Composite steel curved triple U-girder bridge

CONTENTS

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1. System 001 : Input receipt

2. System 001 : Results reactions

3. System 001 : Results longitudinal beams

4. System 001 : Results bracings

5. System 001 : Results deck

6. Results steel composite design (vacant)

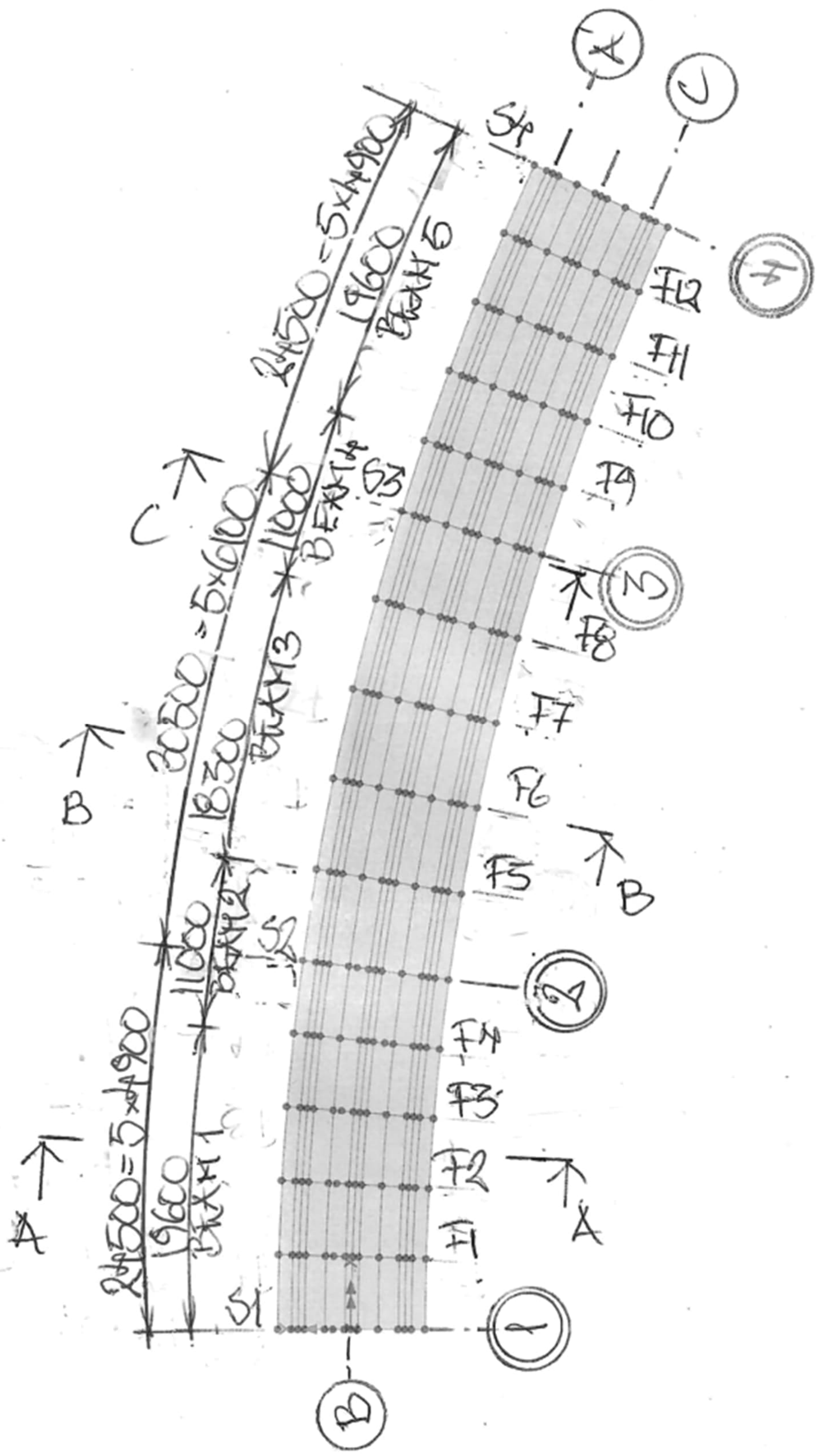
1. GENERAL / MEASUREMENT

1.1 CONSTRUCTION TYPE

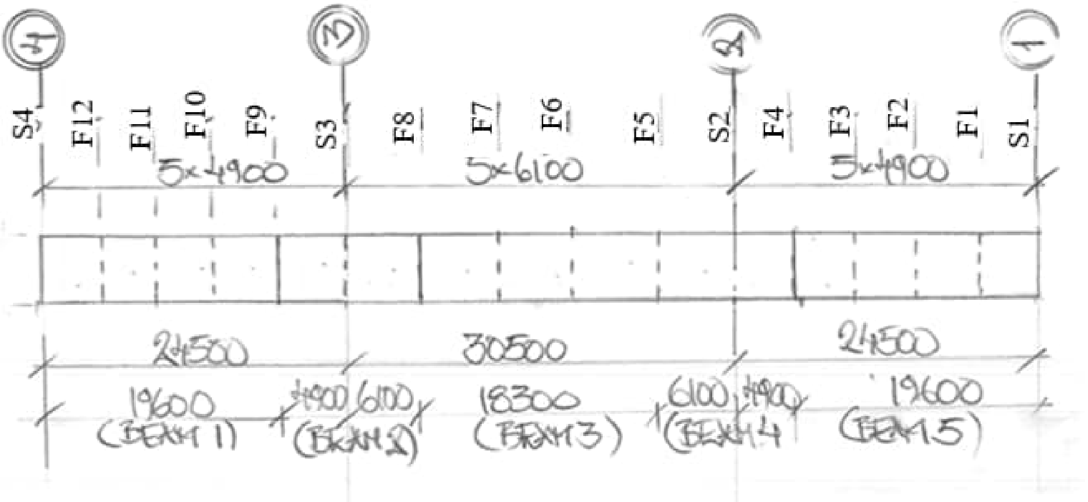
Composite steel girders.

