# Assessment of a Composite Bridge Deck to Eurocodes

| | |
|---|---|
| For LUSAS version: | 19.1 or above |
| For software product(s): | LUSAS Bridge or LUSAS Bridge plus |
| With product option(s): | Steel and Composite Deck Designer (PontiEC4 – V3.4.2 or above) |
| With additional software | Microsoft Excel installed |

## Description

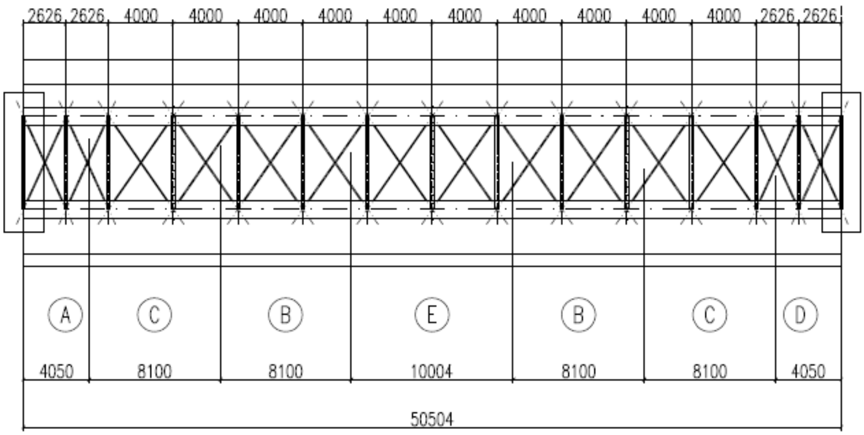
The global analysis and the assessment of the main girders of a two span continuous bridge is to be carried out using the Steel and Composite Deck Designer (PontiEC4) software option and LUSAS Bridge.

Because the primary aim of this particular example is to show the use of the PontiEC4 Composite Deck Designer and the interaction between it and LUSAS, no step-by-step instruction is provided for construction of the supplied LUSAS model that is used in this example. A separate example 'Composite Highway Bridge Design' shows the LUSAS model building requirements to allow a design check with PontiEC4 to be carried out.

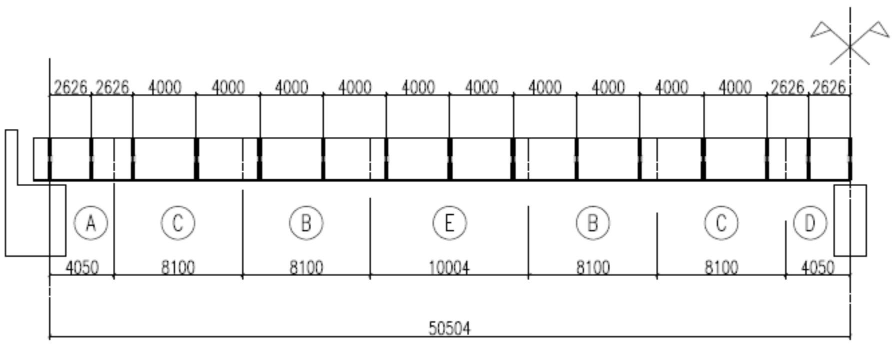
The bridge has a symmetrical composite two-girder structure with two spans of 50.504m. For the purposes of the example the following geometrical simplifications have been made:

- The horizontal alignment is straight
- The top face of the deck is flat
- The bridge is straight, that is, not skewed
- The structural steel main girders are of a constant depth of 2700mm

Plan, elevation and typical cross section views of the bridge deck are shown on the following pages.




Plan of left-hand span.
(Note that transverse ladder bracing is modelled; X-bracing is not modelled.)

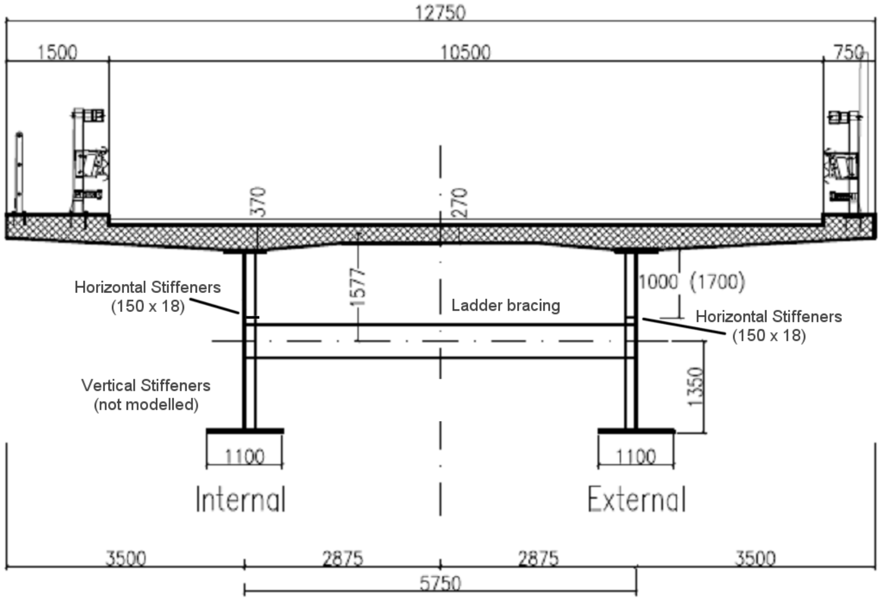



Elevation of left-hand span. Right-hand span is similar but handed.

**Note.**

- The girder shown above is formed from five **Segments** (lengths having the same beam section size) that are labelled A, B, C, D, and E.
- **Sections** are locations defined within a segment at which geometric properties are defined or calculated.

Both terms are used throughout this example.




Typical cross section

The total slab width is 12.75m. The centre-to-centre spacing between the main girders is 5.75m and the slab cantilever either side is 3.5m long. The main girder dimensions, for each segment, are summarized in the following table.

### Table of main girder dimensions

| Segment name | Top flange width (mm) | Top flange thickness (mm) | Height of beam (mm) | Web thickness (mm) | Bottom flange width (mm) | Bottom flange thickness (mm) |
|---|---|---|---|---|---|---|
| A | 600 | 20 | 2700 | 20 | 1100 | 20 |
| C | 600 | 30 | 2700 | 22 | 1100 | 40 |
| B | 600 | 30 | 2700 | 18 | 1100 | 40 |
| E | 600 | 30 | 2700 | 18 | 1100 | 50 |
| D | 1100 | 40 | 2700 | 25 | 1200 | 50 |

The slab thickness varies from 0.37m over the main girders to 0.27m at its free edges and at its axis of symmetry. For simplification reasons, the actual slab cross-section of a half-deck is modelled by a rectangular area, which is the same as the actual width (i.e. 12.75/2 m), and a second rectangular area modelling the concrete haunch, which has the same width as the upper structural steel flange. The equivalent thickness of slab is 273mm and the equivalent height of the haunch is 75mm.

# Steel and Composite Deck Designer (PontiEC4 )

The Steel and Composite Deck Designer (PontiEC4) is a software option that carries out comprehensive calculations for multiple sections on steel/composite bridge decks to the Eurocodes. Force and moment results for selected bridge deck sections are provided by a corresponding LUSAS model, and loadcase combinations defined within LUSAS are associated with design limit states and phases defined in PontiEC4.

Design calculations covering ULS bending, stress, shear and interaction; SLS stress, web breathing and cracking, and fatigue checks for main members and connectors are carried out. Results, output in tabbed dialogs, visually show values that pass or fail. Graphs and a report containing all input data and output with references to the Eurocode clauses can be easily created.

In the Steel and Composite Deck Designer (PontiEC4) the units in use are always indicated in the input and output dialogs, and in general forces are expressed in N (Newton), lengths in mm (millimetres), and moments expressed in Nm (Newton Metres). The units used for the LUSAS model will therefore be N, m, kg, s, C.

### Keywords

**Steel, Composite, Deck, Designer, EC4, Design, Checking, Import, Export, ULS, SLS, Graphing, Detailed design.**

### Associated files

These are provided as part of a PONTI EC4 installation.

- **Composite_Bridge_Deck_Initial.csv** – Contains initial material and geometric data / definitions for use with PontiEC4
- **Materials_Sections_Rev0.vbs** - A file created by PontiEC4 containing materials and geometric section data to import into LUSAS. A version of this file is supplied also, but is for use only in case of difficulties in manually creating the appropriate data
- **Composite_Bridge_Deck.mdl** – A supplied LUSAS model file that is to be used to analyse the structure. After solving this model, analysis results are exported from LUSAS or use in PontiEC4 to undertake design checks.
- **Export to ponti EC4.xls** File created by the LUSAS Export to Composite Deck Design dialog containing data to import into PontiEC4. Supplied file is only for use in case of problems in manually creating the appropriate data in the previous section of the example.
- **Composite_Bridge_Deck_Optimized.csv** An input file for PontiEC4 with updated steel flange values for segments D and C.

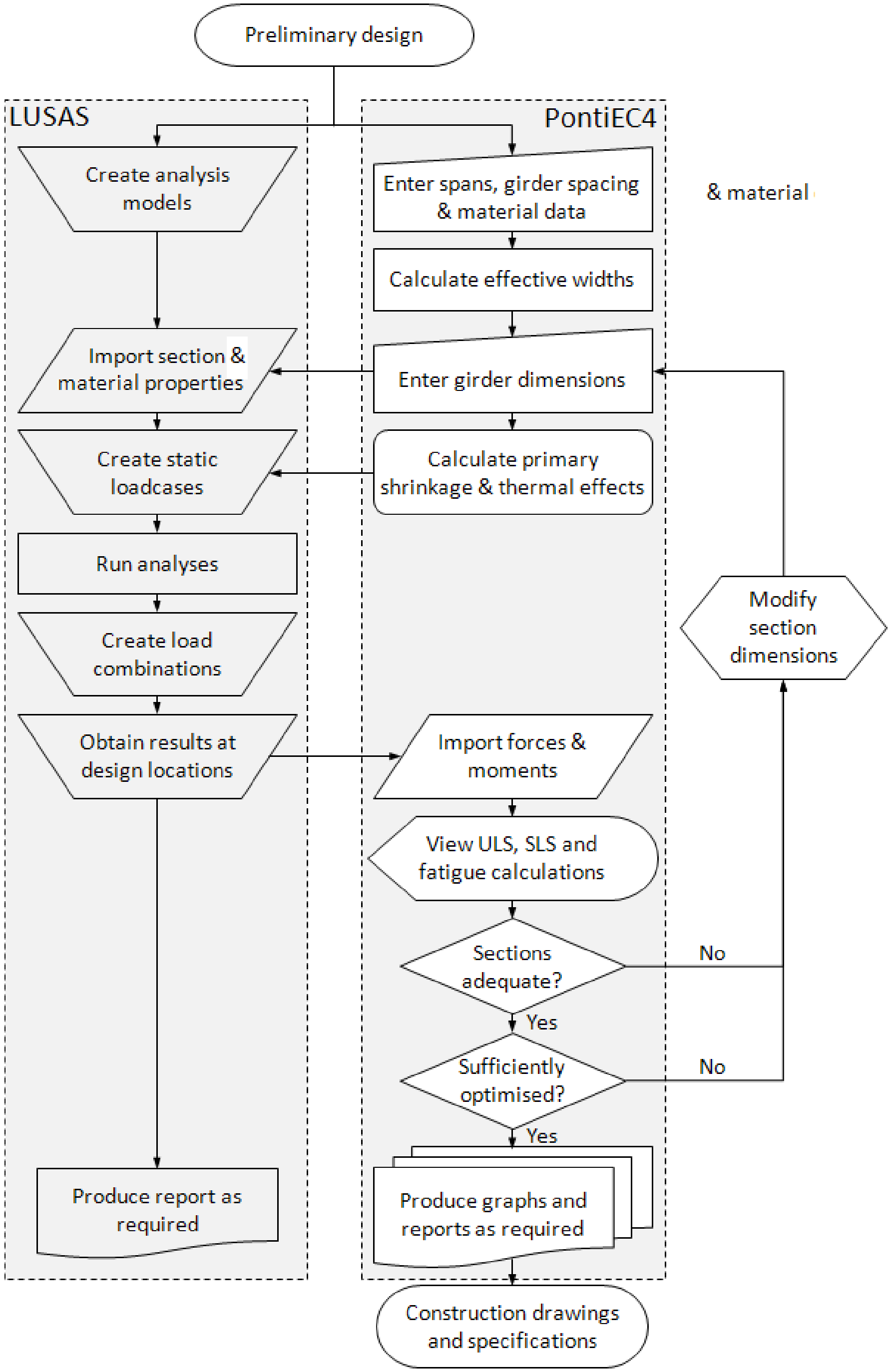
- **Sections_rev1.vbs** - A file created by PontiEC4 containing revised section data to import into LUSAS to update the geometric properties in the LUSAS model.
- **Composite_Bridge_Deck_Optimized.mdl** – A supplied LUSAS model file that is to be used to analyse the structure. After solving this model, analysis results are exported from LUSAS or use in PontiEC4 to undertake design checks.
- **Export to ponti EC4 rev1.xls** File created by the LUSAS Export to Composite Deck Design dialog containing data to import into PontiEC4. Supplied file is only for use in case of problems in manually creating the appropriate data in the previous section of the example.

## Method and Objectives

The main steps in using the Steel and Composite Deck Designer in conjunction with LUSAS can be summarized as follows:

- **Step 1: Define material and geometric properties in the PontiEC4 Steel and Composite Deck Designer. All effective section properties are calculated.**
- **Step 2: Export the geometric and material properties from the PontiEC4 Steel and Composite Deck Designer for use with a corresponding user-defined LUSAS model.**
- **Step 3: Use LUSAS to calculate the forces and moments for all the limit state combinations.**
- **Step 4: Export the force and moment data from LUSAS for use in the PontiEC4 Steel and Composite Deck Designer.**
- **Step 5: Import force and moment data into PontiEC4 Steel and Composite Deck Designer**
- **Step 6: Assess the results and carry out detailed design checks in PontiEC4**
- **Step 7: Optimize the structure (by making adjustments to section sizes if necessary)**

The full interaction between LUSAS Bridge and the PontiEC4 Steel and Composite Deck Designer can be seen by referring to the following flowchart.


Preliminary design
LUSAS
PontiEC4
Create analysis models
Enter spans, girder spacing & material data
& material
Calculate effective widths
Import section & material properties
Enter girder dimensions
Create static loadcases
Calculate primary shrinkage & thermal effects
Run analyses
Modify section dimensions
Create load combinations
Obtain results at design locations
Import forces & moments
View ULS, SLS and fatigue calculations
Sections adequate?
No
Yes
Sufficiently optimised?
No
Yes
Produce report as required
Produce graphs and reports as required
Construction drawings and specifications

### File types used / generated / saved

| LUSAS | PontiEC4 |
|---|---|
| LUSAS Model data **(.mdl**) | PontiEC4 dialog values and settings (**.csv**) |
| Forces and Moment data calculated by LUSAS for import into PontiEC4 (**.xls**) | Effective geometric section properties data calculated by PontiEC4 for import into LUSAS (**.vbs**) |
| Saved values and settings made on the Export Force and Moment dialog (**.inp**) | PontiEC4 analysis log file for all section calculations (**.log**) |

# Step 1: Define material and geometric properties in PontiEC4

This section covers the definition of material and geometric properties in the PontiEC4 Composite Deck Designer in order to calculate effective section properties. Once done, the beam cross section and material properties are exported to a VBS file for subsequent importing into LUSAS.

## Defining material properties

To define the required data for this worked example three options are available, according to what it is that you need to achieve from carrying out this example. Values and settings can be entered into dialogs in three ways:

- **(Option 1) Manually entering all material and geometric data** (so that an appreciation is obtained for all aspects of using and entering data into the various dialogs). This will obviously take the longest of the three options to input. See the heading *'**Option 1: Manually entering all material and geometric data**'* for this option.
- **(Option 2) Loading the material dialog with default values and settings** This option reduces the material data input, but requires careful checking and updating of non-default values and settings in the material dialog as required by the example. Geometric data will still need to be entered. See the heading *'**Option 2: Loading the material dialog with default values**'* for this option.
- **(Option 3) Loading all material and geometry data from a csv file (**to automatically populate the material and geometry dialogs with <u>all</u> the initial values and settings required by the example). This is the fastest option and would be used if it was simply required to see the main processes and steps involved in order to view the results obtained for this example and its accompanying LUSAS model. See the heading *'**Option 3: Loading all material and initial geometric data from a csv** **file**'*, that follows, for this option.

The example is written assuming that manual entering of all values is done. (Option 1 above), but using Option 2 or Option 3 will save time in entering data.

The text that follows, having a grey background, shows the steps required for the options stated. **The options are listed in reverse order to the above, according to the amount of data entry required, with the least amount of data entry first.**

The example is written to manually enter all required data so that an understanding of the data entry can be appreciated.

## Option 3: Loading all material and initial geometry data from a csv file:

A file is supplied if it is desired to automatically populate the material and geometry dialogs with the initial values required by the example (as opposed to manually defining the values required).

### Associated file

- **Composite_Bridge_Deck_Initial.csv** – Contains initial material and geometric data / definitions for use with PontiEC4. To use this file:

### Run the Steel and Composite Deck Designer (PontiEC4)

- Run the Steel and Composite Deck Designer (**PontiEC4**)
- Select the **File > Open** menu item, and browse in the **\<PontiEC4 Installation Folder>\Help\Examples\Composite_Bridge_Deck** folder for the **Composite_Bridge_Deck_Initial.csv** file and click **Open**. All dialogs will be filled with data initially required by the example.
- Expand the size of the PontiEC4 window and select the **File> Save as** menu item and **save the PontiEC4 dialog data to a working project folder different from the PontiEC4 installation folder**, (this would normally be a project folder in which a LUSAS model would also be created) with the name **Composite_Bridge_Deck.csv**
- Continue at Step 2 in the example entitled '***Step 2: Export geometric properties from PontiEC4 to LUSAS***'

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## Option 2: Loading the material dialog with default values and settings:

### Run the Steel and Composite Deck Designer (PontiEC4)

- Run the Steel and Composite Deck Designer (**PontiEC4**)
- Select the **File> New** menu item to create a new PontiEC4 project.
- On the Materials dialog, press the **Defaults** button.

- Select the **File> Save as** menu item to **save the PontiEC4 dialog data to a working project folder different from the PontiEC4 installation folder**, (this would normally be a project folder in which a LUSAS model would also be created) with the name **Composite_Bridge_Deck.csv**
- Continue at the heading entitled '***Defining material properties'***, *below*, checking that each dialog panel contains the values that are shown in this example.

## Option 1: Manually entering all material and geometric data:

### Run the Steel and Composite Deck Designer (PontiEC4)

- Run the Steel and Composite Deck Designer (**PontiEC4**)
- Select the **File> New** menu item to create a new PontiEC4 project.
- Select the **File> Save as** menu item to save the PontiEC4 dialog data to a working project folder different from the PontiEC4 installation folder (this would normally be a project folder in which a LUSAS model would also be created), with the name **Composite_Bridge_Deck.csv**

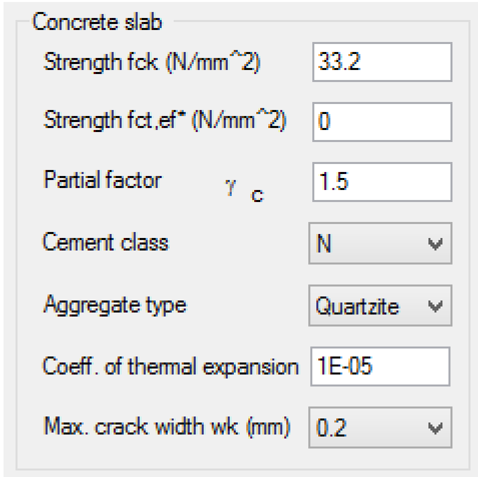
**Note.** All data entered in the various PontEC4 dialogs will be saved to this file. Previously created and saved data, or supplied data (held in .csv files) can be loaded into the PontiEC4 dialogs by using the File> Open menu item.

## Defining material properties

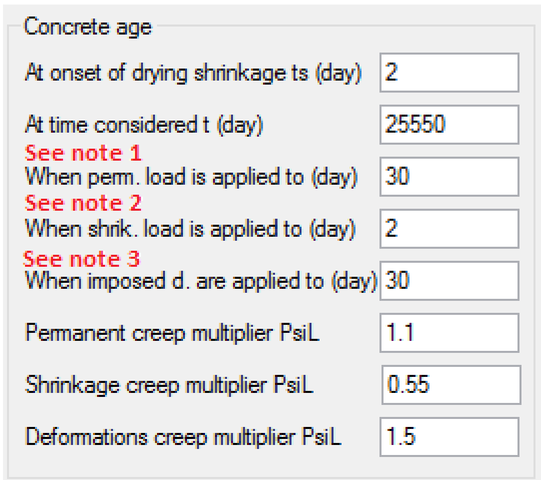
The material dialog is immediately available when you start a new project or when you open an existing one. The material dialog is organized into separate panels; Concrete, Concrete age, Steel etc.

