Verification of a Continuous Girder – Shrinkage and Thermal Effects

For LUSAS version:	22.0 or above
For software product(s):	LUSAS Bridge or LUSAS Bridge plus
With product option(s):	Steel and Composite Deck Designer (PontiEC4 – v3.6.1 or above)
With additional software	Microsoft Excel installed

Description

This example presents the design verification of a composite steel-concrete girder, with particular emphasis on shrinkage and thermal effects. It provides a step-by-step guide covering all input stages, along with instructions for interpreting key results.

The example provides all the necessary data to calculate design forces and moments using finite element analysis (FEA) outside of PontiEC4, as well as the information needed to perform design verification within PontiEC4. It is divided into two parts:

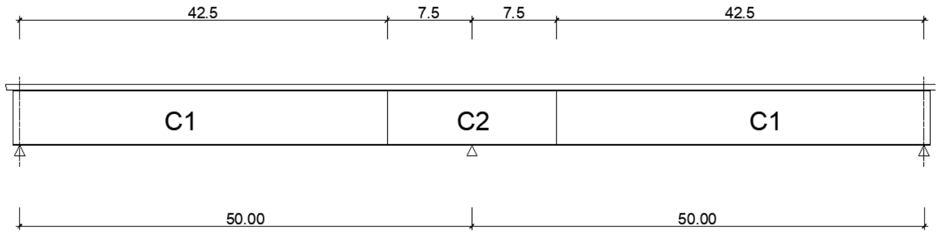
Part 1 focuses on extracting the required forces and moments using a finite element model. An Excel file containing these forces and moments, necessary for design checks in PontiEC4, can be directly exported from LUSAS and imported into PontiEC4. Users who do not use LUSAS will need to prepare this Excel file manually.

Part 2 covers the verification of the girder using the imported forces and moments within PontiEC4.

The worked examples "Composite Bridge Deck to Eurocodes" and "Composite Highway Bridge" offer valuable guidance on using PontiEC4 and demonstrate its seamless integration with LUSAS.

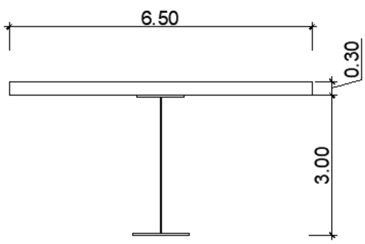
Description of Structure

This example involves a continuous girder with two spans, each 50 metres long. The girder is divided into segments, which are shown below. The global analysis uses uncracked properties for Segment C1 and cracked properties for Segment C2.



Segments C1 and C2.

The cross-section dimensions are shown in the figure below.



Cross-section dimensions.

Metallic Girders

The dimensions of the steel girders are summarised in the table below.

Segment Name	Top Flange Width (mm)	Top Flange Thickness (mm)	Steel Girder Height (mm)	Web Thickness (mm)	Bottom Flange Width (mm)	Bottom Flange Thickness (mm)
C1	1000	40	3000	22	1200	40
C2	1200	60	3000	25	1200	60

Material

Concrete: Class C35/45

Structural steel: Grade S355

Ordinary reinforcement: Class B450

Ultimate strength of shear connectors (N/mm²): 450

For the calculation of concrete time-dependent effects:

Age at onset of drying shrinkage (days): 2

Age at time considered (days): 36500

Age when permanent loads are applied (days): 30

Age when shrinkage loads are applied (days): 2

Age when imposed displacements are applied (days): 30

Exposed area (mm^2): 1950000 (= 6500 x 300)

Exposed perimeter (mm): 6500

Relative humidity (%): 75

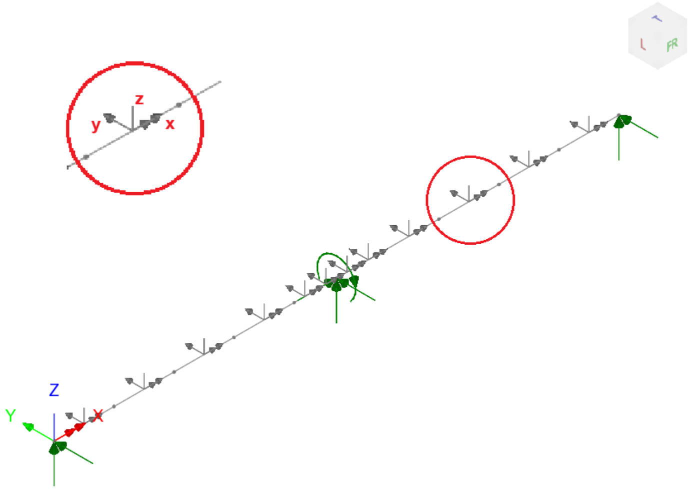
All partial safety factors are set to their default values, which can be automatically applied by clicking the **Default** button located at the bottom right of the **Materials** dialog window.

Part 1: Finite Element Analysis - LUSAS

The finite element analysis (FEM) was conducted using LUSAS Bridge software, though specific software details are excluded in the following sections. Instead, only the essential data is provided to enable users to independently reproduce the force/moment calculations.
A brief overview of the calculation model is presented, along with the fundamental loadcases and their applied loads, as well as the load combinations. The resulting internal forces are illustrated through diagrams and tables for clarity.

Description of the Finite Element Model and Analysis Phases

The girder is modelled as a line beam, discretised into beam elements with six degrees of freedom at each node. At the central support, all translational movements and torsion are fully restrained. Longitudinally guided roller supports are provided at both ends of the girder. The mesh plane is positioned at the top flange (extrados) of the steel girders. The figure below depicts the finite element mesh along with the local axes of the elements.

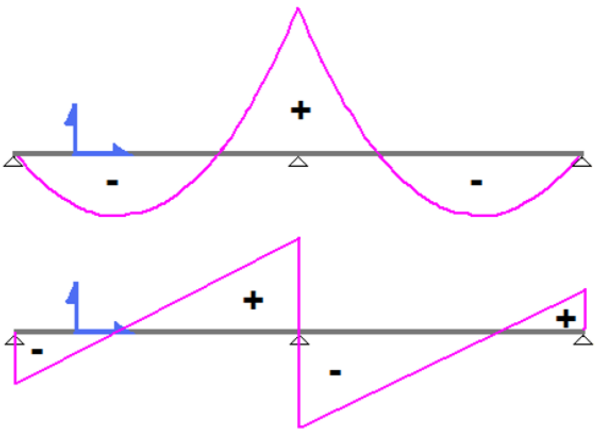


Finite element model of the girder created in LUSAS.

The local *z*-axis is directed upwards, and the following sign conventions are adopted:

- **Axial force**: positive in tension
- **Bending moment**: positive if it causes tension in the top fibre of the section
- **Shear force**: positive when directed upwards (on the positive faces of the beam elements)

For a uniformly distributed load, the moment and shear diagrams follow the shapes and signs shown in the figure below.



Two-span beam under a vertical uniformly distributed load: bending moment and shear force diagrams with sign conventions.

The units adopted are as follows:

Length: metres (m)

Forces and moments: Newtons (N) and Newton-metres (Nm)

For internal forces, both in the finite element analysis and the Excel input file for PontiEC4, the following notations are used:

Fx: axial force

Fy: shear force acting in the horizontal plane

Fz: shear force acting in the vertical plane

Mx: torsional moment

My: bending moment about y

Mz: bending moment about z

These notations correspond to those used in the Eurocodes and their introductory chapters. The following Eurocode-compliant alternatives may also be used:

M (or **Mf**) instead of **My**

V instead of **Fz**

T instead of **Mx**

The verification is based solely on **Fx**, **Fz**, and **My**, as the influences of **Fy**, **Mx**, and **Mz** are considered negligible.

Separate analyses are conducted to represent the four design phases considered:

Phase 1: The bare steel girder is analysed without considering composite action. The slab is treated as a dead load, and the casting sequence of slab segments is ignored, assuming they are cast simultaneously.

Phase 2a: The composite girder is analysed using the long-term properties of concrete, considering only permanent loads.

Phase 2b: The composite girder is analysed with long-term concrete properties, focusing exclusively on shrinkage effects.

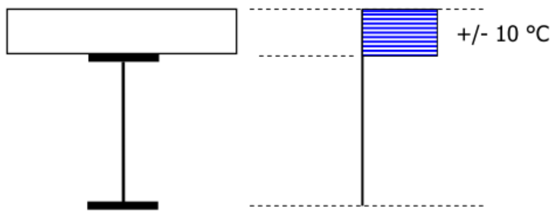
Phase 3: The composite girder is analysed using the short-term properties of concrete, accounting for traffic loads and thermal effects.

Loadcases

The phases, along with their associated loads and loadcases, are summarised in the table below.

Analysis	Loads	Loadcases
Phase 1	Steel self-weight: -19500 N/m Slab self-weight: -48750 N/m	Weight (G1)
Phase 2a	Non-structural permanent loads: -23400 N/m	Permanent (G2)
Phase 2b	Shrinkage in segment C1 – $\varepsilon_{sh} = -2.692*10^{-4}$ in the slab	Shrinkage (Gsh)
Phase 3a	Slab heating: $\Delta T = +10°$	Thermal_Heat (ΔM^{+})
	Slab cooling: $\Delta T = -10°$	Thermal_Cold (ΔM^{-})
Phase 3b	UDL = -60000 N/m on span 1 UDL = -27000 N/m on span 2	Traffic 1 (Q1)
	UDL = -27000 N/m on span 1 UDL = -60000 N/m on span 2	Traffic 2 (Q2)
	UDL = -60000 N/m on span 1	Traffic 3 (Q3)
	UDL = -60000 N/m on span 2	Traffic 4 (Q4)

Note. Where allowed by national annexes, it is recommended to use Approach 1 of EN 1991-1-5 to calculate thermal variations. This method applies linear temperature gradients that produce only global hyperstatic effects, without causing internal hyperstatic stresses within the sections. In the following example, Approach 2 of EN 1991-1-5 is used to model thermal variation. This approach applies a non-linear temperature difference of ±10°C to the slab (see figure). This choice aims to help users understand how to perform verifications under more complex thermal conditions.



In the finite element model, the hyperstatic effects of shrinkage and thermal variation in the slab are accounted for by applying a mean strain and curvature to the continuous girder, following the procedure outlined below.

Mean strain

$$\varepsilon = \frac{N}{E_{acc} \cdot A}$$

Mean curvature (1/mm)

$$\mu = \frac{N \cdot e}{E_{acc} \cdot I}$$

where:

$N = \varepsilon_{sh} A_{cls} E_{acc} / n_{Phase\ 2b}$ Axial force due to shrinkage (N)

$N = \alpha\Delta T A_{cls} E_{acc} / n_{Phase\ 3}$ Axial force due to thermal variation (N)

ε_{sh} imposed shrinkage strain

$\alpha\Delta T$ imposed thermal strain

α thermal expansion coefficient (=1E-5 1/C)

A_{cls} slab concrete area (mm^2)

E_{acc} modulus of elasticity of steel (N/mm^2)

$n_{Phase\ 2b}$ long-term modular ratio for Phase 2b

$n_{Phase\ 3}$ short-term modular ratio for Phase 3

e distance (mm) between the centroid of the slab and the centroid of the composite section in Phase 2b (shrinkage) and Phase 3 (thermal effects)

A area (mm^2) of the equivalent steel section in Phase 2b (shrinkage) and Phase 3 (thermal effects)

I moment of inertia (mm^4) of the equivalent steel section in Phase 2b (shrinkage) and Phase 3 (thermal effects)

The mean strain and curvature can also be expressed as equivalent temperature variation and gradient using the following formulas.

$$\Delta T_{eq} = \frac{\varepsilon}{\alpha}$$

$$Grad_{eq} = \frac{\mu}{\alpha} \ (\frac{C°}{mm})$$

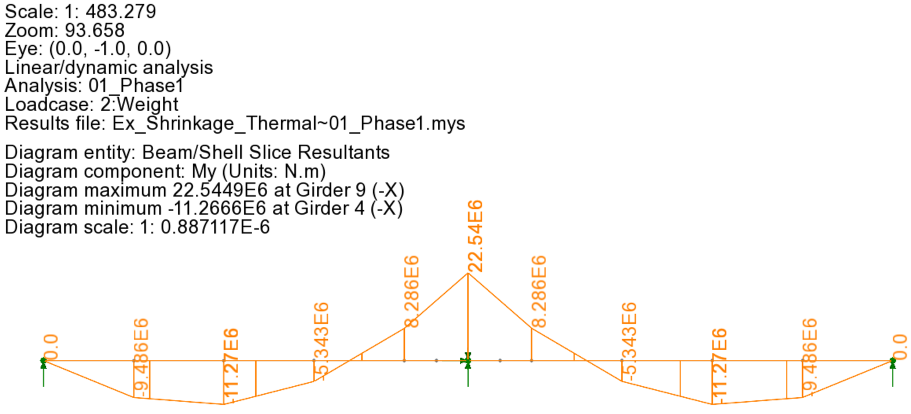
PontiEC4 automatically calculates the values of ΔT_{eq} and $Grad_{eq}$ for each segment under *Utilities > Equivalent ΔT > Shrinkage, Thermal*. In this example, these values are applied only to segment C1, as segment C2 is assumed to have cracked section properties.

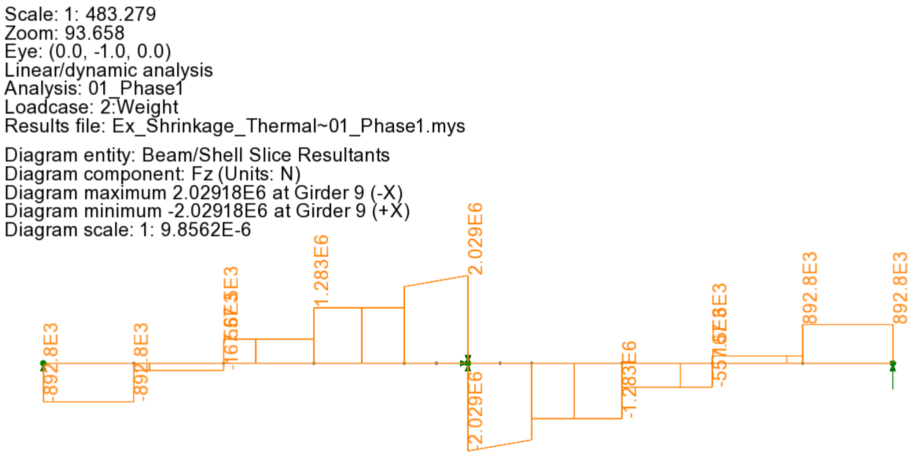
In a finite element model, where shell elements represent the concrete slab and beam elements represent the steel girder, hyperstatic effects can also be considered by directly applying the imposed strains (ε_{sh} for shrinkage and $\alpha\Delta T$ for thermal effects) to the slab. It is then necessary to use tools that can integrate the stresses computed across the slab and girder to determine the internal forces at the composite section level.

Internal Force Diagrams

The bending moment and shear force diagrams for each phase and loadcase are presented below. Axial forces are zero in this example.