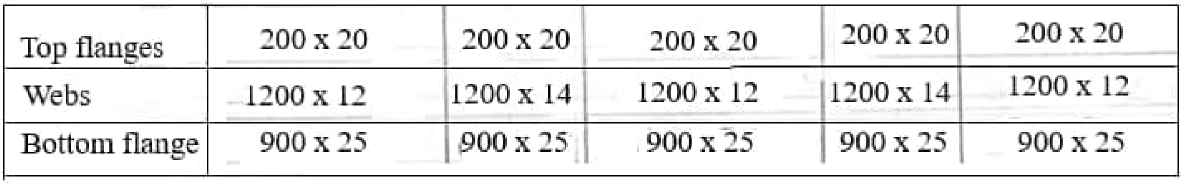
Superstructure is modelled using girders modeled as shells (web) and flanges (beam) with deck as shells.

1.2 MEASURMENT



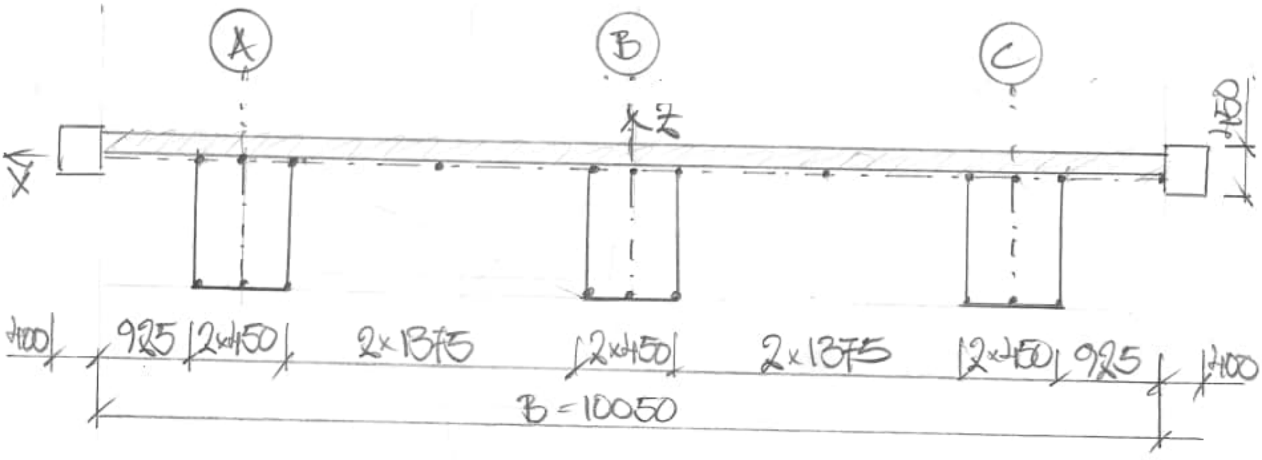
PLAN



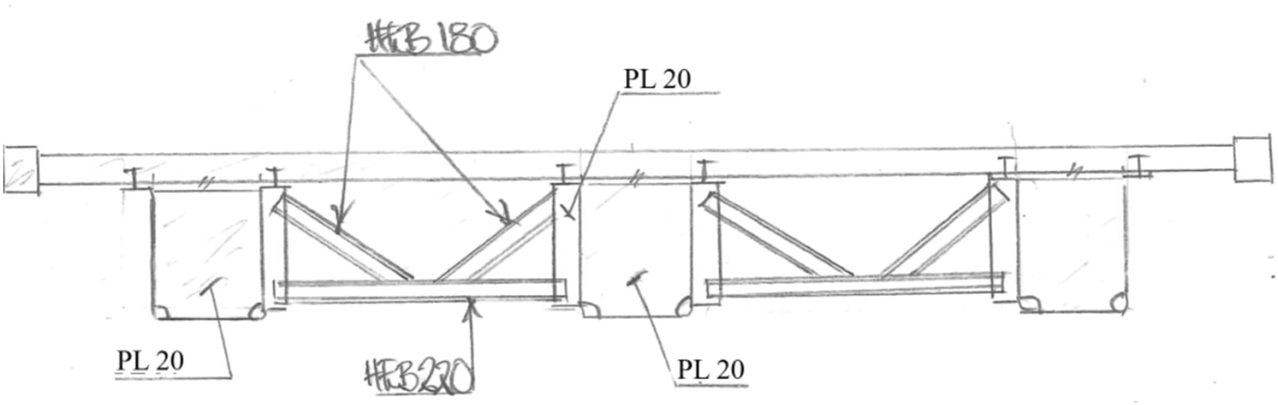


Top flanges	200 x 20	200 x 20	200 x 20	200 x 20	200 x 20
Webs	1200 x 12	1200 x 14	1200 x 12	1200 x 14	1200 x 12
Bottom flange	900 x 25	900 x 25	900 x 25	900 x 25	900 x 25

