Example nº 11
Concrete slab bridge

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11 EXAMPLE Nº 11: CONCRETE SLAB BRIDGE

11.1 AIM

The aim of this exercise is to show the possibilities of the bridges module and the prestressed concrete module for the creation and calculation of a bridge slab.

11.2 DESCRIPTION OF THE EXAMPLE

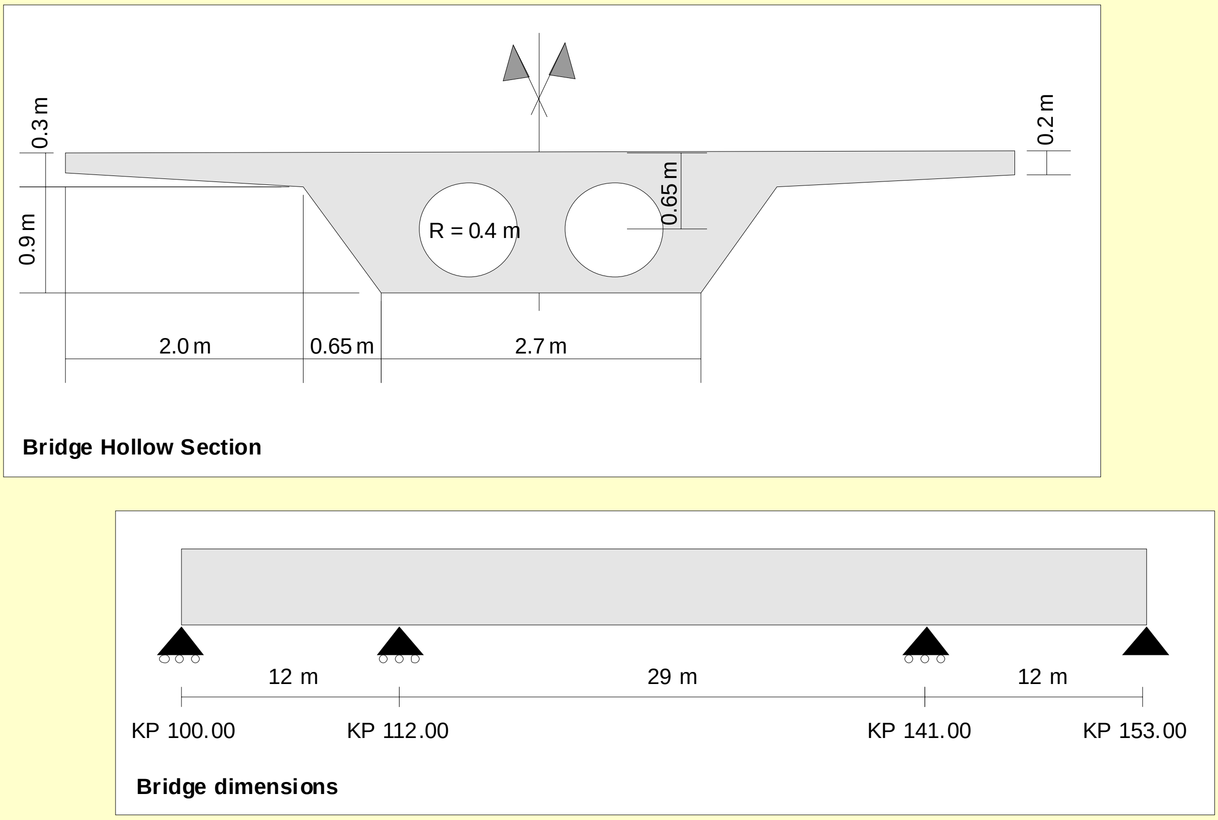
The model is a straight bridge with a concrete cross section (slab with circular holes). Two types of sections will be used, a solid one for the supports area and another one with two circular holes for the spans. The bridge has an overall length of 53 meters and is divided in three spans (a central one of 29 m and two of 12 m) and will have of six prestressing tendons.

The example includes the creatin of the bridge and the generation of the loads. The loads simple states are:

- Live load: a single heavy vehicle in a lane (heavy vehicle according to IAP code).
- Self weight.
- Dead load (mainly the board): 33200 N/m^2.
- Surface load (applied on all the board): 40000 N/m^2.
- Initial (t = 0 days) and final (t = 106 days) prestressing.
- Thermal increment of 5ºC.

These loads will be combined to obtain the most unfavourable situation, according to the loading criteria of the EHE code.

TYPE OF ACTION	Coefficients γ	
	Favourable effect	Unfavourable effect
Vehicle	0.90	1.10
Initial prestressing	0.90	1.10
Final prestressing	0.90	1.10
Own weight	1.00	1.35
Dead load	1.00	1.35
Surface load	0.00	1.50
Thermal Gradient	1.00	1.35



Structure's sketch

The used materials are:

Concrete	HA-35 (EHE code)
Passive reinforcement	S-500 (EC2 code)
	40 ϕ20 at the upper face
	14 ϕ20 at the lower face
	Mechanical cover = 5 cm
Active reinforcement	Y1860 S7 (EHE code)

For the cracking checking the following properties are considered:

Separation between bars	20 mm
ρ (effective quantity in as much by one)	104.2 (superior Armor) 212.4 (inferior Armor)

For the calculation of losses and control of the prestressed sections, the following data will be used:

Friction coefficient between tendon and casing	$\mu = 0.21$
Unintentional angular displacement	$K = 0.0126\ m^{-1}$
Anchorage slip	A = 5 mm
Area of each tendon	21 cm^2
Casing diameter	9 cm
Post-tensioning method	Tension from the initial end

The tendons in plan view are straight, parallel to the deck, at a distance of the axis of the bridge of:

Tendon	Distance
1	0.09 m
2	-0.09 m
3	1.10 m
4	-1.10 m
5	1.30 m
6	-1.30 m

(positive is considered towards the right of the axis, according to the mileage points increment).

The layout in elevation view of the prestressing tendons is the following one (referred to the section axes):

Tendons 1, 3 and 4

x (m)	0.0	4.5	12.5	27.0	41.5	49.5	53.0
y (m)	-0.613	-0.613	-0.135	-1.065	-0.135	-0.613	-0.613
Slope	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distance to next inflection point (ratio)	0.5	0.8	0.2	0.8	0.2	0.5	0.5

The location of the inflection points, in absolute coordinates of the model is:

x (m)	10.8	15.3	37.7	42.9
y (m)	-0.23	-0.32	-0.32	-0.23

Tendons 2, 5 and 6

x (m)	0.0	4.5	12.5	27.0	41.5	49.5	53.0
y (m)	-0.212	-0.212	-0.135	-1.065	-0.135	-0.212	-0.212
Slope	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distance to next inflection point (ratio)	0.5	0.8	0.2	0.8	0.2	0.5	0.5

The situation of the flexion points, in absolute coordinates of the model is:

x (m)	10.8	15.3	37.7	42.9
y (m)	-0.145	-0.320	-0.320	-0.145

The tendons are prestressed at 3125 kN relaxing the force later until it reaches 2930 kN, and then the anchorages are placed.