Phase 1 – Weight

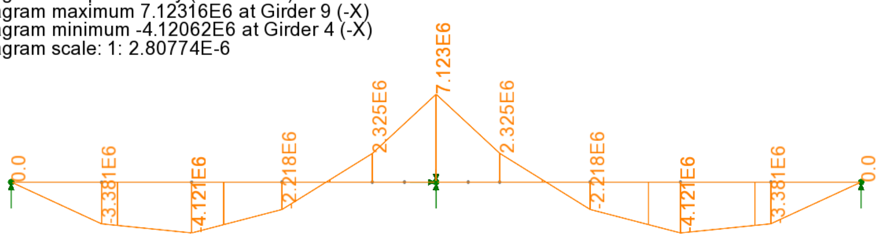




Phase 2a – Permanent

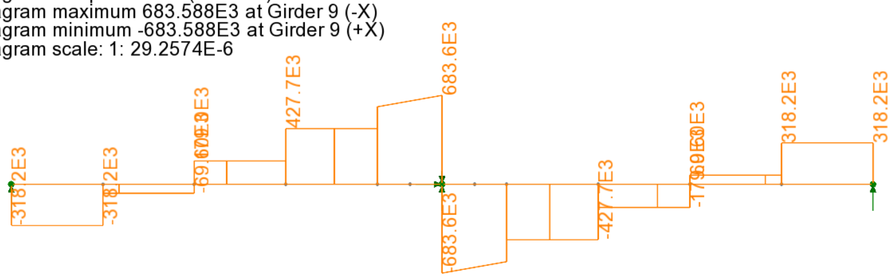
Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 02_Phase2a
Loadcase: 3:Permanent
Results file: Ex_Shrinkage_Thermal~02_Phase2a.mys

Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 7.12316E6 at Girder 9 (-X)
Diagram minimum -4.12062E6 at Girder 4 (-X)
Diagram scale: 1: 2.80774E-6



Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 02_Phase2a
Loadcase: 3:Permanent
Results file: Ex_Shrinkage_Thermal~02_Phase2a.mys

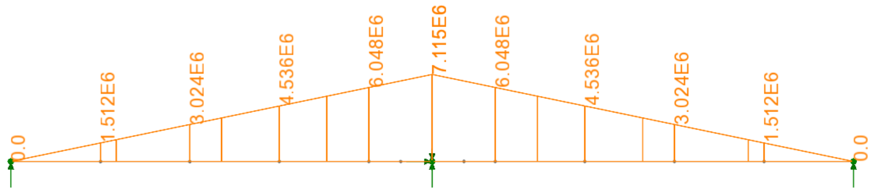
Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 683.588E3 at Girder 9 (-X)
Diagram minimum -683.588E3 at Girder 9 (+X)
Diagram scale: 1: 29.2574E-6



Phase 2b – Shrinkage

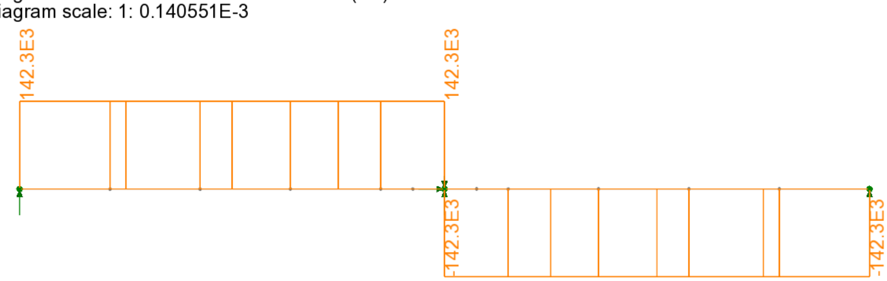
Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 03_Phase2b
Loadcase: 4:Shrinkage
Results file: Ex_Shrinkage_Thermal~03_Phase2b.mys

Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 7.11486E6 at Girder 9 (-X)
Diagram scale: 1: 2.81102E-6



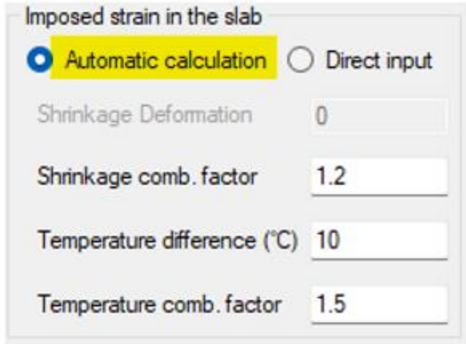
Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 03_Phase2b
Loadcase: 4:Shrinkage
Results file: Ex_Shrinkage_Thermal~03_Phase2b.mys

Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 142.297E3 at Girder 2 (-X)
Diagram minimum -142.297E3 at Girder 9 (+X)
Diagram scale: 1: 0.140551E-3



Note. The diagrams above show the **hyperstatic effects** resulting from the imposed shrinkage strain ε_{sh} applied to the slab. These hyperstatic effects must be combined with the corresponding **isostatic (primary) effects**, which PontiEC4 calculates directly from the input provided below:

1) In the **Materials** dialog window, under the **Imposed strain in the slab** section, select the **Automatic Calculation** option, as shown below. Alternatively, you can select the **Direct Input** option and manually enter the shrinkage strain (including the sign) in the **Shrinkage Deformation** field – for example, –2.7E–4.



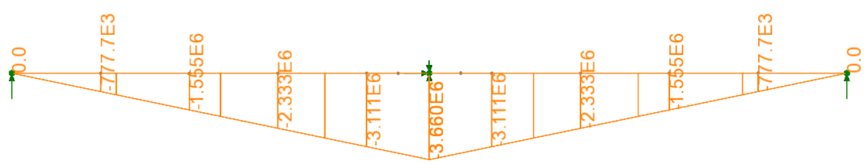
The combination factors for shrinkage and thermal effects are used solely to calculate the Ultimate Limit State (ULS) shear force per unit length at the deck's end regions. They do not apply to the isostatic effects resulting from shrinkage or thermal variation.

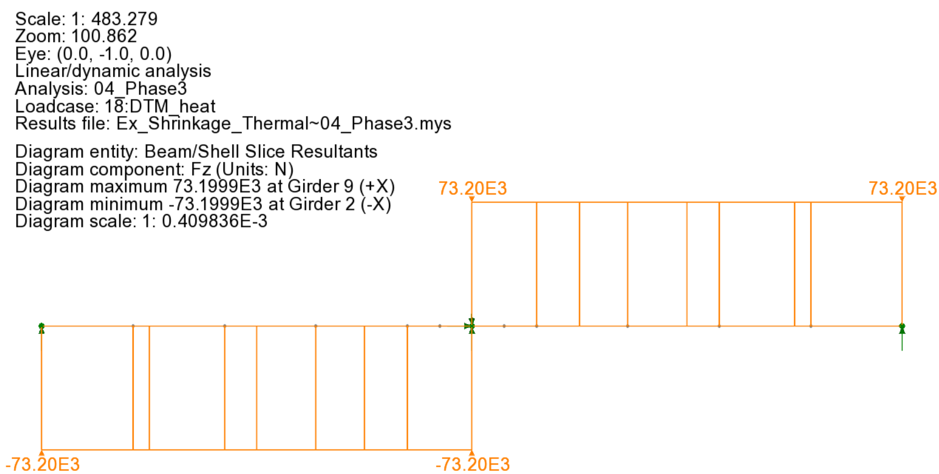
2) In the **Forces and moments** dialog window, under **Phase 2b**, a positive value must be entered in the **gam*psi** column for each section. This value depends on the limit state being considered and may vary according to the National Annex in use. For example, for the Ultimate Limit State (ULS), a typical value is 1.2. The gam*psi ($\gamma \cdot \psi$) factor enables PontiEC4 to compute the isostatic (primary) effect by applying a shrinkage strain equal to $\varepsilon sh \cdot \gamma \cdot \psi = \varepsilon sh \cdot 1.2$. For sections considered cracked in the global analysis – where the isostatic shrinkage effect is not to be taken into account – the $\gamma \cdot \psi$ value should be set to 0.

Phase 3a – Thermal_Heat

Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 04_Phase3
Loadcase: 18:DTM_heat
Results file: Ex_Shrinkage_Thermal~04_Phase3.mys

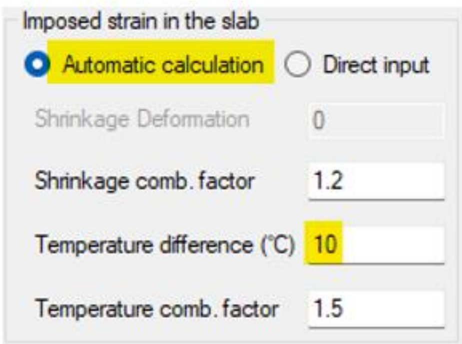
Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram minimum -3.66E6 at Girder 9 (-X)
Diagram scale: 1: 5.46449E-6





Note. The diagrams above show the **hyperstatic effects** resulting from a positive thermal variation, **ΔT = +10°C**, applied to the slab. These hyperstatic effects must be combined with the corresponding **isostatic (primary) effects**, which PontiEC4 calculates directly from the input provided below:

1) In the **Materials** dialog window, within the **Imposed strain in the slab** section, the temperature difference (°C) can be entered. In this case, a value of 10°C is specified.

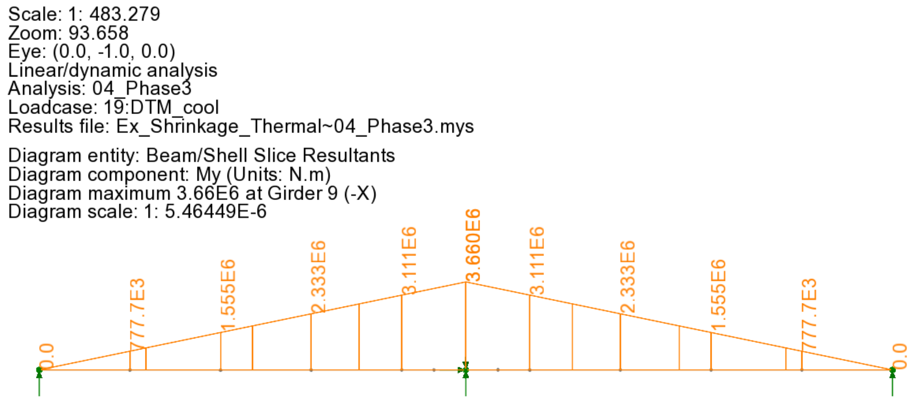


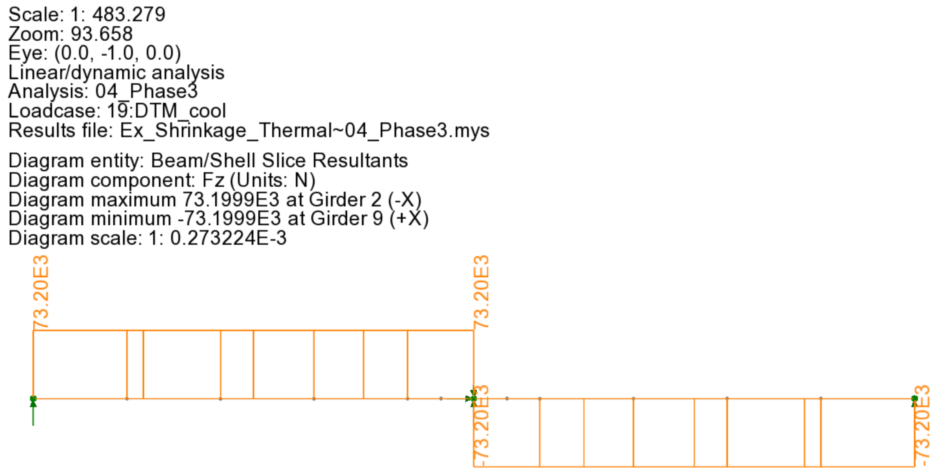
The combination factors for shrinkage and thermal effects are used solely to calculate the Ultimate Limit State (ULS) shear force per unit length at the deck's end regions. They do not apply to the isostatic effects resulting from shrinkage or thermal variation.

2) In the **Forces and moments** dialog window, under **Phase 3a**, a positive value must be entered in the **gam*psi** column for each section. This value depends on the limit state being considered and may vary according to the National Annex in use. For example, for the Ultimate Limit State (ULS), when traffic loading is

the dominant loadcase, a value of 0.9 (i.e., 1.5·0.6) may be used. The gam*psi (γ·ψ) factor enables PontiEC4 to compute the isostatic (primary) effect by applying a thermal difference equal to ΔT·γ·ψ = ΔT·0.9. For sections considered cracked in the global analysis – where the isostatic thermal effect is not to be taken into account – the γ·ψ value should be set to 0.

Phase 3a – Thermal_Cool



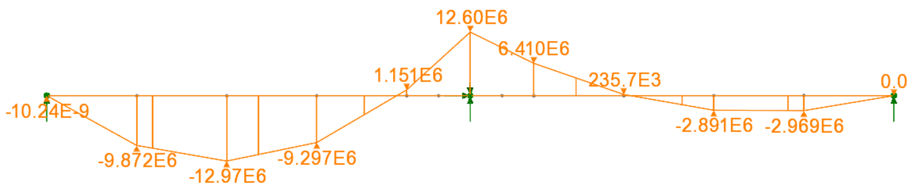


Note. The diagrams above show the **hyperstatic effects** resulting from a negative thermal variation, **ΔT = -10°C**, applied to the slab. To associate these hyperstatic effects with the corresponding **isostatic (primary) effects**, in PontiEC4, in addition to the value already entered in the **Materials** dialog window (as explained in the previous note), appropriate values must be entered for γ·ψ. In the **Forces and moments** dialog window, under **Phase 3a**, a negative value must be entered in the **gam*psi** column for each section. For example, for the Ultimate Limit State (ULS), when traffic loading is the dominant loadcase, a value of -0.9 (i.e., -1.5·0.6) may be used. The gam*psi (γ·ψ) factor enables PontiEC4 to compute the isostatic (primary) effect by applying a thermal difference equal to $\Delta T \cdot \gamma \cdot \psi = -\Delta T \cdot 0.9$. For sections considered cracked in the global analysis – where the isostatic thermal effect is not to be taken into account – the $\gamma \cdot \psi$ value should be set to 0.

Phase 3b – Traffic 1

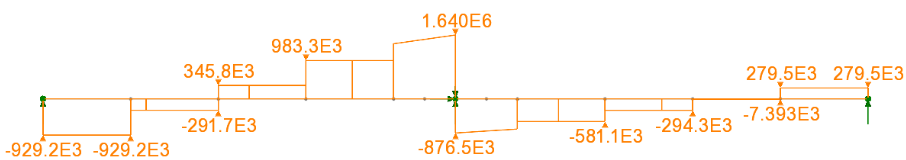
Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 04_Phase3
Loadcase: 1:Traffic1
Results file: Ex_Shrinkage_Thermal~04_Phase3.mys

Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 12.604E6 at Girder 9 (-X)
Diagram minimum -12.9714E6 at Girder 4 (-X)
Diagram scale: 1: 1.15639E-6



Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 04_Phase3
Loadcase: 1:Traffic1
Results file: Ex_Shrinkage_Thermal~04_Phase3.mys

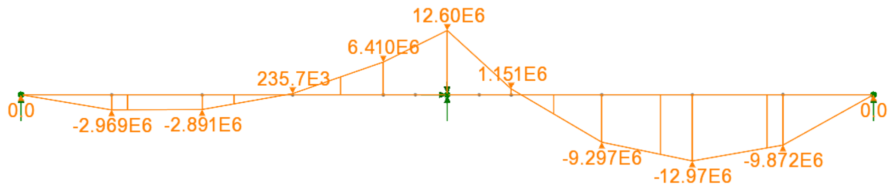
Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 1.63958E6 at Girder 9 (-X)
Diagram minimum -929.17E3 at Girder 2 (-X)
Diagram scale: 1: 9.14868E-6



Phase 3b – Traffic 2

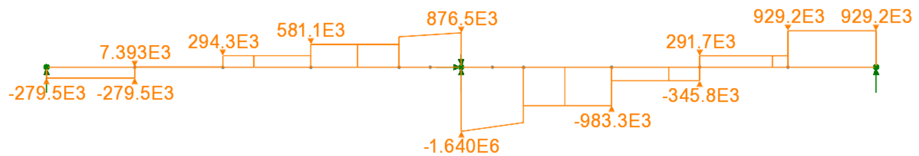
Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 04_Phase3
Loadcase: 5:Traffic2
Results file: Ex_Shrinkage_Thermal~04_Phase3.mys

Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 12.604E6 at Girder 9 (-X)
Diagram minimum -12.9714E6 at Girder 14 (-X)
Diagram scale: 1: 1.15639E-6



Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 04_Phase3
Loadcase: 5:Traffic2
Results file: Ex_Shrinkage_Thermal~04_Phase3.mys

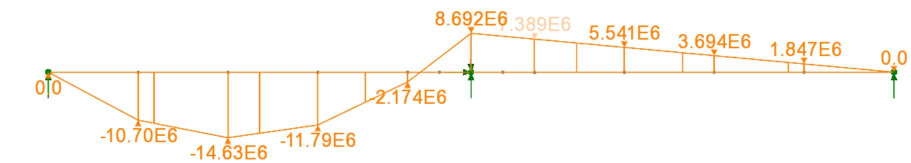
Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 929.17E3 at Girder 16 (+X)
Diagram minimum -1.63958E6 at Girder 9 (+X)
Diagram scale: 1: 9.14868E-6



Phase 3b – Traffic 3

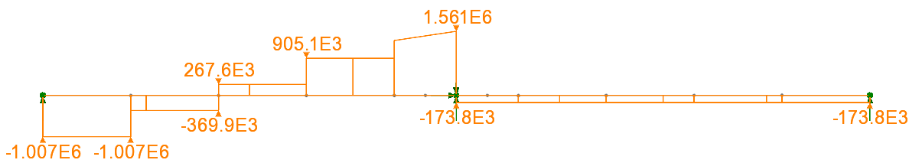
Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 04_Phase3
Loadcase: 6:Traffic3
Results file: Ex_Shrinkage_Thermal~04_Phase3.mys

Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 8.69243E6 at Girder 9 (-X)
Diagram minimum -14.6338E6 at Girder 4 (-X)
Diagram scale: 1: 1.02502E-6



Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 04_Phase3
Loadcase: 6:Traffic3
Results file: Ex_Shrinkage_Thermal~04_Phase3.mys

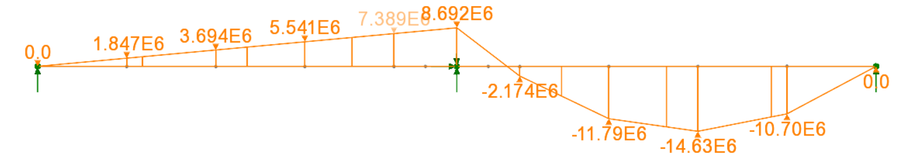
Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 1.56135E6 at Girder 9 (-X)
Diagram minimum -1.0074E6 at Girder 2 (-X)
Diagram scale: 1: 9.60708E-6



Phase 3b – Traffic 4

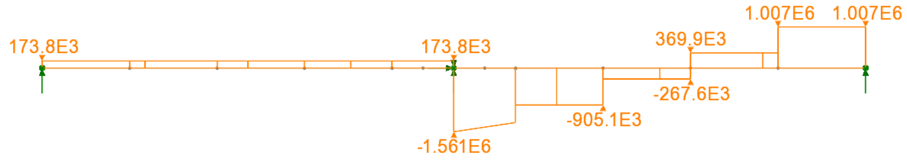
Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 04_Phase3
Loadcase: 17:Traffic4
Results file: Ex_Shrinkage_Thermal~04_Phase3.mys

Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 8.69243E6 at Girder 9 (-X)
Diagram minimum -14.6338E6 at Girder 14 (-X)
Diagram scale: 1: 1.02502E-6



Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Linear/dynamic analysis
Analysis: 04_Phase3
Loadcase: 17:Traffic4
Results file: Ex_Shrinkage_Thermal~04_Phase3.mys

Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 1.0074E6 at Girder 16 (+X)
Diagram minimum -1.56135E6 at Girder 9 (+X)
Diagram scale: 1: 9.60708E-6



ULS Combinations

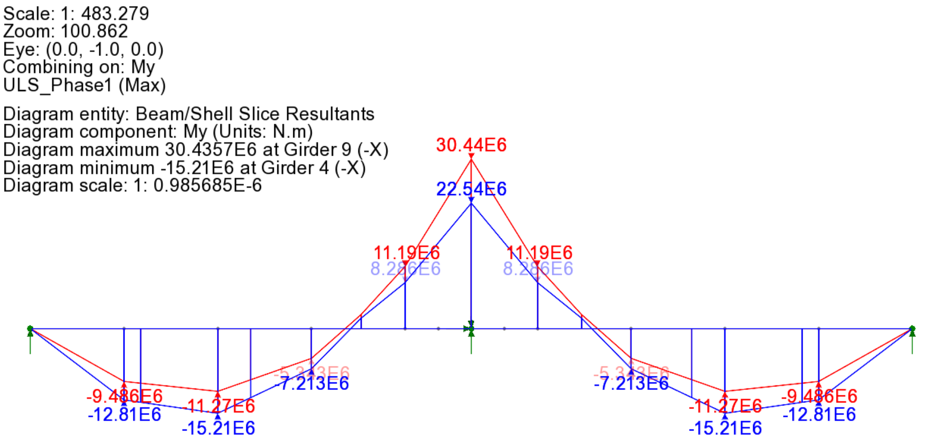
Load combinations are defined using the partial factors shown in the table below. Traffic loading is assumed to be the dominant variable action.