- For each panel on the dialog enter the material data shown in the following images.

## Concrete slab



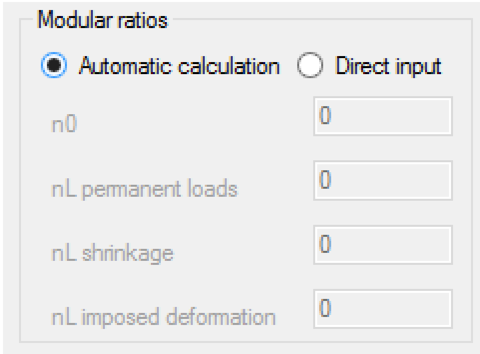

## Concrete age



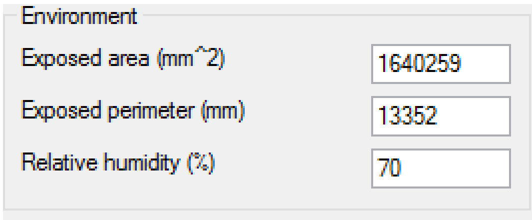

**Notes:**

1. Age of concrete when permanent load is applied
2. Age of concrete when shrinkage load is applied
3. Age of concrete when imposed deformations are applied.

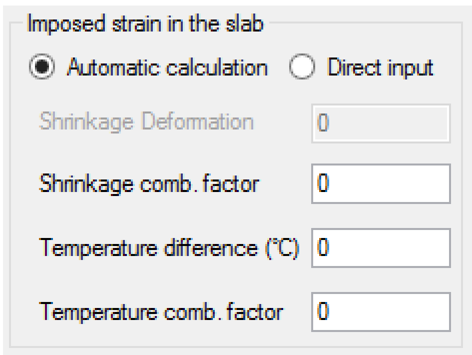
## Modular ratios



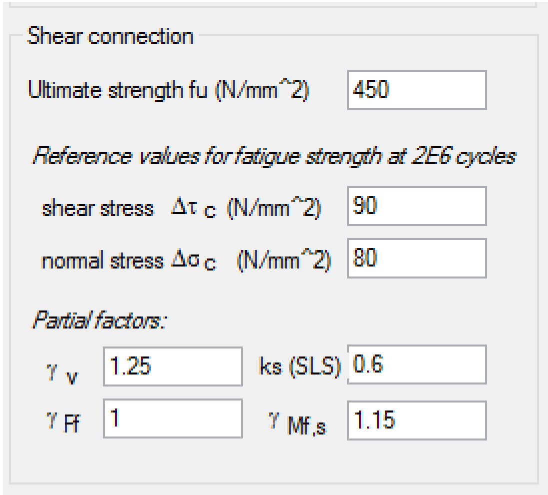

## Environment




## Imposed strain in the slab

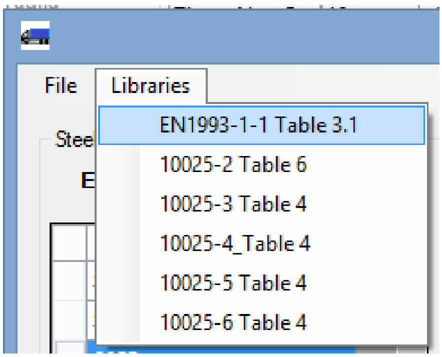


### Shear connection

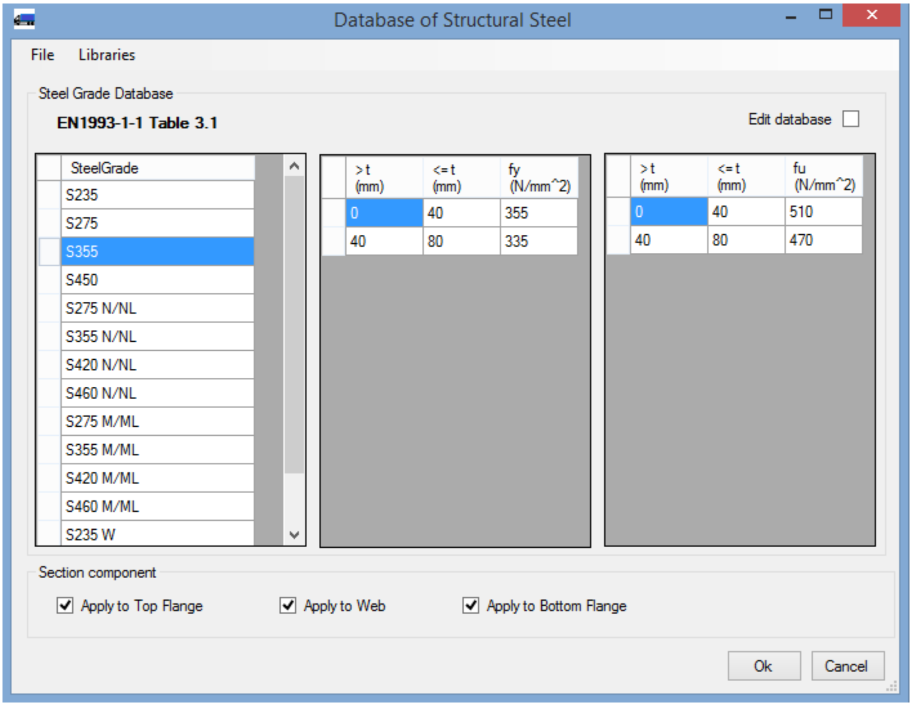



### Steel

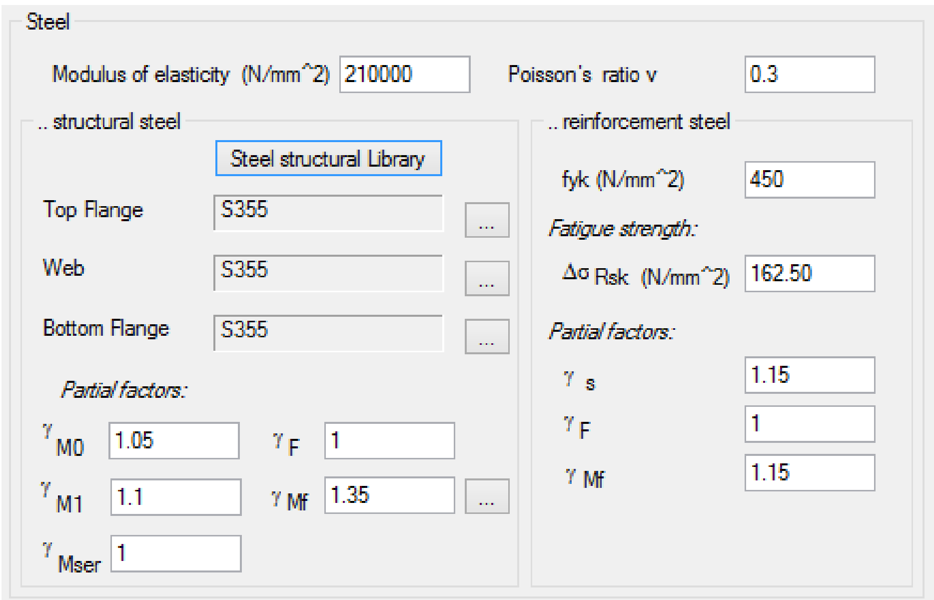
- Click on the   tton, to open the Database of Structural Steel, and on Libraries menu select *EN1993-1-1 Table 3.1* as shown:



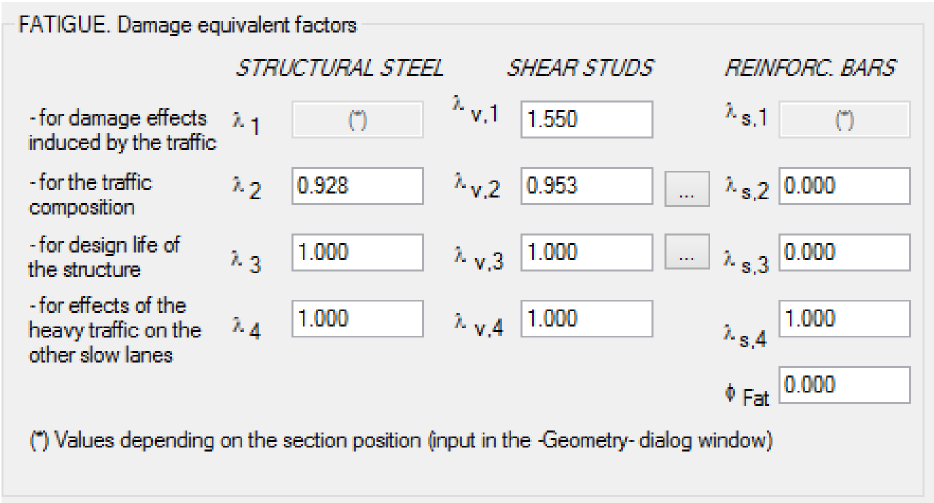

- Select S355 and tick all component checkboxes in the *Section component* region, as in the picture below, then click OK.

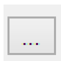


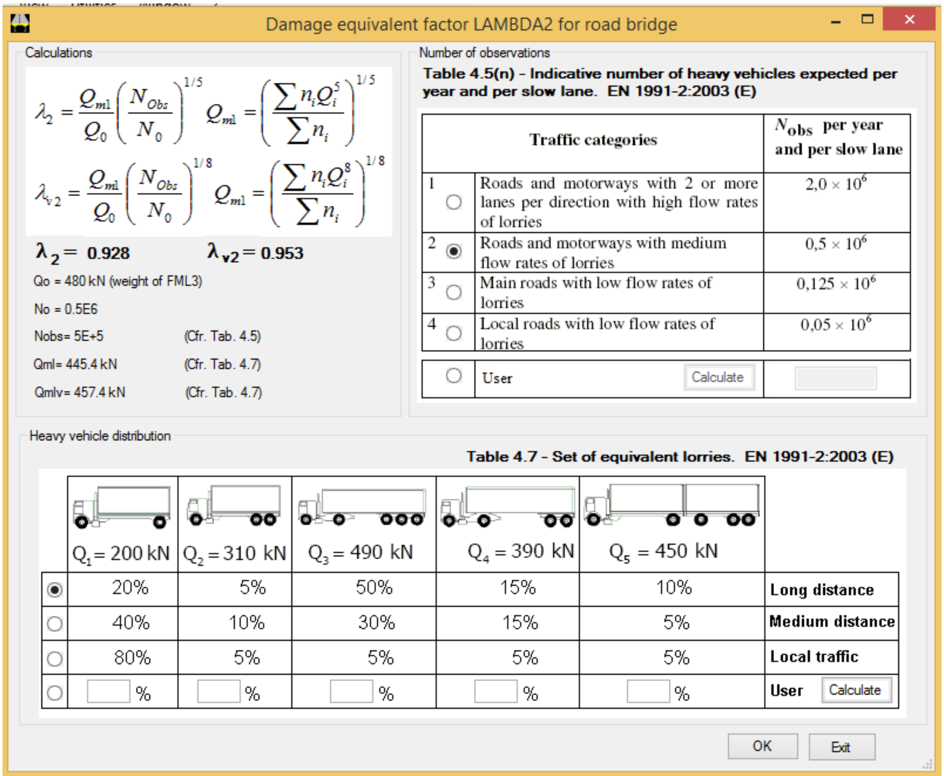

- Define all other values as shown below



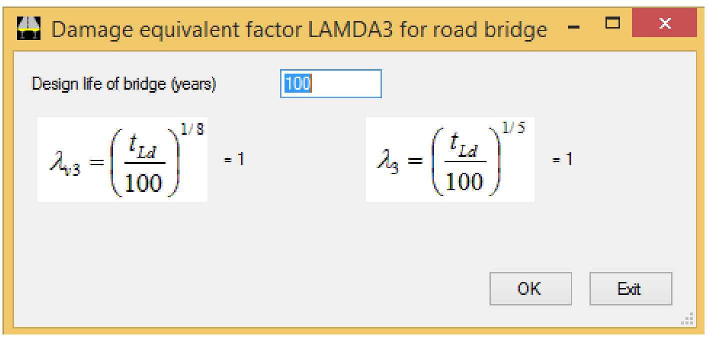
## Fatigue




- Note that $\lambda_2$ can be calculated from selections made in the dialog that appears when you click on the  button next to the $\lambda_{v,2}$ input field. In this case, make the selections as shown below:




- Note that $\lambda_3$ can be calculated from data entered in the dialog that appears when you click on the  button next to the $\lambda_{v,3}$ input field. In this case, input the data below:




This completes the definition of the materials.

## Save the data entered

- Select the **File> Save** menu item to save the PontiEC4 dialog data to the current working project folder.

## Defining Geometric properties

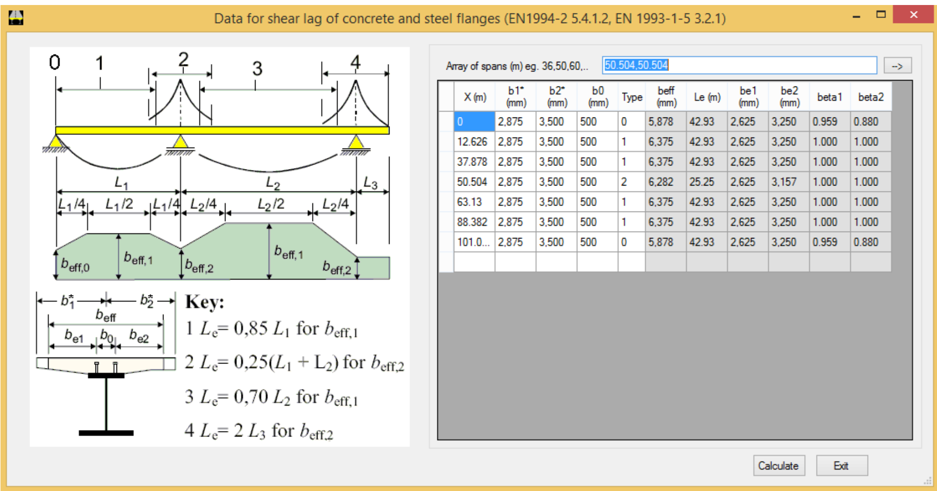
Prior to defining the geometric section properties for the spans, the span lengths and the effective concrete slab width (beff) of each section, defined at various distances along the section, need to be defined.

## Defining shear lag slab and flanges

- To input data for the effective slab width calculation, select the **Utilities> Shear lag slab and flanges** menu item.
- Input an array of the bridge spans (the span lengths) in the text box in the top right corner: **50.504,50.504** and click on the --> button. The X distance where the effective slab width changes will be automatically set up in the table
- For each row input the flange widths b1*, b2*, b0 as **2875, 3500, 500** respectively.

**Note.** Values in the table can be selected and copied and pasted into other cells by using the context menu.

- In the **Type** column ensure that the code **0** is used for the first and last section, **1** for the sagging regions, and **2** for the middle support.
- Click the **Calculate** button to calculate $\mathbf{b_{eff}}$,




| X (m) | b1* (mm) | b2* (mm) | b0 (mm) | Type | beff (mm) | Le (m) | be1 (mm) | be2 (mm) | beta1 | beta2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 2,875 | 3,500 | 500 | 0 | 5,878 | 42.93 | 2,625 | 3,250 | 0.959 | 0.880 |
| 12.626 | 2,875 | 3,500 | 500 | 1 | 6,375 | 42.93 | 2,625 | 3,250 | 1.000 | 1.000 |
| 37.878 | 2,875 | 3,500 | 500 | 1 | 6,375 | 42.93 | 2,625 | 3,250 | 1.000 | 1.000 |
| 50.504 | 2,875 | 3,500 | 500 | 2 | 6,282 | 25.25 | 2,625 | 3,157 | 1.000 | 1.000 |
| 63.13 | 2,875 | 3,500 | 500 | 1 | 6,375 | 42.93 | 2,625 | 3,250 | 1.000 | 1.000 |
| 88.382 | 2,875 | 3,500 | 500 | 1 | 6,375 | 42.93 | 2,625 | 3,250 | 1.000 | 1.000 |
| 101.0... | 2,875 | 3,500 | 500 | 0 | 5,878 | 42.93 | 2,625 | 3,250 | 0.959 | 0.880 |

- Click the **Exit** button to close the dialog and return to the material dialog

**Note.** Values of effective length Le can be used to manage the shear lag of the flanges.

## Defining geometry for segment A

The geometric data for each segment and/or section along the bridge now needs to be defined starting with segment A.

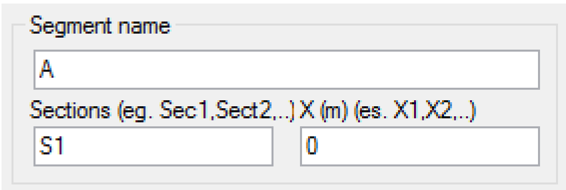
- From the main menu select **Windows> 2 Geometry** to display the Geometry dialog.

Note at this stage it is not necessary to define all the sections in each segment that will be checked; it will be enough to define just one section for each segment, and input a distance to automatically obtain the corresponding effective width of slab from the shear lag slab table previously defined.

**Note.** No entered data is saved with a segment name until the **Add to list** button is clicked. This is done at the end of this section of the example.

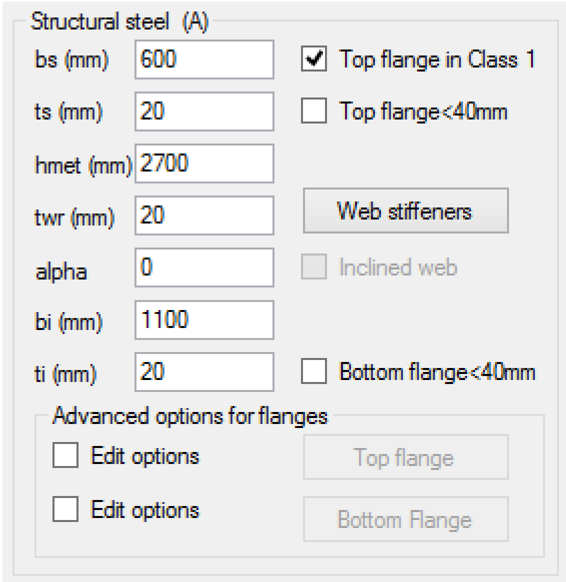
### Segment name, sections, x-distances

- Input the data for the first Segment as shown in the following image.




### Structural steel plate details

- With reference to the main table of girder dimensions, enter the following values:



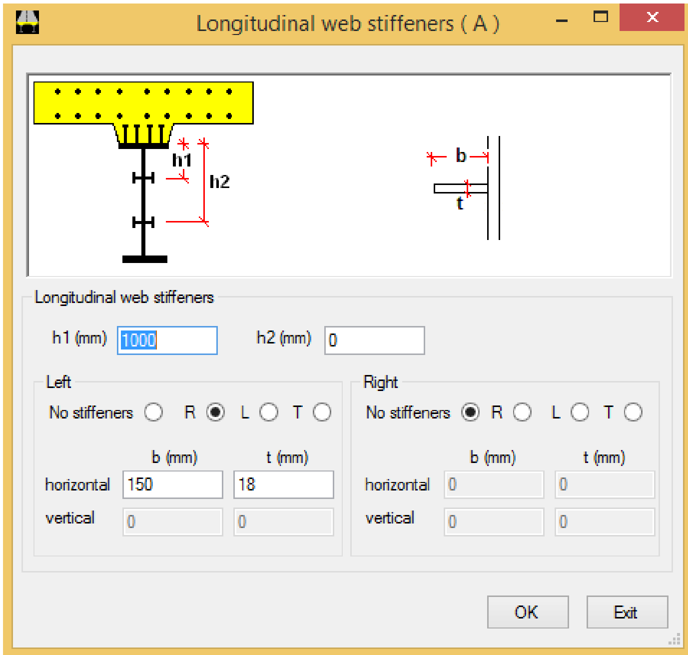

- Make sure that **Top flange in Class 1** is checked (ticked).

**Note.** The checkboxes for Top / Bottom flange <40mm should be only checked (ticked) for flanges that have a total thickness above 40mm, when they are made up from a number of plates each of a thickness less than 40mm. When done, ultimate and yielding tension for steel below 40mm thickness will be used.