11.3 RESULTS TO BE OBTAINED

The aim of the example is to calculate the total vertical displacement and the maximum and minimum bending moment throughout the bridge, due to the combinations of the indicated loads. In the same way, Bending+Axial checking and cracking checking will be done according to the EHE code (for a maximum crack width of 0.3 mm).

11.4 CALCULATION LOG

11.4.1 Introduction

The reinforced concrete EHE code and the International System of units are selected.

Next, the parameters of the model (geometry) are set. This way it is easy to modify the model and adapt it to another geometry, or to test different configuration, to perform an optimisation analysis, etc.

The first step in the bridge creation is to choose the materials. The ones described in the example are selected, and the properties of these, different from the default values, are changed.

The model will be built using BEAM44 elements.

The first stage in the construction of the bridge model (after defining the materials and element type to use) is to create the cross section of the bridge. This process is done using the bridges sections library, in which the section type more suitable with the one needed is selected (type TF) and its dimensions are entered.

Then the mileage points (MPs) are defined. They are the imaginary line that constitutes the axis of the highway. In this example they will be aligned without any slope.

On this layout the bridge characteristic sections are placed. Even though only one section has been defined, it is possible to select if the section will be considered hollow or solid when it is applied on each mileage point.

From here, CivilFEM generates the bridge automatically. It is necessary to specify that it is a beam model. For the definition of the model, CivilFEM will create all the necessary entities automatically. It will introduce the necessary nodes and elements for the complete definition of the model, as well as the cross sections and beam properties for each of the elements.

Once CivilFEM has created the 14 cross sections, it is necessary to define the reinforcement and the cracking properties in each one of these. Since in this case these properties are equal in all the sections, a loop in *APDL* has been created (**DO* and **ENDDO* commands) that will repeat the same operations 14 times (one by section).

The boundary conditions (supports of the bridge) are placed by location. As the beams created have three nodes (the third one is used for the axes orientation) only the nodes that will be part of the structure are selected (located on the Y = 0.0 m axis). Of these, the ones with supports are select (X = 0.0 m, X = 12.0 m, X = 41.0 m, X = 53.0 m) and the corresponding boundary conditions are placed.

For the definition of the prestressing tendons the tendon editor is used, for which it is necessary to capture the support beam. The tendons definition is included inside an *APDL* macro named *tendndef.mac*. The content of this macro can be completely done, in a graphical way, with the tendon editor.

Once the model has been created, the loads will be defined. With the automatic load generator it is only necessary to selecting the type of vehicle (IAP code) and apply it to a family, which was previously defined. The family of the vehicle is number 1001 and has been defined as *INCOMPATIBLE*, because the vehicle can only occupy a position in each step. CivilFEM will automatically generate all the loads states and it will introduce them in the family. The path of the vehicle is taken from the layout of the bridge of automatically (*~BRSKTCH* command defines a lines component that will be used for the loads generation).

With *~BLSOLVE* command all the load states assigned to families are solved (from 1 to 18 for the vehicle).

Next, the remaining simple load states are completed (short term prestressing actions, long term prestressing actions, self weight, dead load, surface load and thermal increment) that are sored successively in load files (*~CFLSWRT* command).

It is important to consider that after creating a load file corresponding to a simple state, it is necessary to delete the loads of the model, so that they do not also appear in the next simple state.

Finally, all the simple states are solved (from 19 to 24, because the first 18 were generated for the vehicle).

Once solved, the first step to postprocess results is to convert the family of the vehicle into a combination (it will maintain the same numbering).

Next, the combination targets are defined. CivilFEM will look for these results when combining load states.

All the necessary combinations are created according to the following scheme:

Nº	Description	Start States	Type	Nº Start States	Cf1	Cf2
1001	Vehicle Load	LS1:18	INCOMP	18	1	0
1002	Total with short term Prestressing actions	CMB1001	SELECTVC	6	0.90	1.10
		LS19			0.90	1.10
		LS21			1.00	1.35
		LS22			1.00	1.35
		LS23			0.00	1.50
		LS24			1.00	1.35
1003	Total with long term Prestressing actions	CMB1001	SELECTVC	6	0.90	1.10
		LS20			0.90	1.10
		LS21			1.00	1.35
		LS22			1.00	1.35
		LS23			0.00	1.50
		LS24			1.00	1.35
1004	Total with short term or long term Prestressing actions	CMB1002 CMB1003	OPTION	2	1.00	1.00

Combination 1001 is automatically created from the family to which the vehicle was assigned.

Load Steps 19 to 24 correspond with the following simple load states:

Nº	Description
19	Short Term Prestressing Actions
20	Long Term Prestressing Actions
21	Self Weight
22	Dead Load
23	Surface Load
24	Thermal Gradient

Finally the results are checked according to the EHE code (bending and cracking).

The checking is done for the total loads combination, in each one of its targets: maximum and minimum bending moment. Next the envelope of the checking is calculated to contemplate the two hypotheses.

In order to more accurately cover all the possible results, it would have been advisable to perform the combinations with two more targets: maximum and minimum axial force. This way the code checkings would contemplate the four hypotheses of extreme axial forces and bending moments. These calculations have not been included in the resolution in order to simplify the example.