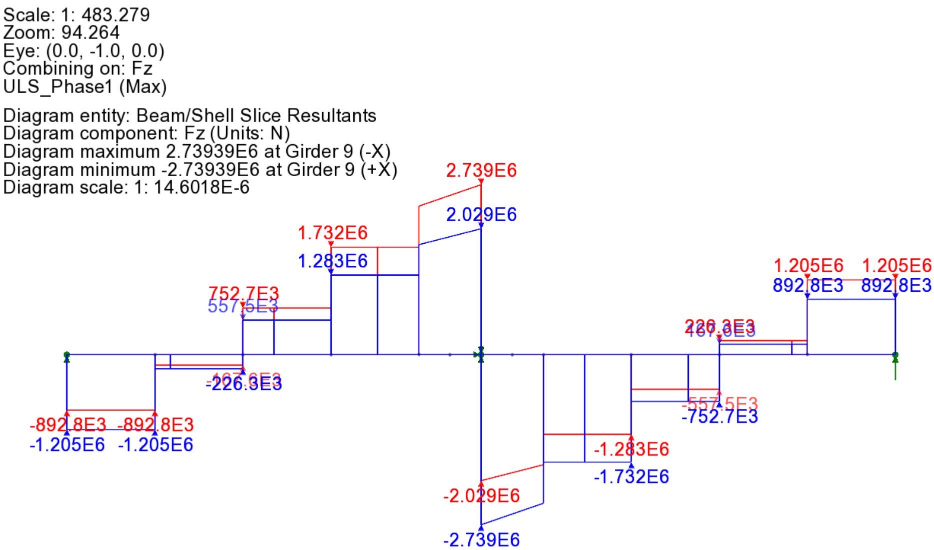
<table>
<tr><th>Analysis</th><th>Loadcases</th><th>Favourable factor</th><th>Unfavourable factor</th></tr>
<tr><td>Phase 1</td><td>Weight (G1)</td><td>1.00</td><td>1.35</td></tr>
<tr><td>Phase 2a</td><td>Permanent (G2)</td><td>1.00</td><td>1.35</td></tr>
<tr><td>Phase 2b</td><td>Shrinkage (Gsh)</td><td>1.00</td><td>1.20</td></tr>
<tr><td rowspan="2">Phase 3</td><td>Envelope {Traffic 1 (Q1), Traffic 2 (Q2), Traffic 3 (Q3), Traffic 4(Q4)}</td><td>0</td><td>1.35</td></tr>
<tr><td>Envelope {Thermal_Heat (ΔM^{+}), Thermal_Cold (ΔM^{-})}</td><td>0</td><td>1.50x0.6</td></tr>
</table>

Design Envelopes

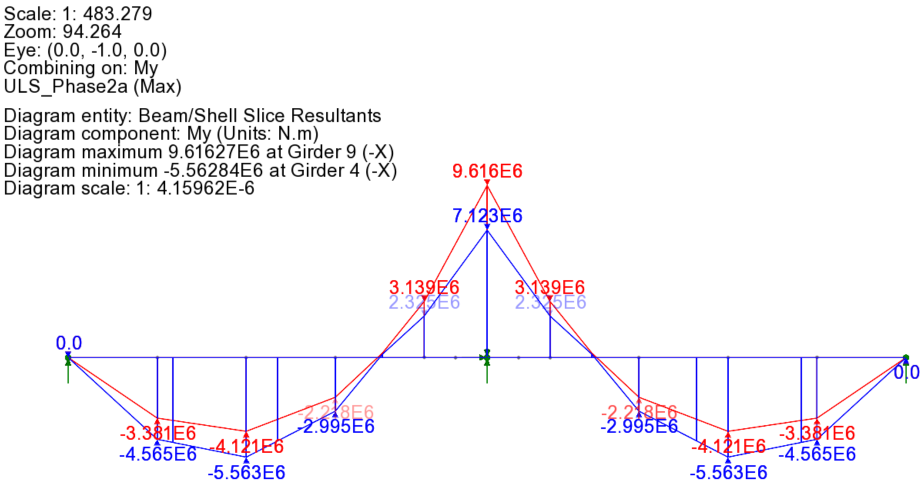
The Ultimate Limit State (ULS) design envelopes, grouped by design phase, are presented below. The design envelopes should be organised by phase, as in the case of composite cross-sections, stress states may be superimposed, but internal forces should not. Maximum values are shown in red, and minimum values in blue.

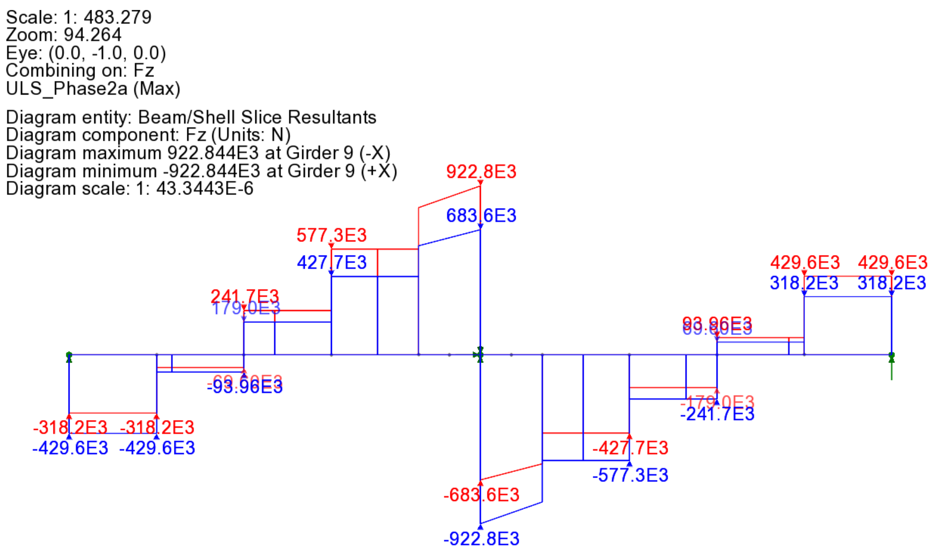
Phase 1 – ULS





Phase 2a – ULS

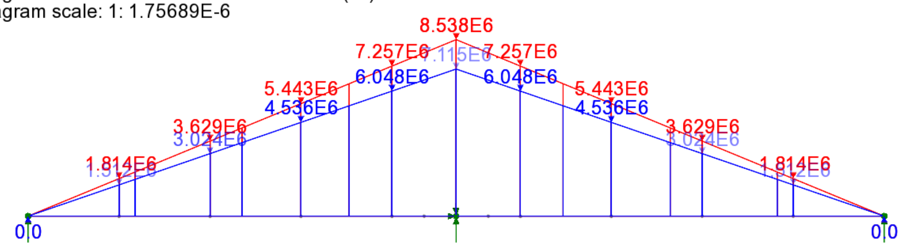

Scale: 1: 483.279
Zoom: 94.264
Eye: (0.0, -1.0, 0.0)
Combining on: My
ULS_Phase2a (Max)
Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 9.61627E6 at Girder 9 (-X)
Diagram minimum -5.56284E6 at Girder 4 (-X)
Diagram scale: 1: 4.15962E-6
9.616E6
7.123E6
3.139E6
2.325E6
3.139E6
2.325E6
0.0
0.0
-2.218E6
-2.995E6
-2.218E6
-2.995E6
-3.381E6
-4.565E6
-4.121E6
-5.563E6
-4.121E6
-5.563E6
-3.381E6
-4.565E6


Scale: 1: 483.279
Zoom: 94.264
Eye: (0.0, -1.0, 0.0)
Combining on: Fz
ULS_Phase2a (Max)
Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 922.844E3 at Girder 9 (-X)
Diagram minimum -922.844E3 at Girder 9 (+X)
Diagram scale: 1: 43.3443E-6
922.8E3
683.6E3
577.3E3
427.7E3
241.7E3
179.0E3
429.6E3
318.2E3
429.6E3
318.2E3
93.96E3
69.60E3
-69.60E3
-93.96E3
-318.2E3
-429.6E3
-318.2E3
-429.6E3
-179.0E3
-241.7E3
-427.7E3
-577.3E3
-683.6E3
-922.8E3

Phase 2b – ULS

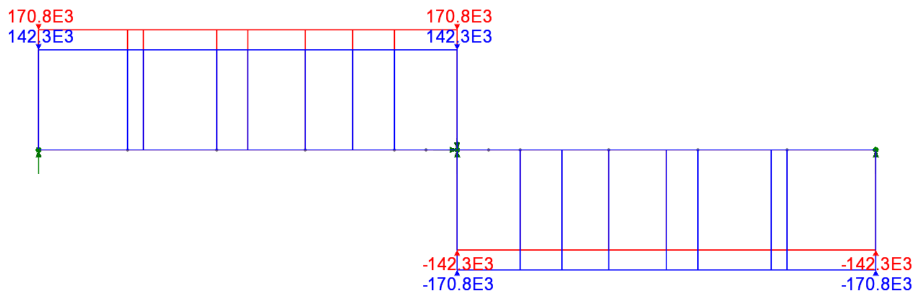
Scale: 1: 483.279
Zoom: 93.658
Eye: (0.0, -1.0, 0.0)
Combining on: My
ULS_Phase2b (Max)

Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 8.53784E6 at Girder 9 (-X)
Diagram scale: 1: 1.75689E-6



Scale: 1: 483.279
Zoom: 100.862
Eye: (0.0, -1.0, 0.0)
Combining on: Fz
ULS_Phase2b (Max)

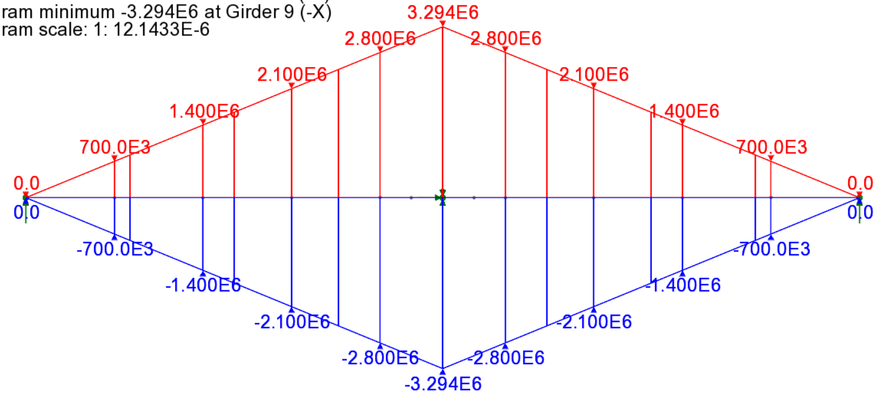
Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 170.757E3 at Girder 2 (-X)
Diagram minimum -170.757E3 at Girder 9 (+X)
Diagram scale: 1: 0.175689E-3



Phase 3a – ULS

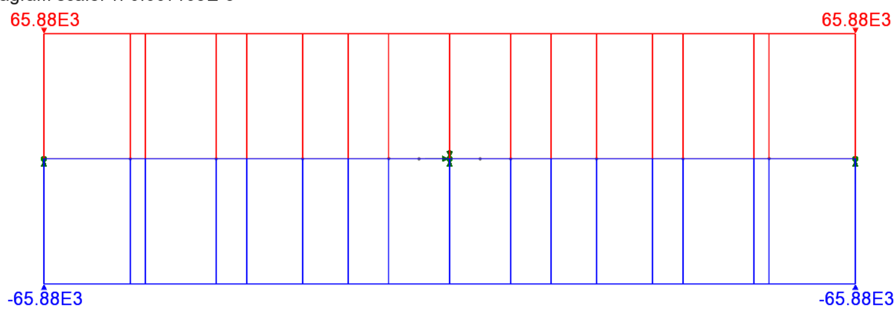
Scale: 1: 483.279
Zoom: 94.264
Eye: (0.0, -1.0, 0.0)
Combining on: My
ULS_Phase3a (Max)

Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 3.294E6 at Girder 9 (-X)
Diagram minimum -3.294E6 at Girder 9 (-X)
Diagram scale: 1: 12.1433E-6



Scale: 1: 483.279
Zoom: 94.264
Eye: (0.0, -1.0, 0.0)
Combining on: Fz
ULS_Phase3a (Max)

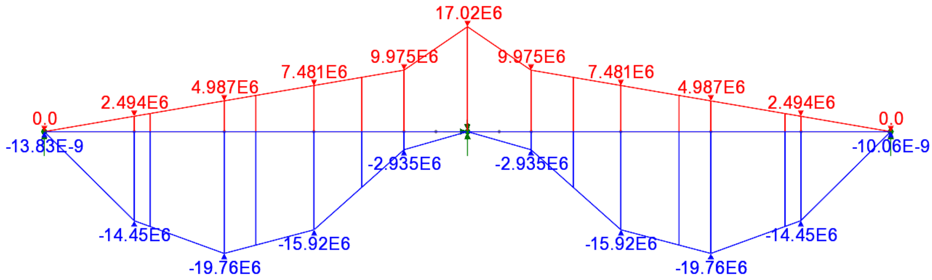
Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 65.8799E3 at Girder 2 (-X)
Diagram minimum -65.8799E3 at Girder 2 (-X)
Diagram scale: 1: 0.607165E-3



Phase 3b – ULS

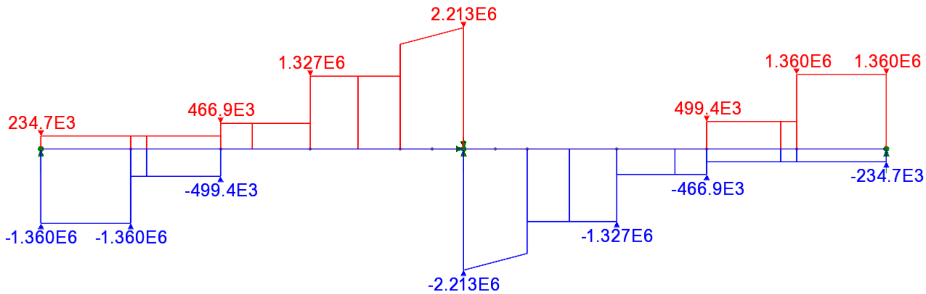
Scale: 1: 483.279
Zoom: 100.862
Eye: (0.0, -1.0, 0.0)
Combining on: My
ULS_Phase3b (Max)

Diagram entity: Beam/Shell Slice Resultants
Diagram component: My (Units: N.m)
Diagram maximum 17.0154E6 at Girder 9 (-X)
Diagram minimum -19.7557E6 at Girder 4 (-X)
Diagram scale: 1: 1.51855E-6



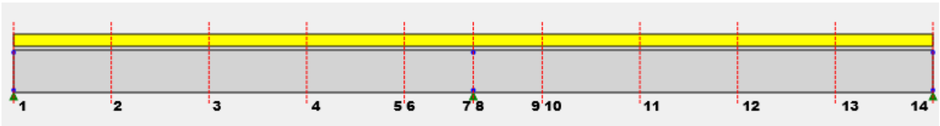
Scale: 1: 483.279
Zoom: 100.862
Eye: (0.0, -1.0, 0.0)
Combining on: Fz
ULS_Phase3b (Max)

Diagram entity: Beam/Shell Slice Resultants
Diagram component: Fz (Units: N)
Diagram maximum 2.21343E6 at Girder 9 (-X)
Diagram minimum -2.21343E6 at Girder 9 (+X)
Diagram scale: 1: 13.5536E-6



Sections to be checked in PontiEC4

The sections to be checked, along with their corresponding positions, are shown in the figure and table below.