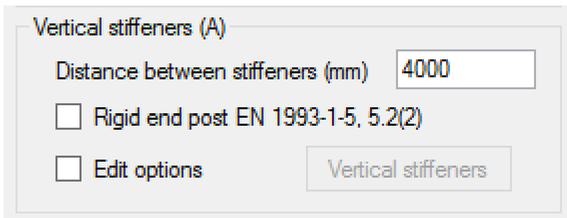
### Longitudinal web stiffeners details

Properties of longitudinal stiffeners are necessary to perform web panel buckling calculations.

- Click the **Web stiffeners** button and input data as shown in the following image, then click **OK**.



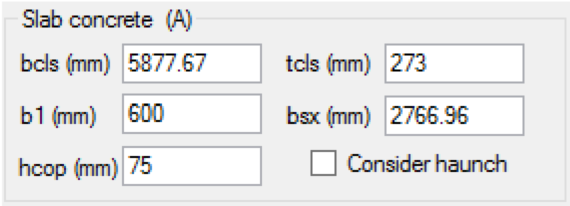

## Vertical web stiffener distance




**Note.**. A vertical stiffeners check is optional and is not carried out in the example. Specifying the distance between vertical stiffeners is the only mandatory value in this panel.

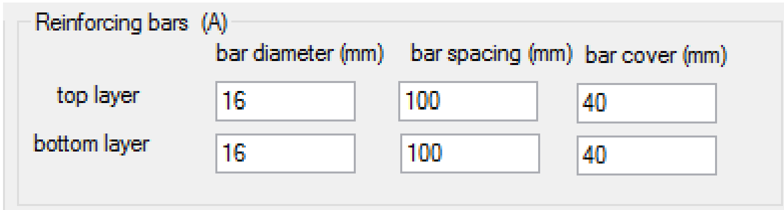
## Slab concrete

- In the Slab concrete panel right-click inside the bcls field and select **Calculate beff.** The width of slab will be computed using data previously defined in the shear lag table. Input other data as shown in the following image.

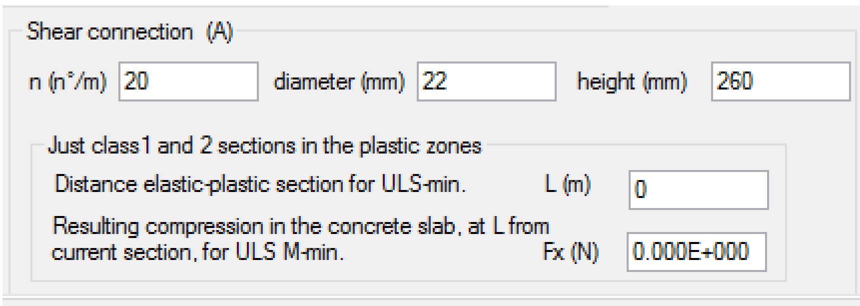



For the purposes of this example the section properties of the concrete haunch will be ignored in any calculations made, so it is left un-checked.

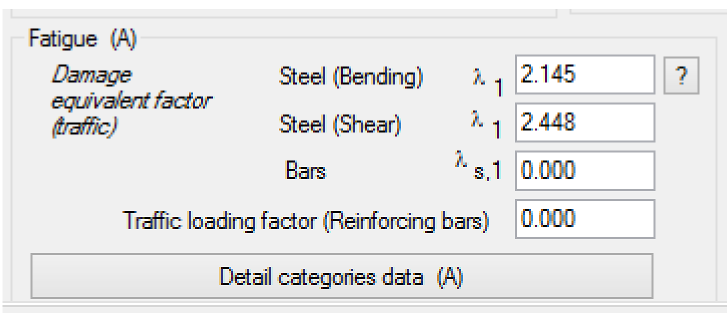
## Reinforcing bars



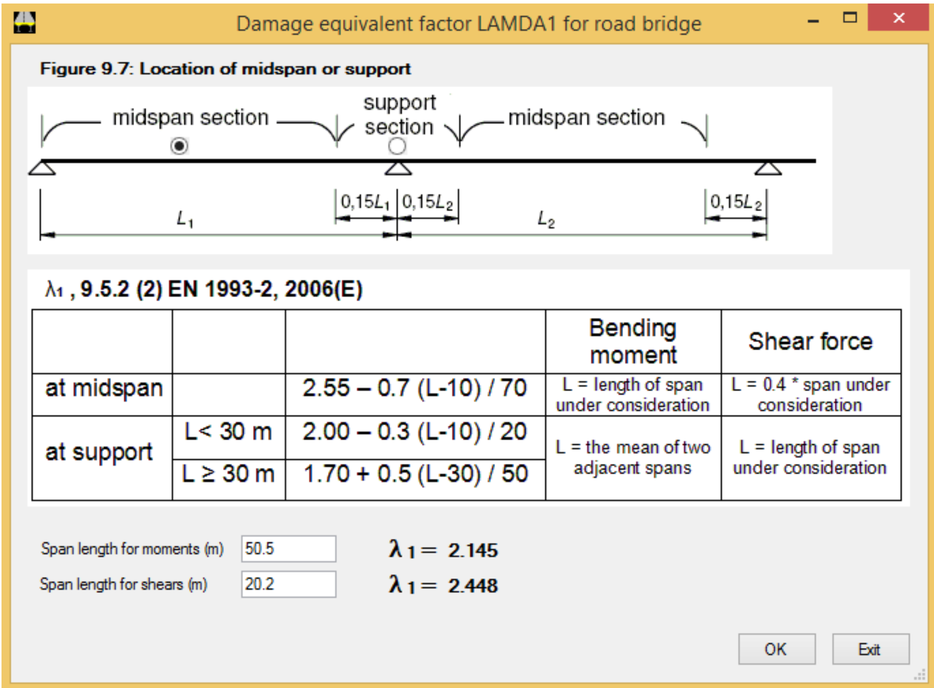

## Shear connection




## Fatigue data

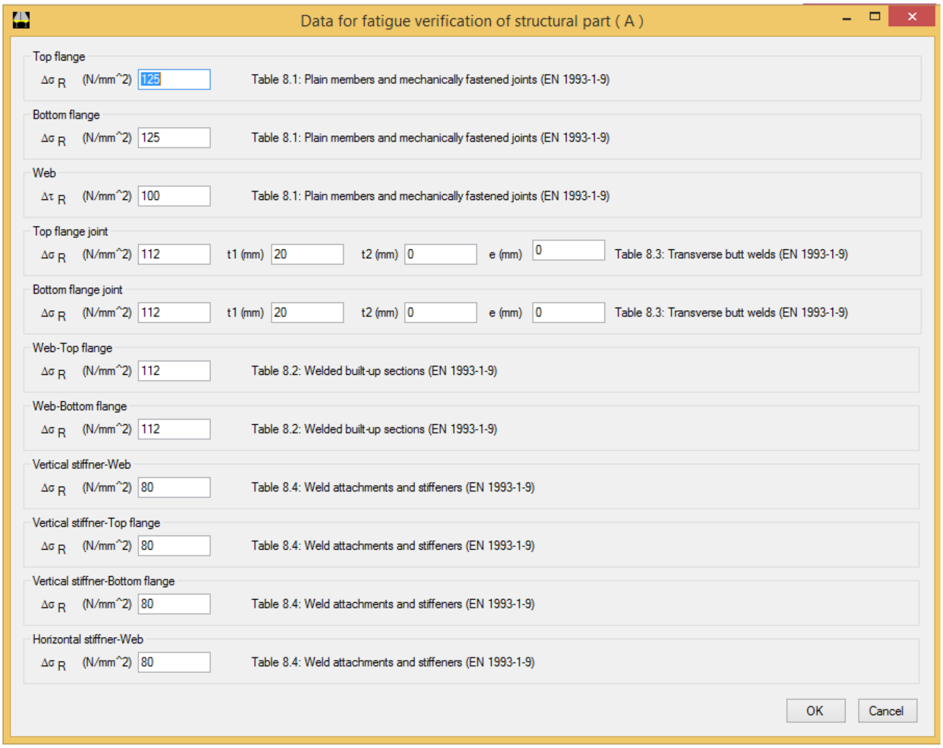



- $\lambda_1$ can be calculated automatically by clicking the Question mark button ? next to the input field and then, on the Damage equivalent factor dialog, select the radio button for the **midspan section** and enter **50.5** for the Span length for moments and **20.2** for the Span length for shears.




## Detail categories

- In the Fatigue data panel, select the **Detail categories data** button and input the data as shown on the following image, then click **OK.**




## Adding data for segment A to the segment treeview

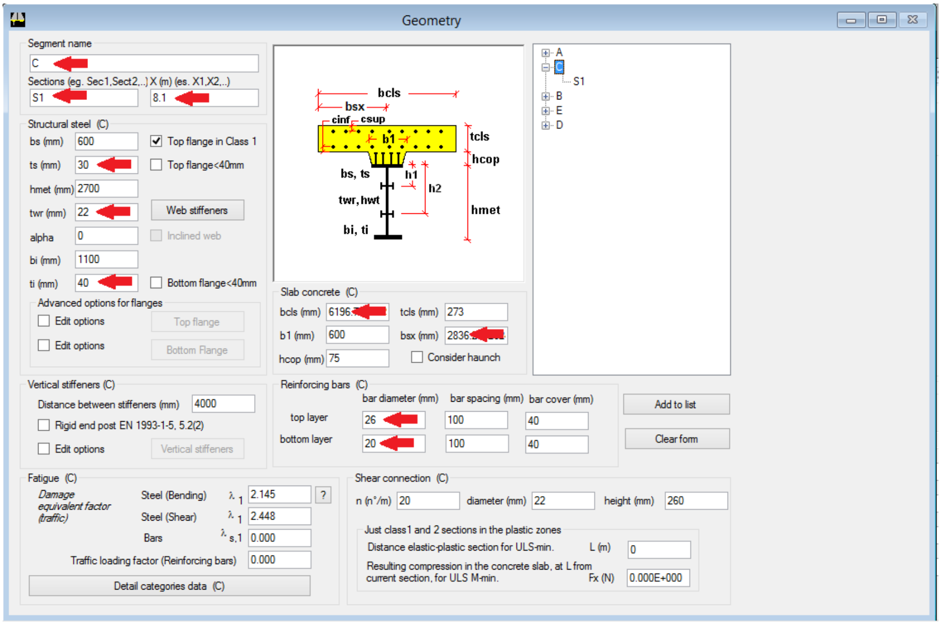
- Finally, click on the **Add to list button** located under the segment treeview to save all the data previously entered for Segment A.
- Before entering data for other segments, in the segment treeview **double-click** on the name of the segment **A**. All data previously input is now available for use in defining the next section.

**Note. Double-clicking on a segment name in the Segment treeview panel will switch PontiEC4 from EDIT MODE to INPUT MODE. The status bar at the bottom-left of the screen will always show what mode is being used at any time.**

## Defining Segment C

With the status bar stating 'INPUT GEOMETRY:'

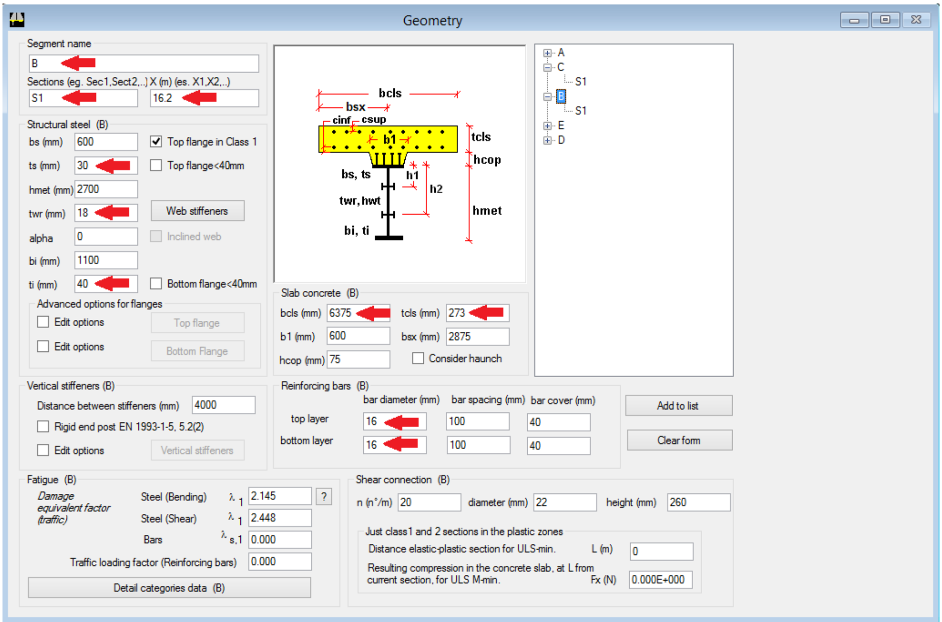
- In the Segment name field delete **A** and type **C**. Then, with reference to the following image, change or ensure that the dialog fields marked have entries as shown. Remember that the values of bcls and bsx can be calculated automatically by selecting **Calculate beff** from the context menu for both fields.




- When complete, click the **Add to list** button to save the data entered.

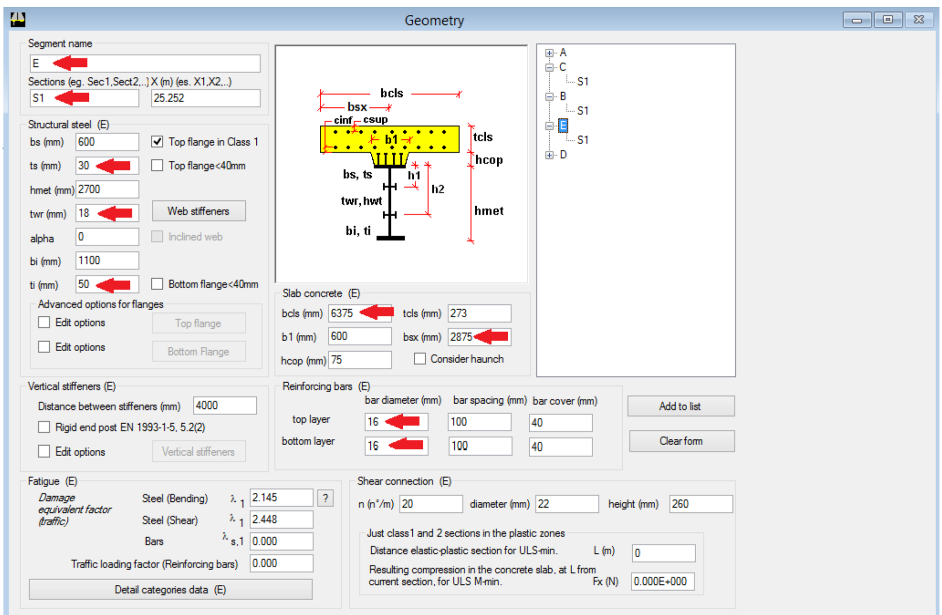
## Defining Segment B

- Ensure that the dialog fields marked have the entries shown. When complete click the **Add to list** button to save the segment data entered.



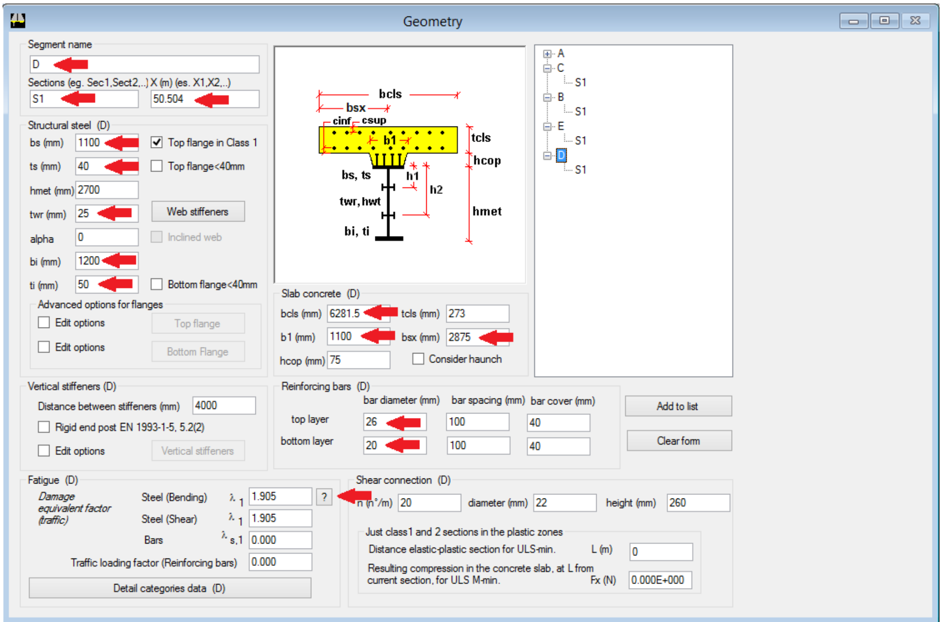

## Segment E

- Ensure that the dialog fields marked have the entries shown. When complete click the **Add to list** button to save the segment data entered.

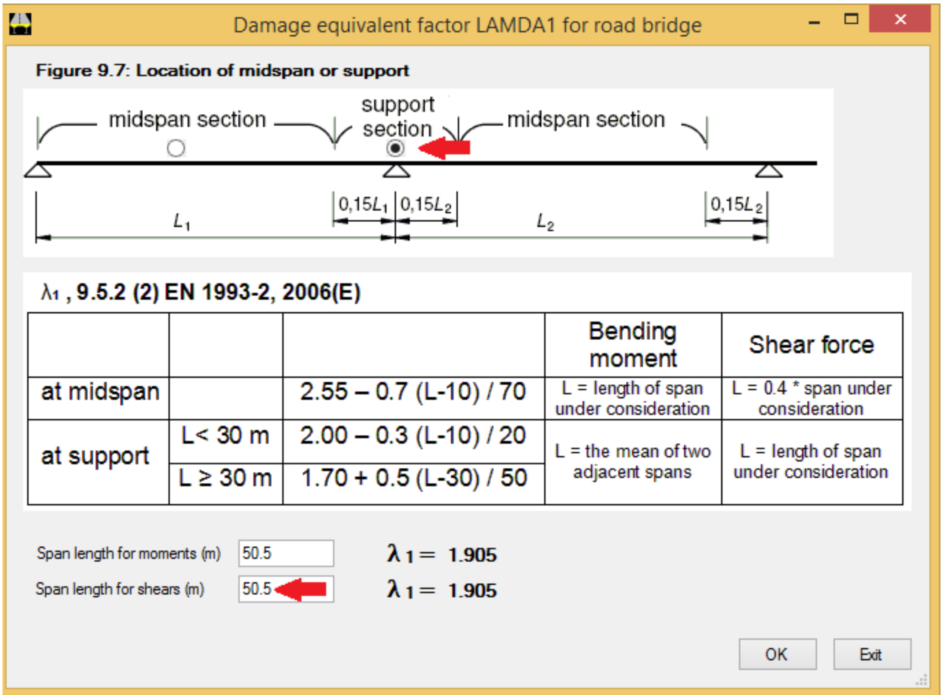


# Segment D

- With reference to the following image change or ensure that the dialog fields highlighted have the entries shown.




- Click on the Question mark button  next to the Steel (Bending moment) field and specify a **support section** and a Span length for shears of **50.5** as shown in the following image.




- When complete click the **Add to list** button to save the segment data entered.

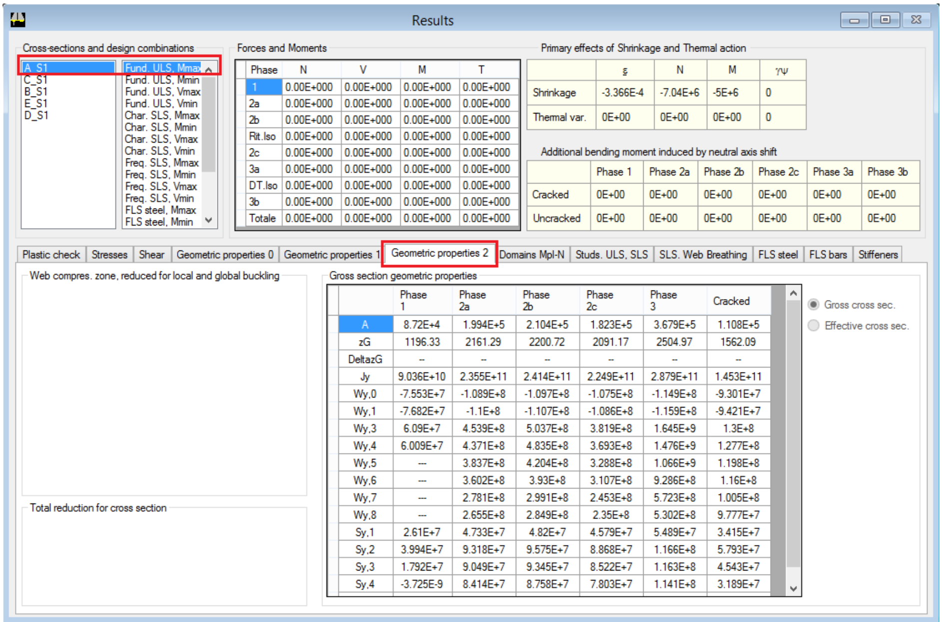
### Save the entered data

- Select the **File> Save** menu item to save the PontiEC4 dialog data to the current working project folder.

