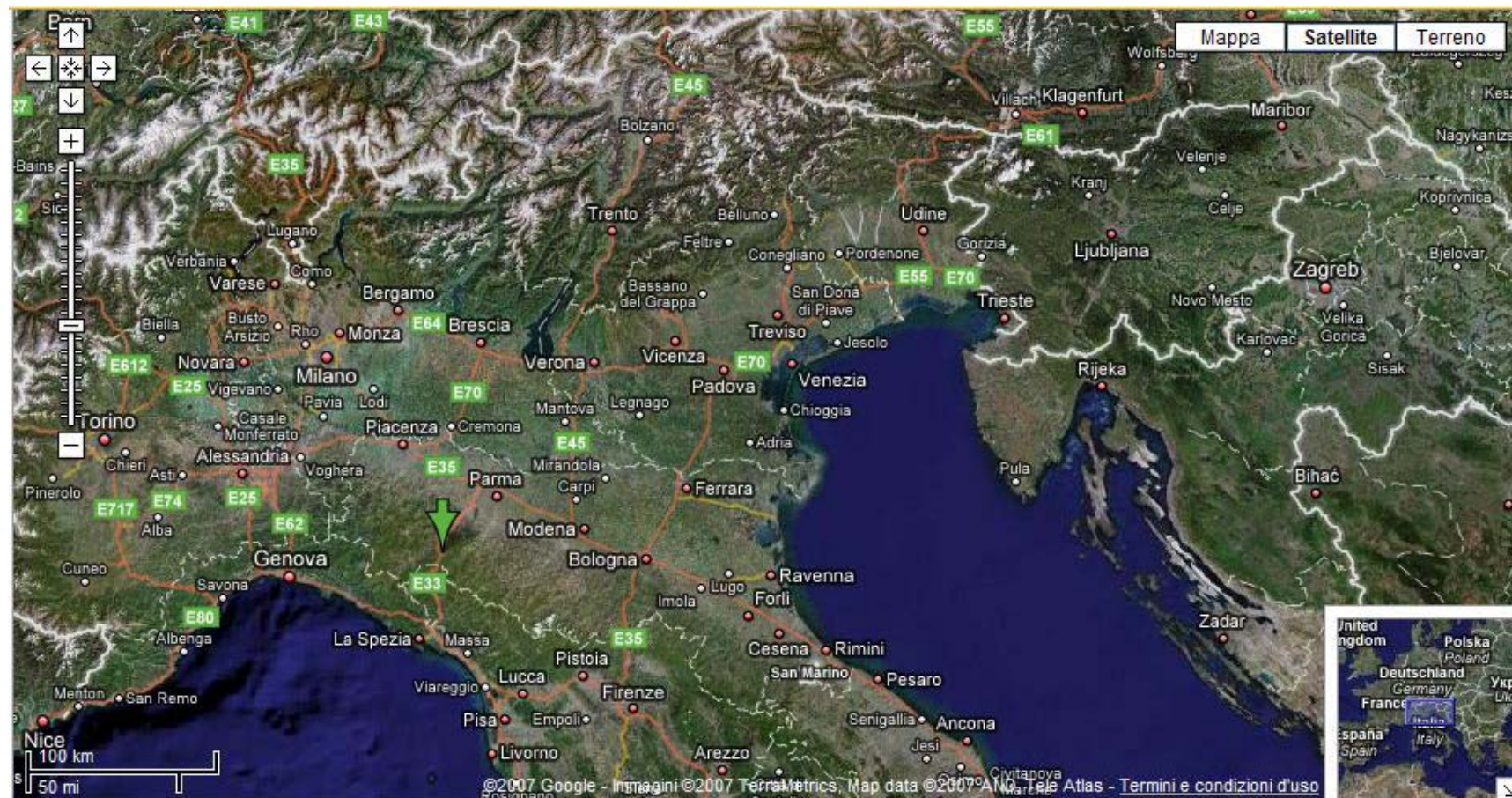
ROCCAPREBALZA VIADUCT

***Composite box-girder continuous beam
on slender piers***



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Geographical positioning







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Conceptual design

Three possible solutions

Segmental
construction with
match cast joints and
use of launching
girder



Very high cost of
launching girder
(vertical hinge)

Classical cantilever
cast in situ segments
and mixed
prestressing
(internal/external)



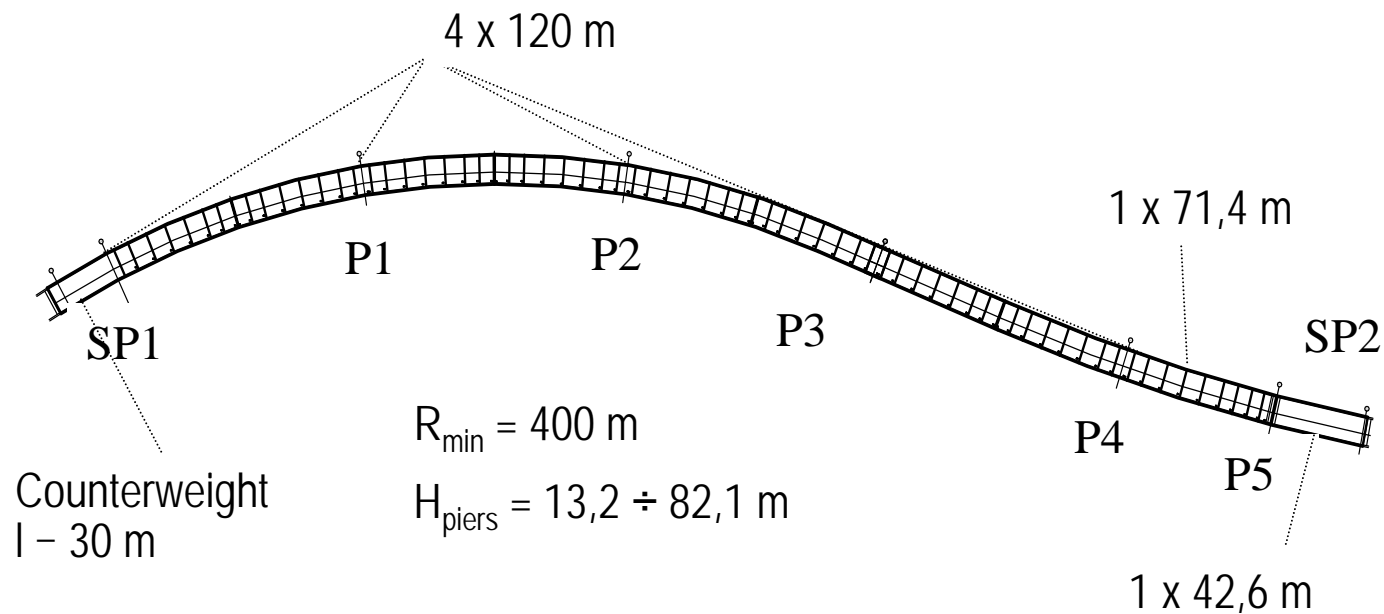
Too long construction
time (only one couple of
scaffolding compatible
with the total cost)

Classical cantilever
with composite deck
and mixed
prestressing
(internal/external)

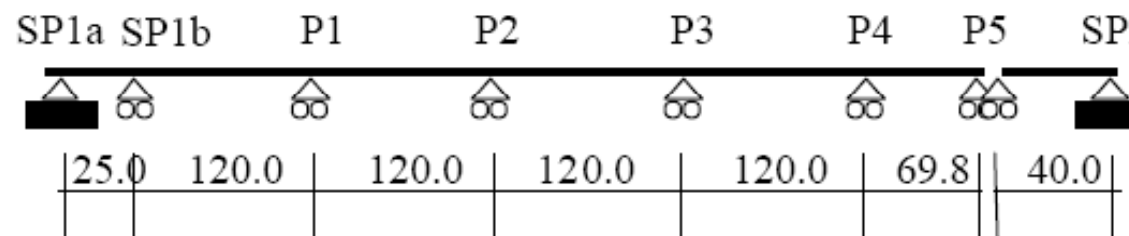


Reduction of execution
time and elimination of
launching girder
(mounting with tower
cranes used for the pier
construction)