Section	X (m)
C1_1	0.000
C1_2	10.625
C1_3	21.250
C1_4	31.875
C1_5	42.500
C2_cracked_6	42.501
C2_cracked_7	50.000

Section	X (m)
C2_cracked_8	50.001
C2_cracked_9	57.500
C1_10	57.501
C1_11	68.125
C1_12	78.750
C1_13	89.375
C1_14	100.000

Summary Table of Internal Forces

The internal forces corresponding to the Ultimate Limit State are reported at the specified sections and are organised by **design phase**, **force component** (maximum or minimum), and **section name**. Only the shear force Fz and bending moment My are reported here, as the remaining internal forces are expected to have a negligible impact. In the $\gamma \cdot \psi$ column (Phases 2b and 3a), the coefficients used to compute the primary effects of shrinkage and thermal variation are included.

Section	Component	Phase	Fz	My	γ ψ
C1_1	Fz (Max)	Phase 1	-8.9277E+05	0.0000E+00	
C1_2	Fz (Max)	Phase 1	-8.9277E+05	-9.4857E+06	
C1_3	Fz (Max)	Phase 1	7.5268E+05	-1.5210E+07	
C1_4	Fz (Max)	Phase 1	1.7316E+06	-7.2128E+06	
C1_5	Fz (Max)	Phase 1	2.3939E+06	1.1186E+07	
C2_cracked_6	Fz (Max)	Phase 1	2.3939E+06	1.1186E+07	
C2_cracked_7	Fz (Max)	Phase 1	2.7394E+06	3.0436E+07	
C2_cracked_8	Fz (Max)	Phase 1	2.7394E+06	3.0436E+07	
C2_cracked_9	Fz (Max)	Phase 1	-1.7732E+06	8.2859E+06	
C1_10	Fz (Max)	Phase 1	-1.7732E+06	8.2859E+06	
C1_11	Fz (Max)	Phase 1	-1.2827E+06	-5.3428E+06	
C1_12	Fz (Max)	Phase 1	-5.5754E+05	-1.5210E+07	

Section	Component	Phase	Fz	My	γ ψ
C1_13	Fz (Max)	Phase 1	1.2052E+06	-1.2806E+07	
C1_14	Fz (Max)	Phase 1	1.2052E+06	0.0000E+00	
C1_1	Fz (Min)	Phase 1	-1.2052E+06	0.0000E+00	
C1_2	Fz (Min)	Phase 1	-1.2052E+06	-1.2806E+07	
C1_3	Fz (Min)	Phase 1	5.5754E+05	-1.5210E+07	
C1_4	Fz (Min)	Phase 1	1.2827E+06	-5.3428E+06	
C1_5	Fz (Min)	Phase 1	1.7732E+06	8.2859E+06	
C2_cracked_6	Fz (Min)	Phase 1	1.7732E+06	8.2859E+06	
C2_cracked_7	Fz (Min)	Phase 1	-2.7394E+06	3.0436E+07	
C2_cracked_8	Fz (Min)	Phase 1	-2.7394E+06	3.0436E+07	
C2_cracked_9	Fz (Min)	Phase 1	-2.3939E+06	1.1186E+07	
C1_10	Fz (Min)	Phase 1	-2.3939E+06	1.1186E+07	
C1_11	Fz (Min)	Phase 1	-1.7316E+06	-7.2128E+06	
C1_12	Fz (Min)	Phase 1	-7.5268E+05	-1.5210E+07	
C1_13	Fz (Min)	Phase 1	8.9277E+05	-9.4857E+06	
C1_14	Fz (Min)	Phase 1	8.9277E+05	0.0000E+00	
C1_1	My (Max)	Phase 1	-8.9277E+05	0.0000E+00	
C1_2	My (Max)	Phase 1	-8.9277E+05	-9.4857E+06	
C1_3	My (Max)	Phase 1	5.5754E+05	-1.1267E+07	
C1_4	My (Max)	Phase 1	1.2827E+06	-5.3428E+06	
C1_5	My (Max)	Phase 1	2.3939E+06	1.1186E+07	
C2_cracked_6	My (Max)	Phase 1	2.3939E+06	1.1186E+07	
C2_cracked_7	My (Max)	Phase 1	-2.7394E+06	3.0436E+07	
C2_cracked_8	My (Max)	Phase 1	-2.7394E+06	3.0436E+07	
C2_cracked_9	My (Max)	Phase 1	-2.3939E+06	1.1186E+07	
C1_10	My (Max)	Phase 1	-2.3939E+06	1.1186E+07	
C1_11	My (Max)	Phase 1	-1.2827E+06	-5.3428E+06	
C1_12	My (Max)	Phase 1	-5.5754E+05	-1.1267E+07	
C1_13	My (Max)	Phase 1	8.9277E+05	-9.4857E+06	
C1_14	My (Max)	Phase 1	8.9277E+05	0.0000E+00	
C1_1	My (Min)	Phase 1	-1.2052E+06	0.0000E+00	
C1_2	My (Min)	Phase 1	-1.2052E+06	-1.2806E+07	
C1_3	My (Min)	Phase 1	7.5268E+05	-1.5210E+07	
C1_4	My (Min)	Phase 1	1.7316E+06	-7.2128E+06	
C1_5	My (Min)	Phase 1	1.7732E+06	8.2859E+06	
C2_cracked_6	My (Min)	Phase 1	1.7732E+06	8.2859E+06	
C2_cracked_7	My (Min)	Phase 1	-2.0292E+06	2.2545E+07	
C2_cracked_8	My (Min)	Phase 1	-2.0292E+06	2.2545E+07	

Section	Component	Phase	Fz	My	γ ψ
C2_cracked_9	My (Min)	Phase 1	-1.7732E+06	8.2859E+06	
C1_10	My (Min)	Phase 1	-1.7732E+06	8.2859E+06	
C1_11	My (Min)	Phase 1	-1.7316E+06	-7.2128E+06	
C1_12	My (Min)	Phase 1	-7.5268E+05	-1.5210E+07	
C1_13	My (Min)	Phase 1	1.2052E+06	-1.2806E+07	
C1_14	My (Min)	Phase 1	1.2052E+06	0.0000E+00	
C1_1	Fz (Max)	Phase 2a	-3.1822E+05	0.0000E+00	
C1_2	Fz (Max)	Phase 2a	-3.1822E+05	-3.3811E+06	
C1_3	Fz (Max)	Phase 2a	2.4168E+05	-5.5628E+06	
C1_4	Fz (Max)	Phase 2a	5.7733E+05	-2.9949E+06	
C1_5	Fz (Max)	Phase 2a	8.0438E+05	3.1392E+06	
C2_cracked_6	Fz (Max)	Phase 2a	8.0438E+05	3.1392E+06	
C2_cracked_7	Fz (Max)	Phase 2a	9.2284E+05	9.6163E+06	
C2_cracked_8	Fz (Max)	Phase 2a	9.2284E+05	9.6163E+06	
C2_cracked_9	Fz (Max)	Phase 2a	-5.9584E+05	2.3253E+06	
C1_10	Fz (Max)	Phase 2a	-5.9584E+05	2.3253E+06	
C1_11	Fz (Max)	Phase 2a	-4.2765E+05	-2.2185E+06	
C1_12	Fz (Max)	Phase 2a	-1.7903E+05	-5.5628E+06	
C1_13	Fz (Max)	Phase 2a	4.2960E+05	-4.5645E+06	
C1_14	Fz (Max)	Phase 2a	4.2960E+05	0.0000E+00	
C1_1	Fz (Min)	Phase 2a	-4.2960E+05	0.0000E+00	
C1_2	Fz (Min)	Phase 2a	-4.2960E+05	-4.5645E+06	
C1_3	Fz (Min)	Phase 2a	1.7903E+05	-5.5628E+06	
C1_4	Fz (Min)	Phase 2a	4.2765E+05	-2.2185E+06	
C1_5	Fz (Min)	Phase 2a	5.9584E+05	2.3253E+06	
C2_cracked_6	Fz (Min)	Phase 2a	5.9584E+05	2.3253E+06	
C2_cracked_7	Fz (Min)	Phase 2a	-9.2284E+05	9.6163E+06	
C2_cracked_8	Fz (Min)	Phase 2a	-9.2284E+05	9.6163E+06	
C2_cracked_9	Fz (Min)	Phase 2a	-8.0438E+05	3.1392E+06	
C1_10	Fz (Min)	Phase 2a	-8.0438E+05	3.1392E+06	
C1_11	Fz (Min)	Phase 2a	-5.7733E+05	-2.9949E+06	
C1_12	Fz (Min)	Phase 2a	-2.4168E+05	-5.5628E+06	
C1_13	Fz (Min)	Phase 2a	3.1822E+05	-3.3811E+06	
C1_14	Fz (Min)	Phase 2a	3.1822E+05	0.0000E+00	
C1_1	My (Max)	Phase 2a	-4.2960E+05	0.0000E+00	
C1_2	My (Max)	Phase 2a	-3.1822E+05	-3.3811E+06	
C1_3	My (Max)	Phase 2a	1.7903E+05	-4.1206E+06	
C1_4	My (Max)	Phase 2a	4.2765E+05	-2.2185E+06	

Section	Component	Phase	Fz	My	γ ψ
C1_5	My (Max)	Phase 2a	8.0438E+05	3.1392E+06	
C2_cracked_6	My (Max)	Phase 2a	8.0438E+05	3.1392E+06	
C2_cracked_7	My (Max)	Phase 2a	-9.2284E+05	9.6163E+06	
C2_cracked_8	My (Max)	Phase 2a	-9.2284E+05	9.6163E+06	
C2_cracked_9	My (Max)	Phase 2a	-8.0438E+05	3.1392E+06	
C1_10	My (Max)	Phase 2a	-8.0438E+05	3.1392E+06	
C1_11	My (Max)	Phase 2a	-4.2765E+05	-2.2185E+06	
C1_12	My (Max)	Phase 2a	-1.7903E+05	-4.1206E+06	
C1_13	My (Max)	Phase 2a	3.1822E+05	-3.3811E+06	
C1_14	My (Max)	Phase 2a	3.1822E+05	0.0000E+00	
C1_1	My (Min)	Phase 2a	-3.1822E+05	0.0000E+00	
C1_2	My (Min)	Phase 2a	-4.2960E+05	-4.5645E+06	
C1_3	My (Min)	Phase 2a	2.4168E+05	-5.5628E+06	
C1_4	My (Min)	Phase 2a	5.7733E+05	-2.9949E+06	
C1_5	My (Min)	Phase 2a	5.9584E+05	2.3253E+06	
C2_cracked_6	My (Min)	Phase 2a	5.9584E+05	2.3253E+06	
C2_cracked_7	My (Min)	Phase 2a	-6.8359E+05	7.1232E+06	
C2_cracked_8	My (Min)	Phase 2a	-6.8359E+05	7.1232E+06	
C2_cracked_9	My (Min)	Phase 2a	-5.9584E+05	2.3253E+06	
C1_10	My (Min)	Phase 2a	-5.9584E+05	2.3253E+06	
C1_11	My (Min)	Phase 2a	-5.7733E+05	-2.9949E+06	
C1_12	My (Min)	Phase 2a	-2.4168E+05	-5.5628E+06	
C1_13	My (Min)	Phase 2a	4.2960E+05	-4.5645E+06	
C1_14	My (Min)	Phase 2a	4.2960E+05	0.0000E+00	
C1_1	Fz (Max)	Phase 2b	1.7076E+05	0.0000E+00	1.20
C1_2	Fz (Max)	Phase 2b	1.7076E+05	1.8143E+06	1.20
C1_3	Fz (Max)	Phase 2b	1.7076E+05	3.6286E+06	1.20
C1_4	Fz (Max)	Phase 2b	1.7076E+05	5.4429E+06	1.20
C1_5	Fz (Max)	Phase 2b	1.7076E+05	7.2572E+06	1.20
C2_cracked_6	Fz (Max)	Phase 2b	1.7076E+05	7.2572E+06	0.00
C2_cracked_7	Fz (Max)	Phase 2b	1.7076E+05	8.5378E+06	0.00
C2_cracked_8	Fz (Max)	Phase 2b	1.7076E+05	8.5378E+06	0.00
C2_cracked_9	Fz (Max)	Phase 2b	-1.4230E+05	6.0476E+06	0.00
C1_10	Fz (Max)	Phase 2b	-1.4230E+05	6.0476E+06	1.20
C1_11	Fz (Max)	Phase 2b	-1.4230E+05	4.5357E+06	1.20
C1_12	Fz (Max)	Phase 2b	-1.4230E+05	3.0238E+06	1.20
C1_13	Fz (Max)	Phase 2b	-1.4230E+05	1.5119E+06	1.20
C1_14	Fz (Max)	Phase 2b	-1.4230E+05	0.0000E+00	1.20

Section	Component	Phase	Fz	My	γ ψ
C1_1	Fz (Min)	Phase 2b	1.4230E+05	0.0000E+00	1.20
C1_2	Fz (Min)	Phase 2b	1.4230E+05	1.5119E+06	1.20
C1_3	Fz (Min)	Phase 2b	1.4230E+05	3.0238E+06	1.20
C1_4	Fz (Min)	Phase 2b	1.4230E+05	4.5357E+06	1.20
C1_5	Fz (Min)	Phase 2b	1.4230E+05	6.0476E+06	1.20
C2_cracked_6	Fz (Min)	Phase 2b	1.4230E+05	6.0476E+06	0.00
C2_cracked_7	Fz (Min)	Phase 2b	-1.7076E+05	8.5378E+06	0.00
C2_cracked_8	Fz (Min)	Phase 2b	-1.7076E+05	8.5378E+06	0.00
C2_cracked_9	Fz (Min)	Phase 2b	-1.7076E+05	7.2572E+06	0.00
C1_10	Fz (Min)	Phase 2b	-1.7076E+05	7.2572E+06	1.20
C1_11	Fz (Min)	Phase 2b	-1.7076E+05	5.4429E+06	1.20
C1_12	Fz (Min)	Phase 2b	-1.7076E+05	3.6286E+06	1.20
C1_13	Fz (Min)	Phase 2b	-1.7076E+05	1.8143E+06	1.20
C1_14	Fz (Min)	Phase 2b	-1.7076E+05	0.0000E+00	1.20
C1_1	My (Max)	Phase 2b	1.4230E+05	0.0000E+00	1.20
C1_2	My (Max)	Phase 2b	1.7076E+05	1.8143E+06	1.20
C1_3	My (Max)	Phase 2b	1.7076E+05	3.6286E+06	1.20
C1_4	My (Max)	Phase 2b	1.7076E+05	5.4429E+06	1.20
C1_5	My (Max)	Phase 2b	1.7076E+05	7.2572E+06	1.20
C2_cracked_6	My (Max)	Phase 2b	1.7076E+05	7.2572E+06	0.00
C2_cracked_7	My (Max)	Phase 2b	1.7076E+05	8.5378E+06	0.00
C2_cracked_8	My (Max)	Phase 2b	1.7076E+05	8.5378E+06	0.00
C2_cracked_9	My (Max)	Phase 2b	-1.7076E+05	7.2572E+06	0.00
C1_10	My (Max)	Phase 2b	-1.7076E+05	7.2572E+06	1.20
C1_11	My (Max)	Phase 2b	-1.7076E+05	5.4429E+06	1.20
C1_12	My (Max)	Phase 2b	-1.7076E+05	3.6286E+06	1.20
C1_13	My (Max)	Phase 2b	-1.7076E+05	1.8143E+06	1.20
C1_14	My (Max)	Phase 2b	-1.4230E+05	0.0000E+00	1.20
C1_1	My (Min)	Phase 2b	1.7076E+05	0.0000E+00	1.20
C1_2	My (Min)	Phase 2b	1.4230E+05	1.5119E+06	1.20
C1_3	My (Min)	Phase 2b	1.4230E+05	3.0238E+06	1.20
C1_4	My (Min)	Phase 2b	1.4230E+05	4.5357E+06	1.20
C1_5	My (Min)	Phase 2b	1.4230E+05	6.0476E+06	1.20
C2_cracked_6	My (Min)	Phase 2b	1.4230E+05	6.0476E+06	0.00
C2_cracked_7	My (Min)	Phase 2b	1.4230E+05	7.1149E+06	0.00
C2_cracked_8	My (Min)	Phase 2b	1.4230E+05	7.1149E+06	0.00
C2_cracked_9	My (Min)	Phase 2b	-1.4230E+05	6.0476E+06	0.00
C1_10	My (Min)	Phase 2b	-1.4230E+05	6.0476E+06	1.20