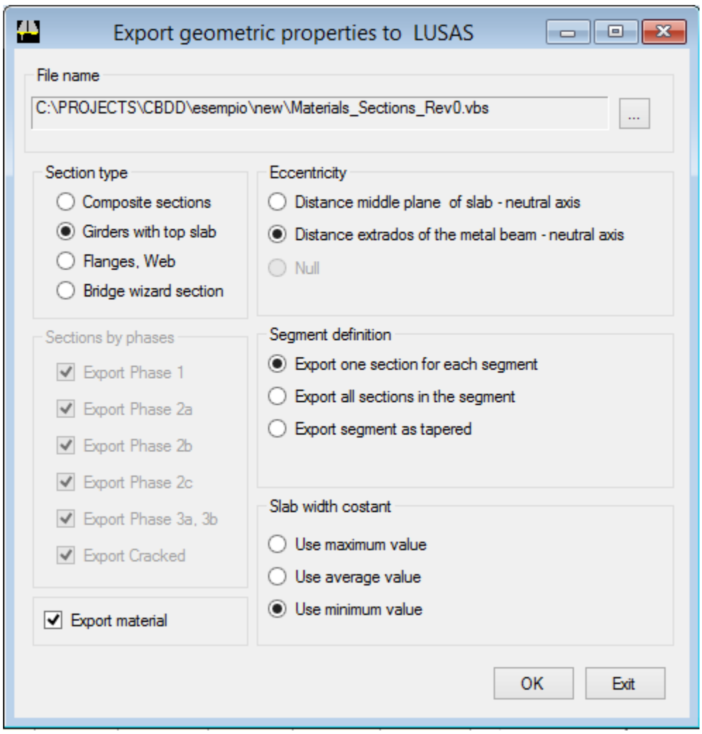
## Step 2: Export geometric properties from PontiEC4 to LUSAS

Prior to exporting geometric properties PontiEC4 needs to check that all the data that has been input is valid, and then run part of the EC4 code check to calculate the required geometric properties of each defined cross section. This is automatically done when requesting to view the Results window/dialog and should always be done prior to exporting properties subsequently.

- On the main PontiEC4 menu select **Window> 4 Results** to set the **Results** dialog active. After a short delay whilst a partial code check is run, the geometric properties of each cross section will be calculated. This can be confirmed by selecting a Cross-section and Design combination with the **Geometric properties 2** tab active.




- When complete, select **File> Export geometric properties to LUSAS**



- On the dialog presented browse to a suitable project folder and enter a filename of **“Materials_Sections_Rev0.vbs”.**
- Select the **Girders with top slab** option.
- In the Eccentricity panel, select **Distance extrados of the metal beam - neutral axis**
- In the slab width, beam height panel, select **Assume slab width constant and use minimum value,**
- Finally, ensure the **Export material** check box is ticked, and click **OK** to finish.

The file created can be imported into LUSAS to create new, or overwrite any similarly named geometric and material properties.

# Discussion: Modelling and Analysis with LUSAS

Because the primary aim of this particular example is to show the use of the PontiEC4 Composite Deck Designer and the interaction between it and LUSAS, no step-by-step instruction is provided for construction of the supplied LUSAS model that is used in this example. A separate example ‘Composite Highway Bridge design’ shows the LUSAS model building requirements to allow a design check with PontiEC4 to be carried out.

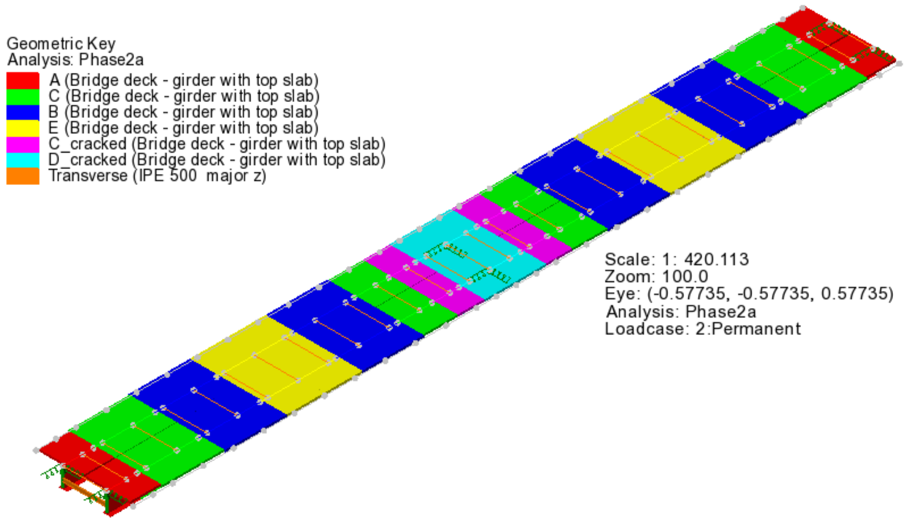
Several modelling approaches are possible in order to analyse a structure and obtain the forces and moments required for a design check of the composite sections. Possible options include grillage, ribbed-plate, 3D shell models, or line beam methods. Users can choose the most suitable approach to their method of working, and obtain forces and moments as required.

## Modelling

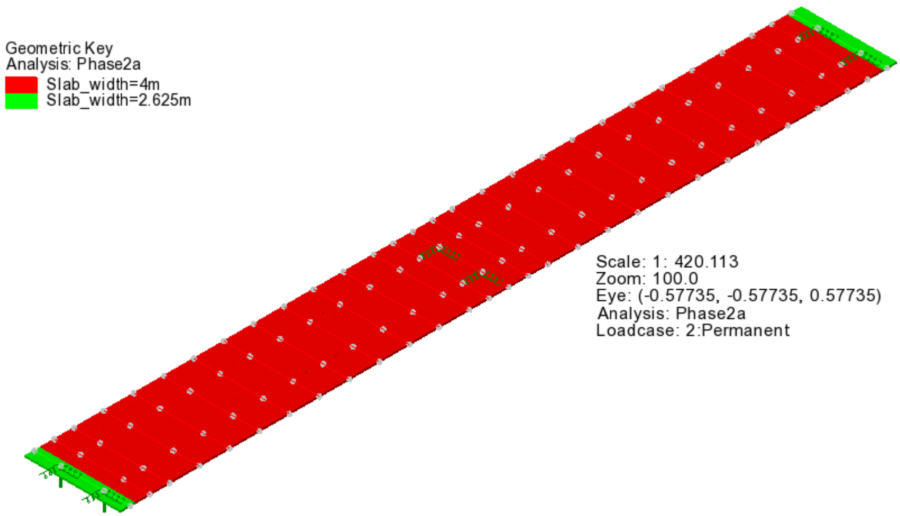
The model supplied for use with this example is a grillage model. Longitudinal grillage members have been placed at the location of the two girders and at the deck edges. Transverse members have been placed at the locations of the transverse beams and at the deck ends. Between the main girders, coincident lines are used to model both the transverse beams and the transverse segments of the slab deck separately.

### Meshing

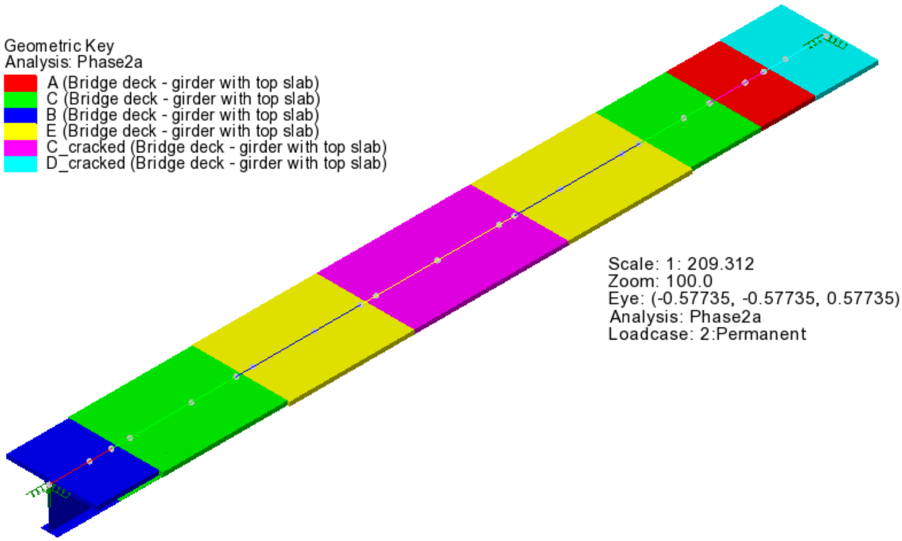
BMI21 elements have been used throughout and all mesh lies on the extrados of the metal beam: the cross sections of the main girders and transverse beams are given an appropriate eccentricity within LUSAS. The edge longitudinal lines have a ‘Null’ mesh (element type = None) and are included in the model to enable processing of the discrete loads. The following figures show the model mesh with rendering.




Longitudinal and transverse beams




Transverse slabs




Details of half external beam

### Geometric properties

Geometric properties are imported into LUSAS from PontiEC4 for each of the design phases considered. Eccentricities for sections are calculated as part of the PontiEC4 export process, with the extrados of the metal beam sitting on the nodal line if the appropriate option was selected during export. In the LUSAS model supplied, these section properties have already been assigned to corresponding lines of the model. Note that re-importing properties of the same name that have already been assigned to a model simply overwrites the existing definitions.

### Material properties

Material properties, defined in PontiEC4, are imported into the LUSAS model as base Isotropic material properties and Bridge Deck (Grillage) material. These attributes have already been assigned to corresponding lines of the model.

### Supports

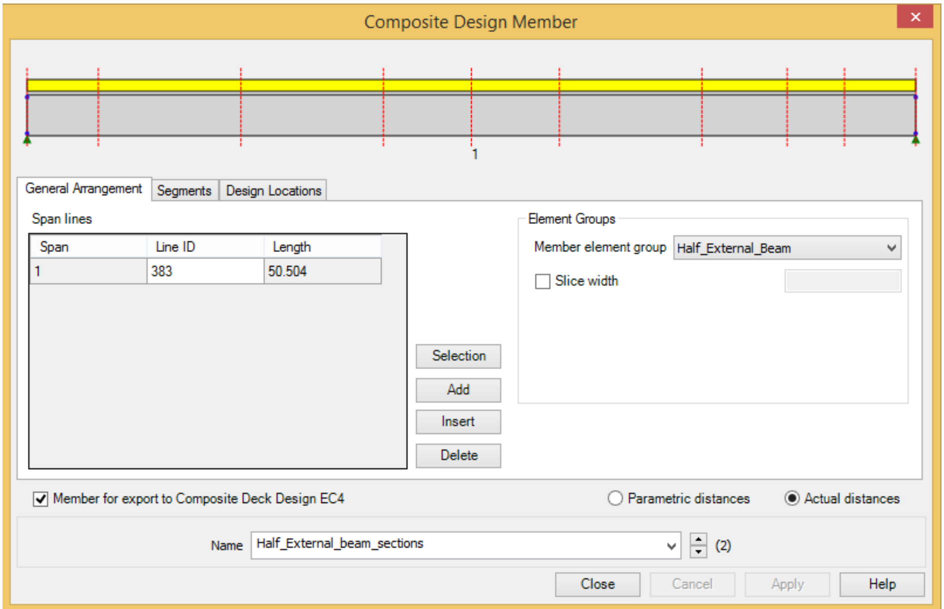
Span lengths, whilst defined in PontiEC4, are not imported into LUSAS to derive support positions. Instead, suitable supports must be defined within LUSAS and assigned to the relevant features of the LUSAS model. In this worked example all supports are fixed in the Z-direction, and have a spring stiffness of 3.03E6 in the X and Y directions.

### Composite design member

The composite design member is not imported into LUSAS, so to identify the sections at which design checks will be undertaken in PontiEC4, it must be defined within

LUSAS by using the ‘Utilities > Design > Composite Design Member’ menu item. The relevant data (Spans, Segments and Design locations) are shown in the figures below. Given the symmetry of the structure, only the first span and data for half of the external beam length is described in the Composite Design member (CDM). The elements to slice are collected in a dedicated group named ‘Half_External_Beam’. The CDM utility is also used for the definition of Slice resultants beam/shell and Influence surfaces for the DMI and VLO analysis.

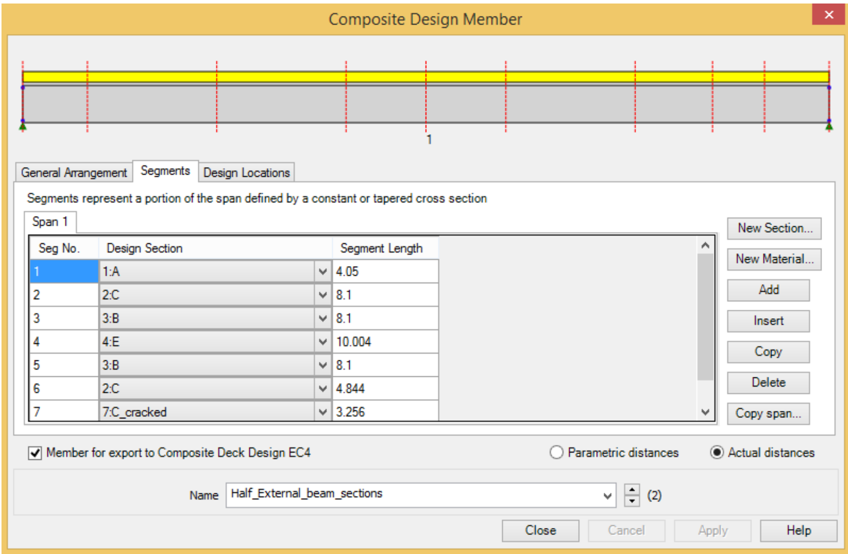
When defining a design member, ensure the option ‘Member for export to Composite Deck Design EC4’ is checked to switch to the suitable display mode, and ensure ‘Actual distances’ is selected too.




General Arrangement Tab – First span and half external beam

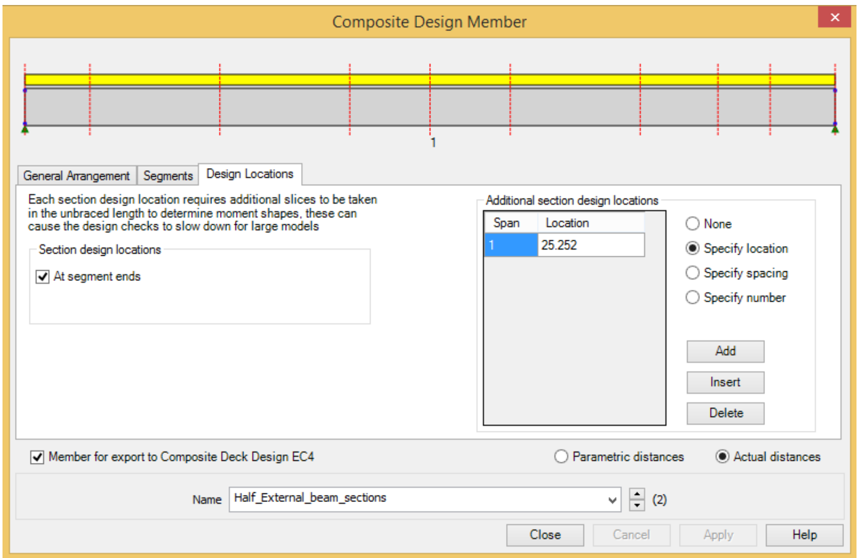
For each Segment, the following Design section name and relative Segment length would be input.

| Segment No. | Design section | Segment length |
|---|---|---|
| 1 | 1:A | 4.05 |
| 2 | 2:C | 8.1 |
| 3 | 3:B | 8.1 |
| 4 | 4:E | 10.004 |
| 5 | 3:B | 8.1 |
| 6 | 2:C | 4.844 |
| 7 | 7:C_cracked | 3.256 |
| 8 | 8:D_cracked | 4.05 |




Segment Tab – Design Section and Segment Length

Design locations (where design checks will be carried out) can be specified to be at segment ends and, additionally, at distances measured from the start of each span




Design Locations Tab – Sections to Check in PontiEC4

### Analysis

The LUSAS multiple analysis facility is used, with separate analyses being defined to represent the four design phases that need to be considered, and two specialized analysis to handle traffic loading optimization. These are:

1. **Phase 1** – Where **the slab is present just as weight**; the cross sections are only steel and not composite. The concreting order of the slab segments has been ignored, supposing that the concreting of the slab occurs at the same time.
2. **Phase 2a** - The composite section has been calculated using the **long term** properties of the concrete, and the long term loadings considered are the **permanent** ones.
3. **Phase 2b** - The composite section has been calculated using the **long term** properties of the concrete, and the long term loading considered is the **shrinkage of the concrete**.
4. **Phase 3** - The composite section has been calculated using the **short term** properties of the concrete. **All variable actions** are considered in this analysis. A series of loadcases has been created to represent thermal action, fatigue vehicle FLM3 and wind effects.
5. **DMI Analysis** - The composite section has been calculated using the **short term** properties of the concrete. The influence surfaces of Moments and Shear forces have been assigned to the sections to check in PontiEC4, by definition of a **Composite design member.**
6. **VLO Analysis -** The composite section has been calculated using the **short term** properties of the concrete. A series of loadcases has been created to represent traffic loading effects (Group 1a - LM1) in characteristic and frequent combination.

### Notes

- Phase 2c in PontiEC4 represents the actions arising from prestressing and is therefore not required in this example.
- Transverse slab sections have been calculated based on the appropriate width of slab with appropriate time-dependant concrete properties applied in each phase. For the purposes of this example any possible reduction in torsional stiffness for these sections is not considered.

## Loading and load cases

The following table summarizes the loadings and load cases used for each analysis.

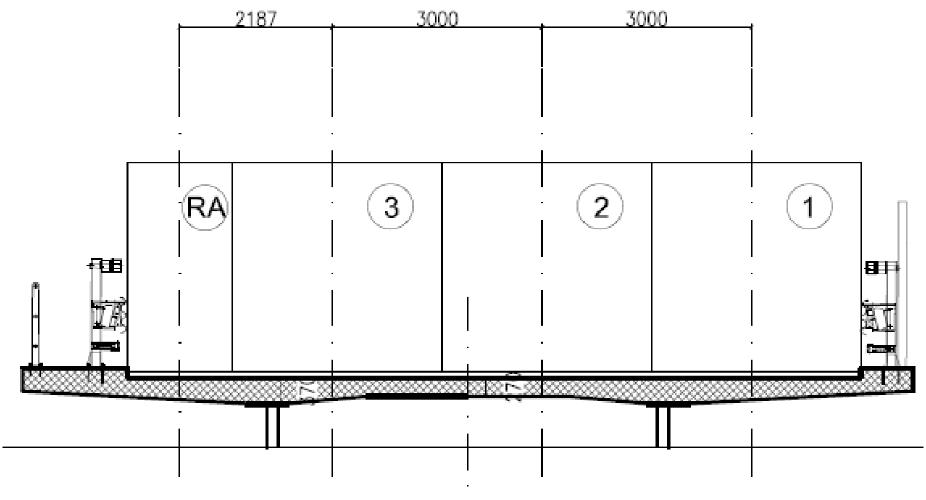
| Analysis | Loadings | Loadcases |
|---|---|---|
| Phase1 | PHASE 1 Longitudinal and transv. beams Weight (m/s^2)<br>PHASE 1 Stud Weight (N/m) __for_beam<br>PHASE 1 Slab Weight (N/m)__for_beam | Self_Weight |

| Analysis | Loadings | Loadcases |
|---|---|---|
| | PHASE 1 Curb Weight w=750mm (N/m)__external_beam<br>PHASE 1 Curb Weight w=1500mm (N/m)__internal_beam | |
| Phase2a | PHASE 2a Permanent loading (N/m)__x_external_beam<br>PHASE 2a Permanent loading (N/m)__x_internal_beam | Permanent |
| Phase2b | PHASE2b Internal support settlement | Settlement |
| | Shrinkage_A_S1<br>Shrinkage_C_S1<br>Shrinkage_B_S1<br>Shrinkage_E_S1<br>Shrinkage_S_S1 | Shrinkage |
| Phase3 | PHASE 3a Thermal Heat | Thermal_Heat |
| | PHASE 3a Thermal Cold | Thermal_Cold |
| | PHASE 3b Wind V (N/m)__x_internal_beam<br>PHASE 3b Wind V (N/m)__x_external_beam | Wind |
| | FLM3 (Eurocode Fatigue Load Model 3 120000N) | From ID=520 Pos=1<br>to ID=629 Pos=110 |
| DMI | Influence surfaces of sections to check (frequent and characteristic combination) | |
| VLO Analysis | LM1 Tandem and udl | From ID=410 to ID=477 |

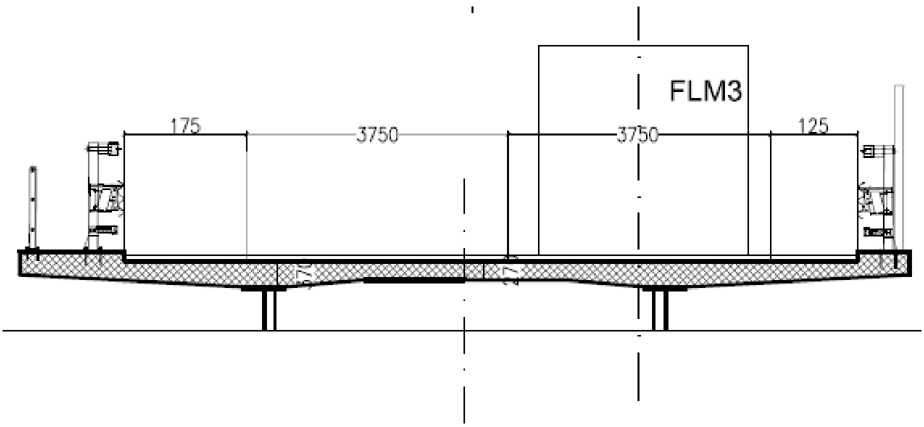
## Traffic loading

The traffic loading LM1 has been generated from a VLO Analysis performed to maximize bending moments and shears in the right (external) girder beam. The influence surface related to the VLO Analysis has been defined by the Composite Design member utility.