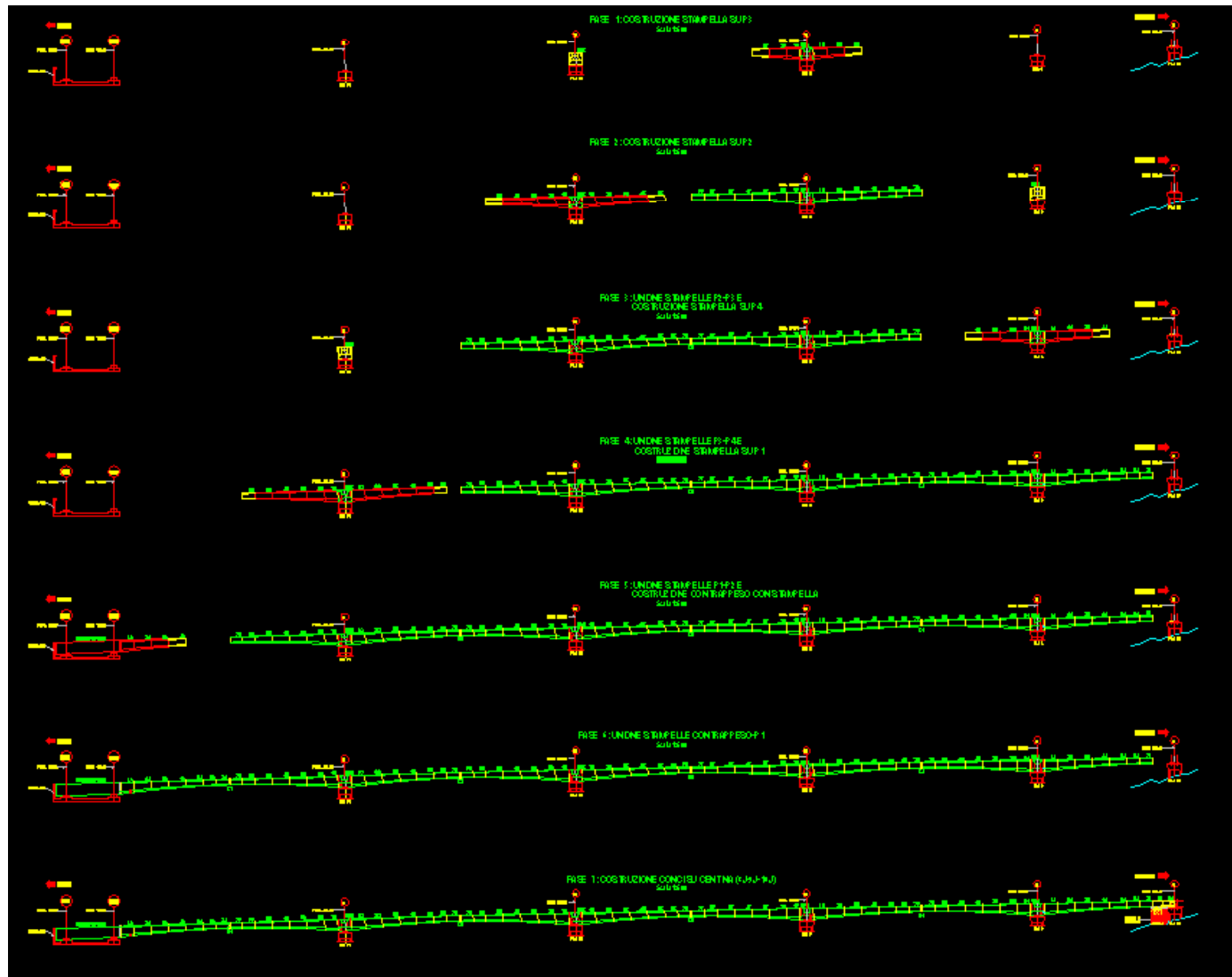
Top view of viaduct



Static scheme



Construction phases



ROCCAPREBALZA VIADUCT

Deck construction procedure

Deck construction procedure

1 PIER SEGMENT

1a Positioning of steel box pier segment
(formwork for concrete diaphragm casting)

1b Connection to the pier body with vertical prestressing to
grant robustness during the construction



Pier segment steel frame



1a Positioning of steel box pier segment



1b Prestressing connecting the hammer to the pier



Pier segment: detail of the anchorages of external tendons

Deck construction procedure

2

Webs assembling by bolts and adjustment/stiffening by temporary ties



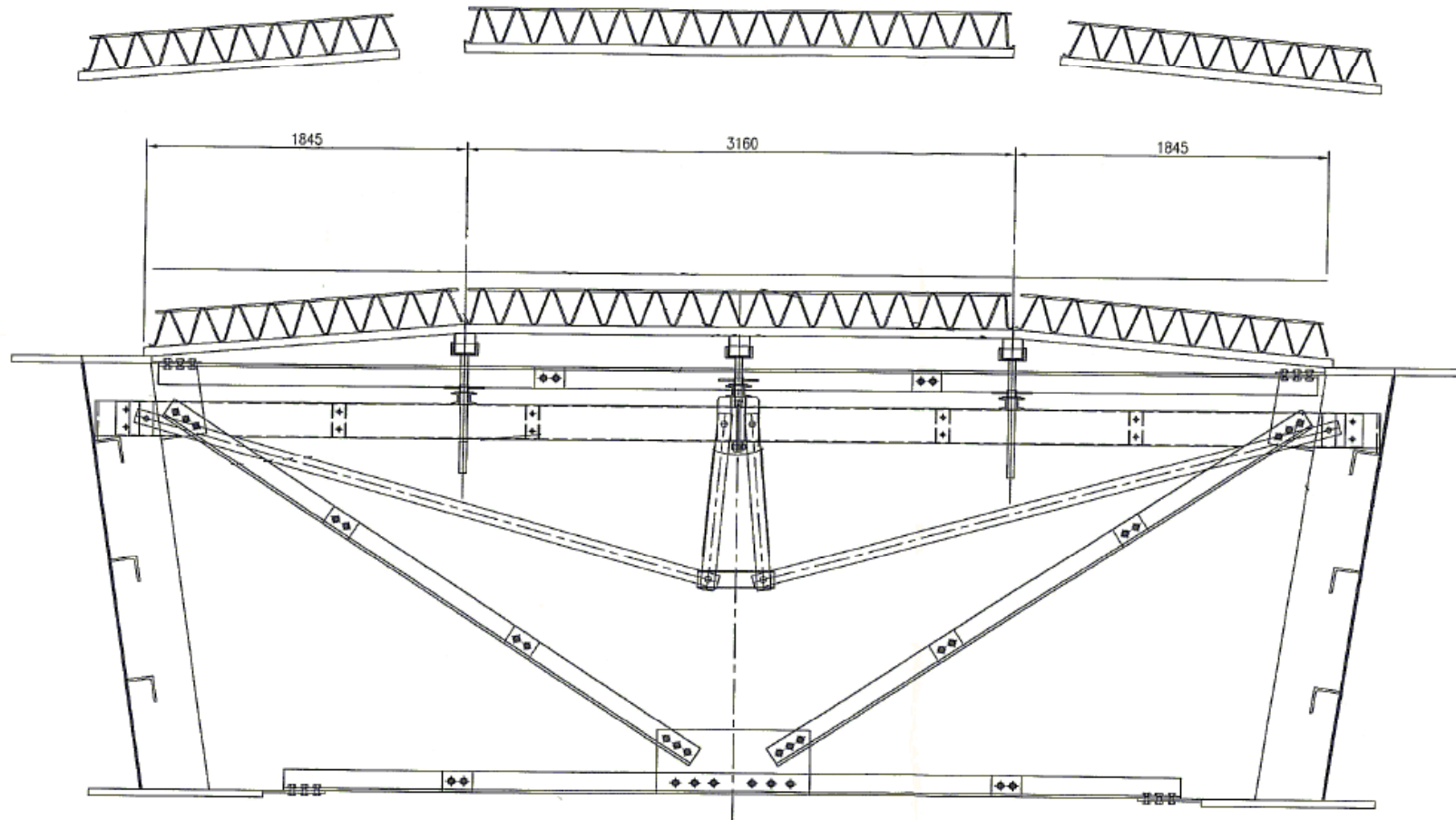


Hammer construction procedure

3 SLABS

3a Positioning of precast slabs (60 mm, stiffened by steel lattice) on the bottom chord serving as formwork for the casting

3b Assembling of scaffolding and formwork for casting of top slab



3b Top slab internal scaffolding



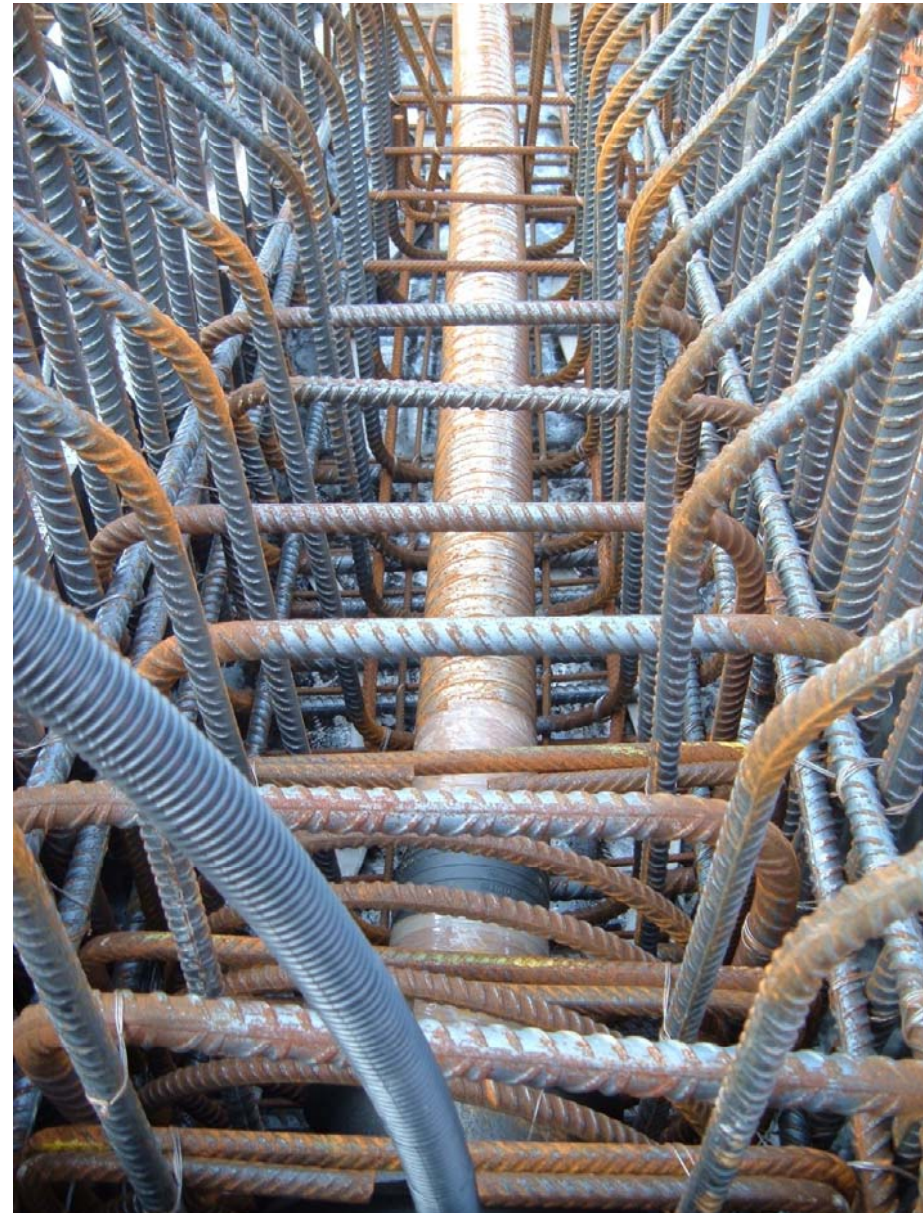
3b Top slab internal scaffolding

Deck construction procedure

- 4** Insertion and tensioning of internal tendons anchored in precast blocks designed with indented construction joints (EN 1992-1-1 and EN 1992-2)



Layout of the
connection
reinforcement
between precast
anchorage blocks and
upper slab.