Section	Component	Phase	Fz	My	γ ψ
C1_11	My (Min)	Phase 2b	-1.4230E+05	4.5357E+06	1.20
C1_12	My (Min)	Phase 2b	-1.4230E+05	3.0238E+06	1.20
C1_13	My (Min)	Phase 2b	-1.4230E+05	1.5119E+06	1.20
C1_14	My (Min)	Phase 2b	-1.7076E+05	0.0000E+00	1.20
C1_1	Fz (Max)	Phase 3a	6.5880E+04	0.0000E+00	0.90
C1_2	Fz (Max)	Phase 3a	6.5880E+04	6.9997E+05	-0.90
C1_3	Fz (Max)	Phase 3a	6.5880E+04	1.3999E+06	-0.90
C1_4	Fz (Max)	Phase 3a	6.5880E+04	2.0999E+06	-0.90
C1_5	Fz (Max)	Phase 3a	6.5880E+04	2.7999E+06	-0.90
C2_cracked_6	Fz (Max)	Phase 3a	6.5880E+04	2.7999E+06	0.00
C2_cracked_7	Fz (Max)	Phase 3a	6.5880E+04	3.2940E+06	0.00
C2_cracked_8	Fz (Max)	Phase 3a	6.5880E+04	3.2940E+06	0.00
C2_cracked_9	Fz (Max)	Phase 3a	6.5880E+04	-2.7999E+06	0.00
C1_10	Fz (Max)	Phase 3a	6.5880E+04	-2.7999E+06	0.90
C1_11	Fz (Max)	Phase 3a	6.5880E+04	-2.0999E+06	0.90
C1_12	Fz (Max)	Phase 3a	6.5880E+04	-1.3999E+06	0.90
C1_13	Fz (Max)	Phase 3a	6.5880E+04	-6.9997E+05	0.90
C1_14	Fz (Max)	Phase 3a	6.5880E+04	0.0000E+00	0.90
C1_1	Fz (Min)	Phase 3a	-6.5880E+04	0.0000E+00	0.90
C1_2	Fz (Min)	Phase 3a	-6.5880E+04	-6.9997E+05	0.90
C1_3	Fz (Min)	Phase 3a	-6.5880E+04	-1.3999E+06	0.90
C1_4	Fz (Min)	Phase 3a	-6.5880E+04	-2.0999E+06	0.90
C1_5	Fz (Min)	Phase 3a	-6.5880E+04	-2.7999E+06	0.90
C2_cracked_6	Fz (Min)	Phase 3a	-6.5880E+04	-2.7999E+06	0.00
C2_cracked_7	Fz (Min)	Phase 3a	-6.5880E+04	-3.2940E+06	0.00
C2_cracked_8	Fz (Min)	Phase 3a	-6.5880E+04	-3.2940E+06	0.00
C2_cracked_9	Fz (Min)	Phase 3a	-6.5880E+04	2.7999E+06	0.00
C1_10	Fz (Min)	Phase 3a	-6.5880E+04	2.7999E+06	-0.90
C1_11	Fz (Min)	Phase 3a	-6.5880E+04	2.0999E+06	-0.90
C1_12	Fz (Min)	Phase 3a	-6.5880E+04	1.3999E+06	-0.90
C1_13	Fz (Min)	Phase 3a	-6.5880E+04	6.9997E+05	-0.90
C1_14	Fz (Min)	Phase 3a	-6.5880E+04	0.0000E+00	0.90
C1_1	My (Max)	Phase 3a	-6.5880E+04	0.0000E+00	0.90
C1_2	My (Max)	Phase 3a	6.5880E+04	6.9997E+05	-0.90
C1_3	My (Max)	Phase 3a	6.5880E+04	1.3999E+06	-0.90
C1_4	My (Max)	Phase 3a	6.5880E+04	2.0999E+06	-0.90
C1_5	My (Max)	Phase 3a	6.5880E+04	2.7999E+06	-0.90
C2_cracked_6	My (Max)	Phase 3a	6.5880E+04	2.7999E+06	0.00

Section	Component	Phase	Fz	My	γ ψ
C2_cracked_7	My (Max)	Phase 3a	6.5880E+04	3.2940E+06	0.00
C2_cracked_8	My (Max)	Phase 3a	6.5880E+04	3.2940E+06	0.00
C2_cracked_9	My (Max)	Phase 3a	-6.5880E+04	2.7999E+06	0.00
C1_10	My (Max)	Phase 3a	-6.5880E+04	2.7999E+06	-0.90
C1_11	My (Max)	Phase 3a	-6.5880E+04	2.0999E+06	-0.90
C1_12	My (Max)	Phase 3a	-6.5880E+04	1.3999E+06	-0.90
C1_13	My (Max)	Phase 3a	-6.5880E+04	6.9997E+05	-0.90
C1_14	My (Max)	Phase 3a	6.5880E+04	0.0000E+00	0.90
C1_1	My (Min)	Phase 3a	6.5880E+04	0.0000E+00	0.90
C1_2	My (Min)	Phase 3a	-6.5880E+04	-6.9997E+05	0.90
C1_3	My (Min)	Phase 3a	-6.5880E+04	-1.3999E+06	0.90
C1_4	My (Min)	Phase 3a	-6.5880E+04	-2.0999E+06	0.90
C1_5	My (Min)	Phase 3a	-6.5880E+04	-2.7999E+06	0.90
C2_cracked_6	My (Min)	Phase 3a	-6.5880E+04	-2.7999E+06	0.00
C2_cracked_7	My (Min)	Phase 3a	-6.5880E+04	-3.2940E+06	0.00
C2_cracked_8	My (Min)	Phase 3a	-6.5880E+04	-3.2940E+06	0.00
C2_cracked_9	My (Min)	Phase 3a	6.5880E+04	-2.7999E+06	0.00
C1_10	My (Min)	Phase 3a	6.5880E+04	-2.7999E+06	0.90
C1_11	My (Min)	Phase 3a	6.5880E+04	-2.0999E+06	0.90
C1_12	My (Min)	Phase 3a	6.5880E+04	-1.3999E+06	0.90
C1_13	My (Min)	Phase 3a	6.5880E+04	-6.9997E+05	0.90
C1_14	My (Min)	Phase 3a	-6.5880E+04	0.0000E+00	0.90
C1_1	Fz (Max)	Phase 3b	2.3470E+05	0.0000E+00	
C1_2	Fz (Max)	Phase 3b	2.3470E+05	2.4936E+06	
C1_3	Fz (Max)	Phase 3b	4.6687E+05	-1.7511E+07	
C1_4	Fz (Max)	Phase 3b	1.3275E+06	-1.2551E+07	
C1_5	Fz (Max)	Phase 3b	1.9097E+06	1.5537E+06	
C2_cracked_6	Fz (Max)	Phase 3b	1.9097E+06	1.5537E+06	
C2_cracked_7	Fz (Max)	Phase 3b	2.2134E+06	1.7015E+07	
C2_cracked_8	Fz (Max)	Phase 3b	2.2134E+06	1.7015E+07	
C2_cracked_9	Fz (Max)	Phase 3b	0.0000E+00	0.0000E+00	
C1_10	Fz (Max)	Phase 3b	0.0000E+00	0.0000E+00	
C1_11	Fz (Max)	Phase 3b	0.0000E+00	0.0000E+00	
C1_12	Fz (Max)	Phase 3b	4.9937E+05	-1.9756E+07	
C1_13	Fz (Max)	Phase 3b	1.3600E+06	-1.4450E+07	
C1_14	Fz (Max)	Phase 3b	1.3600E+06	0.0000E+00	
C1_1	Fz (Min)	Phase 3b	-1.3600E+06	0.0000E+00	
C1_2	Fz (Min)	Phase 3b	-1.3600E+06	-1.4450E+07	

Section	Component	Phase	Fz	My	γ ψ
C1_3	Fz (Min)	Phase 3b	-4.9937E+05	-1.9756E+07	
C1_4	Fz (Min)	Phase 3b	0.0000E+00	0.0000E+00	
C1_5	Fz (Min)	Phase 3b	0.0000E+00	0.0000E+00	
C2_cracked_6	Fz (Min)	Phase 3b	0.0000E+00	0.0000E+00	
C2_cracked_7	Fz (Min)	Phase 3b	-2.2134E+06	1.7015E+07	
C2_cracked_8	Fz (Min)	Phase 3b	-2.2134E+06	1.7015E+07	
C2_cracked_9	Fz (Min)	Phase 3b	-1.9097E+06	1.5537E+06	
C1_10	Fz (Min)	Phase 3b	-1.9097E+06	1.5537E+06	
C1_11	Fz (Min)	Phase 3b	-1.3275E+06	-1.2551E+07	
C1_12	Fz (Min)	Phase 3b	-4.6687E+05	-1.7511E+07	
C1_13	Fz (Min)	Phase 3b	-2.3470E+05	2.4936E+06	
C1_14	Fz (Min)	Phase 3b	-2.3470E+05	0.0000E+00	
C1_1	My (Max)	Phase 3b	2.3470E+05	0.0000E+00	
C1_2	My (Max)	Phase 3b	2.3470E+05	2.4936E+06	
C1_3	My (Max)	Phase 3b	2.3470E+05	4.9873E+06	
C1_4	My (Max)	Phase 3b	2.3470E+05	7.4809E+06	
C1_5	My (Max)	Phase 3b	2.3470E+05	9.9746E+06	
C2_cracked_6	My (Max)	Phase 3b	2.3470E+05	9.9746E+06	
C2_cracked_7	My (Max)	Phase 3b	2.2134E+06	1.7015E+07	
C2_cracked_8	My (Max)	Phase 3b	2.2134E+06	1.7015E+07	
C2_cracked_9	My (Max)	Phase 3b	-2.3470E+05	9.9746E+06	
C1_10	My (Max)	Phase 3b	-2.3470E+05	9.9746E+06	
C1_11	My (Max)	Phase 3b	-2.3470E+05	7.4809E+06	
C1_12	My (Max)	Phase 3b	-2.3470E+05	4.9873E+06	
C1_13	My (Max)	Phase 3b	-2.3470E+05	2.4936E+06	
C1_14	My (Max)	Phase 3b	-2.3470E+05	0.0000E+00	
C1_1	My (Min)	Phase 3b	-1.2544E+06	0.0000E+00	
C1_2	My (Min)	Phase 3b	-1.3600E+06	-1.4450E+07	
C1_3	My (Min)	Phase 3b	-4.9937E+05	-1.9756E+07	
C1_4	My (Min)	Phase 3b	1.2219E+06	-1.5917E+07	
C1_5	My (Min)	Phase 3b	1.8041E+06	-2.9348E+06	
C2_cracked_6	My (Min)	Phase 3b	1.8041E+06	-2.9348E+06	
C2_cracked_7	My (Min)	Phase 3b	0.0000E+00	0.0000E+00	
C2_cracked_8	My (Min)	Phase 3b	0.0000E+00	0.0000E+00	
C2_cracked_9	My (Min)	Phase 3b	-1.8041E+06	-2.9348E+06	
C1_10	My (Min)	Phase 3b	-1.8041E+06	-2.9348E+06	
C1_11	My (Min)	Phase 3b	-1.2219E+06	-1.5917E+07	
C1_12	My (Min)	Phase 3b	4.9937E+05	-1.9756E+07	

Section	Component	Phase	Fz	My	γ ψ
C1_13	My (Min)	Phase 3b	1.3600E+06	-1.4450E+07	
C1_14	My (Min)	Phase 3b	1.2544E+06	0.0000E+00	

Part 2: Design checks – PontiEC4

This section provides a detailed description of the steps required to perform design checks within PontiEC4.

The units adopted are as follows:

Length: millimetres (mm)

Forces and moments: Newtons (N) and Newton-metres (Nm)

Stresses: N/mm²

Keywords

Steel, Composite, Deck, Designer, EC4, Design, Checking, Import, Export, ULS, Shrinkage, Thermal Variation, Isostatic Effects, Hyperstatic Effects.

Associated files

Reference files associated with this example:

- **Ex_Shrinkage-Thermal_Initial.csv** – Input file containing data related to materials, shear lag, and segment geometry
- **Ex_Shrinkage-Thermal.csv** – Complete input file with materials, geometry, and internal forces
- **Ex_Shrinkage-Thermal_Forces-Moments.xlsx** – Excel file used to input internal forces into PontiEC4
- **Ex_Shrinkage-Thermal_Phase1.csv** – Input file including only Phase 1 forces, with free top flange and no slab
- **Ex_Shrinkage-Thermal.mdl** – LUSAS model

Method and Objectives

The key steps for using the PontiEC4 Steel and Composite Deck Designer with LUSAS are as follows:

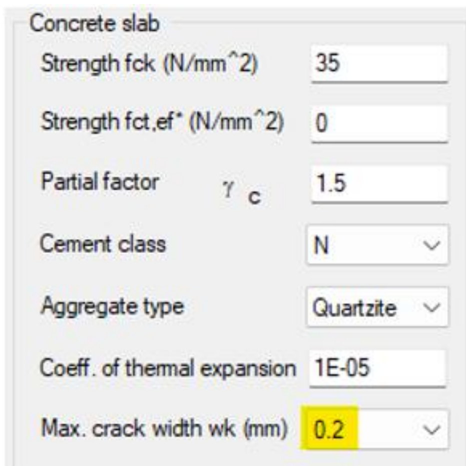
- **Step 1: Input material properties**
- **Step 2: Define effective slab width (shear lag)**
- **Step 3: Input segment geometry**

- **Step 4: Calculate equivalent thermal gradients (shrinkage and thermal variation)**
- **Step 5: Perform structural analysis**
- **Step 6: Prepare internal force input file**
- **Step 7: Import internal forces**
- **Step 8: Visualise results**
- **Step 9: Perform Phase 1 verifications**

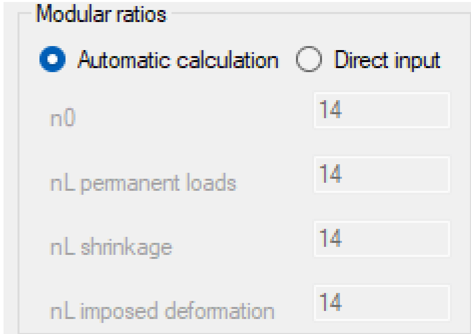
Step 1: Input Material Properties

- Start a new project by selecting *File > New* from the menu. Save the file as **Ex_Shrinkage-Thermal.csv** in your working directory.
- In the **Materials** dialog window, click the **Default** button located at the bottom right.
- Proceed through the input sections as illustrated in the following figures. Fields highlighted in yellow indicate data that has been added or modified from the default values.

Concrete slab



Modular ratios

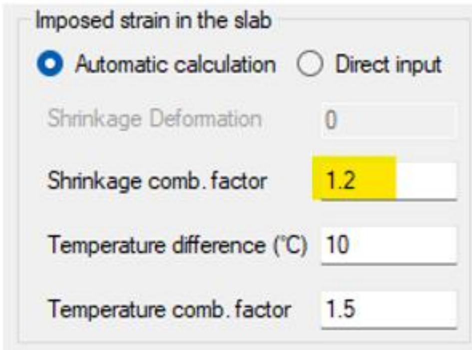


Modular ratios

(●) Automatic calculation ( ) Direct input

n0	14
nL permanent loads	14
nL shrinkage	14
nL imposed deformation	14

Imposed strain in the slab

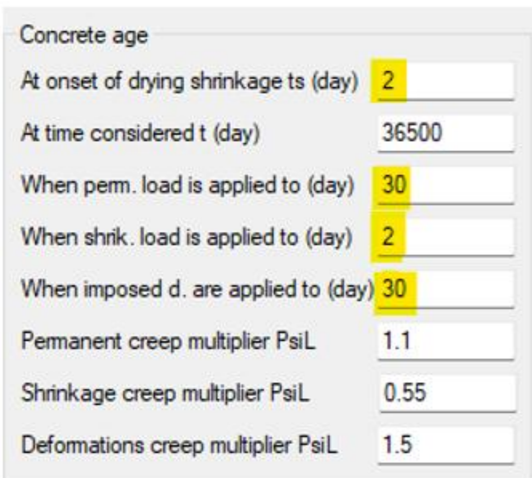


Imposed strain in the slab

(●) Automatic calculation ( ) Direct input

Shrinkage Deformation	0
Shrinkage comb. factor	1.2
Temperature difference (°C)	10
Temperature comb. factor	1.5

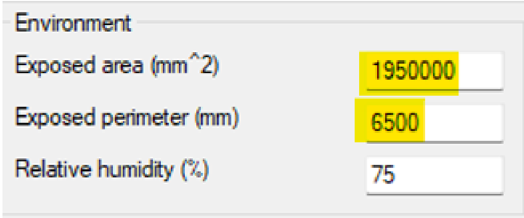
Concrete age



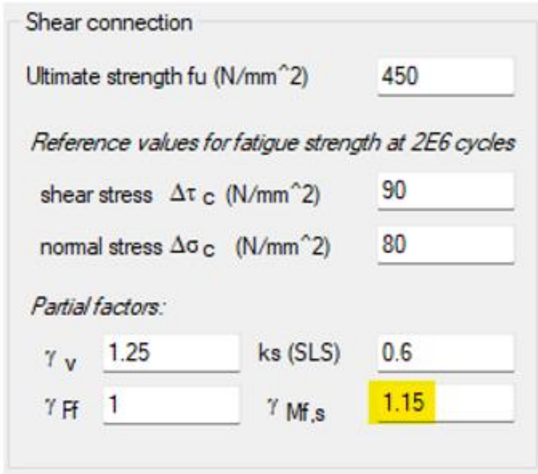
Concrete age

At onset of drying shrinkage ts (day)	2
At time considered t (day)	36500
When perm. load is applied to (day)	30
When shrik. load is applied to (day)	2
When imposed d. are applied to (day)	30
Permanent creep multiplier PsiL	1.1
Shrinkage creep multiplier PsiL	0.55
Deformations creep multiplier PsiL	1.5