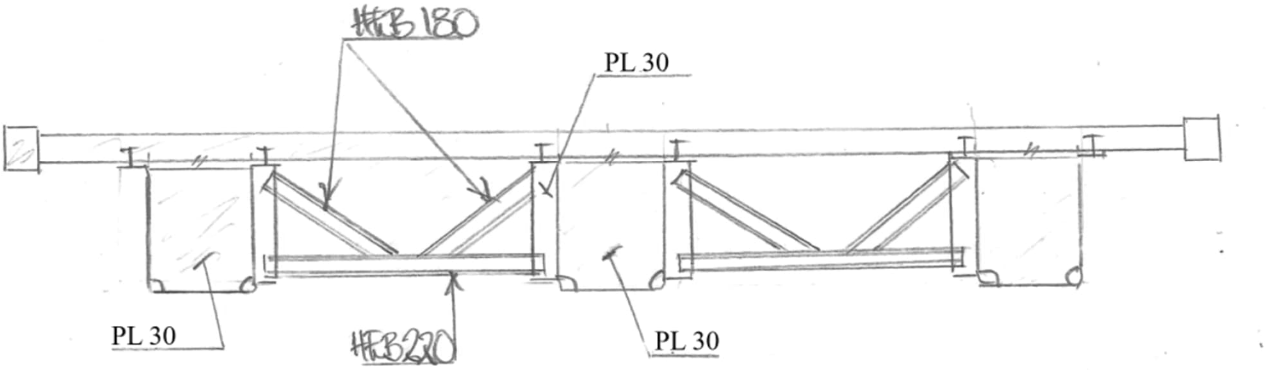
ELEVATION GIRDERS
BEAM 1-5



SECTION A-A
Concrete deck



SECTION B-B
Bracing F (F1-F12)



SECTION C-C
Bracing S (S1-S3)

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1.4 CODE DOCUMENTS

Documents	Version	Name
SS-EN 1990-1997	-	Svensk Standard Eurokod 1-7
TRVINFRA-00226	2.0	KRAV, Bro och broliknande konstruktion, Allmänna krav
TRVINFRA-00227	2.0	KRAV, Bro och broliknande konstruktion, Byggande
TRVINFRA-00228	2.0	KRAV, Bro och broliknande konstruktion, Brounderhåll
TRVINFRA-00331	2.0	KRAV, Bro och broliknande konstruktion, Bärighetsberäkning
TSFS 2018:57		Transportstyrelsens föreskrifter och allmänna råd om tillämpning av eurokoder

1.5 TECHNICAL SERVICE LIFE

Technical life span 120 years (L100).

1.6 MATERIAL

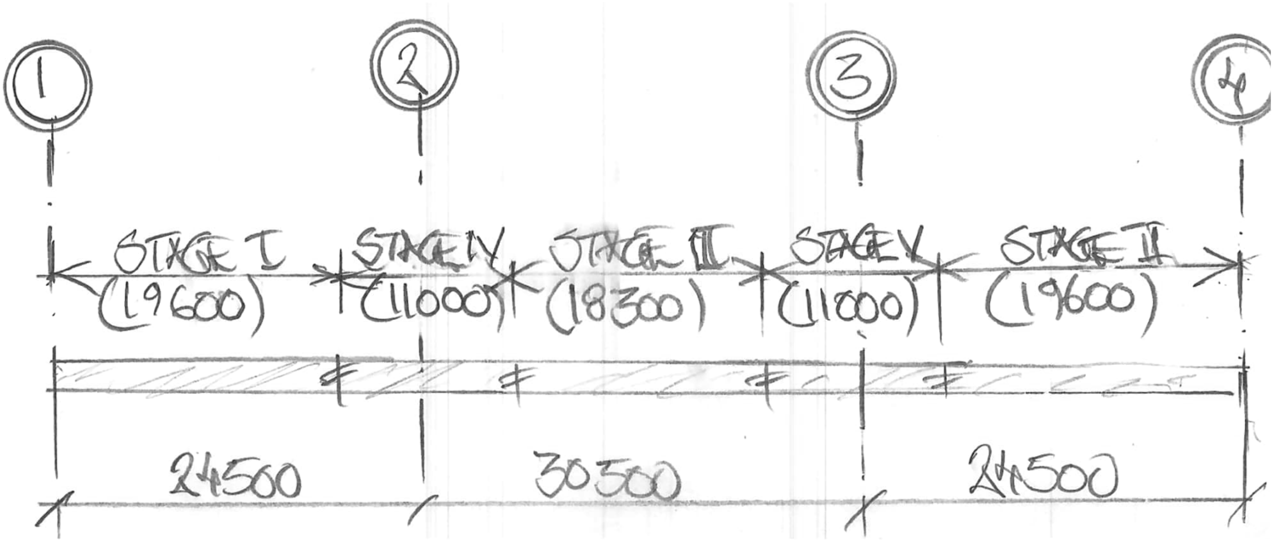
Concrete :	C35/45 (CEM I 42.5 ”Anläggningscement klass N”)
Reinforcement :	B500B
Steel :	S355 or S460 (SS-EN 1993-1-1 tabell 3.1)
Surfacing :	Type “2aIA” with thickness 110 mm.

1.7 SAFETY CLASS

Geotechnical resistance:	SK 2
Bridge structure :	SK 3

1.8 CASTING STAGE

Concrete deck is cast in 5 casting stages seen below.



2. SYSTEM ANALYSIS

2.1 GENERAL

The bridge is a curved steel composite bridge. The bridge has threes spans with a total of 3 U-girders.

Full interaction between steel U-girders and concrete deck is assumed.

No interaction between concrete inside U-girders is assumed. This concrete is not considered to contribute any stiffness, however, only as a load.

No interaction between concrete edge beams and deck is assumed. This concrete is not considered to contribute any stiffness, however, only as a load.

A local coordinate system orientated radial to centre line (R = 183 m).

Static model offers the possibility of staged expansion in the same static calculation. A total of 8 different static systems are used. These are designated Stage I, II, III, IV, V, O:P, O:V and O:TEMP.

The geometric model is the same for these, however, they may have different boundary conditions, material properties, cross-sectional constants and loads. In addition, individual structural parts can also be activated/deactivated.

When determining load effects, the influence of the cracking of the roadway is considered by ignoring the stiffness of the tensile concrete. Only the effect of reinforcement is considered.

Cracking is considered to occur when $\sigma_{SLS\text{-}K} > 2f_{ctm}$ according to SS-EN 1994 sections 5.4.2.3 and 1.5.2.12.