Deck construction procedure

- 5** Repetition of previous operations working in parallel on several piers



...even in severe weather conditions
(500 m on the sea level in northern Italy)



Deck construction procedure

6

Planimetric/altimetric
adjustment



Cantilevers
supported on jacks
during the
construction

Connection of adjacent cantilevers and casting of the
keys



Alignment of bolted joint on webs between two segments

Deck construction procedure

- 7 Placement and tensioning of external tendons
(50% of final force)





Pay attention to the geometrical interferences between
external tendons and stiffeners

Transversal truss
stiffeners detail.

Longitudinal spacing =
3m

The shape of plenty of
them is modified to
avoid external tendons
geometrical
interferences.

(See arrows in the
picture beside and in
the previous slide)



External tendons
deviators detail.

Trumpeting of the
extremities and contact
localization



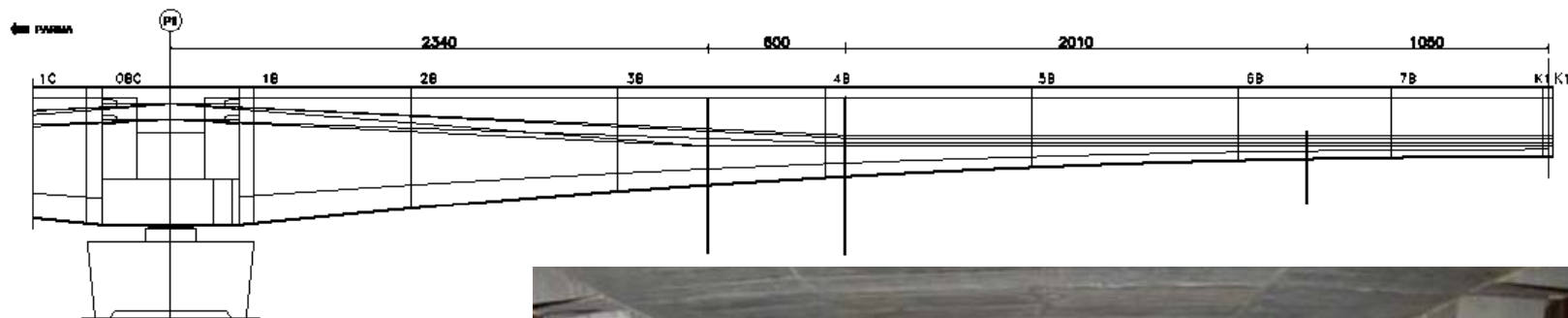
Deviators pipes.

Pay attention to the tube
orientation, they're not
symmetric!