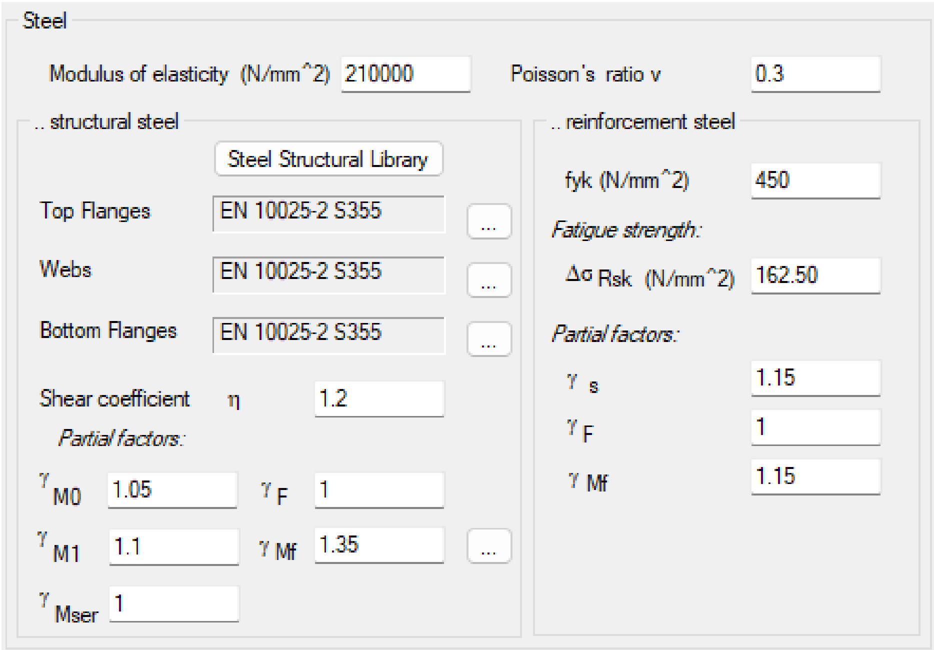
Environment



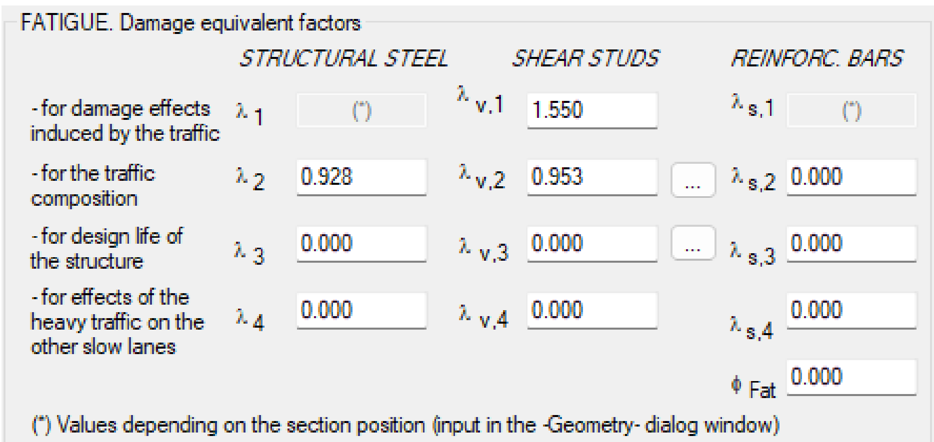
Shear connection



Steel



Fatigue – Equivalent damage factors

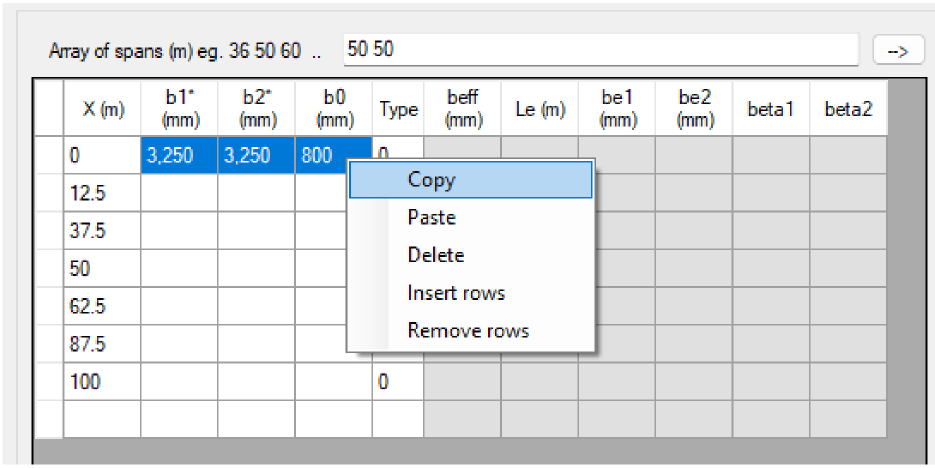


Equivalent damage factors have not been input, as fatigue verification is not part of this example.

- Save the current project from the *File* > *Save* menu.

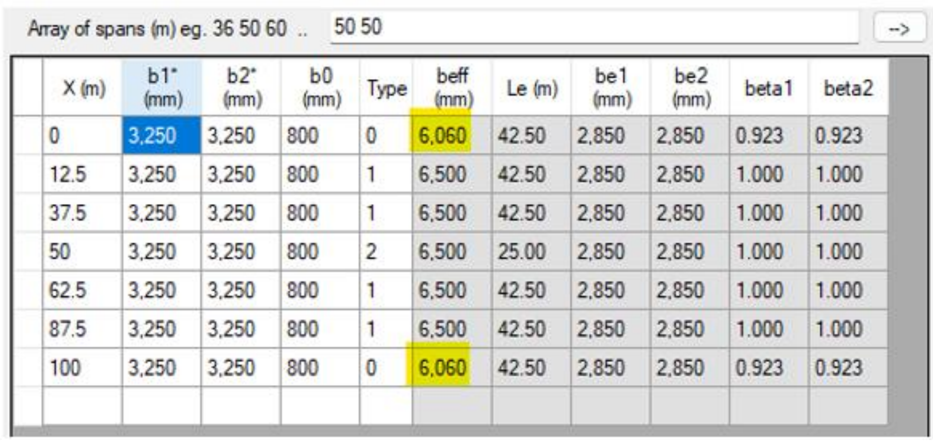
Step 2: Define Effective Slab Width (Shear Lag)

- From the menu, go to *Utilities > Shear lag slab and flanges*.
- In the **Array of spans** field, enter the span lengths: 50 50, then click the button --> located to the right of the input box.
- Enter the required values in the **first row**. To apply the same values to the remaining rows, right-click and use the **Copy/Paste** options.



X (m)	b1* (mm)	b2* (mm)	b0 (mm)	Type	beff (mm)	Le (m)	be1 (mm)	be2 (mm)	beta1	beta2
0	3,250	3,250	800	0						
12.5										
37.5										
50										
62.5										
87.5										
100				0						

- Click the **Calculate** button in the bottom-right corner. The effective widths will be calculated and displayed in the table.



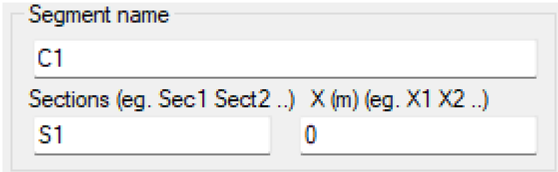
X (m)	b1* (mm)	b2* (mm)	b0 (mm)	Type	beff (mm)	Le (m)	be1 (mm)	be2 (mm)	beta1	beta2
0	3,250	3,250	800	0	6,060	42.50	2,850	2,850	0.923	0.923
12.5	3,250	3,250	800	1	6,500	42.50	2,850	2,850	1.000	1.000
37.5	3,250	3,250	800	1	6,500	42.50	2,850	2,850	1.000	1.000
50	3,250	3,250	800	2	6,500	25.00	2,850	2,850	1.000	1.000
62.5	3,250	3,250	800	1	6,500	42.50	2,850	2,850	1.000	1.000
87.5	3,250	3,250	800	1	6,500	42.50	2,850	2,850	1.000	1.000
100	3,250	3,250	800	0	6,060	42.50	2,850	2,850	0.923	0.923

Edit the effective width at X = 0 m and X = 100 m by setting both to 6500 mm, then click **Exit**.

Step 3: Input Segment Geometry

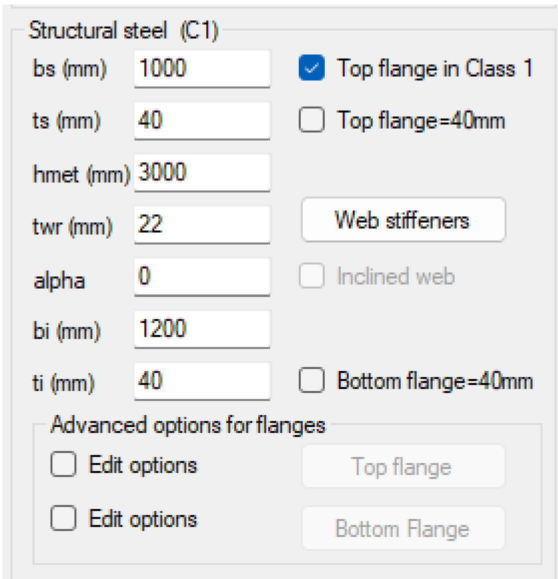
- Enter the input data for segment C1.

Segment name

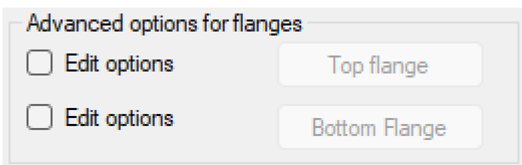


Note. At this stage, only one section, named S1 and positioned at X = 0 m, is added. The remaining sections requiring verification will be imported later from the Excel file containing the internal forces from the finite element analysis.

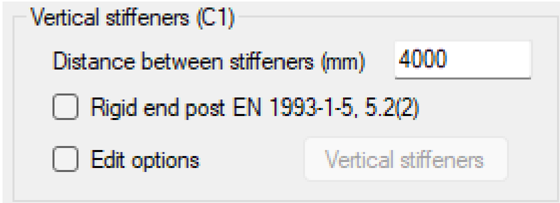
Structural steel



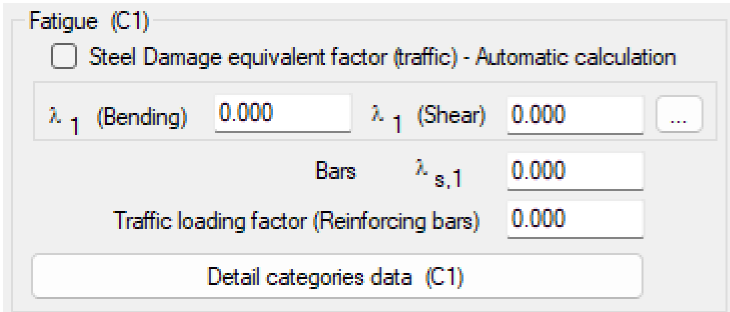
Advanced options for flanges



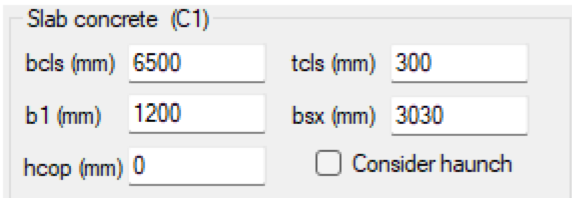
Vertical stiffeners



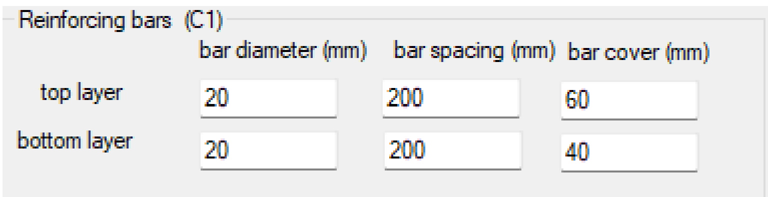
Fatigue



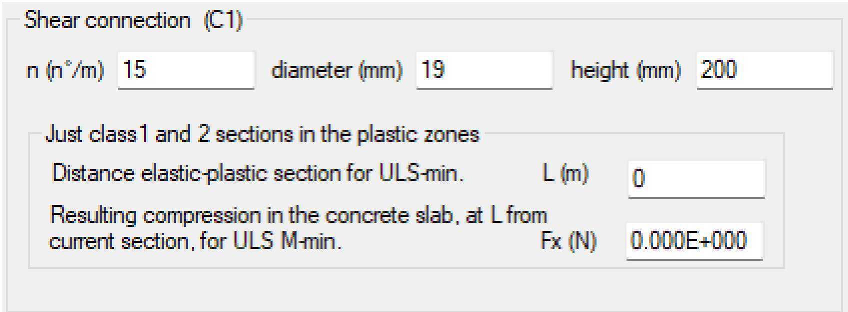
Concrete slab



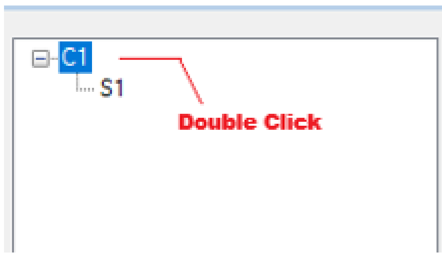
Reinforcing bars



Shear connection

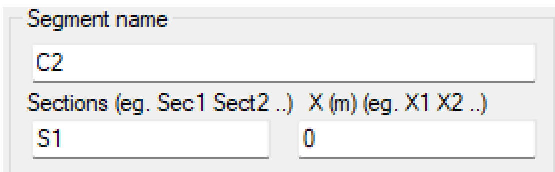


- Click **Add to list** to add Segment C1. It will appear in the treeview on the right-hand side of the Geometry dialog window. PontiEC4 will now be in **GEOMETRY edit** mode, as indicated in the status bar at the bottom left. Any previously entered data can be modified – updates will be applied automatically upon exiting the input fields.
- To add segment C2, double-click on segment C1 (**Input GEOMETRY** mode). This will initiate the input process for a new segment, automatically copying all data previously entered for C1.

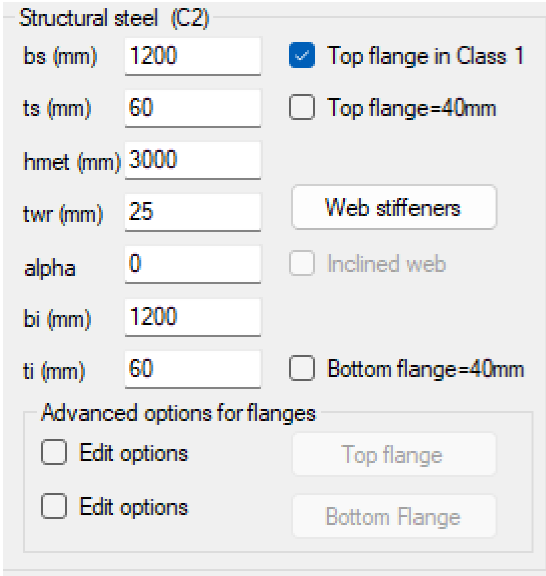


- Consider the following inputs:

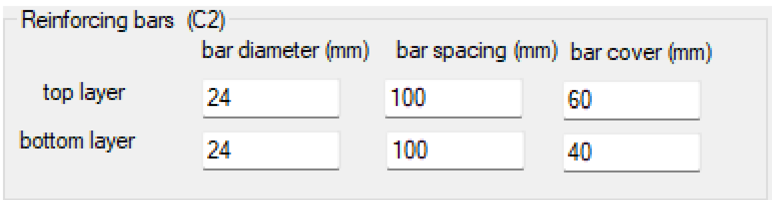
Segment name



Structural steel



Reinforcing bars



- Click **Add to list** to add Segment C2. It will appear in the treeview on the right-hand side of the Geometry dialog window.
- From the **File** menu, select **Save** to save the updated file.

Note. The steps completed so far can be replicated by opening the provided file **Ex_Shrinkage-Thermal_Initial.csv**.

Step 4: Calculate Equivalent Thermal Gradients (Shrinkage and Thermal Variation)

In the case of a single-line model, either imposed strains and curvatures or equivalent temperature variations – both for shrinkage and thermal effects – can be used, as calculated in PontiEC4. Step 4 is optional, since these quantities can also be computed independently, outside of PontiEC4. For a detailed explanation of the provided values and the associated calculation method, refer to the earlier section titled **Loadcases**.

- Open the **Equivalent Temperature Variation** dialog window for **shrinkage** by navigating to: *Utilities > Equivalent DT > Shrinkage*

Segment	e (mm)	N (N)	A (mm^2)	I (mm^4)	Average strain	Curvature (1/m)	Equivalent temperature difference (°C)	Equivalent differential temperature gradient (°C/m)
C1	856.1	-7.622E+006	3.075E+005	4.678E+011	-1.180E-004	-6.642E-008	-11.804	-6.642
C2	871.5	-7.622E+006	4.096E+005	6.395E+011	-8.861E-005	-4.946E-008	-8.861	-4.946

- Open the **Equivalent Temperature Variation** dialog window for **thermal effects** by navigating to: *Utilities > Equivalent DT > Thermal*

Segment	e (mm)	N (N)	A (mm^2)	I (mm^4)	Average strain	Curvature (1/m)	Equivalent temperature difference (°C)	Equivalent differential temperature gradient (°C/m)
C1	538.2	6.645E+006	4.891E+005	5.529E+011	6.470E-005	3.081E-008	6.470	3.081
C2	603.8	6.645E+006	5.912E+005	7.365E+011	5.352E-005	2.594E-008	5.352	2.594

Step 5: Perform Structural Analysis

The information provided in the previous sections can be used to carry out a static analysis and determine the required forces and moments.