Bridge deck is defined by using shell elements applied to horizontal nodal surface in superstructure.

Web of girders are defined by shell element vertical nodal surfaces in superstructure.

Top flanges of girder are defined using beam elements applied to nodal line in superstructure.

Bottom flanges are defined by shell element vertical nodal surfaces in superstructure

Stiffeners and bracings are defined using beam elements applied to nodal line in superstructure.

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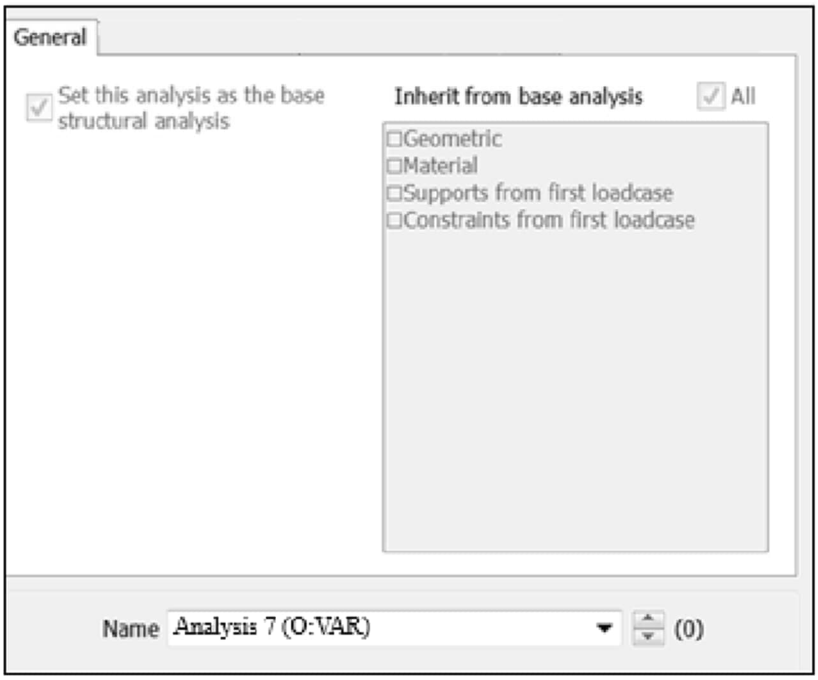
There is a total of 8 analysis.

Analysis 7 is introduced as the “Base Analysis”. It is based on this static system that changes to statics are carried out. It is also this system that is used for traffic load evaluation/VLO.



☑ Set this analysis as the base structural analysis

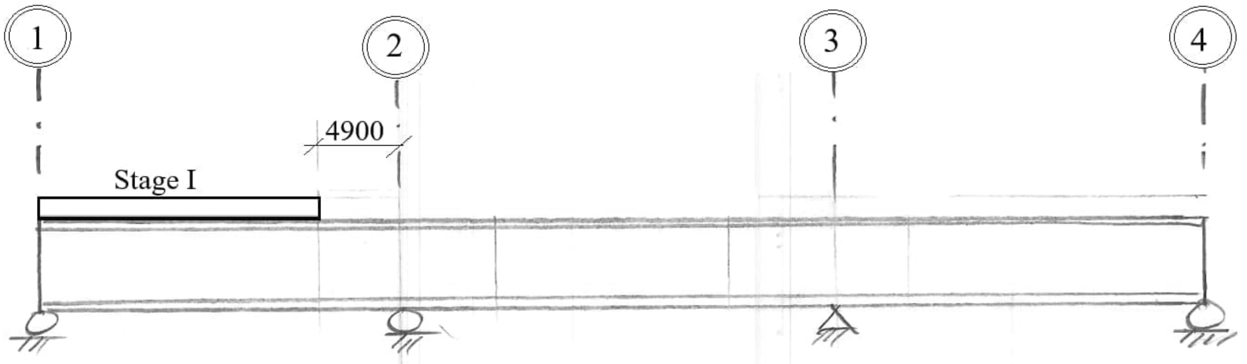
Inherit from base analysis ☑ All

☐Geometric
☐Material
☐Supports from first loadcase
☐Constraints from first loadcase

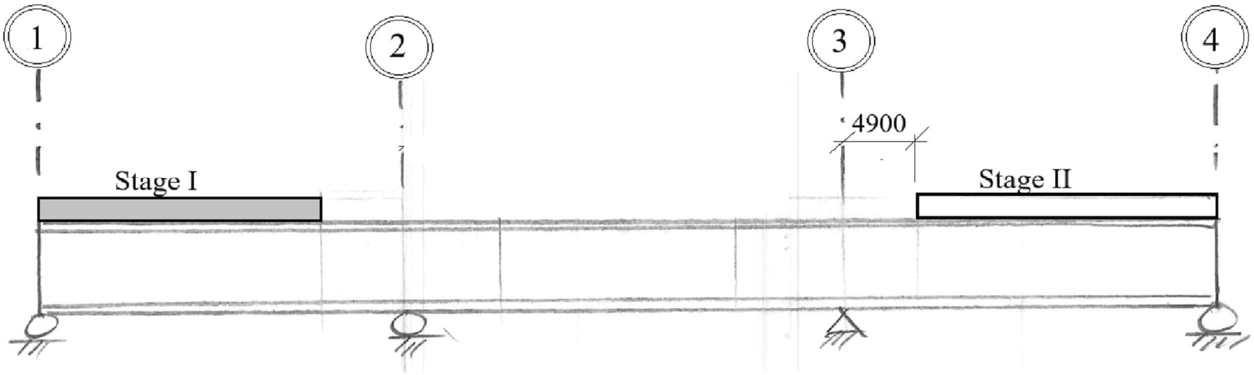
Name Analysis 7 (O:VAR) (0)

Anlaysisp performed within static model SYSTEM 001
(* = Base analysis)