The Fatigue model loading 3 has been generated from the vehicle libraries in LUSAS and positioned using the Moving Load Generator using an incremental distance of 1m. The lane position is the actual position of the heavy traffic lane.



Notional lanes for Load Model 1 (ULS and SLS)




Fatigue Load Model 3 positioning

## Shrinkage

Shrinkage effects in analysis Phase2b have been calculated applying a thermal gradient, equivalent to an imposed curvature. The forces and moments arising from this model represent the hyperstatic effect of the shrinkage. The primary effects of shrinkage are computed directly in PontiEC4 for each section.

## Smart combinations

In order to define the design envelopes for each Phase and for each Limit State, the following smart combinations and envelopes have been defined.

### Preliminary combinations

**Loadcase ID: 288 Title: Thermal_effect_k**
**Sub Type: Smart Combination**
**Loadcases to consider: 1**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 5 | 0 | 1.0 | 1.0 | Thermal_Heat | |
| 6 | 0 | 1.0 | 1.0 | Thermal_Cold | |

**Loadcase ID: 300 Title: Wind_k**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 287 | 0 | -1.0 | 1.0 | Wind | |

**Loadcase ID: 372 Title: VLO Run 1 ~ Characteristic**
**Sub Type: Envelope**

| Loadcase | ResultsFile | Title | Type |
|---|---|---|---|
| 376 | 0 | PontiEC4_1 - M (My) @ 0 - Negative - Characteristic | |
| 377 | 0 | PontiEC4_1 - M (My) @ 4.05 (-X) - Negative - Characteristic | |
| 378 | 0 | PontiEC4_1 - M (My) @ 4.05 (+X) - Negative - Characteristic | |
| 379 | 0 | PontiEC4_1 - M (My) @ 12.15 (-X) - Negative - Characteristic | |
| 380 | 0 | PontiEC4_1 - M (My) @ 12.15 (+X) - Negative - Characteristic | |
| 381 | 0 | PontiEC4_1 - M (My) @ 20.25 (-X) - Negative - Characteristic | |
| 382 | 0 | PontiEC4_1 - M (My) @ 20.25 (+X) - Negative - Characteristic | |
| 383 | 0 | PontiEC4_1 - M (My) @ 25.252 (-X) - Negative - Characteristic | |
| 384 | 0 | PontiEC4_1 - M (My) @ 25.252 (+X) - Negative - Characteristic | |
| 385 | 0 | PontiEC4_1 - M (My) @ 30.254 (-X) - Negative - Characteristic | |
| 386 | 0 | PontiEC4_1 - M (My) @ 30.254 (+X) - Negative - Characteristic | |
| 387 | 0 | PontiEC4_1 - M (My) @ 38.354 (-X) - Negative - Characteristic | |
| 388 | 0 | PontiEC4_1 - M (My) @ 38.354 (+X) - Negative - Characteristic | |
| 389 | 0 | PontiEC4_1 - M (My) @ 43.198 - Negative - Characteristic | |
| 390 | 0 | PontiEC4_1 - M (My) @ 46.454 (-X) - Negative - Characteristic | |
| 391 | 0 | PontiEC4_1 - M (My) @ 46.454 (+X) - Negative - Characteristic | |
| 392 | 0 | PontiEC4_1 - M (My) @ 50.504 - Negative - Characteristic | |
| 410 | 0 | PontiEC4_1 - M (My) @ 0 - Positive - Characteristic | |
| 411 | 0 | PontiEC4_1 - M (My) @ 4.05 (-X) - Positive - Characteristic | |
| 412 | 0 | PontiEC4_1 - M (My) @ 4.05 (+X) - Positive - Characteristic | |
| 413 | 0 | PontiEC4_1 - M (My) @ 12.15 (-X) - Positive - Characteristic | |
| 414 | 0 | PontiEC4_1 - M (My) @ 12.15 (+X) - Positive - Characteristic | |
| 415 | 0 | PontiEC4_1 - M (My) @ 20.25 (-X) - Positive - Characteristic | |
| 416 | 0 | PontiEC4_1 - M (My) @ 20.25 (+X) - Positive - Characteristic | |
| 417 | 0 | PontiEC4_1 - M (My) @ 25.252 (-X) - Positive - Characteristic | |
| 418 | 0 | PontiEC4_1 - M (My) @ 25.252 (+X) - Positive - Characteristic | |
| 419 | 0 | PontiEC4_1 - M (My) @ 30.254 (-X) - Positive - Characteristic | |
| 420 | 0 | PontiEC4_1 - M (My) @ 30.254 (+X) - Positive - Characteristic | |
| 421 | 0 | PontiEC4_1 - M (My) @ 38.354 (-X) - Positive - Characteristic | |
| 422 | 0 | PontiEC4_1 - M (My) @ 38.354 (+X) - Positive - Characteristic | |
| 423 | 0 | PontiEC4_1 - M (My) @ 43.198 - Positive - Characteristic | |
| 424 | 0 | PontiEC4_1 - M (My) @ 46.454 (-X) - Positive - Characteristic | |
| 425 | 0 | PontiEC4_1 - M (My) @ 46.454 (+X) - Positive - Characteristic | |
| 426 | 0 | PontiEC4_1 - M (My) @ 50.504 - Positive - Characteristic | |
| 444 | 0 | PontiEC4_1 - V (Fz) @ 0 - Negative - Characteristic | |
| 445 | 0 | PontiEC4_1 - V (Fz) @ 4.05 (-X) - Negative - Characteristic | |
| 446 | 0 | PontiEC4_1 - V (Fz) @ 4.05 (+X) - Negative - Characteristic | |
| 447 | 0 | PontiEC4_1 - V (Fz) @ 12.15 (-X) - Negative - Characteristic | |
| 448 | 0 | PontiEC4_1 - V (Fz) @ 12.15 (+X) - Negative - Characteristic | |
| 449 | 0 | PontiEC4_1 - V (Fz) @ 20.25 (-X) - Negative - Characteristic | |
| 450 | 0 | PontiEC4_1 - V (Fz) @ 20.25 (+X) - Negative - Characteristic | |
| 451 | 0 | PontiEC4_1 - V (Fz) @ 25.252 (-X) - Negative - Characteristic | |
| 452 | 0 | PontiEC4_1 - V (Fz) @ 25.252 (+X) - Negative - Characteristic | |
| 453 | 0 | PontiEC4_1 - V (Fz) @ 30.254 (-X) - Negative - Characteristic | |
| 454 | 0 | PontiEC4_1 - V (Fz) @ 30.254 (+X) - Negative - Characteristic | |
| 455 | 0 | PontiEC4_1 - V (Fz) @ 38.354 (-X) - Negative - Characteristic | |
| 456 | 0 | PontiEC4_1 - V (Fz) @ 38.354 (+X) - Negative - Characteristic | |
| 457 | 0 | PontiEC4_1 - V (Fz) @ 43.198 - Negative - Characteristic | |
| 458 | 0 | PontiEC4_1 - V (Fz) @ 46.454 (-X) - Negative - Characteristic | |
| 459 | 0 | PontiEC4_1 - V (Fz) @ 46.454 (+X) - Negative - Characteristic | |
| 460 | 0 | PontiEC4_1 - V (Fz) @ 50.504 - Negative - Characteristic | |
| 478 | 0 | PontiEC4_1 - V (Fz) @ 0 - Positive - Characteristic | |
| 479 | 0 | PontiEC4_1 - V (Fz) @ 4.05 (-X) - Positive - Characteristic | |
| 480 | 0 | PontiEC4_1 - V (Fz) @ 4.05 (+X) - Positive - Characteristic | |
| 481 | 0 | PontiEC4_1 - V (Fz) @ 12.15 (-X) - Positive - Characteristic | |
| 482 | 0 | PontiEC4_1 - V (Fz) @ 12.15 (+X) - Positive - Characteristic | |
| 483 | 0 | PontiEC4_1 - V (Fz) @ 20.25 (-X) - Positive - Characteristic | |
| 484 | 0 | PontiEC4_1 - V (Fz) @ 20.25 (+X) - Positive - Characteristic | |
| 485 | 0 | PontiEC4_1 - V (Fz) @ 25.252 (-X) - Positive - Characteristic | |
| 486 | 0 | PontiEC4_1 - V (Fz) @ 25.252 (+X) - Positive - Characteristic | |
| 487 | 0 | PontiEC4_1 - V (Fz) @ 30.254 (-X) - Positive - Characteristic | |
| 488 | 0 | PontiEC4_1 - V (Fz) @ 30.254 (+X) - Positive - Characteristic | |
| 489 | 0 | PontiEC4_1 - V (Fz) @ 38.354 (-X) - Positive - Characteristic | |
| 490 | 0 | PontiEC4_1 - V (Fz) @ 38.354 (+X) - Positive - Characteristic | |
| 491 | 0 | PontiEC4_1 - V (Fz) @ 43.198 - Positive - Characteristic | |
| 492 | 0 | PontiEC4_1 - V (Fz) @ 46.454 (-X) - Positive - Characteristic | |
| 493 | 0 | PontiEC4_1 - V (Fz) @ 46.454 (+X) - Positive - Characteristic | |
| 494 | 0 | PontiEC4_1 - V (Fz) @ 50.504 - Positive - Characteristic | |

**Loadcase ID: 374 Title: VLO Run 1 ~ Frequent**
**Sub Type: Envelope**

| Loadcase | ResultsFile | Title | Type |
|---|---|---|---|
| 393 | 0 | PontiEC4_1 - M (My) @ 0 - Negative - Frequent | |
| 394 | 0 | PontiEC4_1 - M (My) @ 4.05 (-X) - Negative - Frequent | |
| 395 | 0 | PontiEC4_1 - M (My) @ 4.05 (+X) - Negative - Frequent | |
| 396 | 0 | PontiEC4_1 - M (My) @ 12.15 (-X) - Negative - Frequent | |
| 397 | 0 | PontiEC4_1 - M (My) @ 12.15 (+X) - Negative - Frequent | |
| 398 | 0 | PontiEC4_1 - M (My) @ 20.25 (-X) - Negative - Frequent | |
| 399 | 0 | PontiEC4_1 - M (My) @ 20.25 (+X) - Negative - Frequent | |
| 400 | 0 | PontiEC4_1 - M (My) @ 25.252 (-X) - Negative - Frequent | |
| 401 | 0 | PontiEC4_1 - M (My) @ 25.252 (+X) - Negative - Frequent | |
| 402 | 0 | PontiEC4_1 - M (My) @ 30.254 (-X) - Negative - Frequent | |
| 403 | 0 | PontiEC4_1 - M (My) @ 30.254 (+X) - Negative - Frequent | |
| 404 | 0 | PontiEC4_1 - M (My) @ 38.354 (-X) - Negative - Frequent | |
| 405 | 0 | PontiEC4_1 - M (My) @ 38.354 (+X) - Negative - Frequent | |
| 406 | 0 | PontiEC4_1 - M (My) @ 43.198 - Negative - Frequent | |
| 407 | 0 | PontiEC4_1 - M (My) @ 46.454 (-X) - Negative - Frequent | |
| 408 | 0 | PontiEC4_1 - M (My) @ 46.454 (+X) - Negative - Frequent | |
| 409 | 0 | PontiEC4_1 - M (My) @ 50.504 - Negative - Frequent | |
| 427 | 0 | PontiEC4_1 - M (My) @ 0 - Positive - Frequent | |
| 428 | 0 | PontiEC4_1 - M (My) @ 4.05 (-X) - Positive - Frequent | |
| 429 | 0 | PontiEC4_1 - M (My) @ 4.05 (+X) - Positive - Frequent | |
| 430 | 0 | PontiEC4_1 - M (My) @ 12.15 (-X) - Positive - Frequent | |
| 431 | 0 | PontiEC4_1 - M (My) @ 12.15 (+X) - Positive - Frequent | |
| 432 | 0 | PontiEC4_1 - M (My) @ 20.25 (-X) - Positive - Frequent | |
| 433 | 0 | PontiEC4_1 - M (My) @ 20.25 (+X) - Positive - Frequent | |
| 434 | 0 | PontiEC4_1 - M (My) @ 25.252 (-X) - Positive - Frequent | |
| 435 | 0 | PontiEC4_1 - M (My) @ 25.252 (+X) - Positive - Frequent | |
| 436 | 0 | PontiEC4_1 - M (My) @ 30.254 (-X) - Positive - Frequent | |
| 437 | 0 | PontiEC4_1 - M (My) @ 30.254 (+X) - Positive - Frequent | |
| 438 | 0 | PontiEC4_1 - M (My) @ 38.354 (-X) - Positive - Frequent | |
| 439 | 0 | PontiEC4_1 - M (My) @ 38.354 (+X) - Positive - Frequent | |
| 440 | 0 | PontiEC4_1 - M (My) @ 43.198 - Positive - Frequent | |
| 441 | 0 | PontiEC4_1 - M (My) @ 46.454 (-X) - Positive - Frequent | |
| 442 | 0 | PontiEC4_1 - M (My) @ 46.454 (+X) - Positive - Frequent | |
| 443 | 0 | PontiEC4_1 - M (My) @ 50.504 - Positive - Frequent | |
| 461 | 0 | PontiEC4_1 - V (Fz) @ 0 - Negative - Frequent | |
| 462 | 0 | PontiEC4_1 - V (Fz) @ 4.05 (-X) - Negative - Frequent | |
| 463 | 0 | PontiEC4_1 - V (Fz) @ 4.05 (+X) - Negative - Frequent | |
| 464 | 0 | PontiEC4_1 - V (Fz) @ 12.15 (-X) - Negative - Frequent | |
| 465 | 0 | PontiEC4_1 - V (Fz) @ 12.15 (+X) - Negative - Frequent | |
| 466 | 0 | PontiEC4_1 - V (Fz) @ 20.25 (-X) - Negative - Frequent | |
| 467 | 0 | PontiEC4_1 - V (Fz) @ 20.25 (+X) - Negative - Frequent | |
| 468 | 0 | PontiEC4_1 - V (Fz) @ 25.252 (-X) - Negative - Frequent | |
| 469 | 0 | PontiEC4_1 - V (Fz) @ 25.252 (+X) - Negative - Frequent | |
| 470 | 0 | PontiEC4_1 - V (Fz) @ 30.254 (-X) - Negative - Frequent | |
| 471 | 0 | PontiEC4_1 - V (Fz) @ 30.254 (+X) - Negative - Frequent | |
| 472 | 0 | PontiEC4_1 - V (Fz) @ 38.354 (-X) - Negative - Frequent | |
| 473 | 0 | PontiEC4_1 - V (Fz) @ 38.354 (+X) - Negative - Frequent | |
| 474 | 0 | PontiEC4_1 - V (Fz) @ 43.198 - Negative - Frequent | |
| 475 | 0 | PontiEC4_1 - V (Fz) @ 46.454 (-X) - Negative - Frequent | |
| 476 | 0 | PontiEC4_1 - V (Fz) @ 46.454 (+X) - Negative - Frequent | |
| 477 | 0 | PontiEC4_1 - V (Fz) @ 50.504 - Negative - Frequent | |
| 495 | 0 | PontiEC4_1 - V (Fz) @ 0 - Positive - Frequent | |
| 496 | 0 | PontiEC4_1 - V (Fz) @ 4.05 (-X) - Positive - Frequent | |
| 497 | 0 | PontiEC4_1 - V (Fz) @ 4.05 (+X) - Positive - Frequent | |
| 498 | 0 | PontiEC4_1 - V (Fz) @ 12.15 (-X) - Positive - Frequent | |
| 499 | 0 | PontiEC4_1 - V (Fz) @ 12.15 (+X) - Positive - Frequent | |
| 500 | 0 | PontiEC4_1 - V (Fz) @ 20.25 (-X) - Positive - Frequent | |
| 501 | 0 | PontiEC4_1 - V (Fz) @ 20.25 (+X) - Positive - Frequent | |
| 502 | 0 | PontiEC4_1 - V (Fz) @ 25.252 (-X) - Positive - Frequent | |
| 503 | 0 | PontiEC4_1 - V (Fz) @ 25.252 (+X) - Positive - Frequent | |
| 504 | 0 | PontiEC4_1 - V (Fz) @ 30.254 (-X) - Positive - Frequent | |
| 505 | 0 | PontiEC4_1 - V (Fz) @ 30.254 (+X) - Positive - Frequent | |
| 506 | 0 | PontiEC4_1 - V (Fz) @ 38.354 (-X) - Positive - Frequent | |
| 507 | 0 | PontiEC4_1 - V (Fz) @ 38.354 (+X) - Positive - Frequent | |
| 508 | 0 | PontiEC4_1 - V (Fz) @ 43.198 - Positive - Frequent | |
| 509 | 0 | PontiEC4_1 - V (Fz) @ 46.454 (-X) - Positive - Frequent | |
| 510 | 0 | PontiEC4_1 - V (Fz) @ 46.454 (+X) - Positive - Frequent | |
| 511 | 0 | PontiEC4_1 - V (Fz) @ 50.504 - Positive - Frequent | |

## ULS design combinations

**Loadcase ID: 302 Title: ULS_Fundamental_Phase1**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 1 | 0 | 1.0 | 1.35 | Self_Weight | |

**Loadcase ID: 304 Title: ULS_Fundamental_Phase2a**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 2 | 0 | 1.0 | 1.35 | Permanent | |

**Loadcase ID: 306 Title: ULS_Fundamental_Phase2b**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 3 | 0 | 0.0 | 1.2 | Settlement | |
| 4 | 0 | 1.2 | 1.2 | Shrinkage | |

**Loadcase ID: 308 Title: ULS_Fundamental_Phase3a**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 288 | 0 | 1.2 | 1.2 | Thermal_effect_k (Max) | |
| 289 | 0 | 1.2 | 1.2 | Thermal_effect_k (Min) | |

**Loadcase ID: 310 Title: ULS_Fundamental_Phase3b**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 300 | 0 | 0.9 | 0.9 | Wind_k (Max) | |
| 301 | 0 | 0.9 | 0.9 | Wind_k (Min) | |
| 372 | 0 | 0.0 | 1.35 | VLO Run 1 ~ Characteristic (Max) | |
| 373 | 0 | 0.0 | 1.35 | VLO Run 1 ~ Characteristic (Min) | |

## SLS characteristic design combinations

**Loadcase ID: 312 Title: SLS_Characteristic_Phase1**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 1 | 0 | 1.0 | 1.0 | Self_Weight | |

**Loadcase ID: 314 Title: SLS_Characteristic_Phase2a**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 2 | 0 | 1.0 | 1.0 | Permanent | |

**Loadcase ID: 316 Title: SLS_Characteristic_Phase2b**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 3 | 0 | 0.0 | 1.0 | Settlement | |
| 4 | 0 | 1.0 | 1.0 | Shrinkage | |

**Loadcase ID: 318  Title: SLS_Characteristic_Phase3a**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 288 | 0 | 1.0 | 2.0 | Thermal_effect_k (Max) | |
| 289 | 0 | 1.0 | 1.0 | Thermal_effect_k (Min) | |

**Loadcase ID: 320  Title: SLS_Characteristic_Phase3b**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 300 | 0 | 0.6 | 0.6 | Wind_k (Max) | |
| 301 | 0 | 0.6 | 0.6 | Wind_k (Min) | |
| 372 | 0 | 0.0 | 1.0 | VLO Run 1 ~ Characteristic (Max) | |
| 373 | 0 | 0.0 | 1.0 | VLO Run 1 ~ Characteristic (Min) | |

## SLS frequent design combinations

**Loadcase ID: 322  Title: SLS_Frequent_Phase1**
**Sub Type: Smart Combination**
**Loadcases to consider: 1**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 1 | 0 | 1.0 | 1.0 | Self_Weight | |

**Loadcase ID: 324  Title: SLS_Frequent_Phase2a**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 2 | 0 | 1.0 | 1.0 | Permanent | |

**Loadcase ID: 326  Title: SLS_Frequent_Phase2b**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 3 | 0 | 0.0 | 1.0 | Settlement | |
| 4 | 0 | 1.0 | 1.0 | Shrinkage | |

**Loadcase ID: 328  Title: SLS_Frequent_Phase3a**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 5 | 0 | 1.0 | 1.0 | Thermal_Heat | |
| 6 | 0 | 1.0 | 1.0 | Thermal_Cold | |

**Loadcase ID: 330  Title: SLS_Frequent_Phase3b**
**Sub Type: Smart Combination**
**Loadcases to consider: All**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 374 | 0 | 0.0 | 1.0 | VLO Run 1 ~ Frequent (Max) | |
| 375 | 0 | 0.0 | 1.0 | VLO Run 1 ~ Frequent (Min) | |

### Fatigue design combinations

**Loadcase ID: 332 Title: Fatigue_Phase3b**
**Sub Type: Smart Combination**
**Loadcases to consider: 1**
**Variable Loadcases: All**

| Loadcase | ResultsFile | BeneficialFactor | AdverseFactor | Title | Type |
|---|---|---|---|---|---|
| 520 | 0 | 1.0 | 1.0 | LoadID=23 Line=387 Dir=Fwd Pos=1 | |
| 521 | 0 | 1.0 | 1.0 | LoadID=23 Line=387 Dir=Fwd Pos=2 | |
| 627 | 0 | 1.0 | 1.0 | LoadID=23 Line=387 Dir=Fwd Pos=108 | |
| 628 | 0 | 1.0 | 1.0 | LoadID=23 Line=387 Dir=Fwd Pos=109 | |
| 629 | 0 | 1.0 | 1.0 | LoadID=23 Line=387 Dir=Fwd Pos=110 | |

# Step 3: Use LUSAS to calculate the forces and moments for all limit state combinations

## Associated Files

- ❑ **Materials_Sections_Rev0.vbs** - A file created by PontiEC4 containing materials and geometric section data to import into LUSAS. A version of this file is supplied also, but is only for use in case of difficulties in manually creating the appropriate data
- ❑ **Composite_Bridge_Deck.mdl** – A supplied LUSAS model file that is to be used to analyse the structure. After solving this model, analysis results are exported from LUSAS or use in PontiEC4 to undertake design checks.