11.4.2 Preprocess

```
  FINISH
  ~CFCLEAR,,1
  /TITLE, 'Prestressed Slab Bridge'

! SETUP
  ~CFACTIV,NLBR,Y        ! Activates Bridge Module
  ~CFACTIV,PRSC,Y        ! Activates Prestressed Module
  ~CODESEL,,EHE,EHE      ! Set EHE codes
  ~UNITS,SI              ! Set SI units

  /PREP7
! INITIAL DATA : PARAMETERS
  btop= 8                ! top width (meters)
  bm= 4                  ! medium width
  bbot=2.7               ! bottom width
  tdepth=1.2             ! total depth
  tbot=.9                ! bottom thickness
  ttop= .2               ! top thickness
  nh=2                   ! number of holes
  rholes=0.4             ! radius
  dbh=1.2                ! distance between holes
  yhole=-0.65            ! Y  hole center coordinate
  zhole=-0.6             ! Z  hole center coordinate

  lslab=53               ! slab length
  lspan_1=12             ! span 1 length
  lspan_2=29             ! center span length
  lspan_3=12             ! span 1 length

  kmo=100                ! initial km

! MATERIALS
  ~CFMP,1,LIB,CONCRETE,EHE,HA-35 ! HA-35 concrete
  ~CFMP,2,LIB,REINF,EC2,S500     ! S-500 reinforcing steel
  ~CFMP,3,LIB,PREST,EHE,Y1860S7  ! Y1860S7 prestressing steel
  ~CFMP,3,Prest,MU,,0.21         ! Friction coefficient
  ~CFMP,3,Prest,K ,,1.26e-002    ! Unintentional friction
  ~CFMP,3,Prest,A ,,5e-003       ! Anchorage slip

! ELEMENT TYPE
  ET,1,BEAM44              ! Beam44 Element type

! BRIDGE SECTIONS DEFINITION
  ~BRSSLAB,1,TF,1,bbot,bm,btop,dbh,tbot,ttop
  ~BRHL,   1,  C  ,yhole,zhole,rholes,, nh,dbh

! BRIDGE MODEL
  ~BRINIP,1,0,0,0,0,0
  ~BRADDPL,kmo-0.5,kmo+lslab
  ~BRADDEL,kmo-0.5,kmo+lslab
```

```
  ~BRSKTCH,5 ! Plots the bridge axis (MP’s path)

! Locate bridge sections

  ! Support 1
  ~BRDEF, kmo-0.5    ,1,,,,,,2
  ~BRDEF, kmo        ,1,,,,,,2
  ~BRDEF, kmo+0.5    ,1,,,,,,0
  ~BRDEF, kmo+4      ,1,,,,,,0

  ! Support 2
  ~BRDEF, kmo+lspan_1-0.5  ,1,,,,,,2
  ~BRDEF, kmo+lspan_1      ,1,,,,,,2
  ~BRDEF, kmo+lspan_1+0.5  ,1,,,,,,0

  ! Center Span
  ~BRDEF, kmo+lspan_1+lspan_2/2 ,1,,,,,,0

  ! Support 3
  ~BRDEF, kmo+lspan_1+lspan_2-0.5   ,1,,,,,,2
  ~BRDEF, kmo+lspan_1+lspan_2       ,1,,,,,,2
  ~BRDEF, kmo+lspan_1+lspan_2+0.5   ,1,,,,,,0

  ! Support 4
  ~BRDEF, kmo+lspan_1+lspan_2+lspan_3-4   ,1,,,,,,0
  ~BRDEF, kmo+lspan_1+lspan_2+lspan_3-1   ,1,,,,,,2
  ~BRDEF, kmo+lspan_1+lspan_2+lspan_3-0.5 ,1,,,,,,2
  ~BRDEF, kmo+lspan_1+lspan_2+lspan_3     ,1,,,,,,2

  ! Bridge Model Generation with beam44 elements
  ~BRGEN,B, , , 1.0,  ! Generates the bridge model

! Cross Section reinforcement
! Faces definition and Reinforcement Groups
  *DO,I,1,14
    ! Face definition
    ~SECMDF,I,FACES,PT_ADD,LOC,,2,0,-4
    ~SECMDF,I,FACES,PT_ADD,LOC,,2,0,4
    ~SECMDF,I,FACES,PT_ADD,LOC,,1,-1.2,1.35
    ~SECMDF,I,FACES,PT_ADD,LOC,,1,-1.2,-1.35
    ! Define a reinforcement group
    ~RNFDEF,I,1,2,1,0,50.000E-03, , ,20.00,20 , , ,4
    ~RNFDEF,I,2,2,2,0,50.000E-03, , ,20.00,40 , , ,4
  *ENDDO

! Cracking Properties
  *DO,I,1,14
    ~SECMDF,I,EHEPROP ,PHI ,,20 ,1
    ~SECMDF,I,EHEPROP ,PHI ,,20 ,2
    ~SECMDF,I,EHEPROP ,C   ,,5e-002,1
    ~SECMDF,I,EHEPROP ,C   ,,5e-002,2
    ~SECMDF,I,EHEPROP ,S   ,,0.2,1
    ~SECMDF,I,EHEPROP ,S   ,,0.2,2
    ~SECMDF,I,EHEPROP ,RHOR,,104.2,1
    ~SECMDF,I,EHEPROP ,RHOR,,212.4,2
  *ENDDO

! Boundary conditions
  NSEL,S,LOC,Y,0
  NSEL,R,LOC,X,0.5
    D,all,UY,0
    D,all,UZ,0
  NSEL,S,LOC,Y,0
  NSEL,R,LOC,X,lspan_1
    D,all,UY,0
    D,all,UZ,0
  NSEL,S,LOC,Y,0
  NSEL,R,LOC,X,lspan_1+lspan_2
```