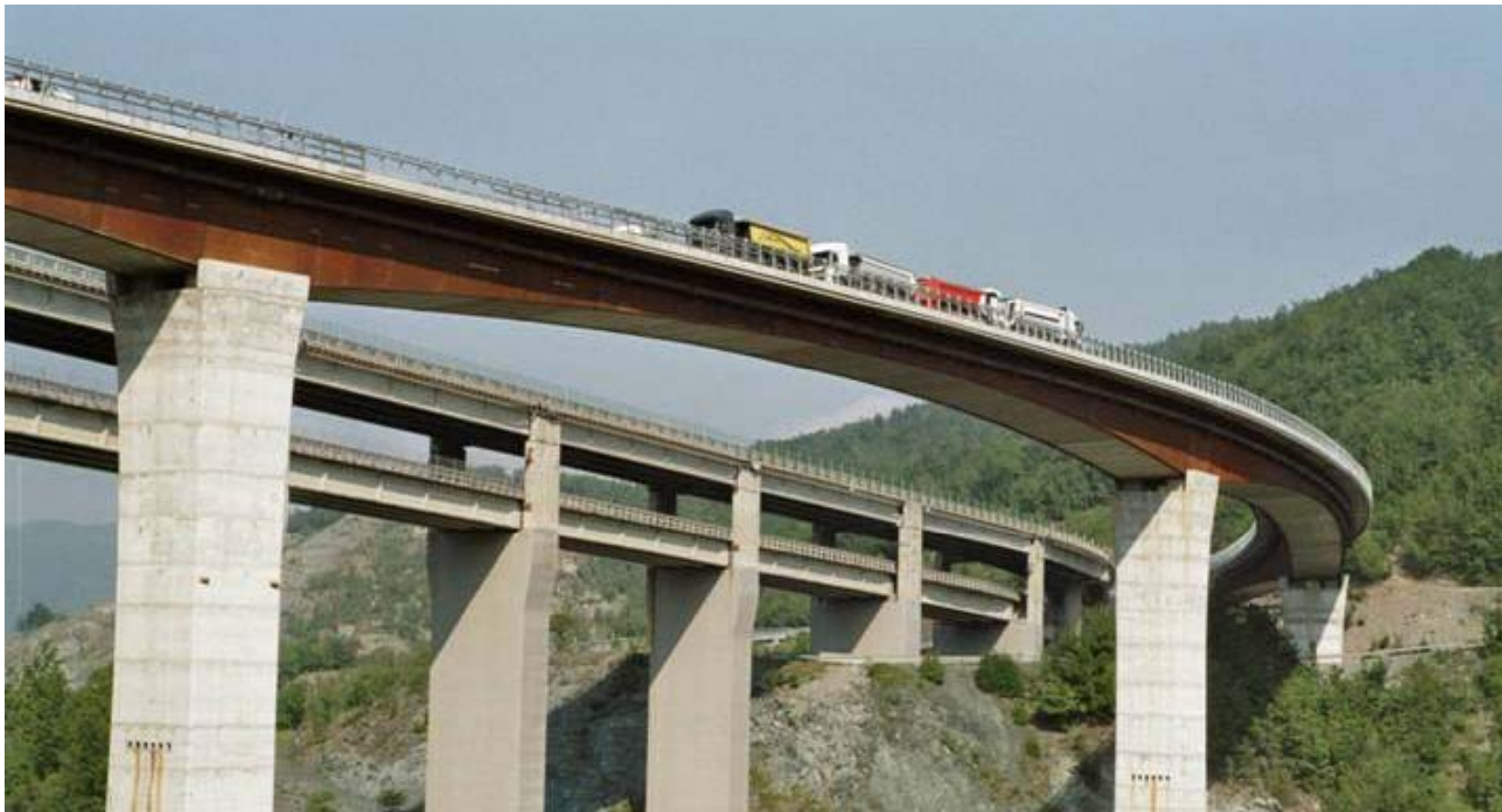
Deck construction procedure

8 Completion of tensioning on the final static scheme



Deck construction procedure

9 Static check before opening





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Design aspects

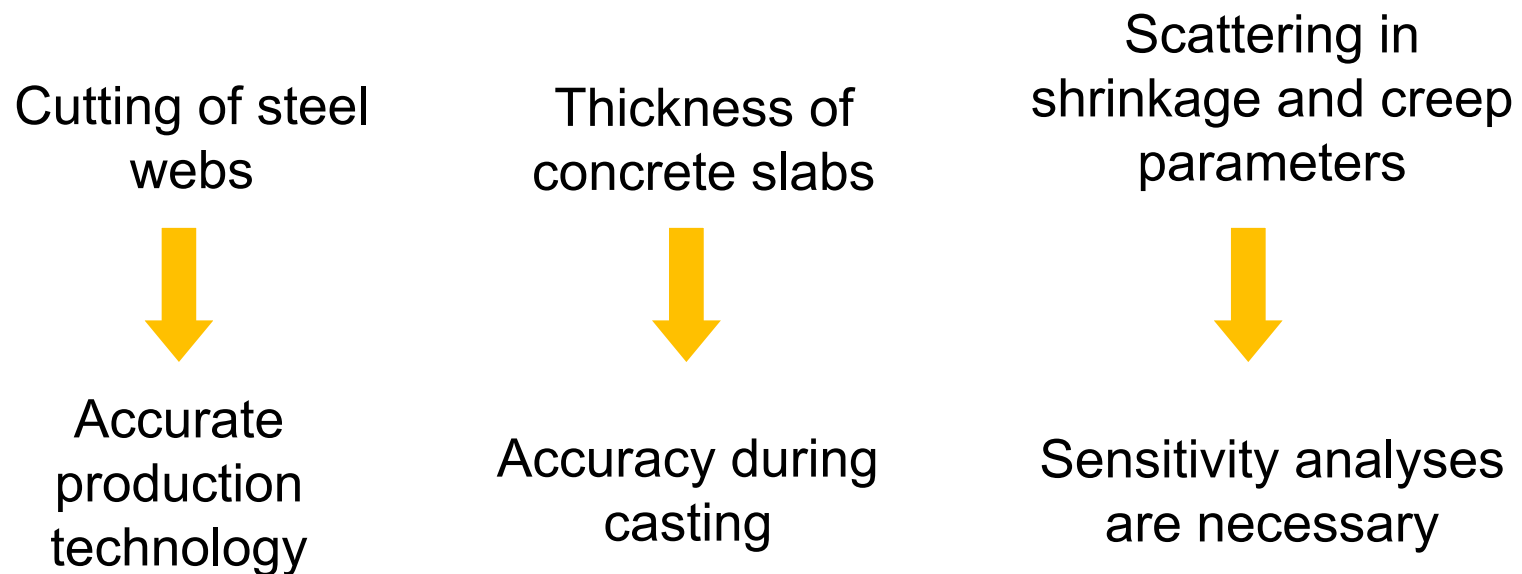
Design aspects

1. Cumbering
2. Stress redistribution due to creep

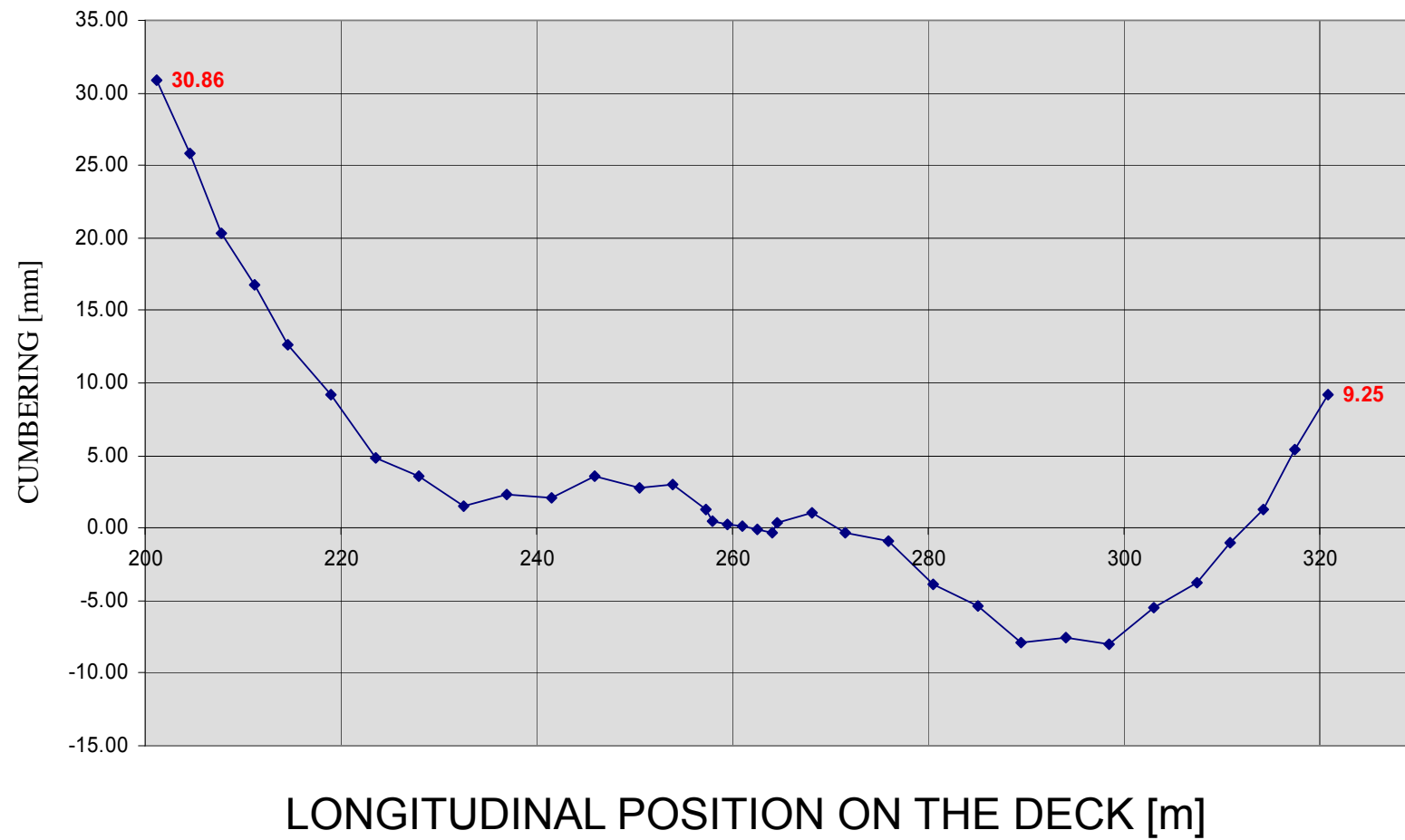
1 Cumbering

Cumbering \Rightarrow Function of construction sequence

Compensation of construction errors



Cumbering of hammer on pier P1



2 Stress redistribution

Redistribution of internal actions, both within the section and within the whole structure, due to the rheological behaviour of concrete



Heterogeneous structure

Principles of linear viscoelasticity **CAN NOT** be used



General method (Step by step analysis / EN 1992-2)

$$\varepsilon_c(t) = \frac{\sigma_0}{E_c(t_0)} + \varphi(t, t_0) \frac{\sigma_0}{E_{c28}} + \sum_{i=1}^n \left(\frac{1}{E_{cti}} + \frac{\varphi(t, t_i)}{E_{c28}} \right) \Delta \sigma(t_i) + \varepsilon_{cs}(t, t_s)$$



Strong redistribution in time of internal actions

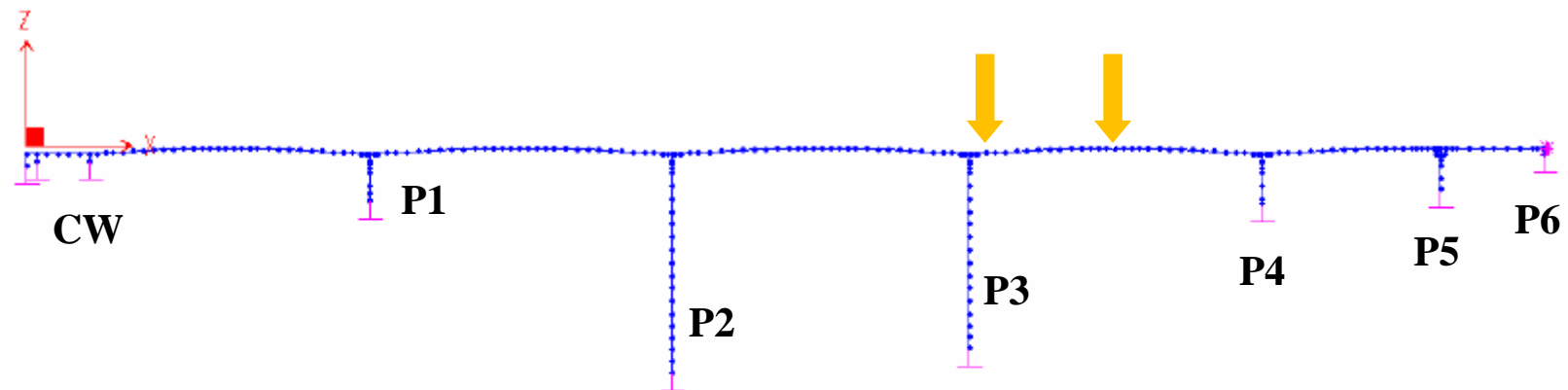
Stresses evolution in 4 representative points of 2 sections:

Section 114 :

1st segment after pier segment of pier n°3

Section 128 :

mid-span segment of span between piers n°3 and 4



Two different models were used to analyze the construction phases:

1st Model :

Detailed construction of each single hammer

2nd Model :

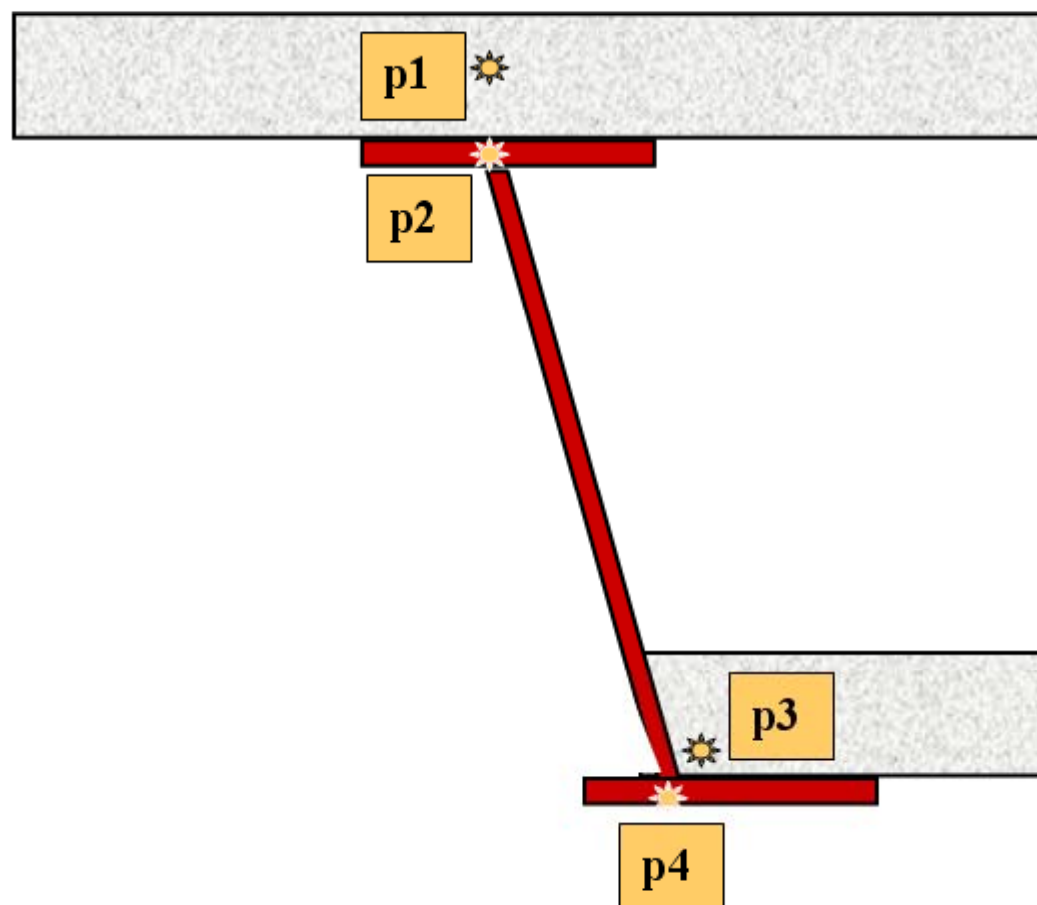
Global assembling of each hammer into the whole structure

The two models have different time histories:

The first one is focused on segments construction and is very detailed. A different analysis is performed for each pier.