### Open the associated LUSAS model

- Run LUSAS Modeller and select the **File> Open** menu item, and open the supplied model named **Composite_Bridge_Deck.mdl** which is located in the **\<PontiEC4 Installation Folder>\Help\Examples\LUSAS_Example** directory.
- Select the **File> Save as** menu item and save the LUSAS model data to the same working project folder as that used to save the PontiEC4 dialog data earlier) keeping the same file name **Composite_Bridge_Deck.mdl**

### Importing the section properties from Ponti EC4

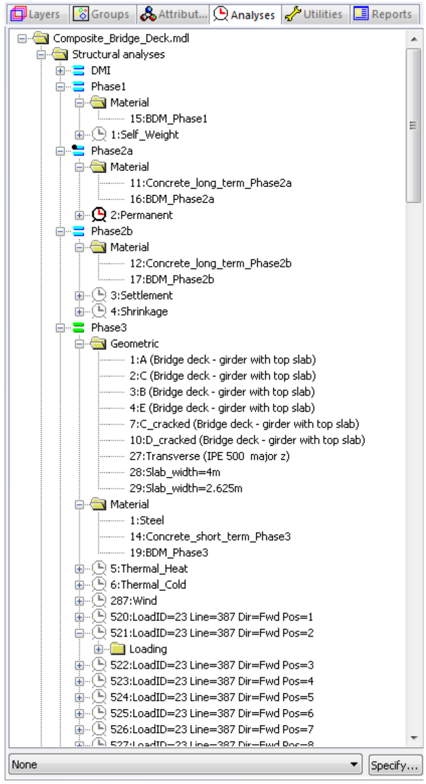
- Select **File> Script> Run Script** and select the PontiEC4 script file "**Materials_Sections_Rev0.vbs**" that was created in the working project folder earlier. This imports the geometric section data from PontiEC4.

**Note.** In this worked example, the geometric beam properties calculated by Ponti EC4 have already been assigned to the relevant lines in the supplied LUSAS model, so re-importing properties of the same name that have already been assigned simply overwrites the existing definitions. Click **Yes** to overwrite each existing definition.

When importing geometric properties for the first time on a real project, the attributes created would need to be assigned to relevant lines of your model. Cracked section properties would be assigned to appropriate lines in the LUSAS model in accordance with the requirements of the code.

### Looking at the Analysis treeview

In the Analyses treeview, notice that Phase 3 has been defined as the 'base' analysis and this shows the geometric assignments made for this, as well as the material properties for this phase.




Material properties for other phases can be seen within each Analysis Phase entry.

The stiffness of the composite section for each phase is determined from the stiffness of the girder and slab, together with the corresponding girder and slab materials assigned to the same line.

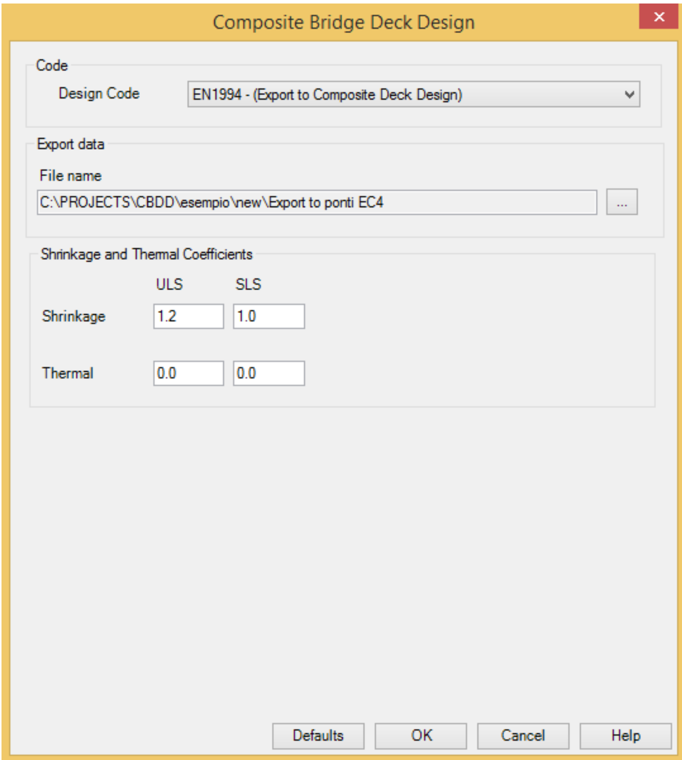
- Press the **Solve** button to compute all loadcases in all the analyses.

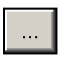
The model contains a large number of loadcases. After a short wait whilst they are all evaluated, results will be obtained.

# Step 4: Export the force and moment data from LUSAS

## Selection of composite bridge deck design Code

The composite deck design code is set via the **Design** > **Composite Bridge Deck Design** menu item, along with options for the export path and the factors for primary effects of shrinkage and thermal effects.




- Select **EN1994 – (Export to Composite Deck Design)** in the drop down list.
- Click the ellipsis button  to choose the folder and name of the xls file to create (e.g.: <current work directory>**Export to ponti EC4.xls**), pressing the **Save** button to return to the main dialog
- Input a Shrinkage coefficient of **1.2** for the ULS, and **1.0** for the SLS.
- **Remove the default thermal coefficient values** that are present and enter values of **0** for both the ULS and SLS Thermal coefficients

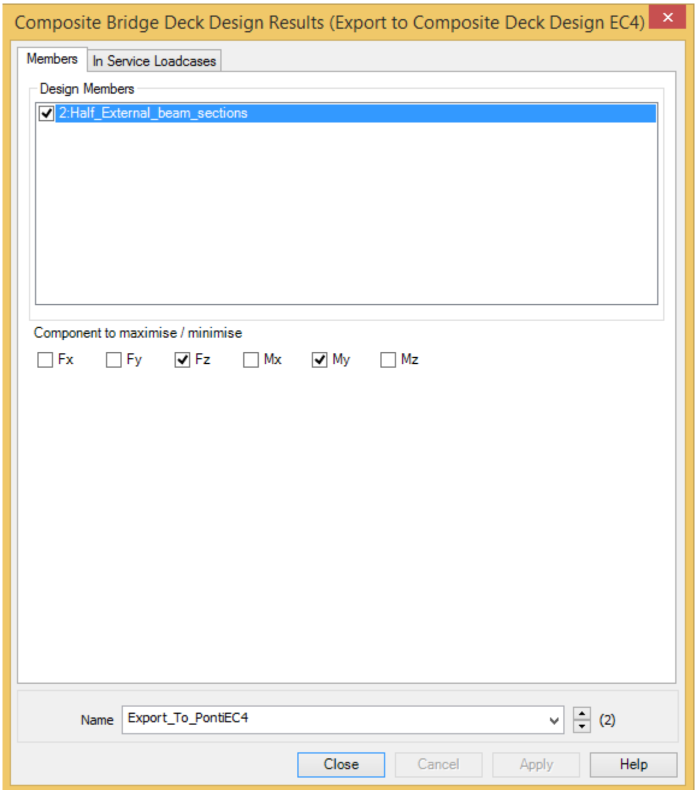
**Note.** These coefficients will be applied to the characteristic primary effects of the shrinkage as directly calculated in PontiEC4. The isostatic effect will be neglected

($\gamma*\psi=0$) in the cracked section (where Slab treatment = Cracked in Tension). The hyperstatic effect of the shrinkage comes from the LUSAS model and the combination factors have been already applied in the LUSAS smart combinations.

- Then, finally, click **OK** to return to the Modeller.

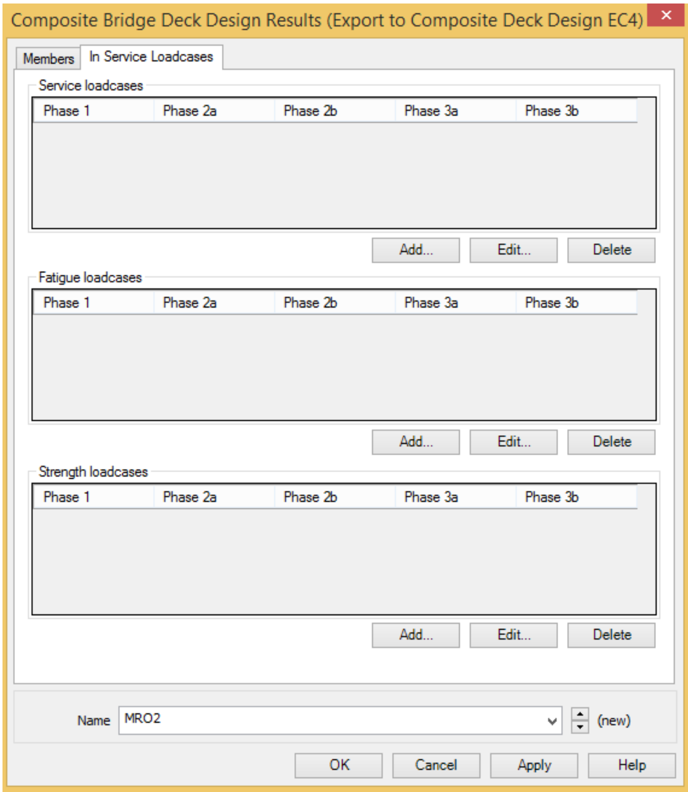
## Export to Composite Deck Design

Select the **Design** > **Export to Composite Deck Design** menu item. This utility is for specifying the loadcases from which the forces and moments will be exported to the PontiEC4 spreadsheet.

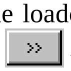



- In the **Members** tab, select the Design Member of interest.
- In the ‘Component to maximize/minimize’ panel ensure **Fz** and **My** are checked. (These are the components that will be considered in the smart combinations)

- Select the **In Service Loadcases** tab where input (or editing) of Design combinations for each Limit States and Phases is done. The dialog will appear as shown below.



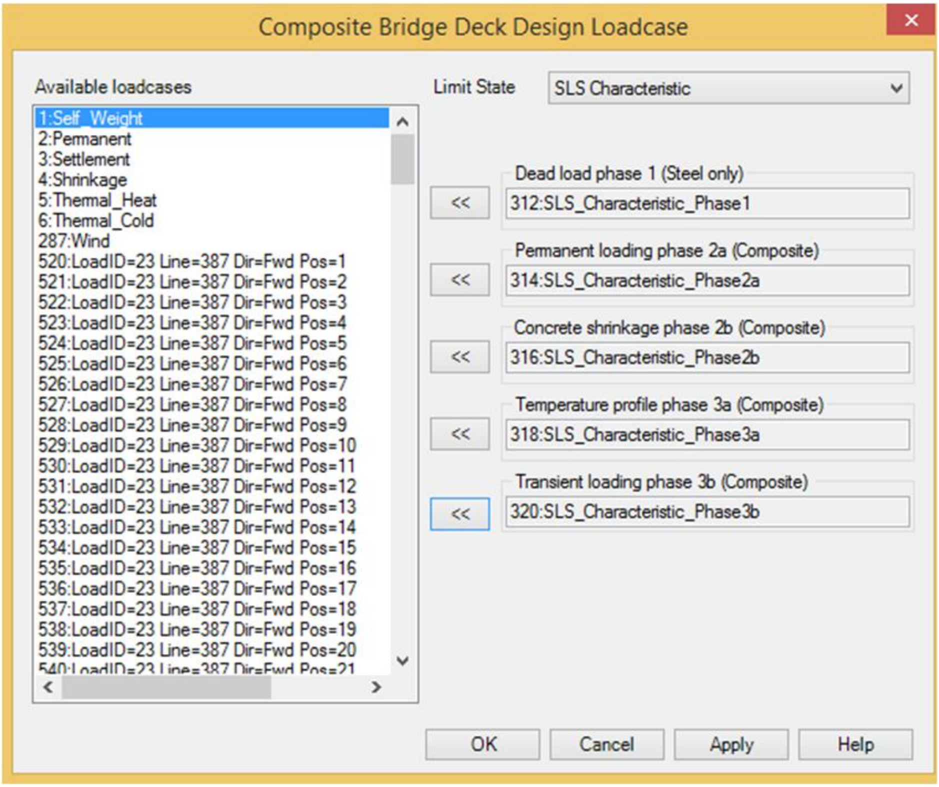

Three limit states are considered - Service, Fatigue and Strength, and appropriate loadcases (with the correct factors applied to those loadcases) must be assigned to each limit state.

- In the ‘Service loadcases’ panel, click the **Add** button.
- From the list of available loadcases, select **SLS_Characteristic_Phase1** and click the ‘Add to’ button  to add the design combination to the right-hand panel, in the **Dead load phase 1** box.
- Proceed by selecting each of the following loadcases, one at a time and assigning to the appropriate phase:

| **Loadcase** | **Phase** |
|---|---|
| **SLS_Characteristic_Phase2a** | **Permanent loading phase 2a** |

| | |
|---|---|
| **SLS_Characteristic_Phase2b** | **Concrete shrinkage phase 2b** |
| **SLS_Characteristic_Phase3a** | **Temperature profile phase 3a** |
| **SLS_Characteristic_Phase3b** | **Transient loading phase 3b** |

Once done, the dialog should look as follows:




- Once correctly assigned, click **OK** to return to the main dialog.
- In the 'Service loadcases' panel, click the **Add** button again.
- Select **SLS Frequent** in the drop down list on the top right of the dialog and proceed by selecting each of the following loadcases, one at a time and assigning to the appropriate phase:

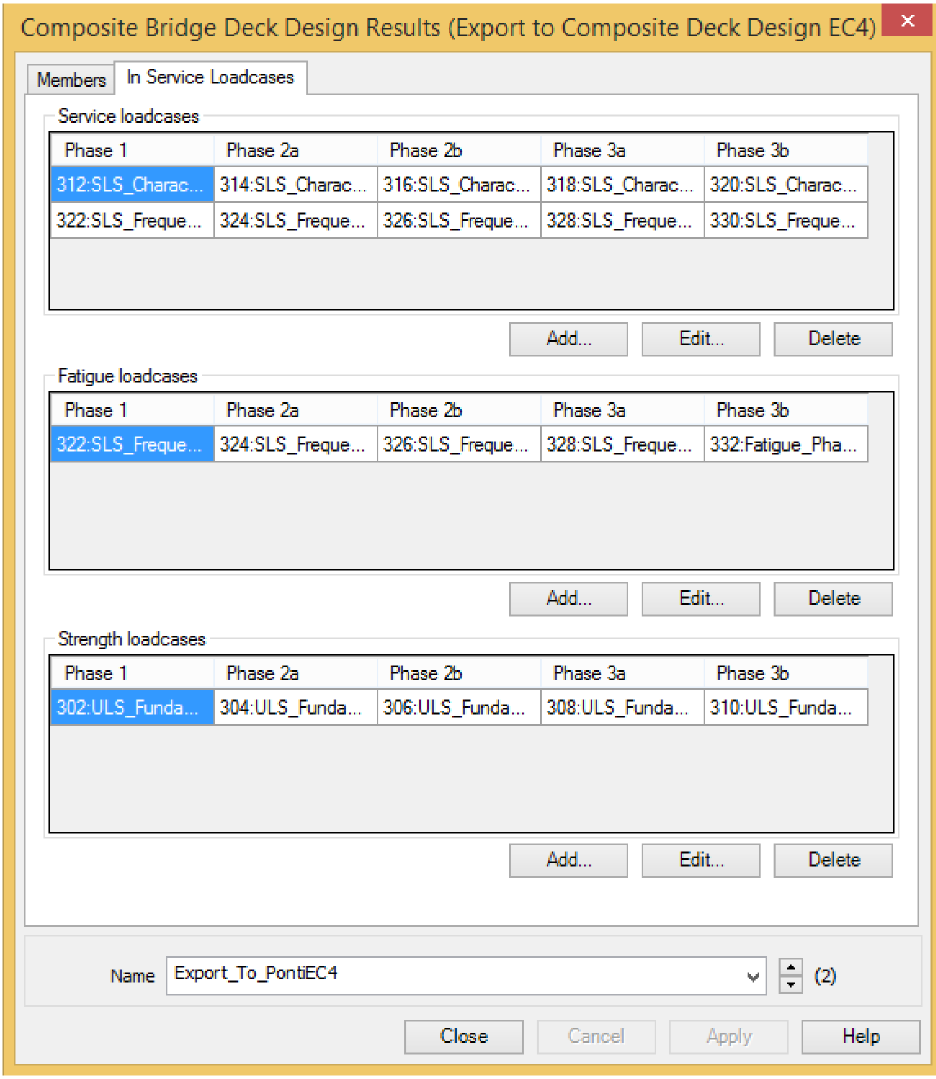
| **Loadcase** | **Phase** |
|---|---|
| **SLS_Frequent_Phase1** | **Dead load phase 1** |
| **SLS_Frequent_Phase2a** | **Permanent loading phase 2a** |
| **SLS_Frequent_Phase2b** | **Concrete shrinkage phase 2b** |

| | |
|---|---|
| **SLS_Frequent_Phase3a** | **Temperature profile phase 3a** |
| **SLS_Frequent_Phase3b** | **Transient loading phase 3b** |

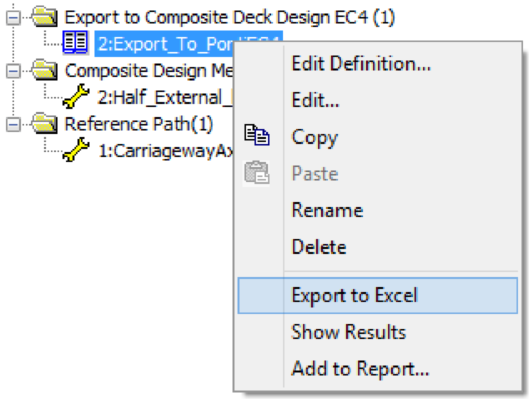
When all added, click **OK**.