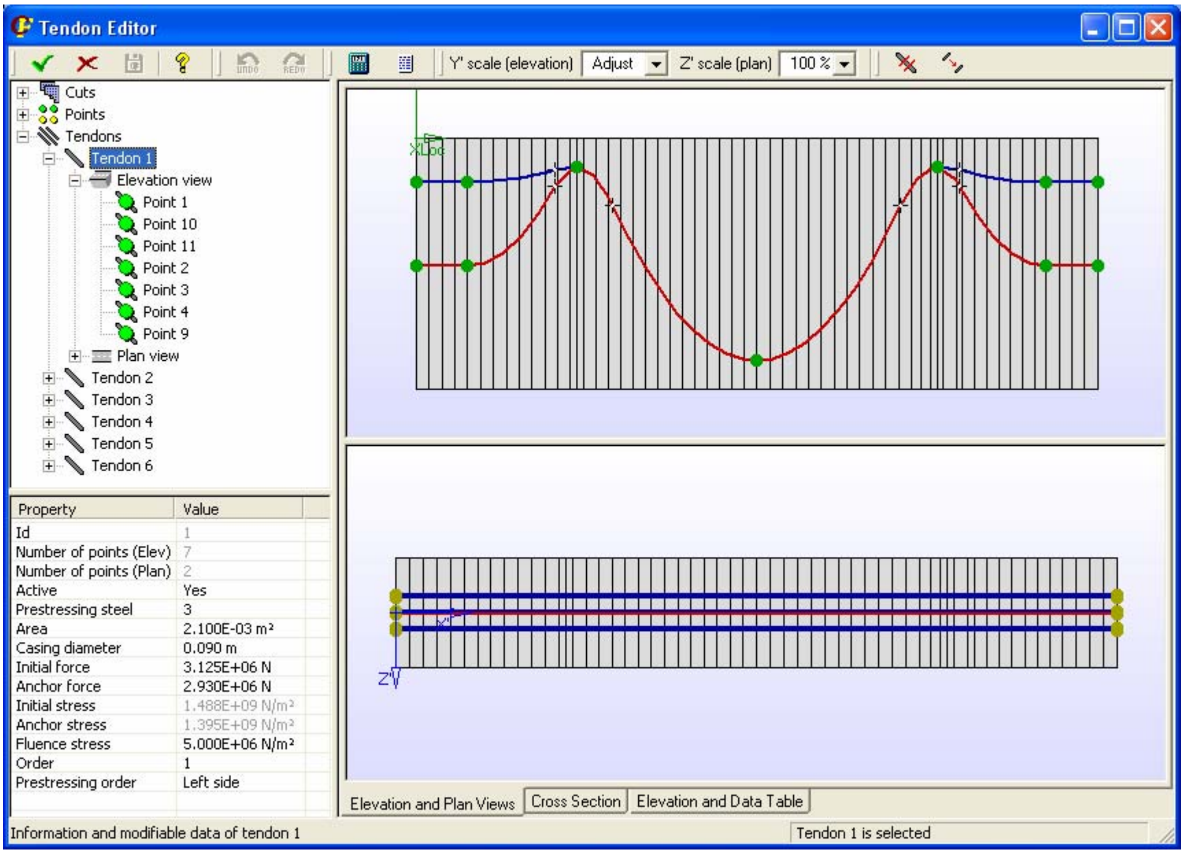
```
    D,all,UY,0
    D,all,UZ,0
  NSEL,S,LOC,Y,0
  NSEL,R,LOC,X,lspan_1+lspan_2+lspan_3
    D,all,UX,0
    D,all,UY,0
    D,all,UZ,0
    D,all,ROTX,0
  ALLSEL

! Support Beam
  LOCAL,11,0,0,0,0,0,+90
  ~SBBMDEF,1   ! Captures the support beam from a beam element model

! Tendon definition
  Tendndef.mac   ! Macro for the 6 tendons definition
```

11.4.3 Macro for the creation of the tendons

This macro can be completely done using the tendon editor:




```
! ~PCPPDEF: Defines tendon points in plan view
! ~PCPPMDF: Modifies points in plan view
! ~PCPPDEF, NUM, CUT, ZCOORD, SLOPE, INFDIST
  ~PCPPDEF,   1,   1,   0.09,     0,  0.500
  ~PCPPDEF,   2,   1,  -0.09,     0,  0.500
  ~PCPPDEF,   3,   1,   1.1 ,     0,  0.500
  ~PCPPDEF,   4,   1,  -1.1 ,     0,  0.500
  ~PCPPDEF,   5,   1,   1.3 ,     0,  0.500
  ~PCPPDEF,   6,   1,  -1.3 ,     0,  0.500
  ~PCPPDEF,   7,  60,   0.09,     0,  0.500
```

```
  ~PCPPDEF,   9,  60,  -0.09,     0,  0.500
  ~PCPPDEF,  11,  60,   1.1 ,     0,  0.500
  ~PCPPDEF,  13,  60,  -1.1 ,     0,  0.500
  ~PCPPDEF,  15,  60,   1.3 ,     0,  0.500
  ~PCPPDEF,  17,  60,  -1.3 ,     0,  0.500

! ~PCEPDEF: Defines tendon points in elevation view
! ~PCEPMDF: Modifies points in elevation view
! ~PCPPDEF, NUM, CUT, ZCOORD, SLOPE, INFDIST
  ~PCEPDEF,  1,   1, -0.613,     0,  0.500
  ~PCEPDEF,  2,   7, -0.613,     0,  0.500
  ~PCEPDEF,  3,  16, -0.135,     0,  0.500
  ~PCEPDEF,  4,  31, -1.065,     0,  0.500
  ~PCEPDEF,  5,   1, -0.212,     0,  0.500
  ~PCEPDEF,  6,   7, -0.212,     0,  0.500
  ~PCEPDEF,  7,  55, -0.212,     0,  0.500
  ~PCEPDEF,  8,  60, -0.212,     0,  0.500
  ~PCEPDEF,  9,  46, -0.135,     0,  0.500
  ~PCEPDEF, 10,  55, -0.613,     0,  0.500
  ~PCEPDEF, 11,  60, -0.613,     0,  0.500

! ~PCTNDEF: Defines and inserts a tendon
! ~PCTNMDF: Modifies the tendon
  *DO,I,1,6
    ~PCTNDEF, I, 3, 2.1e-003, 9e-002,3.125e6,2.930e6,
  *ENDDO

! Tendon 1 trajectory
  ~PCTNMDF, 1, EADD, 1.
  ~PCTNMDF, 1, EADD, 2.
  ~PCTNMDF, 1, EADD, 3.
  ~PCTNMDF, 1, EADD, 4.
  ~PCTNMDF, 1, EADD, 9.
  ~PCTNMDF, 1, EADD,10.
  ~PCTNMDF, 1, EADD,11.
  ~PCTNMDF, 1, PADD, 1.
  ~PCTNMDF, 1, PADD, 7.

! Tendon 2 trajectory
  ~PCTNMDF, 2, EADD, 5.
  ~PCTNMDF, 2, EADD, 6.
  ~PCTNMDF, 2, EADD, 3.
  ~PCTNMDF, 2, EADD, 4.
  ~PCTNMDF, 2, EADD, 9.
  ~PCTNMDF, 2, EADD, 7.
  ~PCTNMDF, 2, EADD, 8.
  ~PCTNMDF, 2, PADD, 2.
  ~PCTNMDF, 2, PADD, 9.

! Tendon 3 trajectory
  ~PCTNMDF, 3, EADD, 1.
  ~PCTNMDF, 3, EADD, 2.
  ~PCTNMDF, 3, EADD, 3.
  ~PCTNMDF, 3, EADD, 4.
  ~PCTNMDF, 3, EADD, 9.
  ~PCTNMDF, 3, EADD,10.
  ~PCTNMDF, 3, EADD,11.
  ~PCTNMDF, 3, PADD, 3.
  ~PCTNMDF, 3, PADD,11.

! Tendon 4 trajectory
  ~PCTNMDF, 4, EADD, 1.
  ~PCTNMDF, 4, EADD, 2.
  ~PCTNMDF, 4, EADD, 3.
  ~PCTNMDF, 4, EADD, 4.
  ~PCTNMDF, 4, EADD, 9.
  ~PCTNMDF, 4, EADD,10.
  ~PCTNMDF, 4, EADD,11.
```

```
  ~PCTNMDF, 4, PADD, 4.
  ~PCTNMDF, 4, PADD,13.

! Tendon 5 trajectory
  ~PCTNMDF, 5, EADD, 5.
  ~PCTNMDF, 5, EADD, 6.
  ~PCTNMDF, 5, EADD, 3.
  ~PCTNMDF, 5, EADD, 4.
  ~PCTNMDF, 5, EADD, 9.
  ~PCTNMDF, 5, EADD, 7.
  ~PCTNMDF, 5, EADD, 8.
  ~PCTNMDF, 5, PADD, 5.
  ~PCTNMDF, 5, PADD,15.

! Tendon 6 trajectory
  ~PCTNMDF, 6, EADD, 5.
  ~PCTNMDF, 6, EADD, 6.
  ~PCTNMDF, 6, EADD, 3.
  ~PCTNMDF, 6, EADD, 4.
  ~PCTNMDF, 6, EADD, 9.
  ~PCTNMDF, 6, EADD, 7.
  ~PCTNMDF, 6, EADD, 8.
  ~PCTNMDF, 6, PADD, 6.
  ~PCTNMDF, 6, PADD,17.


!Modifies the distance ratio of the inflection point in elevation view

  ~PCEPMDF,2,INFDIST,0.8
  ~PCEPMDF,6,INFDIST,0.8
  ~PCEPMDF,3,INFDIST,0.2
  ~PCEPMDF,4,INFDIST,0.8
  ~PCEPMDF,9,INFDIST,0.2

! Post-prestressed method: Prestressed from the initial extreme (cut=1)

  ~PCTNMDF,1,METHOD,1
  ~PCTNMDF,2,METHOD,1
  ~PCTNMDF,3,METHOD,1
  ~PCTNMDF,4,METHOD,1
  ~PCTNMDF,5,METHOD,1
  ~PCTNMDF,6,METHOD,1
```