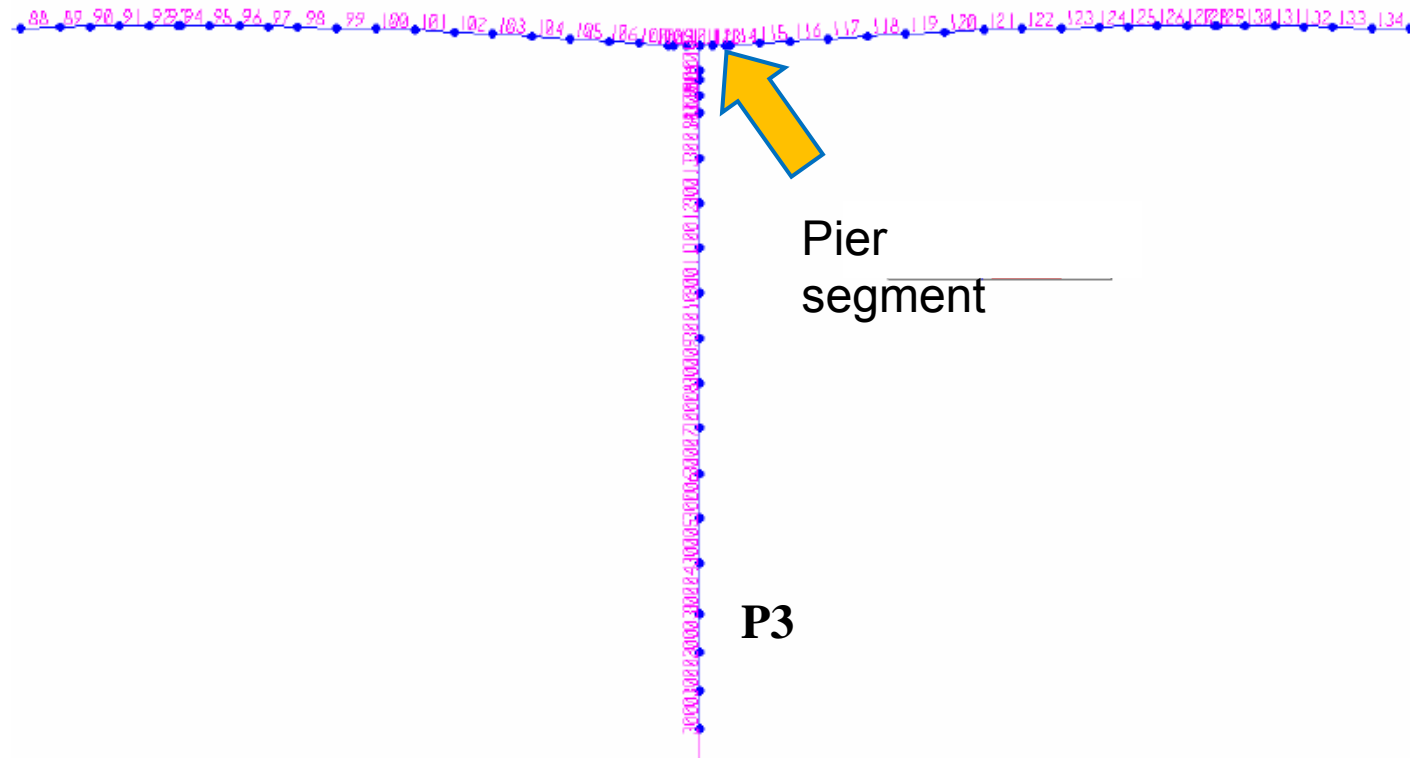
The second one is focused on hammer connection and long term behavior of the structure.