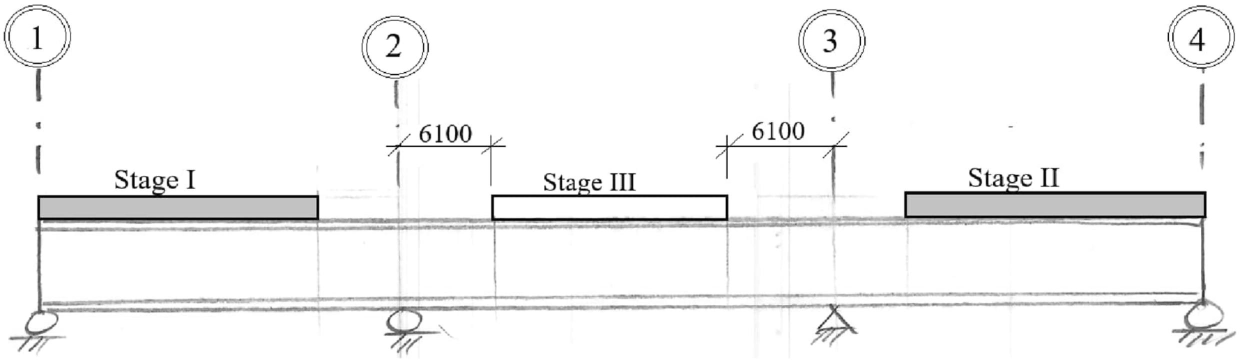
Analysis Nr.	Names	Stage	Casting stage
1	C1	Construction	I
2	C2	Construction	II
3	C3	Construction	III
4	C4	Construction	IV
5	C5	Construction	V
6	O:PERM	Operational	-
7*	O:VAR	Operational	-
8	O:TEMP	Operational	-



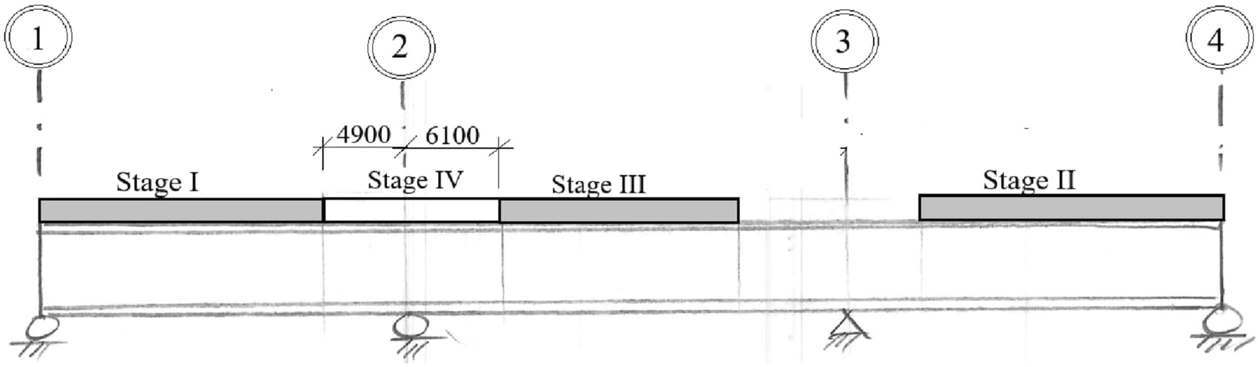
Analysis 1 (C1): Stage I
Construction stage: Wet concrete stage I



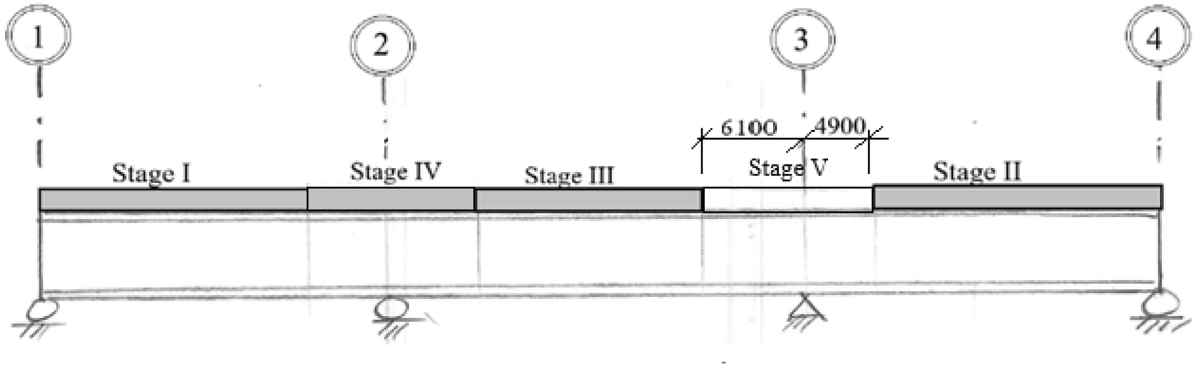
Analysis 2 (C2): Stage II
Construction stage: Wet concrete stage II