Step 6: Prepare Internal Force Input File

An internal force input file is required to provide PontiEC4 with the necessary forces and moments.

- Retrieve the **Ponti EC4 Export Template.xls** file, provided with the software, from the directory: [Installation folder]\Modelli_EN and copy it to your working directory.
- Open the file and save it with a new name in your working directory.
- It is recommended to name the file **Ex_Shrinkage-Thermal_Forces-Moments** and use one of the following formats: .xls, .xlsx, or .xlsm (the .xlsm format should be used if you intend to add your own VBA code).
- All three formats are fully compatible with PontiEC4.

Note. The required forces and moments can be exported directly from LUSAS using the dedicated export tool. The resulting file can then be imported into PontiEC4.

The internal forces import file must contain five predefined worksheets. The user may add additional worksheets, but only after these five.

The allowed names for each worksheet are:

1. **ULS Fundamental** or **SLU fondamentale** or **SLU_fond**
2. **SLS Characteristic** or **SLE caratteristica** or **SLE_caratt**
3. **Fatigue** or **SL fatica** or **SLF**
4. **SLS Frequent** or **SLE frequente** or **SLE_frequente**
5. **Model Info** or **Info_model**

Model Info sheet

Within the Model Info sheet, PontiEC4 processes data only from the Section and X(m) columns, which are highlighted in yellow. The remaining columns are not used by the program, but the user can still fill them in if they want to add extra details for documentation, clarity, or completeness.

1	2	3	4	5	6	7
Element	Node	Section	Cracked	X(m)	Y(m)	Z(m)

Users must provide the list of sections to be checked in PontiEC4 and specify their position along the longitudinal axis of the structure.

Section names must follow the convention: "*Segment Name*" + "_" + "*Section Name*".

In this example, the two segments are designated as C1 and C2, and the sections within each segment are numbered sequentially (see Sections to be checked in PontiEC4). The sections of segment C2 are assumed to be cracked in the global analysis, and the designation "cracked" is added to their names. Columns 3 and 5 must be filled with the data shown in the table below.

Element	Node	Section	Cracked	X(m)	Y(m)	Z(m)
		C1_1		0.000		
		C1_2		10.625		
		C1_3		21.250		
		C1_4		31.875		
		C1_5		42.500		
		C2_cracked_6		42.501		
		C2_cracked_7		50.000		
		C2_cracked_8		50.001		
		C2_cracked_9		57.500		
		C1_10		57.501		
		C1_11		68.125		

		C1_12		78.750		
		C1_13		89.375		
		C1_14		100.000		

Note. The 14 sections listed in the table above are not present in PontiEC4 and will therefore be created automatically when the Excel file is imported. Each section will be linked to the appropriate segment, identified by the text preceding the first special character ("_").

In segment C1, the following sections will be created: 1, 2, …, 5 and 10, 11, …, 14.
In segment C2, the following sections will be created: cracked_6, …, cracked_9.

During the import process, each section will be assigned an effective slab width derived from the shear lag table (see Step 2), using linear interpolation based on the X-coordinate.

Finally, note that coincident X-coordinates will be slightly offset by adding 1 mm to one of them to ensure the correct ordering of sections in all contexts where graphs are plotted as a function of X.

ULS Fundamental sheet

PontiEC4 reads columns 1, 4, 5, 6, 8, 9, 10, and 12, which are highlighted in yellow. While the 9th column (torsional moment) is read, it is not used by the program. The remaining columns are optional and may be completed by the user to provide additional information for documentation, clarity, or completeness.

1	2	3	4	5	6	7	8	9	10	11	12
Ponti EC4					*N*		*V*	*T*	*M*		
Section	Element	GaussPt	Component	Phase	Fx	Fy	Fz	Mx	My	Mz	γ ψ

Each row should contain a set of internal forces, preferably organised by Phase, then by Internal Force, and finally by Section.
However, the sets of internal forces may be arranged in any order, as adherence to this suggested format is not mandatory.

The following phase names must be used:

"Phase 1" or **"Fase 1"** or **"Fase1"**

"Phase 2a" or **"Fase 2a"** or **"Fase2a"**

"Phase 2b" or **"Fase 2b"** or **"Fase2b"**

"Phase 2c" or **"Fase 2c"** or **"Fase2c"**

"Phase 3a" or **"Fase 3a"** or **"Fase3a"**

"Phase 3b" or **"Fase 3b"** or **"Fase3b"**

The following component names must be used:

"My (Max)" or **"Mmax"**

“My (Min)” or **“Mmin”**

“Fz (Max)” or **“Vmax”**

“Fz (Min)” or **“Vmin”**

Maximum and minimum values (Max/Min) must be organised based on the sign of the internal forces, as defined in the **Description of the Finite Element Model and Analysis Phases** section of this example.

The name of each section must be specified in column 1 (Section), and the corresponding internal forces must be provided in columns 6, 8, 9, and 10. Column 12 ($\gamma \cdot \psi$) is used only for Phase 2b and Phase 3a. For Phase 2b, the $\gamma \cdot \psi$ values must be positive, whereas for Phase 3a, they may be either positive or negative. For further information, refer to the notes of the following sections: **Phase 2b – Shrinkage**, **Phase 3a – Thermal_Heat**, and **Phase 3a – Thermal_Cool**.

The information provided to this point is sufficient to complete the **ULS Fundamental** sheet. The necessary internal forces can be obtained either from the **Internal Force Summary Table** paragraph or from the **Ex_Shrinkage-Thermal_Forces-Moments.xls** file.

The steps required to complete the **ULS Fundamental** sheet can likewise be applied to the sheets corresponding to the other limit states, which are not considered in this example.

Step 7: Import Internal Forces

- Reopen PontiEC4 and import the file **Ex_Shrinkage-Thermal_Forces-Moments.xls** file. A notification message will appear, prompting the user to confirm whether the newly detected sections should be added to the existing segments. Click **Yes**.

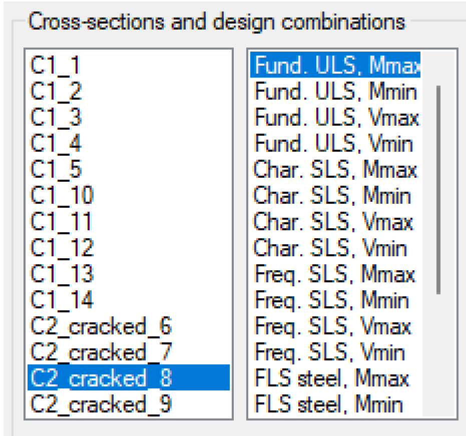
The status bar in the bottom-left corner displays the progress of the import operations.

- In the **Geometry** dialog window, delete sections **C1_S1** and **C2_S1**. After this, only the sections imported from the Excel file will remain.
- Save the current file using the *File* > *Save* menu.

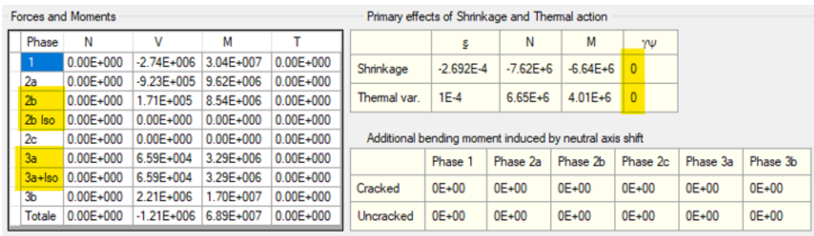
Step 8: Visualise Results

- Open the **Results** window, which provides a detailed view of the results.
- ### Verification of section C2_cracked_8

  Within the **Cross-sections and design combinations** area, select the **C2_cracked_8** section and the **ULS Fundamental, Mmax** combination, as shown below.



- Verify the internal forces against those shown in the diagrams presented earlier.



Forces and Moments

Phase	N	V	M	T
1	0.00E+000	-2.74E+006	3.04E+007	0.00E+000
2a	0.00E+000	-9.23E+005	9.62E+006	0.00E+000
2b	0.00E+000	1.71E+005	8.54E+006	0.00E+000
2b Iso	0.00E+000	0.00E+000	0.00E+000	0.00E+000
2c	0.00E+000	0.00E+000	0.00E+000	0.00E+000
3a	0.00E+000	6.59E+004	3.29E+006	0.00E+000
3a+Iso	0.00E+000	6.59E+004	3.29E+006	0.00E+000
3b	0.00E+000	2.21E+006	1.70E+007	0.00E+000
Totale	0.00E+000	-1.21E+006	6.89E+007	0.00E+000

Primary effects of Shrinkage and Thermal action

	ε	N	M	γψ
Shrinkage	-2.692E-4	-7.62E+6	-6.64E+6	0
Thermal var.	1E-4	6.65E+6	4.01E+6	0

Additional bending moment induced by neutral axis shift

	Phase 1	Phase 2a	Phase 2b	Phase 2c	Phase 3a	Phase 3b
Cracked	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00
Uncracked	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00

Note. The internal forces for Phase 2b are presented in two rows in the **Forces and Moments** table. The first row shows the hyperstatic effect, with M = 8.54E6 Nm. The second row shows the isostatic effect, which is zero for the considered section, since $\gamma \cdot \psi = 0$. Although PontiEC4 calculates the isostatic shrinkage moment, it becomes zero due to $\gamma \cdot \psi = 0$.

For Phase 3a, the internal forces are also presented in two rows. The first row contains the hyperstatic effects, and the second row shows the sum of hyperstatic and isostatic effects. In this case, both rows have the same values because $\gamma \cdot \psi = 0$ for thermal effects.

- Check the classification of the section in the **Plastic check** tab.

  End of Phase 3: In this example, the section is classified as Class 4, so plastic verification is not applicable. Stress verification must instead be carried out on the effective section.

Plastic check | Stresses | Shear | Geometric properties 0 | Geometric properties 1

Determining Class and Plastic verification at Stage 3

	c/t	zpl(mm)	α	ψ	Class
Web	115.2	2861	0.97	-0.79	4
Upper flange	9.79				1
Lower flange	9.79				3
Cross-section class					**4**

=> Plastic verification NOT APPLICABLE

Axial force N		Bending moment M		N-M Interaction	
NEd	0E+00	MEd	6.89E+7	NEd	0E+00
NRd	-1.31E+8	MRd	1.07E+8	MEd	6.89E+7
				MRd	1.07E+8
NEd/NRd	0	MEd/MRd	0.643	MEd/MR	0.643

Phase 1: Upper flange class= 1, Web class =4, Lower flange class= 3

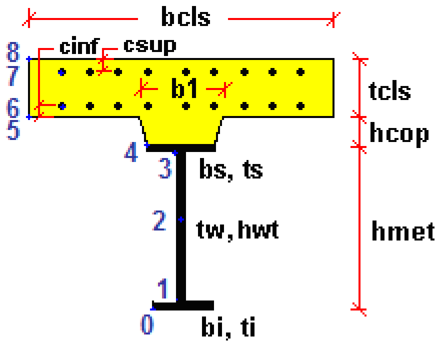
Note. The classification is generally performed for the end of Phase 3, where the top flange is considered stable even under compression, as it is connected to the slab. This assumption can be applied by selecting the **Top flange in Class 1** option in the **Geometry** dialog window. The software also performs classification for the end of Phase 1, disregarding the **Top flange in Class 1** option and considering only the Phase 1 loads. The result of this classification is displayed at the bottom in red. This approach alerts the user to the need for verification for the end of Phase 1 as well, which may be more critical than that for Phase 3.

- Examine the stress check for section C2_cracked_8 in the **Stresses** tab, selecting the **Stresses of effective cross-section** option. The stress calculation is performed on fibres numbered 0 through 8, as shown in the figure.

Plastic check | Stresses | Shear | Geometric properties 0 | Geometric properties 1 | Geometric properties 2 | Domains Mpl-N | Studs. ULS

○ Stresses of gross cross section ● Stresses of effective cross section

id	Ph.1	Ph.2a N.C.	Ph.2a C.	Ph.2b N.C.	Ph.2b C.	Ph.2c N.C.	Ph.2c C.	Ph.2 Tot.	Ph.3a N.C.	Ph.3a C.	Ph.3b N.C.	Ph.3b C.	Ph.3 Tot	Eta1	id
σ 8	**0.0**	1.0	0.0	0.9	0.0	0.0	0.0	**0.0**	0.5	0.0	2.8	0.0	**0.0**	**0.00**	σ 8
σ 7	**0.0**	15.2	27.4	12.8	24.3	0.0	0.0	**51.7**	3.1	9.4	16.0	48.5	**109.5**	**0.28**	σ 7
σ 6	**0.0**	12.0	23.3	10.0	20.7	0.0	0.0	**44.0**	2.2	8.0	11.2	41.3	**93.3**	**0.24**	σ 6
σ 5	**0.0**	0.7	0.0	0.7	0.0	0.0	0.0	**0.0**	0.3	0.0	1.7	0.0	**0.0**	**0.00**	σ 5
σ 4	**125.5**	11.3	22.5	9.5	20.0	0.0	0.0	**168.0**	2.0	7.7	10.2	39.8	**215.5**	**0.68**	σ 4
σ 3	**120.4**	10.4	21.3	8.6	18.9	0.0	0.0	**160.6**	1.7	7.3	8.8	37.7	**205.5**	**0.64**	σ 3
σ 2	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	**0.0**	**0.00**	σ 2
σ 1	**-12...**	-35.3	-37.2	-31.2	-33.0	0.0	0.0	**-196.6**	-11.8	-12.7	-60.8	-65.8	**-275.1**	**0.86**	σ 1
σ 0	**-13...**	-36.3	-38.4	-32.1	-34.1	0.0	0.0	**-204.0**	-12.0	-13.2	-62.2	-67.9	**-285.1**	**0.89**	σ 0



The calculation of stresses in the concrete is performed assuming the section is uncracked. The stresses in fibres 0 – 8 are presented in columns labelled with **N.C.** in the header. As an example, the stress in fibre 8 (top of the slab) is:

$$\sigma 8\ (\text{N.C.}) = 1.00 + 0.94 + 0.55 + 2.84 = 5.33\ \text{MPa}$$

End of Phase 3: The slab is classified as **CRACKED** because the concrete stress in the median fibre is:

$$\sigma = (5.33 + 3.34) / 2 = 4.33 > 0$$

The "**m**" next to **CRACKED** indicates that the check is performed in the median fibre. This setting can be changed via *Tools > Options*.

Slab stresses at Phase 2 (N/mm^2):

Total top stress = 1.94

Total bottom stress = 1.36

=> Section at the end of Phase 2: CRACKED (m.)

Slab stresses at Phase 3 (N/mm^2):

Total top stress = 5.33

Total bottom stress = 3.34

=> Section at the end of Phase 3: CRACKED (m.)

=> El. check Phase 3 PASSED
eta1= 0.894

The **stress verification** is performed assuming the concrete cannot carry tension. In this example, the maximum utilisation factor of the section corresponds to fibre 0:

$$\sigma 0\ (\text{C}) = -131.5 - 38.4 - 34.1 - 13.2 - 67.9 = -285.1\ \text{MPa}$$

η1 = 285.1 / (335 / 1.05) = 0.89

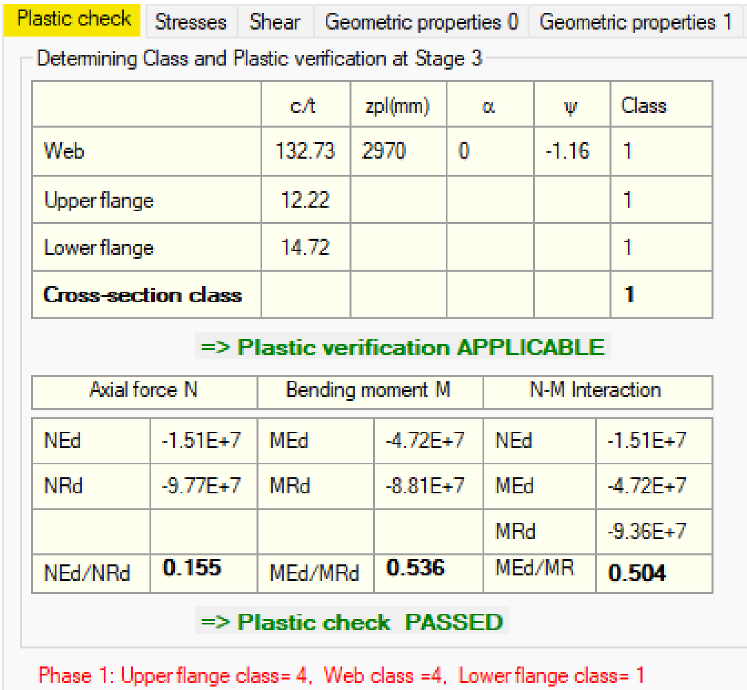
- ## Verification of section C1_3

Within the **Cross-sections and design combinations** area, select the **C1_3** section and the **ULS Fundamental, Mmin** combination.

- Check the classification of the section in the **Plastic check** tab.

End of Phase 3: In this example, the section is classified as Class 1, allowing plastic verification. The resulting utilisation factor is 0.536.