Representative points

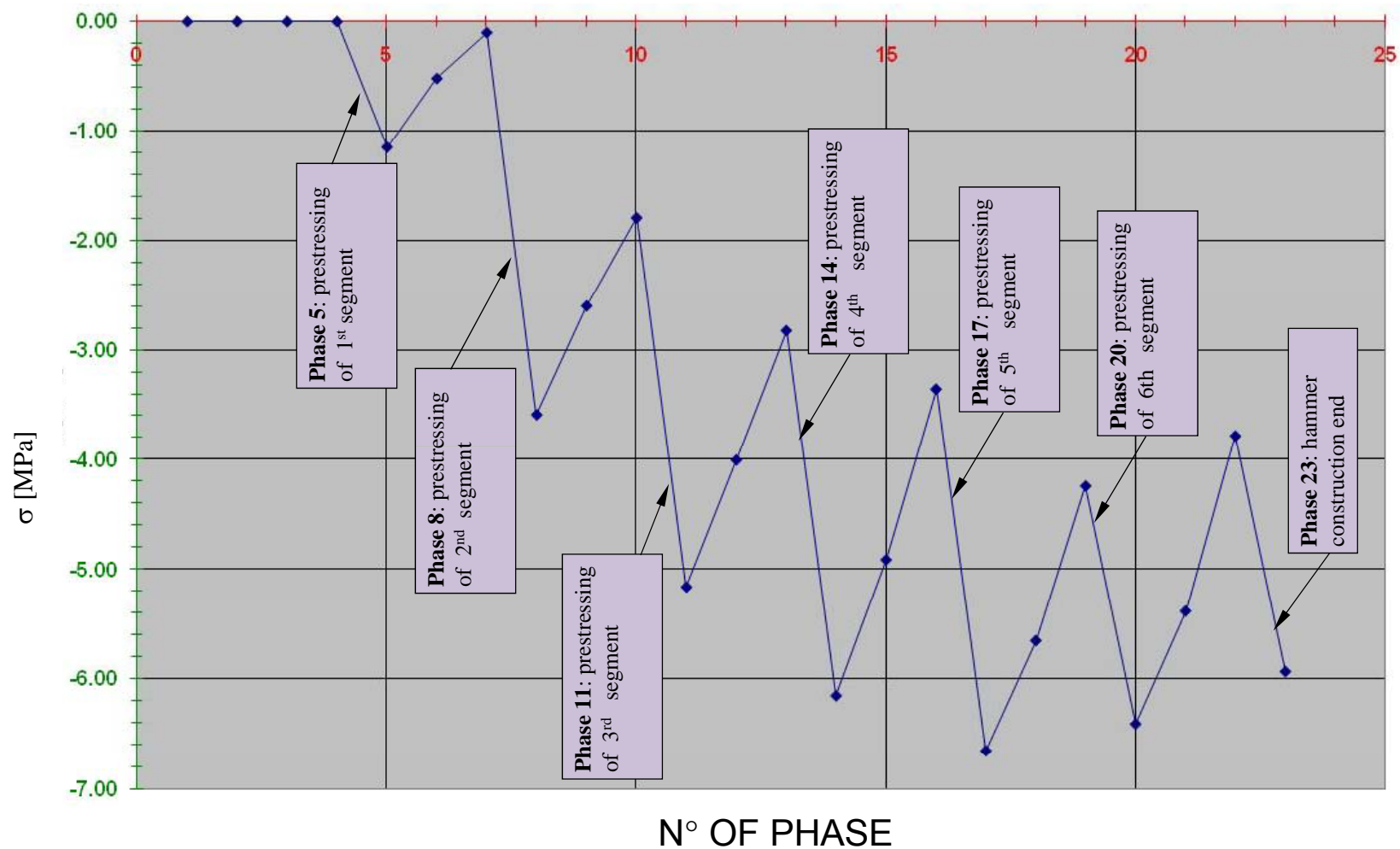


1st Model

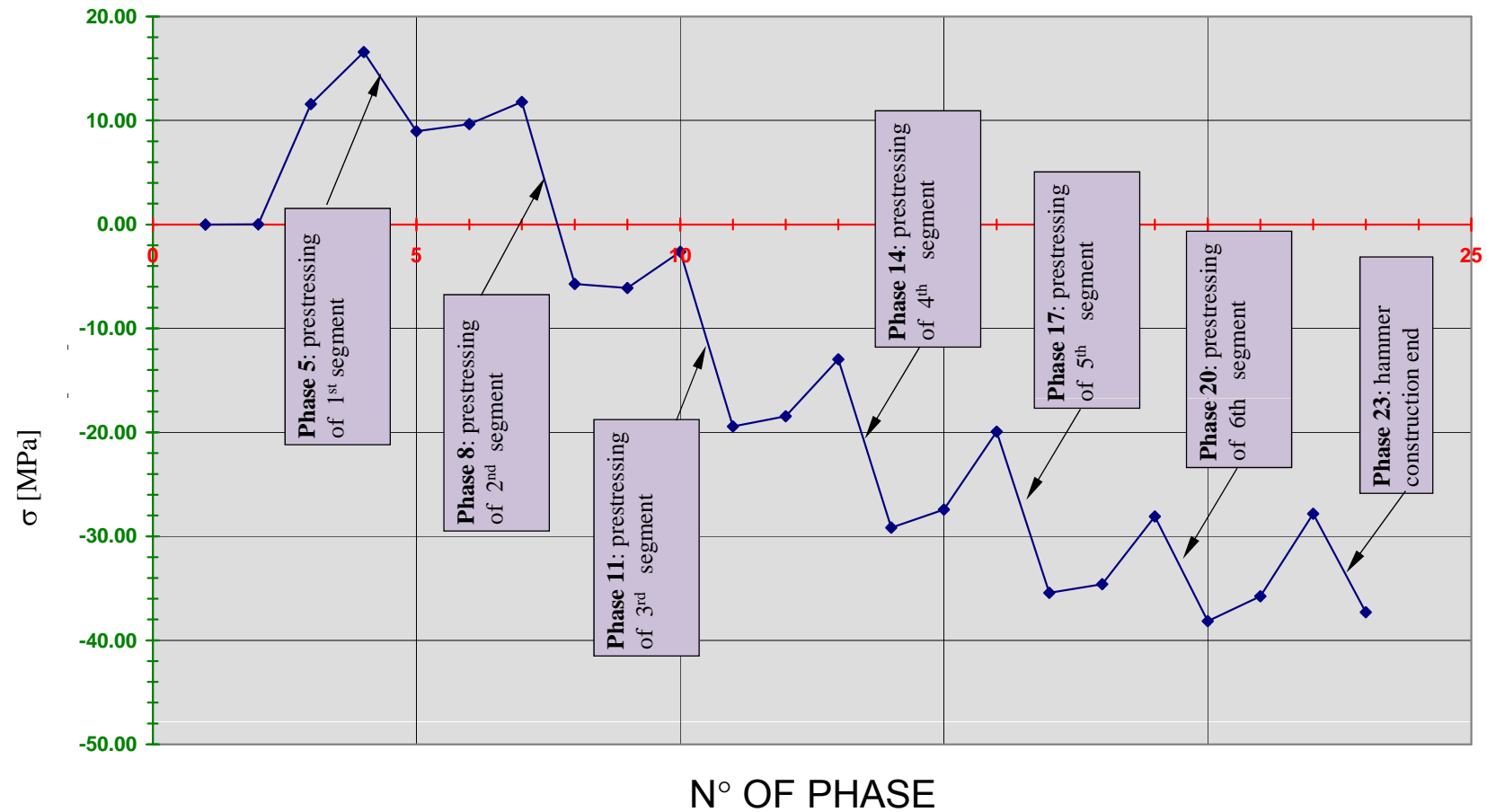
Stresses during construction phases of hammer P3 isolated



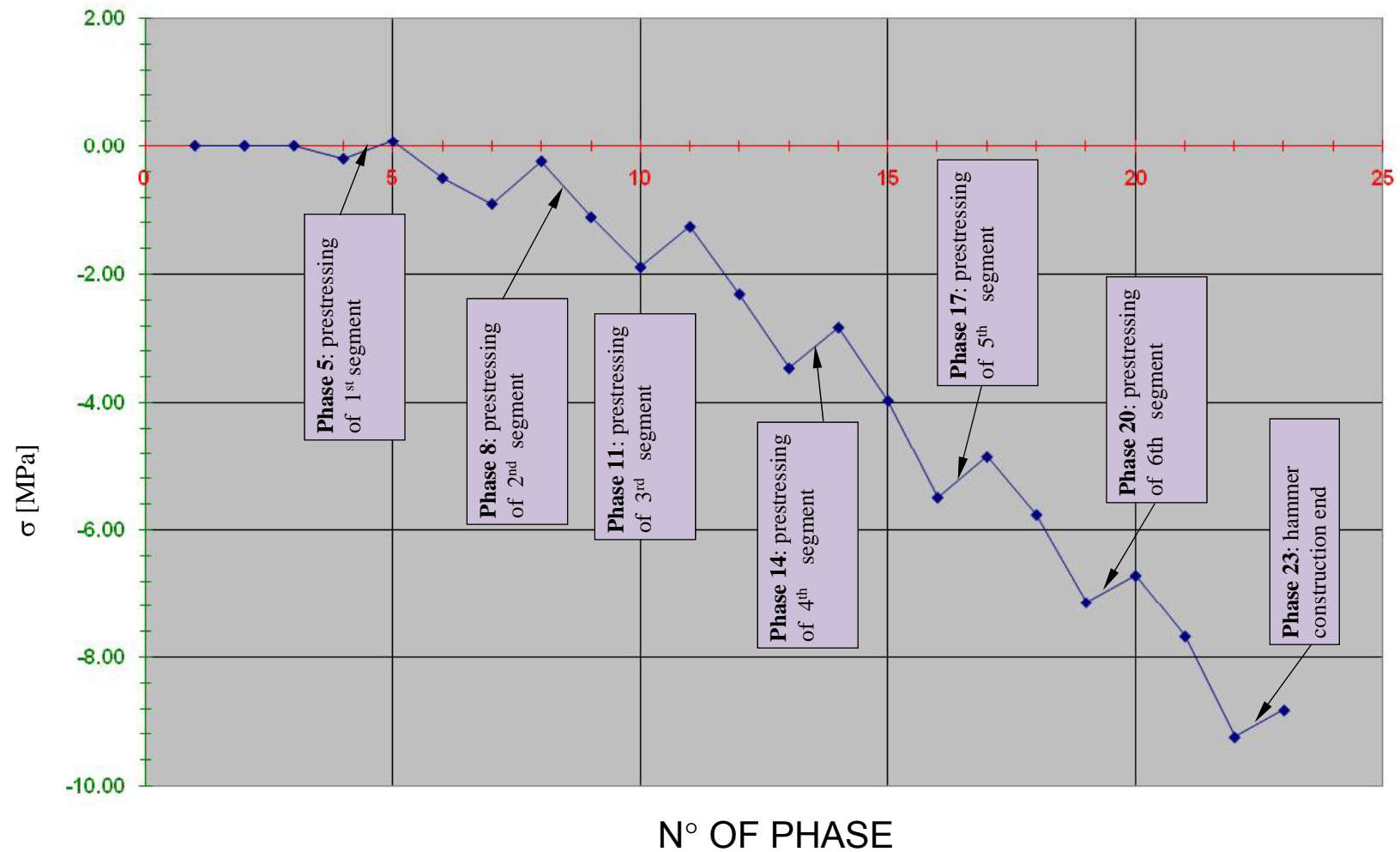
Pier segment : p1 - Concrete top flange stress



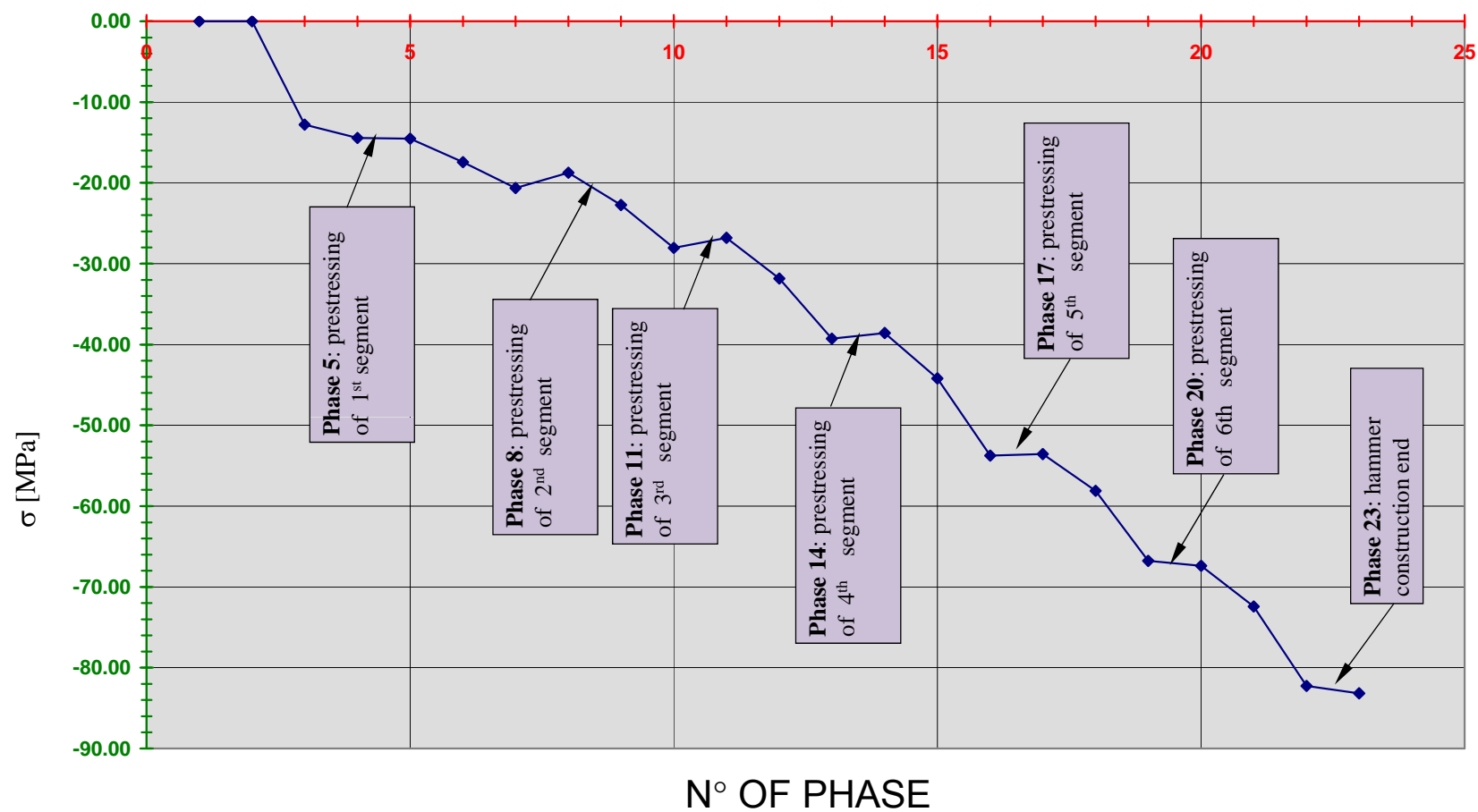
Pier segment : p2 - Iron top flange stress