- Repeat the above procedure for the other Limit States (Fatigue and Strength).
- Note that loadcase SLS_Frequent_Phase3b is not mapped as a Fatigue design limit state; the Fatigue_Phase3b loadcase must be mapped instead.

  On completion, all **Loadcases, and** the corresponding **Design limit state** for each **Phase** should be as shown in the following dialog.




- Name the utility **Export_To_PontiEC4** and click **OK** to add these entry to the Utilities treeview.
- Then, in the Utilities treeview click the right-hand mouse button on the **Export_to_Ponti_EC4** item, and choose **Export to Excel** from the context menu as shown:



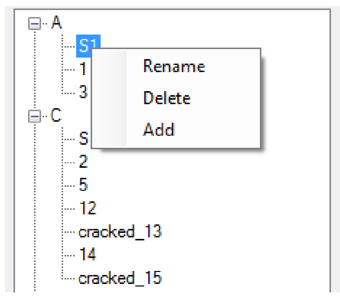

# Step 5: Import force and moment data into PontiEC4

## Associated File

This supplied file is only for use in case of problems in manually creating the appropriate data in the previous section of the example.

- **Export to ponti EC4.xls** File created by the LUSAS Export Forces and Moments dialog containing data to import into PontiEC4.

## Importing force and moment data into PontiEC4




This section covers the import of section force and moment data from LUSAS into PontiEC4. Refer to the 'Forces and moments' section in the PontiEC4 online help file for more information.

Whilst it is possible to manually enter forces and moments into PontiEC4 in the 'Forces and moments' dialog, and it is also possible to copy and paste data into each section, but when used with LUSAS any importing of data is far better achieved by using the automated procedure as follows.

- In PontiEC4, with the current data still loaded (or with the data from the previously saved file **'Composite_Bridge_Deck.csv'** loaded if the example had been saved and closed for some reason at that point), select the **File> Import forces/moments** menu item and load the file **Export to ponti EC4.xls** from working project folder.

PontiEC4 will detect that 17 additional sections are present (these are the sections at the beginning and end of each segment and at midspan) and ask if they are to be added to their corresponding segments.

- Click **Yes** to import the new sections. This operation may take a few seconds to complete. The status bar will show the progress.
- From the main menu select **Windows> 2 Geometry** to display the Geometry dialog. In the Segment treeview the new sections added to each segment can be seen.
- If any previously defined initial sections for each segment (named "**S1**") are present these are no longer necessary and should be deleted. To do this, select each section named S1 in turn, click the right-hand mouse button, and choose **Delete**.

**Note. If any mistakes are made in deleting the unwanted sections, re-importing the forces_and_moments.xls file will re-insert any deleted sections.**

- Select **File> Save As** and enter a file name of **Composite_Bridge_Deck.csv** to save the PontiEC4 dialog data to the working project folder before proceeding to view the results.

This concludes the data input.

## Step 6: Assess the results and detailed design checks in PontiEC4

This section focuses on the procedure required to assess the main girder beams for Ultimate, Serviceability, and Fatigue limit states. It involves:

1. **Viewing utilisation factors for all checks performed**
2. **Updating section sizes for any over-utilised sections**
3. **Viewing updated results**
4. **Updating the LUSAS model and re-analysing the revised sections**

It is usually enough to cycle through steps 1 to 4 once, or perhaps twice, to obtain an optimized structure.

Limited details have been given about all the checks that are carried out. To find out more about the checks performed refer to the PontiEC4 online Help (accessed via the question mark (?) button on the menu banner, where design code and theory details are also supplied.

### Viewing results in PontiEC4

- With the results loaded in **PontiEC4** select the **Window> 5 Summary of results** menu item. This carries out the design computations in PontiEC4 and displays the results for deck sections in a summary form.

The meaning of the coloured utilization factor entries is explained in the following table:

| Colour of value / text | Utilization factor | Meaning |
|---|---|---|
| **Red** | Greater than 1.0 | Value has failed the check carried out. |
| **Green** | Less than 1.0 | Value has passed the check carried out. |
| **Grey** - without parentheses | Any | Value of potential interest but the utilisation factor is not relevant to the code. |
| **(Grey)** - with parentheses | Any | Value of potential interest but the utilisation factor is not relevant to the code in this particular context. |
| **Grey** stating '**No int.**' | Not applicable | No interaction between bending and shear. |

A check of the utilization factors obtained should be made for each limit state. Only a check for the **Fundamental ULS combination** will be shown here.

**Note.** By clicking on a particular header the values in a column can be sorted in increasing or decreasing value.

- Click twice to sort the **SigEd/fy** column in descending order. It can be seen that some of Segments D and C fail the check for normal stresses at ULS, as shown below.

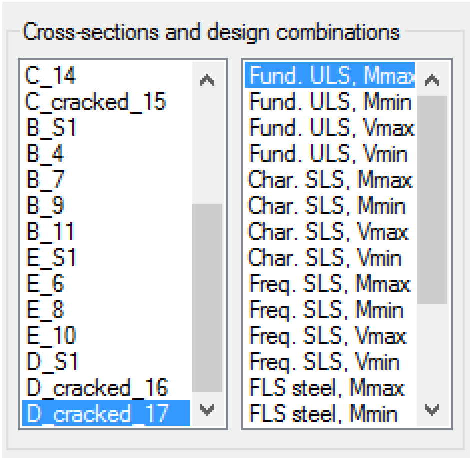
**Fundamental ULS combination**

| Section | X (m) | Combination | Class Ph.1 | Class Ph.3b | MEd/MR | SigEd /fy | VEd/VRd | MEd/Mf,Rd | VEd/Vbw,Rd | V/M/N | vEd/(n*PRd) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D_cracked_17 | 50.504 | Fund. ULS, Mmax | 4 | 4 | (.83) | 1.171 | 0.691 | 1.31 | 0.691 | 1.219 | 0.509 |
| C_cracked_15 | 46.454 | Fund. ULS, Mmax | 4 | 4 | (.73) | 1.164 | 0.651 | 1.21 | 0.651 | 1.196 | 0.364 |
| D_cracked_17 | 50.504 | Fund. ULS, Vmax | 4 | 4 | (.79) | 1.119 | 0.742 | 1.26 | 0.742 | 1.197 | 0.573 |
| C_cracked_15 | 46.454 | Fund. ULS, Vmax | 4 | 4 | (.63) | 1.011 | 0.85 | 1.06 | 0.85 | 1.181 | 0.576 |
| C_14 | 43.198 | Fund. ULS, Mmax | 4 | 4 | (.44) | 0.859 | 0.524 | 0.97 | 0.527 | No int. | 0.27 |
| C_cracked_13 | 43.198 | Fund. ULS, Mmax | 4 | 4 | (.55) | 0.859 | 0.519 | 0.89 | 0.527 | No int. | 0.27 |
| B_7 | 20.250 | Fund. ULS, Mmin | 4 | 1 | 0.72 | (.856) | 0.041 | 1 | 0.041 | No int. | 0.05 |
| D_cracked_16 | 46.454 | Fund. ULS, Mmax | 4 | 4 | (.6) | 0.837 | 0.506 | 0.94 | 0.511 | No int. | 0.332 |
| E_6 | 20.250 | Fund. ULS, Mmin | 4 | 1 | 0.66 | (.772) | 0.04 | 0.88 | 0.041 | No int. | 0.049 |

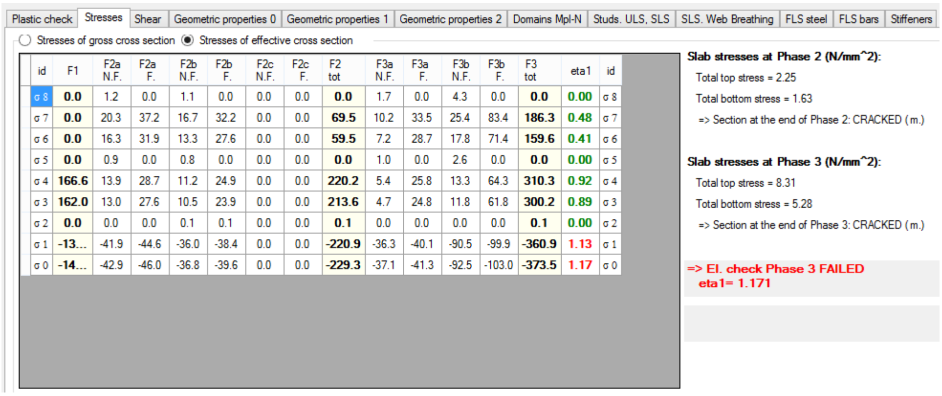
**Note.** Changing from the Geometry, Materials or Forces and moments dialogs to the Results, Summary of results, Report, or Cracking dialogs causes a re-analysis of results.

- Select the **Window> 4 Results** menu item in order to find out more about the failed checks.

- In the Cross-sections and design combinations panel select section **D_cracked_17** and **Fund. ULS, Mmax**




- Then, in the lower part of the Results dialog, select the **Stresses** tab and look at **Stresses of effective cross section**



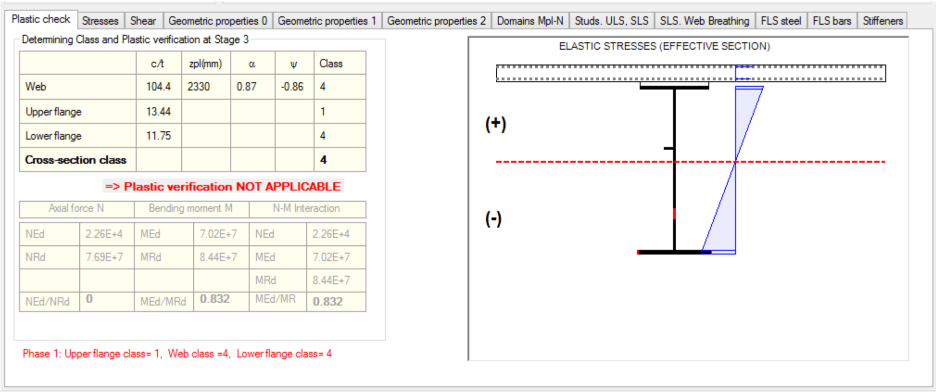

| id | F1 | F2a N.F. | F2a F. | F2b N.F. | F2b F. | F2c N.F. | F2c F. | F2 tot | F3a N.F. | F3a F. | F3b N.F. | F3b F. | F3 tot | eta1 | id |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| σ 8 | 0.0 | 1.2 | 0.0 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 0.0 | 4.3 | 0.0 | 0.0 | 0.00 | σ 8 |
| σ 7 | 0.0 | 20.3 | 37.2 | 16.7 | 32.2 | 0.0 | 0.0 | 69.5 | 10.2 | 33.5 | 25.4 | 83.4 | 186.3 | 0.48 | σ 7 |
| σ 6 | 0.0 | 16.3 | 31.9 | 13.3 | 27.6 | 0.0 | 0.0 | 59.5 | 7.2 | 28.7 | 17.8 | 71.4 | 159.6 | 0.41 | σ 6 |
| σ 5 | 0.0 | 0.9 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 2.6 | 0.0 | 0.0 | 0.00 | σ 5 |
| σ 4 | 166.6 | 13.9 | 28.7 | 11.2 | 24.9 | 0.0 | 0.0 | 220.2 | 5.4 | 25.8 | 13.3 | 64.3 | 310.3 | 0.92 | σ 4 |
| σ 3 | 162.0 | 13.0 | 27.6 | 10.5 | 23.9 | 0.0 | 0.0 | 213.6 | 4.7 | 24.8 | 11.8 | 61.8 | 300.2 | 0.89 | σ 3 |
| σ 2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.00 | σ 2 |
| σ 1 | -13... | -41.9 | -44.6 | -36.0 | -38.4 | 0.0 | 0.0 | -220.9 | -36.3 | -40.1 | -90.5 | -99.9 | -360.9 | 1.13 | σ 1 |
| σ 0 | -14... | -42.9 | -46.0 | -36.8 | -39.6 | 0.0 | 0.0 | -229.3 | -37.1 | -41.3 | -92.5 | -103.0 | -373.5 | 1.17 | σ 0 |

**Note.** Currently, the 'Stresses' tables contain non-English abbreviations in their header that need to be explained: 'F1', 'F2a', 'F2b' etc come from the Italian 'Fase' – meaning 'Phase' in English, as in Phase 1, Phase 2 etc. Additionally 'N.F.' is the Italian abbreviation for 'Non Fessurata' – meaning 'Not Cracked', and 'F' denotes 'Fessurata' – meaning 'Cracked'.

Phase totals listed are a summation of all the Cracked values for each Phase.

The normal stresses are very large in the bottom flange where they exceed fy. They are also quite large in the top flange.

- Select the **Plastic check** tab to view the classification of the section (Class 4).




# Step 7: Optimize the structure

## Associated Files

These supplied files are only for use in case of problems in manually creating the appropriate data in this section of the example.

- ❑ **Composite_Bridge_Deck_Optimized.csv** - the input file for PontiEC4 with updated steel flange values for segments D and C.
- ❑ **Sections_rev1.vbs** - A file created by PontiEC4 containing revised section data to import into LUSAS to update the geometric properties in the LUSAS model.

For this example, optimizing the structure involves making changes to flange plate thicknesses in the PontiEC4 Composite Deck Designer for those segments that failed the design check, then using LUSAS to calculate revised forces and moments, and then re-assessing the revised results and design checks in PontiEC4.

## Revise selected flange thicknesses in PontiEC4:

Flange thicknesses will be increased on those segments that currently fail the check for normal stresses at ULS.

### Segment D

- In PontiEC4, select the **Window> 2 Geometry** menu item, and then click ONCE to select Segment **D** in the segment treeview. Note that the status bar at the bottom of the interface should state: 'Edit GEOMETRY of Segment D' showing that you are only editing an existing segment and not inputting data for a new one.

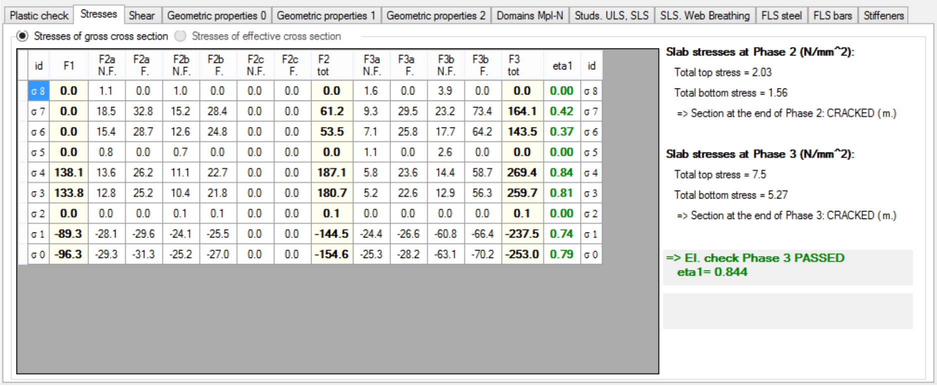
- Increase the top flange thickness (ts) from 40 to **50**

- Increase the bottom flange thickness (ti) from 50 to **80**
- Select the **Window> 4 Results** menu item. This causes the results for Section **D_cracked_17** and **Fund. ULS Mmax** (and all other segments) to be updated.

Because of the modification to the flanges for Segment D, the **Plastic check** dialog will show that it has now moved from Class 4 to Class 3. As a result, the 'Stresses of effective cross section' radio button will no longer be available on the 'Stresses' results page of the Results dialog.

**Note.** Effective stresses are available only for the Class 4 sections.

- Select the **Stresses** tab and look at **Stresses of gross cross section.**

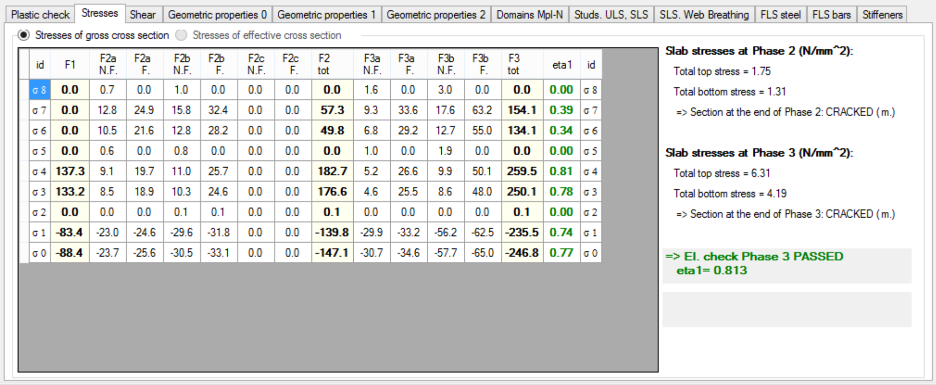



| id | F1 | F2a N.F. | F2a F. | F2b N.F. | F2b F. | F2c N.F. | F2c F. | F2 tot | F3a N.F. | F3a F. | F3b N.F. | F3b F. | F3 tot | eta1 | id |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| σ 8 | 0.0 | 1.1 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 0.0 | 3.9 | 0.0 | 0.0 | 0.00 | σ 8 |
| σ 7 | 0.0 | 18.5 | 32.8 | 15.2 | 28.4 | 0.0 | 0.0 | 61.2 | 9.3 | 29.5 | 23.2 | 73.4 | 164.1 | 0.42 | σ 7 |
| σ 6 | 0.0 | 15.4 | 28.7 | 12.6 | 24.8 | 0.0 | 0.0 | 53.5 | 7.1 | 25.8 | 17.7 | 64.2 | 143.5 | 0.37 | σ 6 |
| σ 5 | 0.0 | 0.8 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 2.6 | 0.0 | 0.0 | 0.00 | σ 5 |
| σ 4 | 138.1 | 13.6 | 26.2 | 11.1 | 22.7 | 0.0 | 0.0 | 187.1 | 5.8 | 23.6 | 14.4 | 58.7 | 269.4 | 0.84 | σ 4 |
| σ 3 | 133.8 | 12.8 | 25.2 | 10.4 | 21.8 | 0.0 | 0.0 | 180.7 | 5.2 | 22.6 | 12.9 | 56.3 | 259.7 | 0.81 | σ 3 |
| σ 2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.00 | σ 2 |
| σ 1 | -89.3 | -28.1 | -29.6 | -24.1 | -25.5 | 0.0 | 0.0 | -144.5 | -24.4 | -26.6 | -60.8 | -66.4 | -237.5 | 0.74 | σ 1 |
| σ 0 | -96.3 | -29.3 | -31.3 | -25.2 | -27.0 | 0.0 | 0.0 | -154.6 | -25.3 | -28.2 | -63.1 | -70.2 | -253.0 | 0.79 | σ 0 |

The flange thickness changes for Segment D now allow it to pass the design check.