11.4.4 Solution

```
/SOLU

! SIMPLE LOAD STATES

! Vehicle Load
/TITLE,Vehicle Load
  ~BLVLIB,1,IAP,VP,1
! Family definition
  ~BLFDF,1001,INCOMPAT
! Asigns vehicle 1 to Family 1001
  ~BLVR,1001,,1,
  ~BLSOLVE
  FDELE,ALL,ALL ! Delete loads

! Initial Prestressing
/TITLE,Initial Prestressing
  ~PCLOSS,0
  ~PCPL
  ~CFLSWRT
  ~PCDEL
```

```
! Final Prestressing
/TITLE,Final Prestressing
  ~PCLOSS,1000000
  ~PCPL
  ~CFLSWRT
  ~PCDEL

! Self Weight
/TITLE,Self Weight
  ACEL,,,9.81
  ~CFLSWRT
  ACEL,

! Dead Load
/TITLE,Dead Load
  SFBEAM,ALL,2,PRES,33200
  ~CFLSWRT
  SFEDELE,ALL,ALL,ALL

! Surface load
/TITLE,Surface load
  SFBEAM,ALL,2,PRES,40000
  ~CFLSWRT
  SFEDELE,ALL,ALL,ALL
  FDELE,ALL,ALL

! Thermal Gradient
/TITLE,Thermal Gradient
  BFE,ALL,TEMP,1,0,0,5,5
  BFE,ALL,TEMP,5,0,0,5,5
  ~CFLSWRT
  BFEDELE,ALL,ALL

  ~CFLSSLV, 19,24,1
```

11.4.5 Postprocess

```
/POST1

! Turn families into combinations
  ~BLF2CMB

! TARGETS: MAXIMUM & MINIMUM MOMENTS
  ~TRGDEF,1,CROSS,M,Z,MAX
  ~TRGDEF,2,CROSS,M,Z,MIN

! Load Combination 1002:
  /TITLE,Total with initial prestressing
  ~CMBDEF, 1002, SELECTVC, 6, 0, 6

  ~STSTDEF, 1002, 1, CMB, 1001   !Vehicle           (0.90/1.10)
  ~STSTCFT, 1002, 1, 0.90, 1.10
  ~STSTDEF, 1002, 2,LSTEP, 19    !Initial prestress (0.90/1.10)
  ~STSTCFT, 1002, 2, 0.90, 1.10
  ~STSTDEF, 1002, 3,LSTEP, 21    !Self weight       (1.00/1.35)
  ~STSTCFT, 1002, 3, 1.00, 1.35
  ~STSTDEF, 1002, 4,LSTEP, 22    !Dead load         (1.00/1.35)
  ~STSTCFT, 1002, 4, 1.00, 1.35
  ~STSTDEF, 1002, 5,LSTEP, 23    !Surface load      (0.00/1.50)
  ~STSTCFT, 1002, 5, 0.00, 1.50
  ~STSTDEF, 1002, 6,LSTEP, 24    !Thermal gradient  (1.00/1.35)
  ~STSTCFT, 1002, 6, 1.00, 1.35

! Load Combination 1003:
  /TITLE,Total with final prestressing
  ~CMBDEF, 1003, SELECTVC, 6, 0, 6
```

```
  ~STSTDEF, 1003, 1, CMB,  1001   !Vehicle           (0.90/1.10)
  ~STSTCFT, 1003, 1, 0.90, 1.10
  ~STSTDEF, 1003, 2,LSTEP, 20     !Final prestress   (0.90/1.10)
  ~STSTCFT, 1003, 2, 0.90, 1.10
  ~STSTDEF, 1003, 3,LSTEP, 21     !Self weight       (1.00/1.35)
  ~STSTCFT, 1003, 3, 1.00, 1.35
  ~STSTDEF, 1003, 4,LSTEP, 22     !Dead load         (1.00/1.35)
  ~STSTCFT, 1003, 4, 1.00, 1.35
  ~STSTDEF, 1003, 5,LSTEP, 23     !Surface load      (0.00/1.50)
  ~STSTCFT, 1003, 5, 0.00, 1.50
  ~STSTDEF, 1003, 6,LSTEP, 24     !Thermal gradient  (1.00/1.35)
  ~STSTCFT, 1003, 6, 1.00, 1.35

! Load Combination 1004:
  /TITLE,Total with initial or final prestressing
  ~CMBDEF, 1004, OPTION,    2
  ~STSTDEF, 1004, 1, CMB, 1002,,2,1,1,1

! Solution
  ~COMBINE

! Points to original or combined results
  ~CMBDAT,2

! Change point of view
  /VIEW,1,,-1

! Loads the combined results corresponding to targets
! Select combination 1004 (all loads), target 1 (maximum MZ)
  ~CMB,1004,,,,,1
  /TITLE,Maximum MZ
  ~PLLSFOR,M,Z, -1

! Select combination 1004 (all loads), target 2 (minimum MZ)
  ~CMB,1004,,,,,2
  /TITLE,Minimum MZ
  ~PLLSFOR,M,Z, -1

! Combination rule 1004 calculated for minimum UZ at center of 1st span
! Plot UZ on all nodes (at center of 1st span will be minimum)
  ~CMBINQ,1004,DISPL,U,Z,MIN,15, ,2,1  ! Center of 1st span (all loads)
  /TITLE,uz min (total)
  PLNSOL,U,Z

! Combination rule 1001 calculated for minimum UZ at center of 1st span
! Plot UZ on all nodes (at center of 1st span will be minimum)
  ~CMBINQ,1001,DISPL,U,Z,MIN,15, ,2,1  ! Center of 1st span (vehicle only)
  /TITLE,uz min (vehicle)
  PLNSOL,U,Z

! Select combination 1004 (all loads), target 1 (maximum MZ)
  ~CMB,1004,,,,,1
! Cracking Checking
  ~CHKPRS,CRACK, ,0,0.3e-3,1.7,0.5
! Bending Checking 2D
  ~CHKPRS,2DB

! Select combination 1004 (all loads), target 2 (minimum MZ)
  ~CMB,1004,,,,,2
! Cracking Checking
  ~CHKPRS,CRACK, ,0,0.3e-3,1.7,0.5
! Bending Checking 2D
  ~CHKPRS,2DB
! 2D Interaction diagram for prestressed concrete
  ~PL2DPRS,BEAM,32,1,0,0,1

! Create checking envelopes
```