Pier segment : p3 - Concrete bottom flange stress

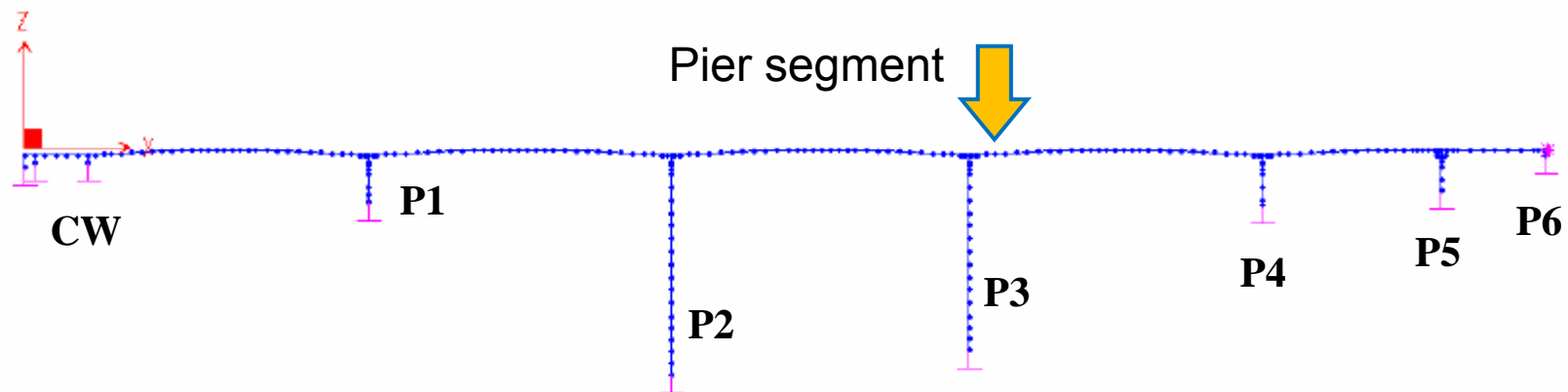


Pier segment : p4 - Iron bottom flange stress

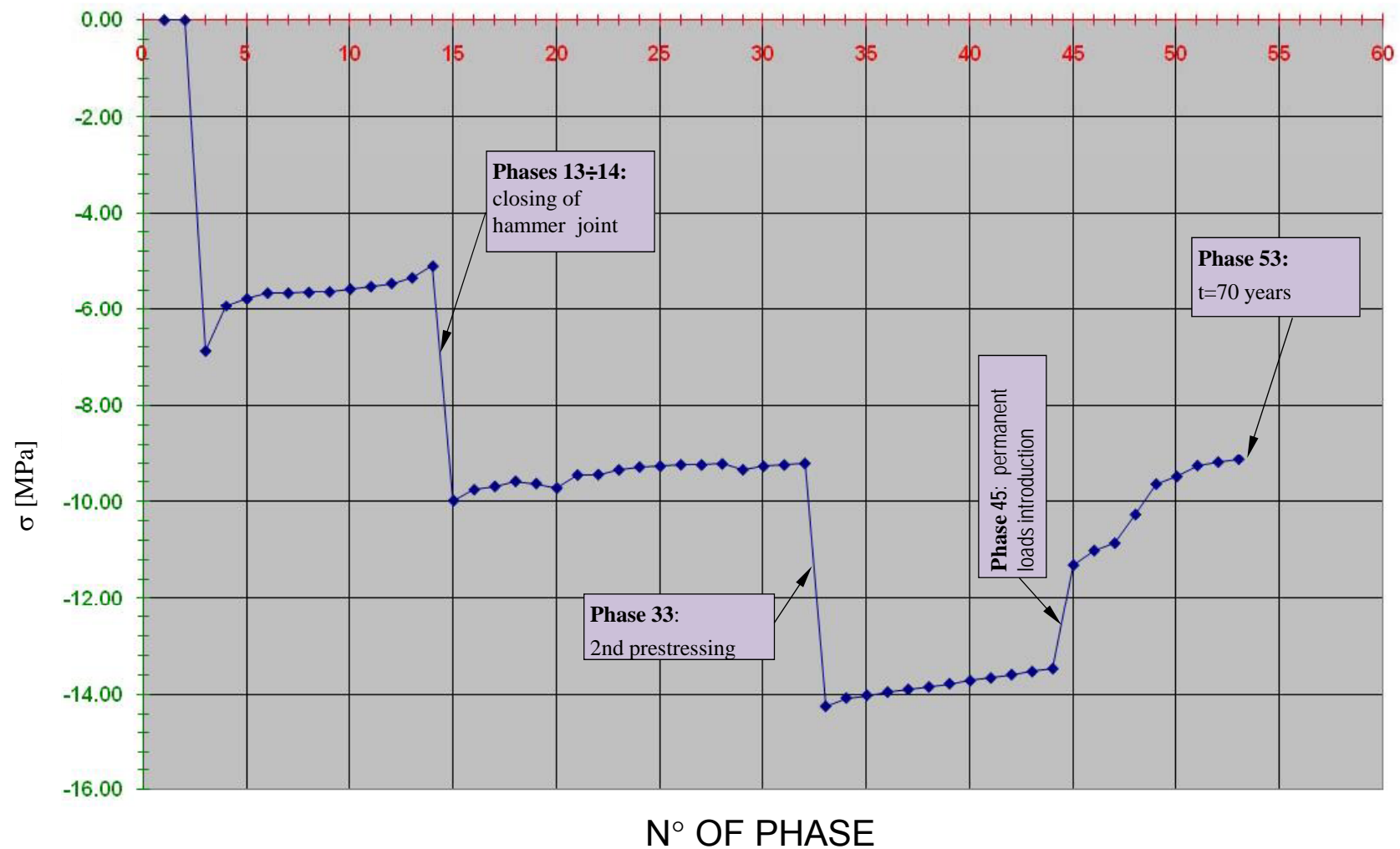


2nd Model

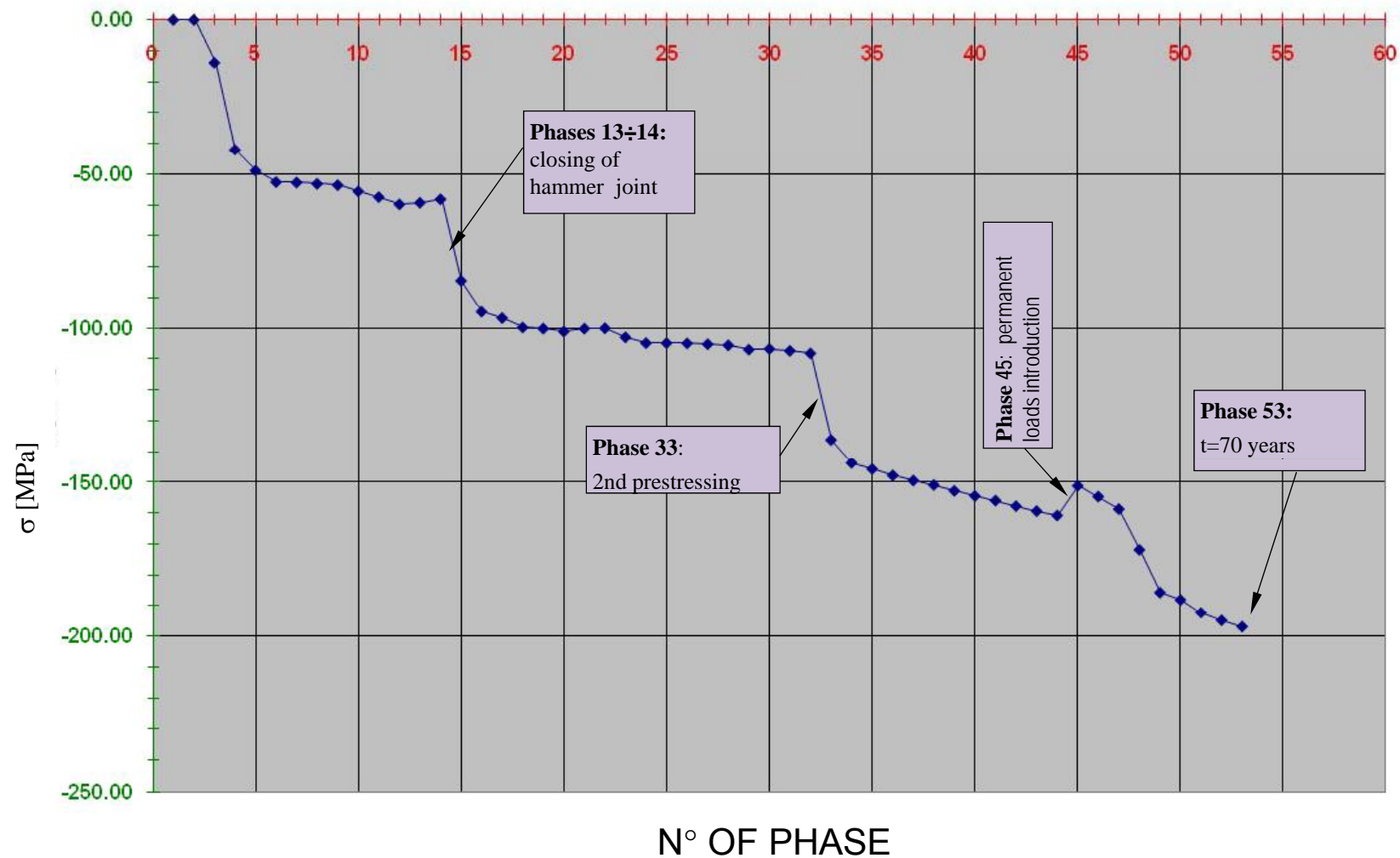
Stresses during construction phases after conjunction of hammer P3 with other hammers