End of Phase 1: In this example, the section is classified as Class 4. **Step 9: Perform Phase 1 Verifications** describes this verification.



Plastic check | Stresses | Shear | Geometric properties 0 | Geometric properties 1

Determining Class and Plastic verification at Stage 3

	c/t	zpl(mm)	α	ψ	Class
Web	132.73	2970	0	-1.16	1
Upper flange	12.22				1
Lower flange	14.72				1
Cross-section class					**1**

=> Plastic verification APPLICABLE

Axial force N		Bending moment M		N-M Interaction	
NEd	-1.51E+7	MEd	-4.72E+7	NEd	-1.51E+7
NRd	-9.77E+7	MRd	-8.81E+7	MEd	-4.72E+7
				MRd	-9.36E+7
NEd/NRd	**0.155**	MEd/MRd	**0.536**	MEd/MR	**0.504**

=> Plastic check PASSED

Phase 1: Upper flange class= 4, Web class =4, Lower flange class= 1

- Examine the stress check for section C1_3 in the **Stresses** tab, selecting the **Stresses of gross cross-section** option. The stress calculation is performed on fibres numbered 0 through 8, as shown in the figure.

Plastic check | **Stresses** | Shear | Geometric properties 0 | Geometric properties 1 | Geometric properties 2 | Domains Mpl-N | Studs. U

(•) Stresses of gross cross section ( ) Stresses of effective cross section

id	Ph.1	Ph.2a N.C.	Ph.2a C.	Ph.2b N.C.	Ph.2b C.	Ph.2c N.C.	Ph.2c C.	Ph.2 Tot.	Ph.3a N.C.	Ph.3a C.	Ph.3b N.C.	Ph.3b C.	Ph.3 Tot	Eta1	id
σ 8	**0.0**	-0.8	0.0	1.9	0.0	0.0	0.0	**0.0**	0.7	0.0	-4.0	0.0	**-2.1**	**0.11**	σ 8
σ 7	**0.0**	-12.0	-30.9	-39.5	16.8	0.0	0.0	**-14.1**	4.6	-7.8	-22.4	-109.7	**-69.3**	**0.18**	σ 7
σ 6	**0.0**	-9.6	-27.1	-37.4	14.7	0.0	0.0	**-12.4**	5.3	-6.8	-15.3	-96.1	**-57.0**	**0.15**	σ 6
σ 5	**0.0**	-0.6	0.0	2.1	0.0	0.0	0.0	**0.0**	0.9	0.0	-2.3	0.0	**0.2**	**0.01**	σ 5
σ 4	**-10...**	-9.1	-26.3	-37.0	14.3	0.0	0.0	**-113.0**	-13.5	-6.6	-13.9	-93.4	**-174.5**	**0.52**	σ 4
σ 3	**-98.5**	-8.6	-25.5	-36.6	13.9	0.0	0.0	**-110.1**	-13.4	-6.4	-12.4	-90.7	**-169.5**	**0.50**	σ 3
σ 2	**0.0**	0.0	0.0	-29.7	0.0	0.0	0.0	**0.0**	-12.2	0.0	0.0	0.0	**-42.0**	**0.12**	σ 2
σ 1	**88.5**	26.9	30.3	-6.6	-16.5	0.0	0.0	**102.4**	-3.8	7.6	91.9	107.7	**197.0**	**0.58**	σ 1
σ 0	**91.1**	27.4	31.1	-6.2	-16.9	0.0	0.0	**105.3**	-3.6	7.8	93.3	110.4	**202.0**	**0.60**	σ 0

End of Phase 3: The slab is classified as **UNCRACKED** because the concrete stress in the median fibre is:

$$\sigma 8 \text{ (N.C.)} = (-2.15 + 0.19) / 2 = -0.98 \text{ MPa}$$

Slab stresses at Phase 2 (N/mm^2):

Total top stress = 1.13

Total bottom stress = 1.57

=> Section at the end of Phase 2: CRACKED (m.)

Slab stresses at Phase 3 (N/mm^2):

Total top stress = -2.15

Total bottom stress = 0.19

=> Section at the end of Phase 3: UNCRACKED (m.)

=> El. check Phase 3 NOT RELEVANT

The **stress verification** is performed assuming the concrete is uncracked. In this example, the maximum utilisation factor of the section corresponds to fibre 0:

$$\sigma 0 \text{ (N.C.)} = 91.1 + 27.4 - 6.2 - 3.6 + 93.3 = 202 \text{ MPa}$$

$$\eta 1 = 202 / (355 / 1.05) = 0.6$$

The stresses calculated for Phases 2b and 3a result from the combined effects of:

1) The stress state due to hyperstatic effects
2) The stress state due to isostatic effects

3) The local stresses in the slab

For shrinkage, the local effect acts only on the concrete, whereas for thermal effects, it also affects the reinforcement.

The forces/moments shown in the following figure, highlighted in yellow, are extracted from the **Results** dialog window.

Cross-sections and design combinations

Cross-section	Design combination
C1_1	Fund. ULS, Mmax
C1_2	Fund. ULS, Mmin
C1_3	Fund. ULS, Vmax
C1_4	Fund. ULS, Vmin
C1_5	Char. SLS, Mmax
C1_10	Char. SLS, Mmin
C1_11	Char. SLS, Vmax
C1_12	Char. SLS, Vmin
C1_13	Freq. SLS, Mmax
C1_14	Freq. SLS, Mmin
C2_cracked_6	Freq. SLS, Vmax
C2_cracked_7	Freq. SLS, Vmin
C2_cracked_8	FLS steel, Mmax
C2_cracked_9	FLS steel, Mmin

Forces and Moments

Phase	N	V	M	T
1	0.00E+000	7.53E+005	-1.52E+007	0.00E+000
2a	0.00E+000	2.42E+005	-5.56E+006	0.00E+000
2b	0.00E+000	1.42E+005	3.02E+006	0.00E+000
2b Iso	-9.15E+006	0.00E+000	-7.83E+006	0.00E+000
2c	0.00E+000	0.00E+000	0.00E+000	0.00E+000
3a	0.00E+000	-6.59E+004	-1.40E+006	0.00E+000
3a+Iso	-5.98E+006	6.59E+004	-1.82E+006	0.00E+000
3b	0.00E+000	-4.99E+005	-1.98E+007	0.00E+000
Total	-1.51E+007	7.03E+005	-4.72E+007	0.00E+000

Primary effects of Shrinkage and Thermal action

	ε	N	M	γψ
Shrinkage	-2.692E-4	-7.62E+6	-6.53E+6	1.2
Thermal var.	1E-4	6.65E+6	3.58E+6	-0.9

The geometric properties used in the calculations are shown in the **Geometric Properties 2** tab.

Geometric properties 1 | Geometric properties 2 | Domains Mpl-N | Studs. ULS, SLS | SLS. Web Breathing | FLS steel

Gross section geometric properties

	Phase 1	Phase 2a	Phase 2b	Phase 2c	Phase 3	Cracked
A	1.522E+5	2.934E+5	3.075E+5	2.712E+5	4.891E+5	1.727E+5
zG	1422.23	2252.65	2293.88	2179.32	2611.78	1625.39
DeltazG	--	--	--	--	--	--
Jy	2.375E+11	4.569E+11	4.678E+11	4.374E+11	5.529E+11	2.908E+11
Wy,0	-1.67E+8	-2.028E+8	-2.039E+8	-2.007E+8	-2.117E+8	-1.789E+8
Wy,1	-1.718E+8	-2.065E+8	-2.076E+8	-2.044E+8	-2.15E+8	-1.834E+8
Wy,3	1.544E+8	6.459E+8	7.023E+8	5.603E+8	1.588E+9	2.179E+8
Wy,4	1.505E+8	6.113E+8	6.625E+8	5.329E+8	1.424E+9	2.116E+8
Wy,5	---	6.113E+8	6.625E+8	5.329E+8	1.424E+9	2.116E+8
Wy,6	---	5.802E+8	6.27E+8	5.082E+8	1.291E+9	2.056E+8
Wy,7	---	4.627E+8	4.945E+8	4.124E+8	8.8E+8	1.801E+8
Wy,8	---	4.362E+8	4.65E+8	3.903E+8	8.033E+8	1.737E+8
Sy,1	6.731E+7	1.072E+8	1.091E+8	1.036E+8	1.244E+8	7.706E+7
Sy,2	8.832E+7	1.61E+8	1.65E+8	1.54E+8	1.972E+8	1.047E+8
Sy,3	6.231E+7	1.555E+8	1.601E+8	1.473E+8	1.958E+8	8.511E+7
Sy,4	1.49E-8	1.264E+8	1.327E+8	1.153E+8	1.811E+8	3.093E+7
nE	1E+300	1.616E+1	1.446E+1	1.979E+1	6.162E+0	1E+300

Calculations for Shrinkage (Phase 2b):

1) Hyperstatic effect: M = 3.02E6 Nm, N = 0
2) Isostatic effect: M = -7.83E6 Nm, N = -9.15E6 N
3) Isostatic effect (concrete): εsh = -2.692E-4 · 1.2

			(1)	(2)	(3)	(1)+(2)+(3)
		Fase 2b	Iperstatico	Isostatico	Locale	Tot
	A (mm^2)	3.075E+05	σ=N/A+M/W,i		σ=-Ec*εsh*(γψ)	
cls	Wy,8 (mm^3)	4.650E+08	0.45	-3.22	4.69	**1.92**
	Wy,7 (mm^3)	4.945E+08	6.11	-45.59		**-39.48**
	Wy,6 (mm^3)	6.270E+08	4.82	-42.24		**-37.43**
cls	Wy,5 (mm^3)	6.625E+08	0.32	-2.88	4.69	**2.13**
	Wy,4 (mm^3)	6.625E+08	4.56	-41.57		**-37.02**
	Wy,3 (mm^3)	7.023E+08	4.30	-40.91		**-36.61**
	Wy,2 (mm^3)	1.00E+50	0.00	-29.76		**-29.76**
	Wy,1 (mm^3)	-2.076E+08	-14.55	7.96		**-6.59**
	Wy,0 (mm^3)	-2.039E+08	-14.81	8.65		**-6.17**
	nE	14.46				

Calculations for Thermal Effects (Phase 3a):

1) + 2) Hyperstatic + Isostatic effects: M = -1.82E6 Nm, N = -5.98E6

3) Local effect in the slab and rebars: ε = α ΔT γψ = 1E-5 · 10 · (-0.9) = -9E-5

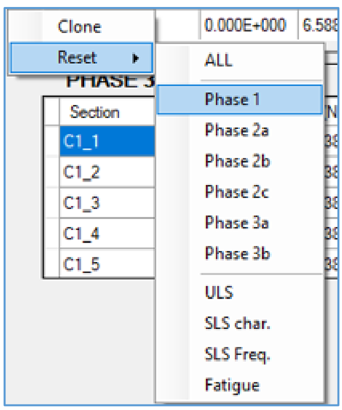
			(1)+(2)	(3)	(1)+(2)+(3)
		Phase 3a	Hyper + Iso	Local	Total
	A (mm^2)	4.891E+05	σ=N/A+M/W,i	σc=-Ec*ε*(γψ) σs=-Ea*ε*(γψ)	
concr.	Wy,8 (mm^3)	8.033E+08	-2.35	3.07	**0.72**
bar	Wy,7 (mm^3)	8.800E+08	-14.29	18.90	**4.61**
bar	Wy,6 (mm^3)	1.291E+09	-13.64	18.90	**5.26**
concr.	Wy,5 (mm^3)	1.424E+09	-2.19	3.07	**0.88**
	Wy,4 (mm^3)	1.424E+09	-13.50		**-13.50**
	Wy,3 (mm^3)	1.588E+09	-13.37		**-13.37**
	Wy,2 (mm^3)	1.00E+50	-12.23		**-12.23**
	Wy,1 (mm^3)	-2.150E+08	-3.76		**-3.76**
	Wy,0 (mm^3)	-2.117E+08	-3.63		**-3.63**
	nE	6.16			

Step 9: Perform Phase 1 Verifications

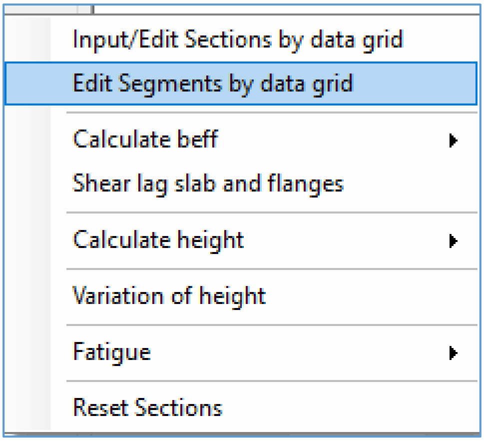
The calculations are carried out under the following assumptions:

1) Phase of the bare steel girder, with the slab inactive
2) The top flange is unrestrained
3) Only Phase 1 loads are considered

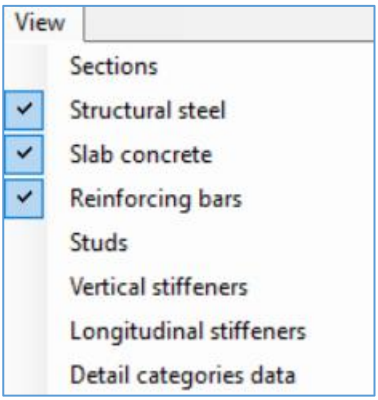
- Save the current project under a new name. For example: **Ex_Shrinkage-Thermal_Phase1.csv**.
- In the **Forces and Moments** dialog window, right-click and select **Reset** to remove all forces/moments previously entered for Phases 2a, 2b, 3a, and 3b.



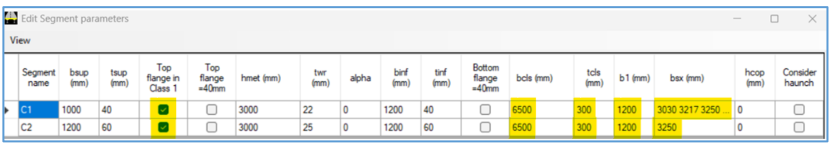
- The changes that must be made in the **Geometry** dialog window can be applied to each segment individually, or more efficiently by right-clicking and selecting **Edit Segments by data grid** to modify multiple segments at once.



- In the **Edit Segment Parameters** dialog window, go to **View** and select only **Structural steel**, **Slab concrete**, and **Reinforcing bars**.



- Next, untick the **Top flange in Class 1** option and set the inputs highlighted in yellow to 0. Click **OK** to apply the changes.

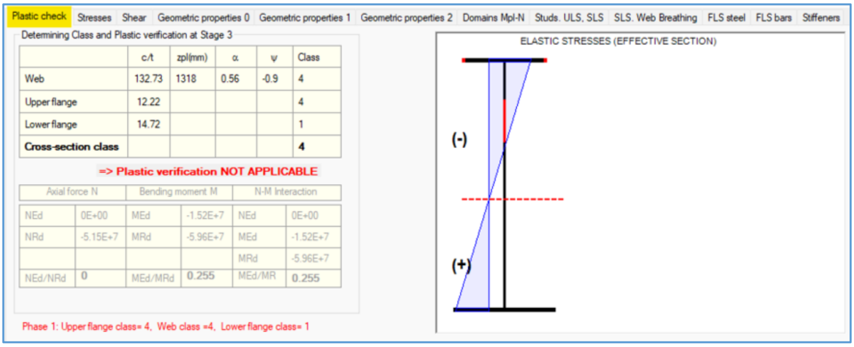

Edit Segment parameters

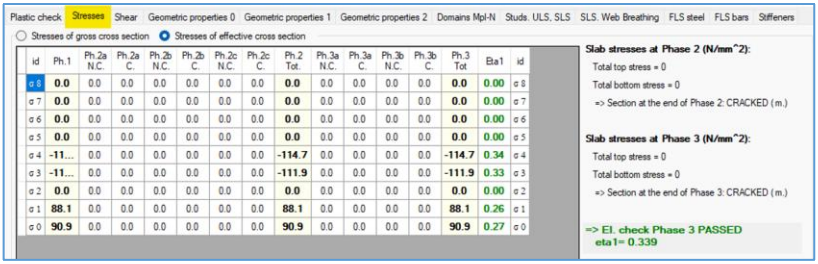
View

Segment name	bsup (mm)	tsup (mm)	Top flange in Class 1	Top flange =40mm	hmet (mm)	twr (mm)	alpha	binf (mm)	tinf (mm)	Bottom flange =40mm	bcls (mm)	tcls (mm)	b1 (mm)	bsx (mm)	hcop (mm)	Consider haunch
C1	1000	40	☑	☐	3000	22	0	1200	40	☐	6500	300	1200	3030 3217 3250 ...	0	☐
C2	1200	60	☑	☐	3000	25	0	1200	60	☐	6500	300	1200	3250	0	☐

bar diamiter top (mm)	bar spacing top (mm)	bar cover top (mm)	bar diamiter bottom (mm)	bar spacing bottom (mm)	bar cover bottom (mm)
20	200	60	20	200	40
24	100	60	24	100	40

- Open the **Results** dialog window to view the verification results for section C1_3. The verification is performed assuming the section is Class 4.





All results can also be reviewed in summarised form in the **Summary of results** dialog window. Reports can be generated through *Window > Report*, and graphs for various entities can be created via *Utilities > Graphs*. For additional information, refer to the PontiEC4 **Help** system.