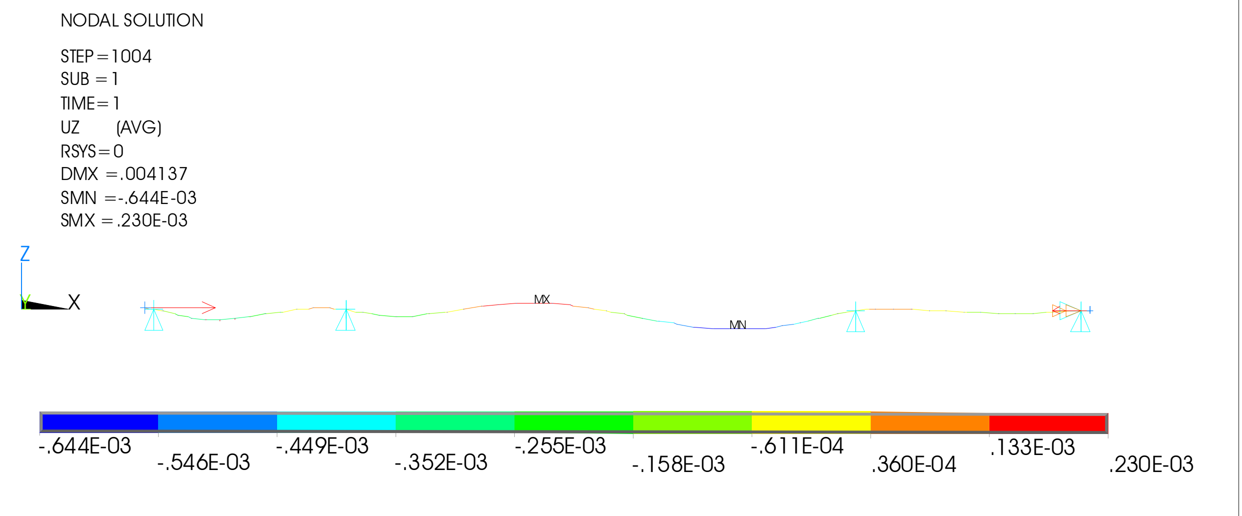
```
! Cracking Checking
  ~ENVDEL,ALL
  ~ENVDEF,1,3,2
  ~ENVELOP,MAX
  ~CFSET,5
  ~PLLSPRS,CRT_TOT
! Bending Checking 2D
  ~ENVDEL,ALL
  ~ENVDEF,2,4,2
  ~ENVELOP,MAX
  ~CFSET,6
  ~PLLSPRS,CRT_TOT
```

11.5 RESULTS

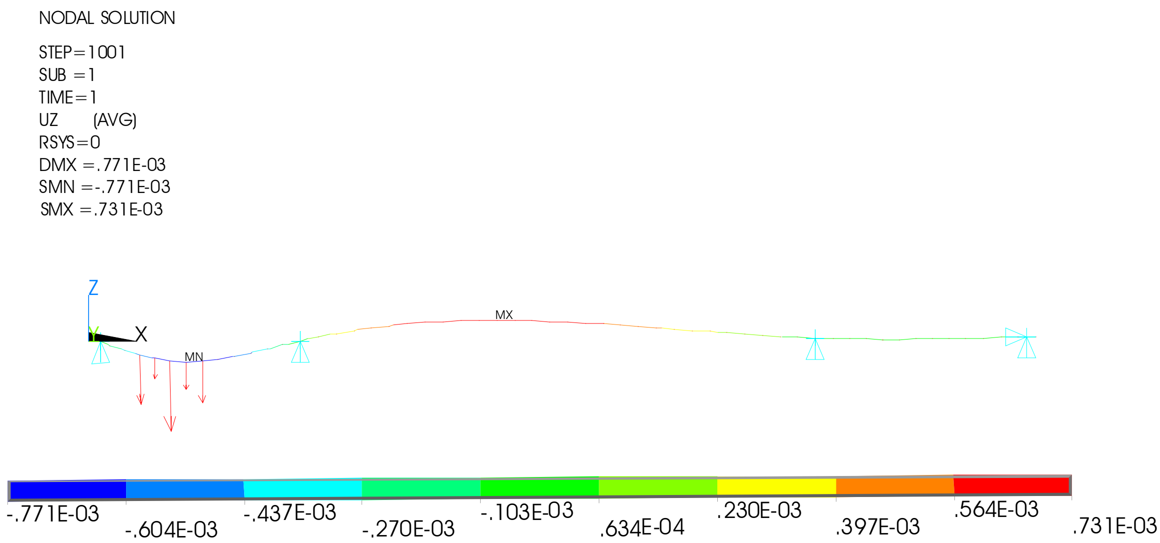
11.5.1 Total vertical displacement

Results for the total displacement have been obtained for the hypothesis of the moving vehicle load, and for the total loads combination.