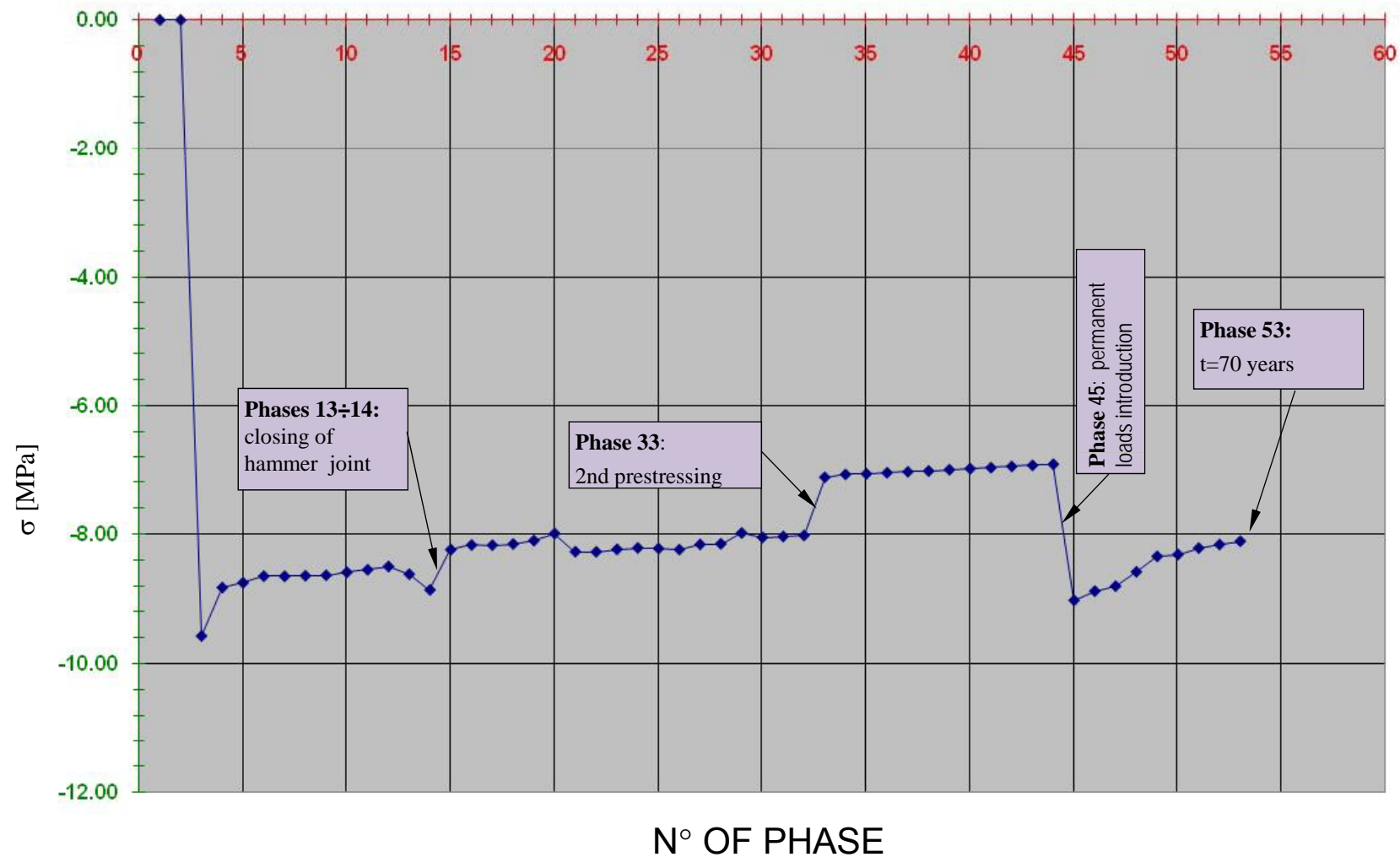
Pier segment : p1 - Concrete top flange stress



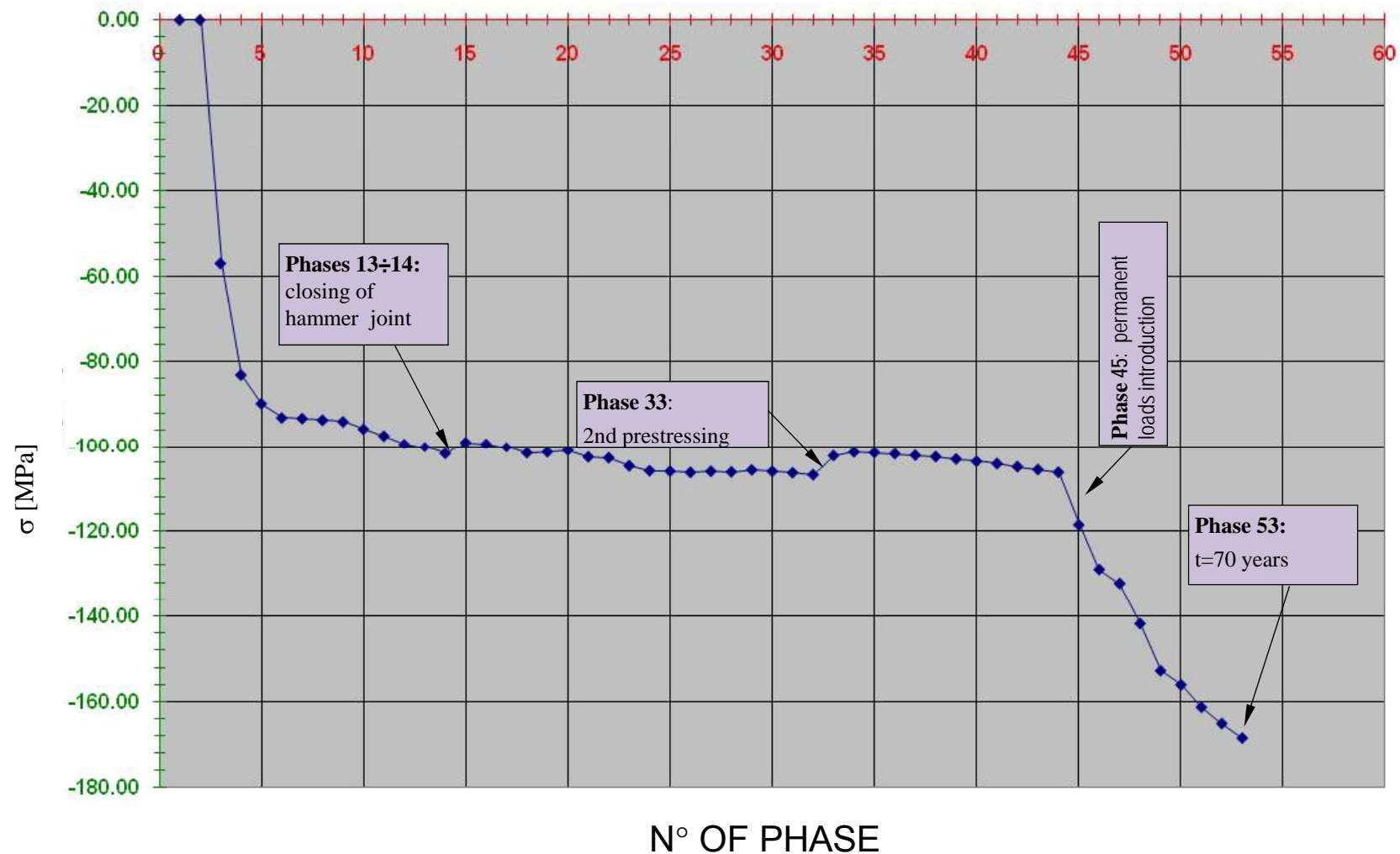
Pier segment : p2 – Iron top flange stress



Pier segment : p3 - Concrete bottom flange stress



Pier segment : p4 - Iron bottom flange stress



Sustainability aspects

Durability ⇒	No tensile stresses in concrete in SLS (Frequent combination)
Economy ⇒	Time saving and elimination of launching girder
Environmental impact ⇒	Elimination of storage areas for segments
Maintenance ⇒	Very easy inspection and control of external tendons
Rehabilitation ⇒	Substitution of external tendons without significant limitation to traffic flow

***Thank you for the
kind attention***