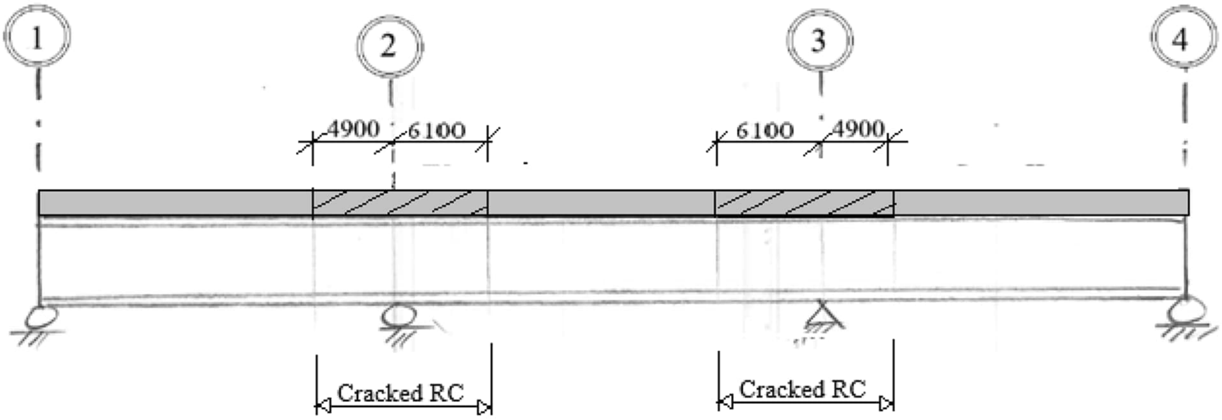
Analysis 3 (C3): Stage III
Construction stage: Wet concrete stage III



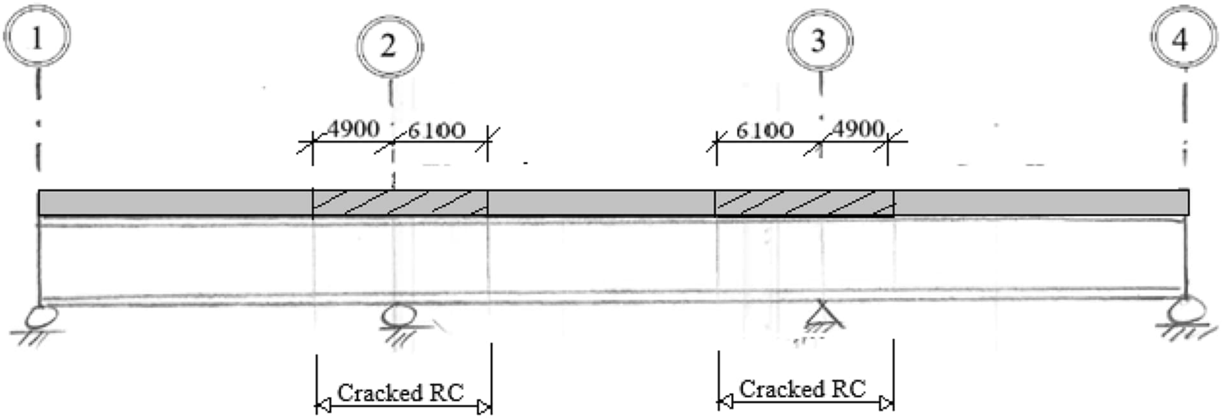
Analysis 4 (C4): Stage IV
Construction stage: Wet concrete stage IV



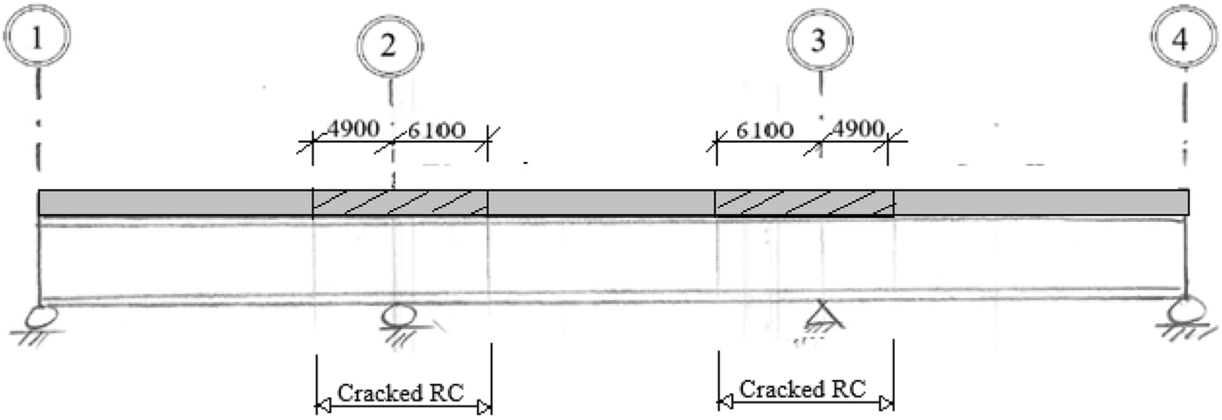
Analysis 5 (C5): Stage V
Construction stage: Wet concrete stage V



Analysis 6 (O:PERM)
Operation bridge: Cracking locally around support 2 & 3



Analysis 7 (O:VAR)
Operation bridge: Cracking locally around support 2 & 3



Analysis 8 (O:TEMP)
Operation bridge: Cracking locally around support 2 & 3

Summary appendices

Appendix	Name
1	Input receipt
2	Results reactions
3	Results longitudinal beams
4	Results bridge deck

2.2 SKETCH SYSTEM ANALYSIS

To describe geometry first POINTS are defined.

Beam elements are defined by applying attributes to LINES.

Shell elements are defined by applying attributes to SURFACES.