In the second figure, the load combination that gives this maximum displacement has been also represented.



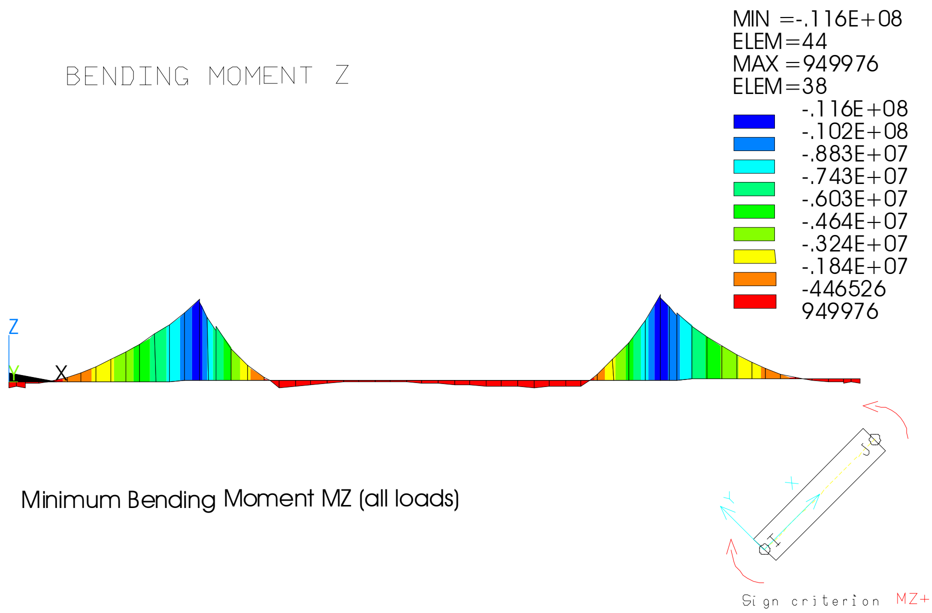
Maximum Negative Displacement (all loads)



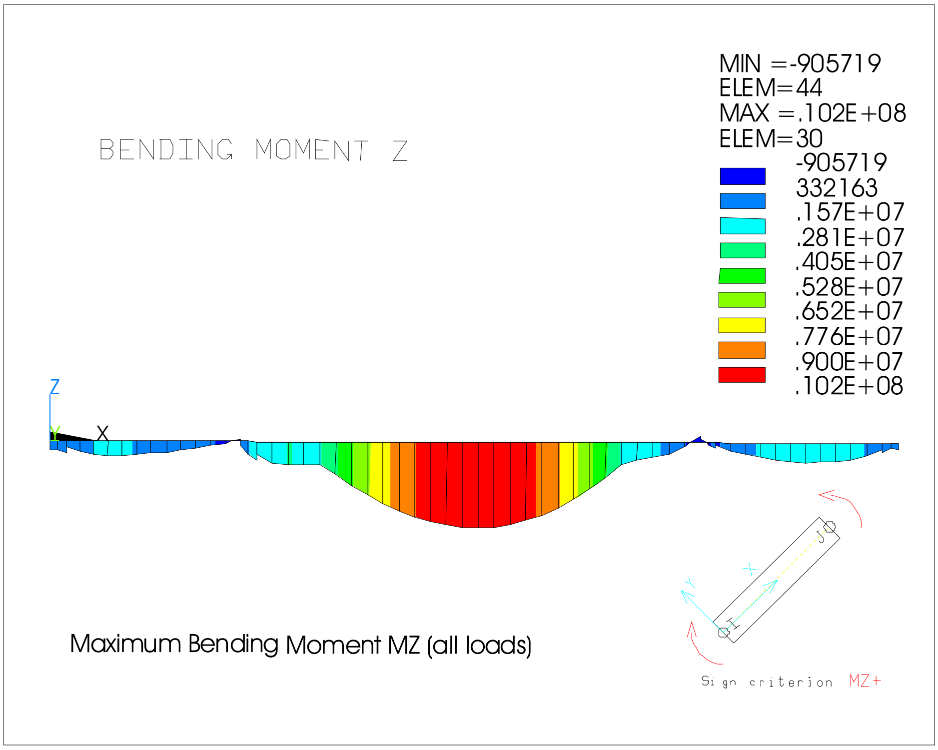
,Maximum Negative Displacement and Load Location (vehicle only)

11.5.2 Maximum and minimum bending moments

In the attached figures the envelope of maximum and minimum bending moments are shown.



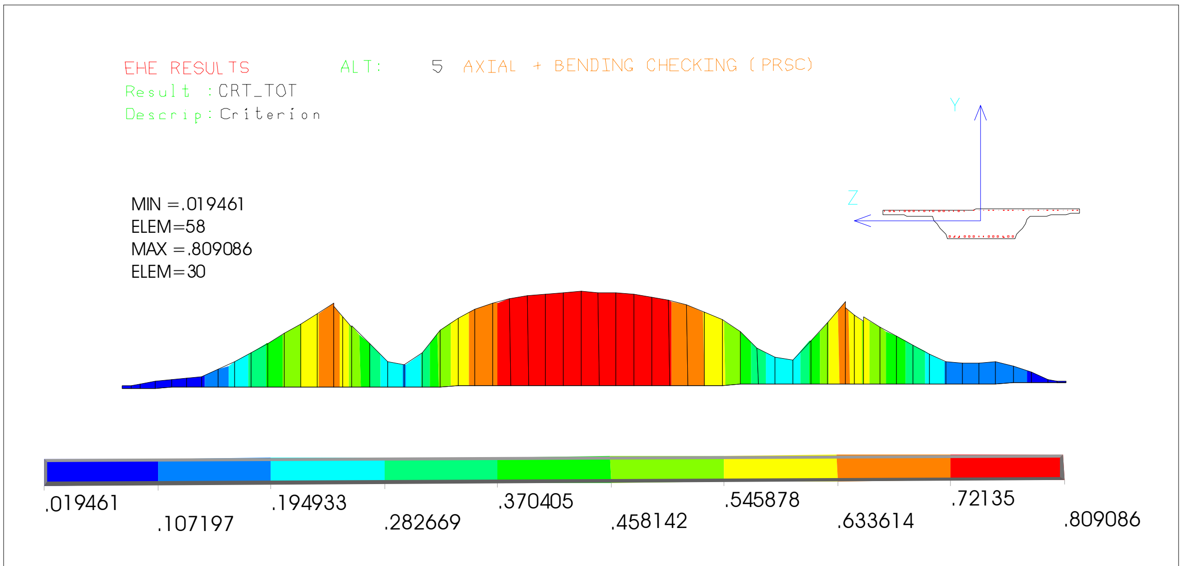
Minimum Bending Moment MZ (all loads)



Maximum Bending Moment MZ (all loads)

11.5.3 Bending checking

The results of the axial+bending bidimensional checking (bending according to section z-axis) is shown next. The checking has been done for the EHE Spanish code.