## Segment C

- Select the **Window> 2 Geometry** menu item, and click once to select Segment **C** in the segment treeview. The status bar should state : 'Edit GEOMETRY of Segment C'
- Increase the top flange thickness (ts) from 30 to **50**
- Increase the web thickness (twr) from 22 to **25**
- Increase the bottom flange thickness (ti) from 40 to **60**
- Select the **Window> 4 Results** menu item and view the updated results for Section **C_cracked_15** and **Fund. ULS Mmax**. The flange thickness changes for Segment C now allow it to pass the design check. (And selecting the Plastic check tab would show that it, too, has moved from Class 4 to Class 3).




| id | F1 | F2a N.F. | F2a F. | F2b N.F. | F2b F. | F2c N.F. | F2c F. | F2 tot | F3a N.F. | F3a F. | F3b N.F. | F3b F. | F3 tot | eta1 | id |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| σ 8 | **0.0** | 0.7 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | **0.0** | 1.6 | 0.0 | 3.0 | 0.0 | **0.0** | 0.00 | σ 8 |
| σ 7 | **0.0** | 12.8 | 24.9 | 15.8 | 32.4 | 0.0 | 0.0 | **57.3** | 9.3 | 33.6 | 17.6 | 63.2 | **154.1** | 0.39 | σ 7 |
| σ 6 | **0.0** | 10.5 | 21.6 | 12.8 | 28.2 | 0.0 | 0.0 | **49.8** | 6.8 | 29.2 | 12.7 | 55.0 | **134.1** | 0.34 | σ 6 |
| σ 5 | **0.0** | 0.6 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | **0.0** | 1.0 | 0.0 | 1.9 | 0.0 | **0.0** | 0.00 | σ 5 |
| σ 4 | **137.3** | 9.1 | 19.7 | 11.0 | 25.7 | 0.0 | 0.0 | **182.7** | 5.2 | 26.6 | 9.9 | 50.1 | **259.5** | 0.81 | σ 4 |
| σ 3 | **133.2** | 8.5 | 18.9 | 10.3 | 24.6 | 0.0 | 0.0 | **176.6** | 4.6 | 25.5 | 8.6 | 48.0 | **250.1** | 0.78 | σ 3 |
| σ 2 | **0.0** | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | **0.1** | 0.0 | 0.0 | 0.0 | 0.0 | **0.1** | 0.00 | σ 2 |
| σ 1 | **-83.4** | -23.0 | -24.6 | -29.6 | -31.8 | 0.0 | 0.0 | **-139.8** | -29.9 | -33.2 | -56.2 | -62.5 | **-235.5** | 0.74 | σ 1 |
| σ 0 | **-88.4** | -23.7 | -25.6 | -30.5 | -33.1 | 0.0 | 0.0 | **-147.1** | -30.7 | -34.6 | -57.7 | -65.0 | **-246.8** | 0.77 | σ 0 |

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

Total top stress = 1.75

Total bottom stress = 1.31

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

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

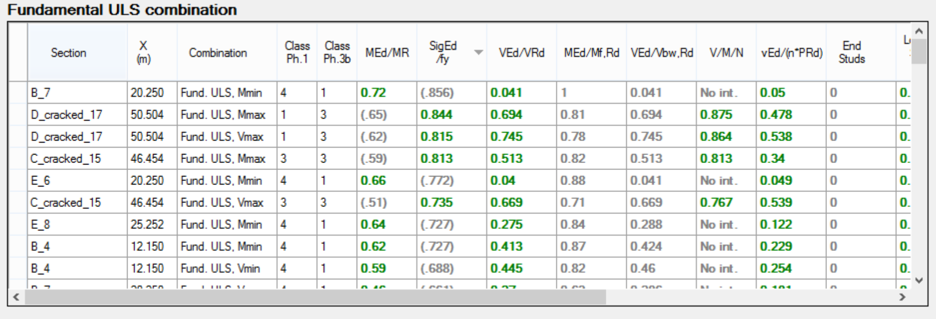
Total top stress = 6.31

Total bottom stress = 4.19

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

**=> El. check Phase 3 PASSED**
**eta1= 0.813**

- Select the **Window> 5 Summary of results** menu item. Sort the **SigEd/fy** column. It can be seen that Segments D and C now both pass the check for normal stresses at ULS, as shown below. Stresses for other combinations are all satisfactory.



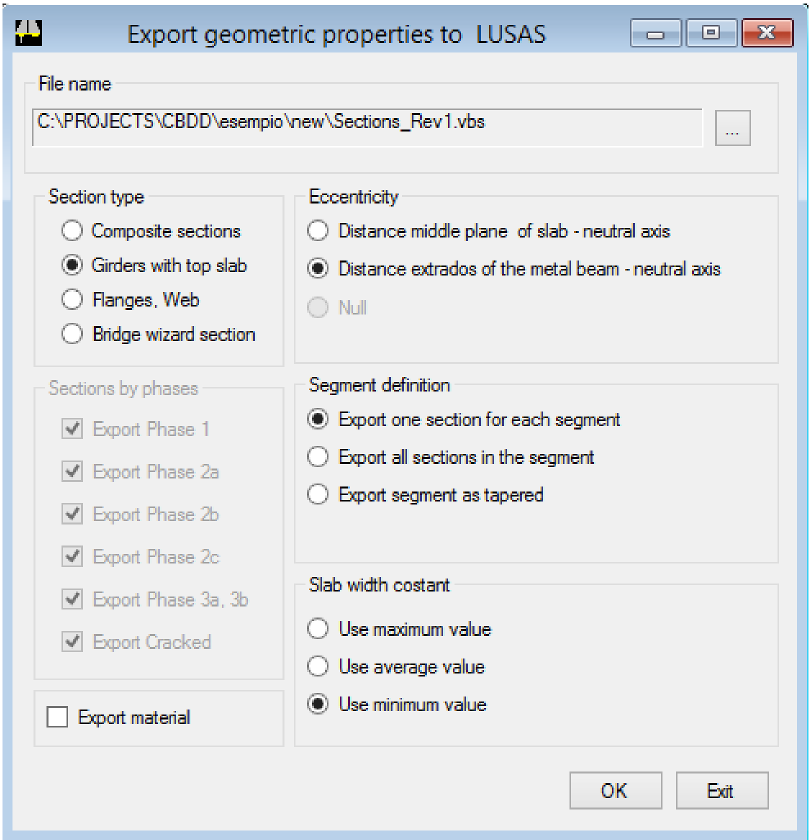
**Fundamental ULS combination**

| Section | X (m) | Combination | Class Ph.1 | Class Ph.3b | MEd/MR | SigEd /fy | VEd/VRd | MEd/Mf,Rd | VEd/Vbw,Rd | V/M/N | vEd/(n*PRd) | End Studs | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B_7 | 20.250 | Fund. ULS, Mmin | 4 | 1 | 0.72 | (.856) | 0.041 | 1 | 0.041 | No int. | 0.05 | 0 | 0. |
| D_cracked_17 | 50.504 | Fund. ULS, Mmax | 1 | 3 | (.65) | 0.844 | 0.694 | 0.81 | 0.694 | 0.875 | 0.478 | 0 | 0. |
| D_cracked_17 | 50.504 | Fund. ULS, Vmax | 1 | 3 | (.62) | 0.815 | 0.745 | 0.78 | 0.745 | 0.864 | 0.538 | 0 | 0. |
| C_cracked_15 | 46.454 | Fund. ULS, Mmax | 3 | 3 | (.59) | 0.813 | 0.513 | 0.82 | 0.513 | 0.813 | 0.34 | 0 | 0. |
| E_6 | 20.250 | Fund. ULS, Mmin | 4 | 1 | 0.66 | (.772) | 0.04 | 0.88 | 0.041 | No int. | 0.049 | 0 | 0. |
| C_cracked_15 | 46.454 | Fund. ULS, Vmax | 3 | 3 | (.51) | 0.735 | 0.669 | 0.71 | 0.669 | 0.767 | 0.539 | 0 | 0. |
| E_8 | 25.252 | Fund. ULS, Mmin | 4 | 1 | 0.64 | (.727) | 0.275 | 0.84 | 0.288 | No int. | 0.122 | 0 | 0. |
| B_4 | 12.150 | Fund. ULS, Mmin | 4 | 1 | 0.62 | (.727) | 0.413 | 0.87 | 0.424 | No int. | 0.229 | 0 | 0. |
| B_4 | 12.150 | Fund. ULS, Vmin | 4 | 1 | 0.59 | (.688) | 0.445 | 0.82 | 0.46 | No int. | 0.254 | 0 | 0. |

- Select **File> Save As** to save the current PontiEC4 project data as **Composite_Bridge_Deck_Optimized.csv**.

## Export the revised geometric data to LUSAS

- Select the **File> Export geometric properties to LUSAS** menu item.
- Ensure that the destination directory is set to <u>your</u> working project folder, and input a filename of **Sections_Rev1.vbs**.
- Then ensure that the option **Girders with top slab** is selected and that **Distance extrados of the metal beam – neutral axis**, and **Assume slab width constant and use minimum value options** are also selected. Click **OK** to finish.




## Calculate revised forces and moments in LUSAS

- In LUSAS, and with the **Composite_Bridge_Deck.mdl** file open, select **File> Script > Run Script** and from the working project folder select the PontiEC4 script file **Sections_Rev1.vbs** to import the optimized sections into the model. Click **Yes** to the LUSAS warning in order to overwrite each of the geometric properties previously used.

- Select the **File> Save As** menu item to save the model to the working project folder as **Composite_Bridge_Deck_Optimized.mdl.** Any open results files will be closed.

- Press the **Solve** button  to compute all loadcases in all the analyses. After a short wait the solving will be completed.

## Export the revised force and moment data from LUSAS

This involves repeating the operations from Step 4 in this example. In summary, this involves:

- Select the **Design > Composite Deck Design** menu item.
- Click the ellipsis button ... to choose the folder and name of the xls file to create (e.g.: <current work directory>**Export to ponti EC4 rev1.xls**), pressing the **Save** button to return to the main dialog.
- Leave all other input data as before, and click **OK** to save data for the revised XLS file for use in PontiEC4.
- Right-click the utilities item **"Export_to_PontiEC4"** and choose **"Export to Excel".**

## Import revised forces and moments into PontEC4

- In PontiEC4, with the current data still loaded, select the **File> Import forces/moments** menu item and load the file **Export to ponti EC4 rev1.xls** that was created by LUSAS from the working project folder.

## Assess the revised results in PontiEC4

- Select the **Window> 5 Summary of results** menu item.
- Sort the **SigEd/fy** column. It can be seen that values of SigEd/fy have changed slightly from the values previously calculated in PontiEC4 that used the initial forces and moments calculated by LUSAS, but values for all segments can be seen to pass the check for normal stresses at ULS.

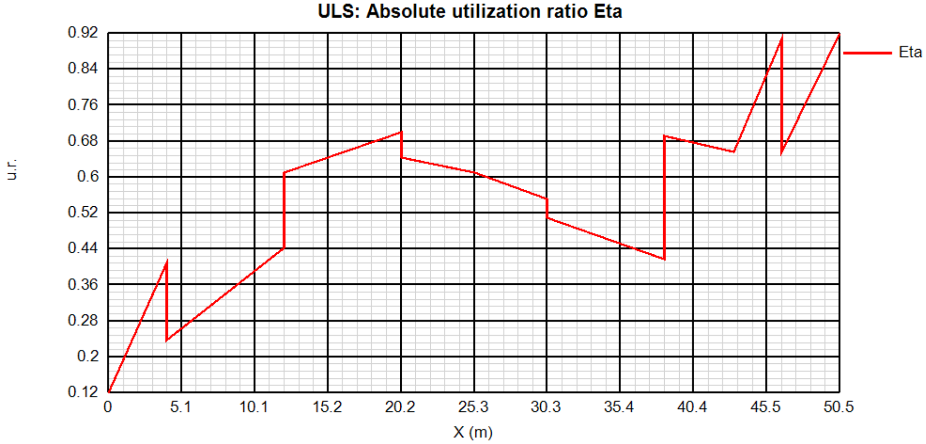
**Fundamental ULS combination**

| Section | X (m) | Combination | Class Ph.1 | Class Ph.3b | MEd/MR | SigEd /fy | VEd/VRd | MEd/Mf,Rd | VEd/Vbw,Rd | V/M/N | vEd/(n*PRd) | End Studs | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D_cracked_17 | 50.504 | Fund. ULS, Mmax | 1 | 3 | (.71) | 0.924 | 0.714 | 0.89 | 0.714 | 0.962 | 0.49 | 0 | 0. |
| C_cracked_15 | 46.454 | Fund. ULS, Mmax | 3 | 3 | (.66) | 0.911 | 0.531 | 0.92 | 0.531 | 0.912 | 0.353 | 0 | 0. |
| D_cracked_17 | 50.504 | Fund. ULS, Vmax | 1 | 3 | (.68) | 0.891 | 0.764 | 0.85 | 0.764 | 0.948 | 0.549 | 0 | 0. |
| B_7 | 20.250 | Fund. ULS, Mmin | 4 | 1 | 0.7 | (.829) | 0.025 | 0.98 | 0.025 | No int. | 0.046 | 0 | 0. |
| C_cracked_15 | 46.454 | Fund. ULS, Vmax | 3 | 3 | (.58) | 0.829 | 0.686 | 0.8 | 0.686 | 0.868 | 0.551 | 0 | 0. |
| E_6 | 20.250 | Fund. ULS, Mmin | 4 | 1 | 0.65 | (.748) | 0.024 | 0.86 | 0.025 | No int. | 0.045 | 0 | 0. |
| B_4 | 12.150 | Fund. ULS, Mmin | 4 | 1 | 0.61 | (.713) | 0.398 | 0.85 | 0.409 | No int. | 0.225 | 0 | 0. |
| E_8 | 25.252 | Fund. ULS, Mmin | 4 | 1 | 0.61 | (.695) | 0.288 | 0.81 | 0.304 | No int. | 0.126 | 0 | 0. |
| B_11 | 38.354 | Fund. ULS, Mmax | 4 | 4 | (.38) | 0.695 | 0.554 | 0.72 | 0.581 | No int. | 0.176 | 0 | 0. |

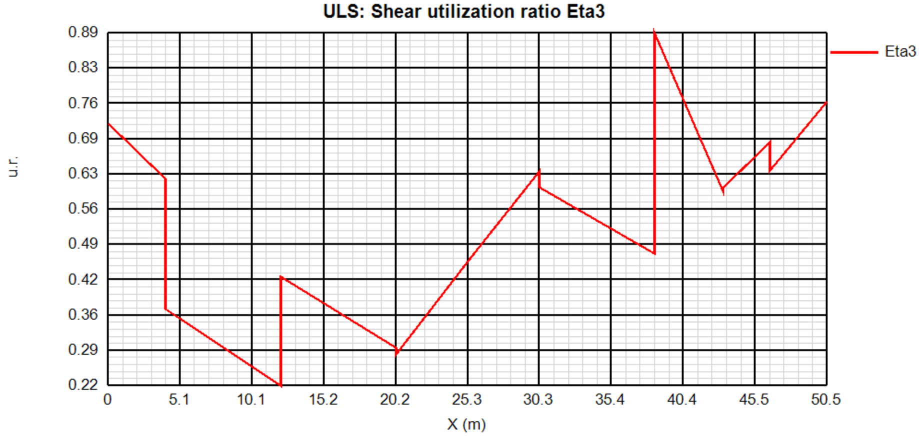
Methods for graphing data and producing detailed results will now be explained.

## Creating Graphs

- In PontiEC4, with the optimized data still loaded, select the **Utilities> Graphs** menu item. (If the optimized data is no longer loaded open the file Composite_Bridge_Deck_Optimized.csv to populate the dialogs)
- From the first drop-down list choose **ULS: Absolute utilization ratio Eta** to plot the following graph:



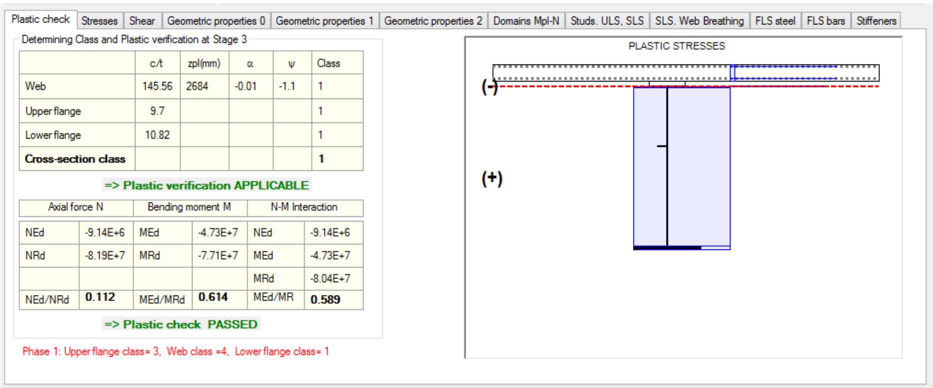

- From the first drop-down list choose **ULS: Shear utilization ratio Eta3** to plot the following graph:




**Note.** Graphs can also be viewed by scrolling the mouse wheel up and down in the graph window.

## Obtaining more detailed results

- With the optimized data stil loaded, select the **Window> 4 Results** menu item.
- In the Cross-sections and design combinations panel, select the center section **E_8** and **Fund. ULS, Mmin**.
- Select the **Stresses** tab to have a look at the elastic stresses on the gross section.
- Then, select the **Plastic check** tab. From this, all details about the classification and plastic check are supplied, and it can be seen that for Stage 3, this section, that is part of the segment in the middle of the span, is in Class 1.

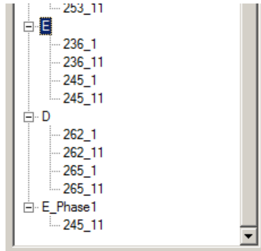



**Note.** At the bottom-left of the Plastic check page the section classification is also provided for Phase 1, where the top (upper) flange cannot be considered to be restrained by the slab. For this case, the section is in Class 4 as highlighted in the red message. For this situation a check of stresses in Phase 1 should be performed, using an effective section rather than a gross section.

## To check stresses on the effective section in Phase1

- Select the **Window> 2 Geometry** menu item.
- On the Geometry dialog, double-click on Segment **E** in the segment treeview to change from Edit mode to Input mode. The status bar should state: "Input GEOMETRY"
- In the Segment name field in the top-left of the dialog page (and not in the segment treeview panel) change the segment name from **E** to **E_Phase1**, then click outside of the text box to be sure that the new name is saved.
- Right-click inside the Sections text box and select **Data grid input**

- Select all rows except for the one with 8 in it (use the Ctrl key for a multiple selection of rows), open the context menu with the right-hand click of the mouse, and select **Remove rows** to leave just **8** remaining. Click **OK.**
- In the Structural steel panel **uncheck** the option **Top Flange in Class 1**
- In the Slab concrete panel input **0** in each of the **bcls**, **b1** and **bsx** text boxes
- Click the **Add to list** button beneath the Segment treeview to add the new segment to the list of other segments in the segment treeview, as shown right.

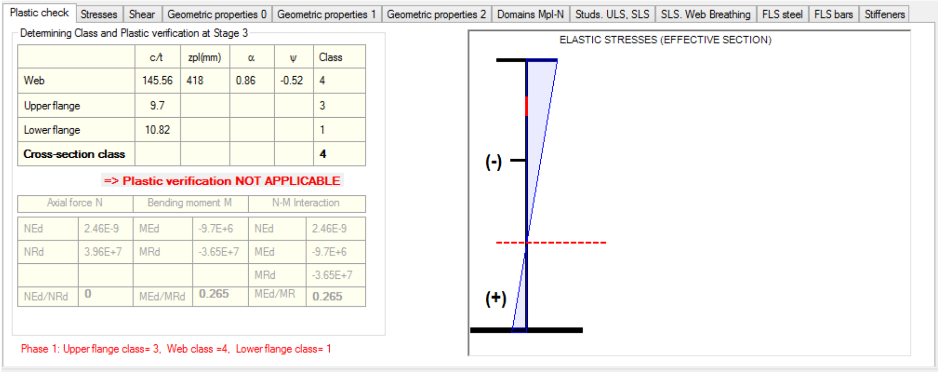



- Select the **Window> 3 Forces and moments** menu item, and on the Results dialog, select **ULS fund., Mmin** in the dropdown list seen in the Cross-sections and design combinations panel in the top-left corner.
- Copy the four cells of forces and moment data for Phase 1 from section **E_8**, (click **No** to not copy the header text) and paste the copied data into the equivalent cells for section **E_Phase1_8**, as shown on the following images.

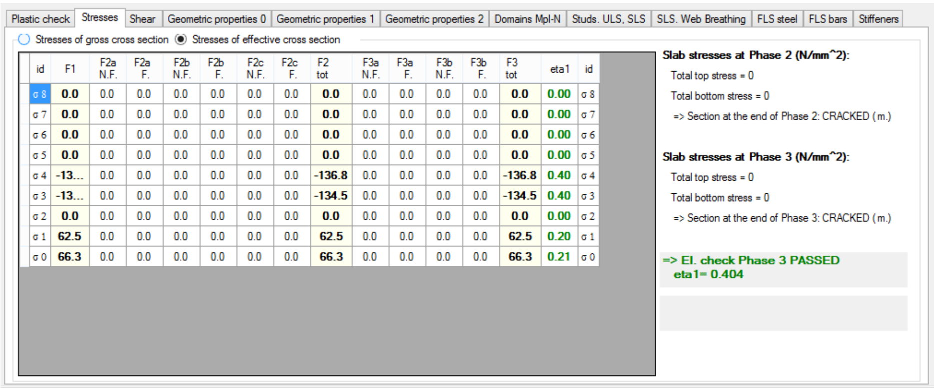
**PHASE 1. Selfweights**

| Section | N (N) | V (N) | M (Nm) | T (Nm) |
|---|---|---|---|---|
| E_8 | 2.457E-009 | 5.309E+005 | -9.697E+006 | -2.796E-001 |
| E_10 | 2.056E-009 | 8.941E+005 | -6.139E+006 | -2.707E-001 |
| D_cracked_16 | 0.000E+000 | 1.535E+006 | 1.318E+007 | -2.064E+000 |
| D_cracked_17 | 0.000E+000 | 1.784E+006 | 1.990E+007 | -1.548E+000 |
| E_Phase1_8 | 2.457E-009 | 5.309E+005 | -9.697E+006 | -2.796E-001 |

- Select the **Window> 4 Results** menu item
- Select Section **E_Phase1_8** and **Fund. ULS, Mmin** from the Cross-sections and design combinations panel.
- Select the **Plastic check** tab to see a coherent classification with an only steel structural section




- Lastly, select the **Stresse**s tab to see the stresses calculated on an effective cross section




This completes the example.