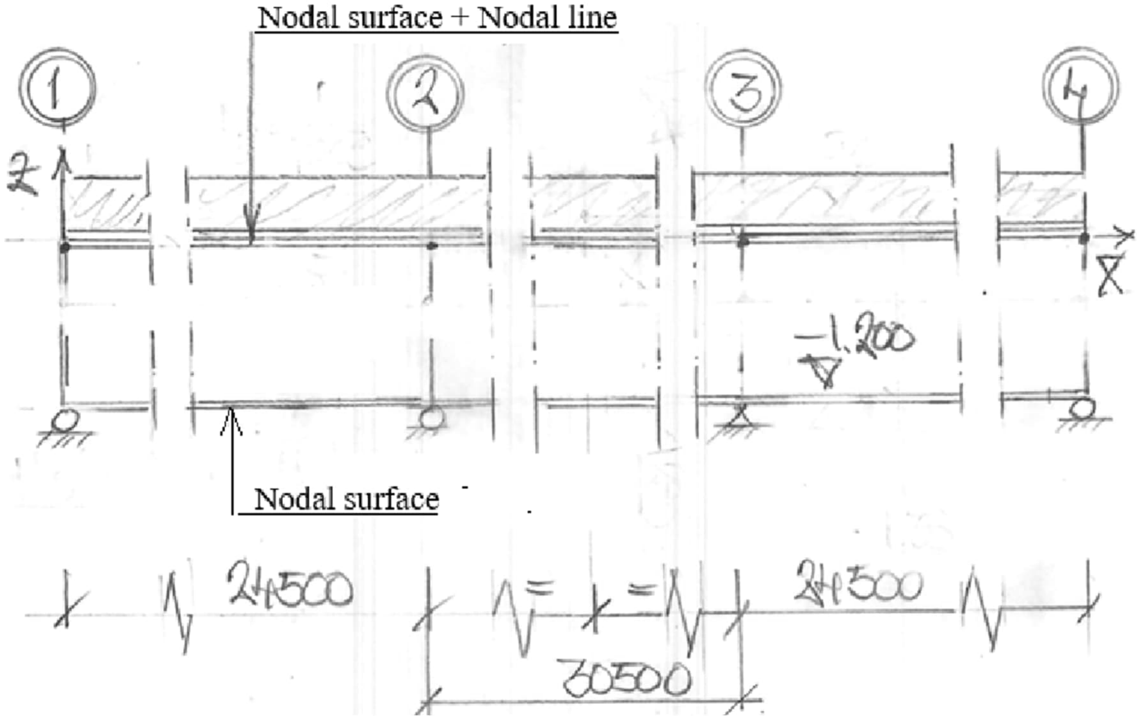
Attached pictures are retrieved from graphical sketches generated by STACTIC MODELL of POINTS, LINES and SURFACES.

All coordinates needed to describe POINTS are found in appendix 1.

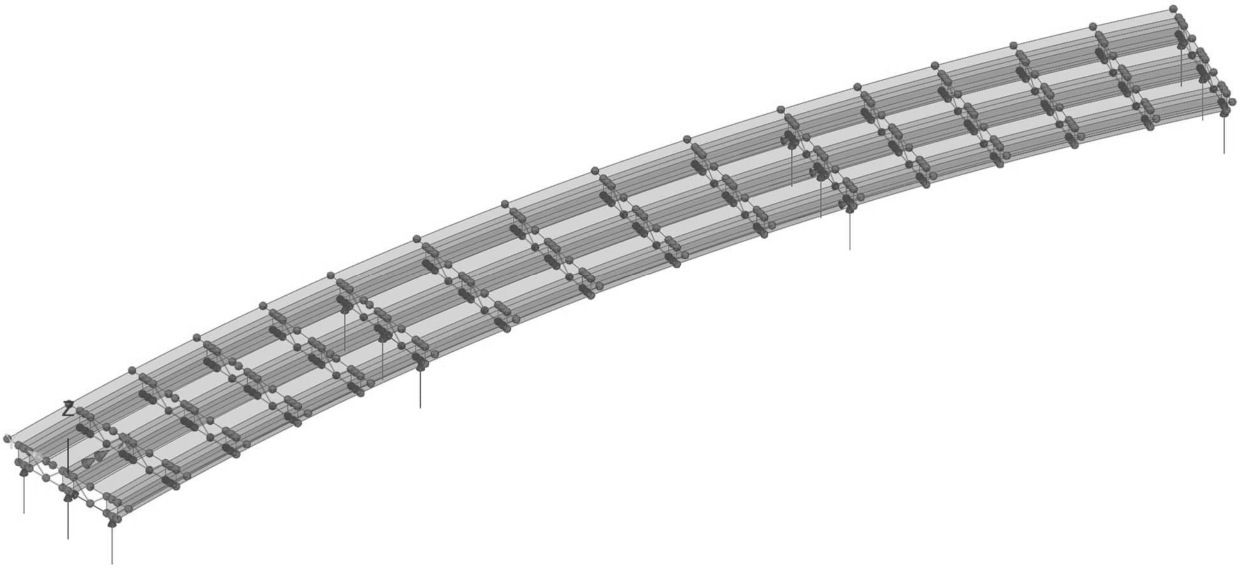
All POINTS needed to describe LINES are found in appendix 1.

All LINES need to describe SURFACE are found in appendix 1.

Superstructure is modelled using Nodal Line and Nodal Surfaces as seen in sketch below

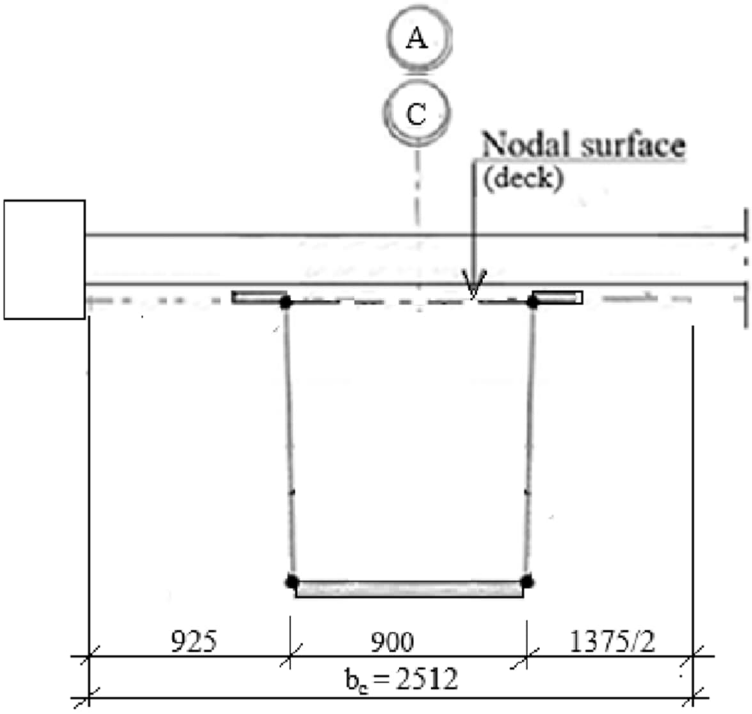


ELEVATION
Principal sketch girders.