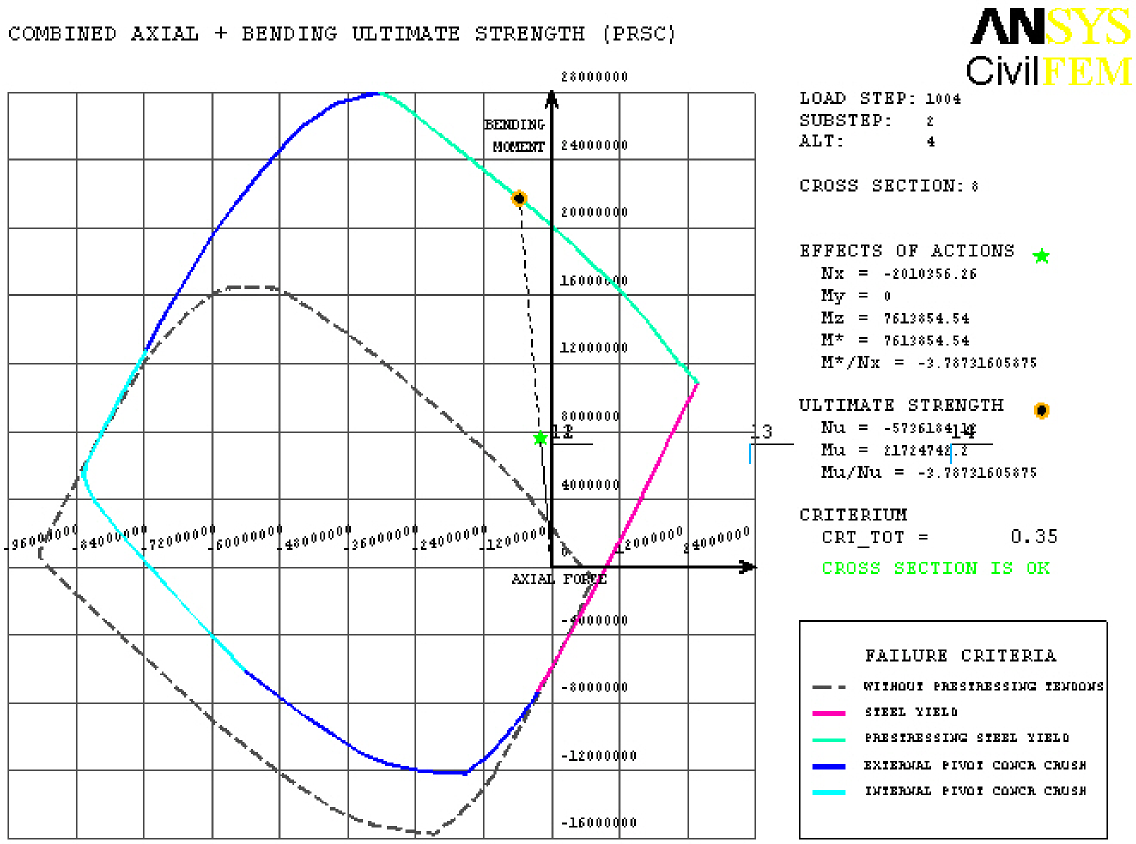


Axial + 2D Bending (Z-axis) Checking Criterion

The represented result of checking is a criterion that indicates the proximity or distance to the limits established by the code. An equal to one criterion indicates that the forces and moments are equal to the limits specified by the code. A criterion greater than one indicates that the code is not being fulfilled and a criterion smaller than one indicates that the code requirements are met.

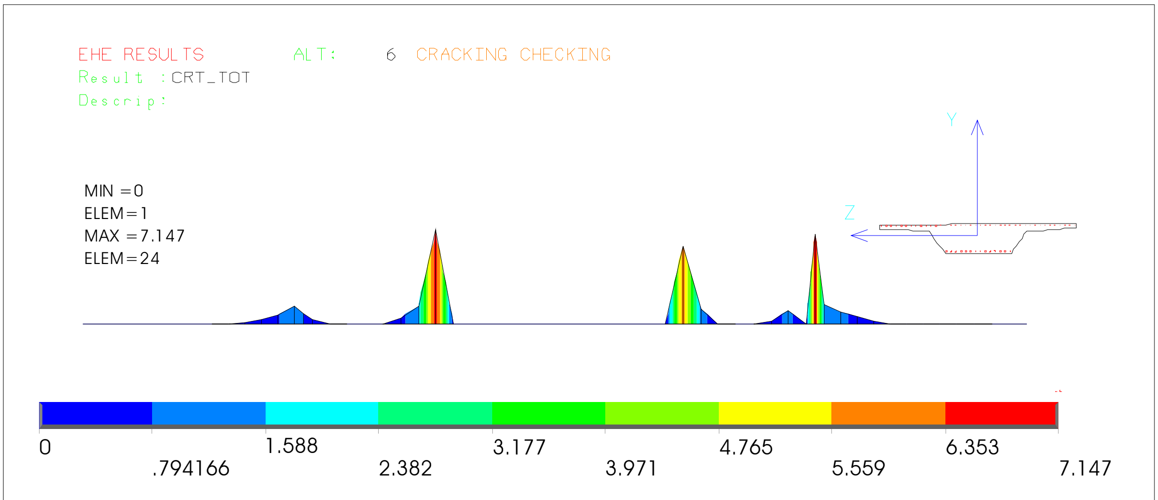
In this case all the elements fulfil the norm.

The following figure represents the interaction diagram of the section located at end I of element 32.



11.5.4 Cracking checking

In the following figure the results of the cracking checking according to the Spanish code (EHE) are represented.



Cracking Checking Criterion

The obtained results are greater than one. This means that the reinforcement indicated in the statement would not be valid in order to fulfil the established cracking criterium.

In order to improve the results it is not necessary to increase the reinforcement area, because the bending checking was correct. The best solution, in this case, would be to decrease the bars spacing.

11.6 SUMMARY

During the resolution of this exercise, the reader has been able to completely practice the functionalities that CivilFEM offers:

- Finite elements model creation.
- Load state concept and families generation.
- Vehicles editor.
- Tendon editor.
- Combination editor.
- Design of reinforcemed and prestressed concrete structures.
- Code checking and results postprocessing.