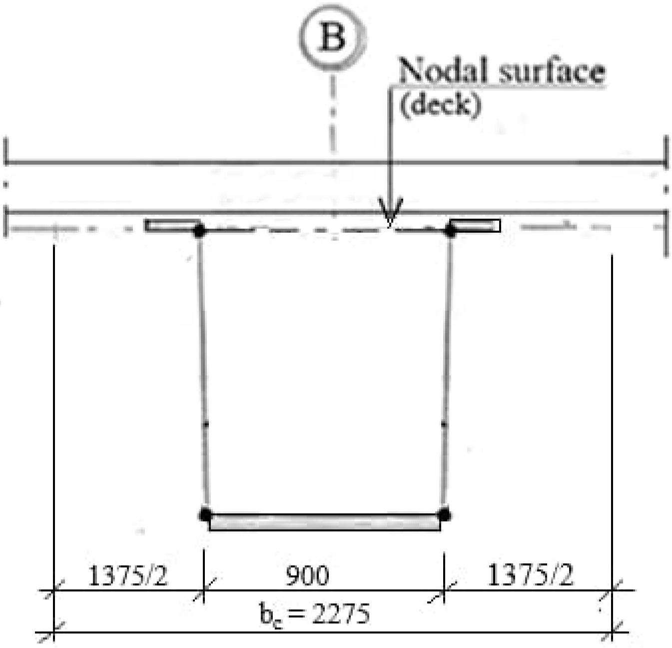


3D sketch
Overview

External beams:

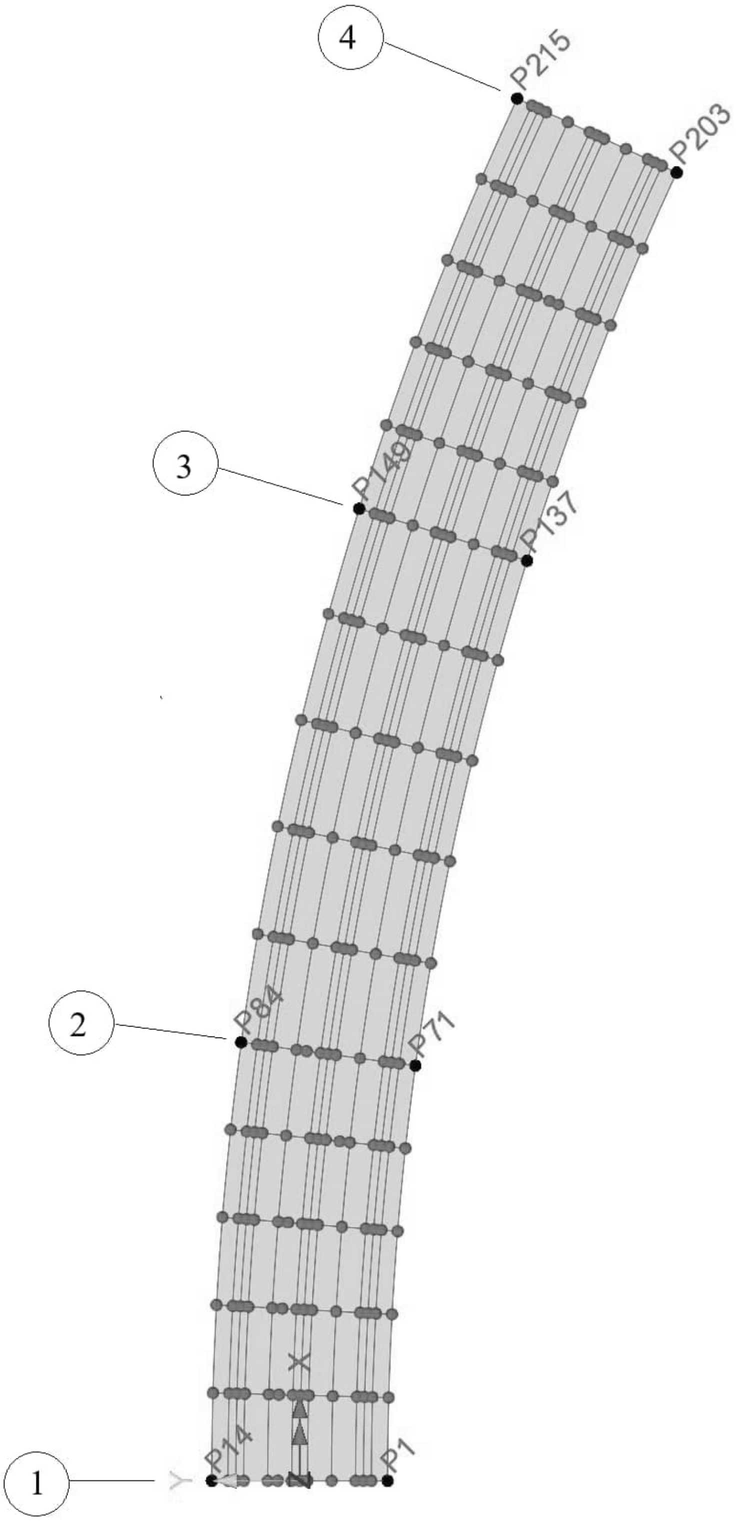


Internal beam:

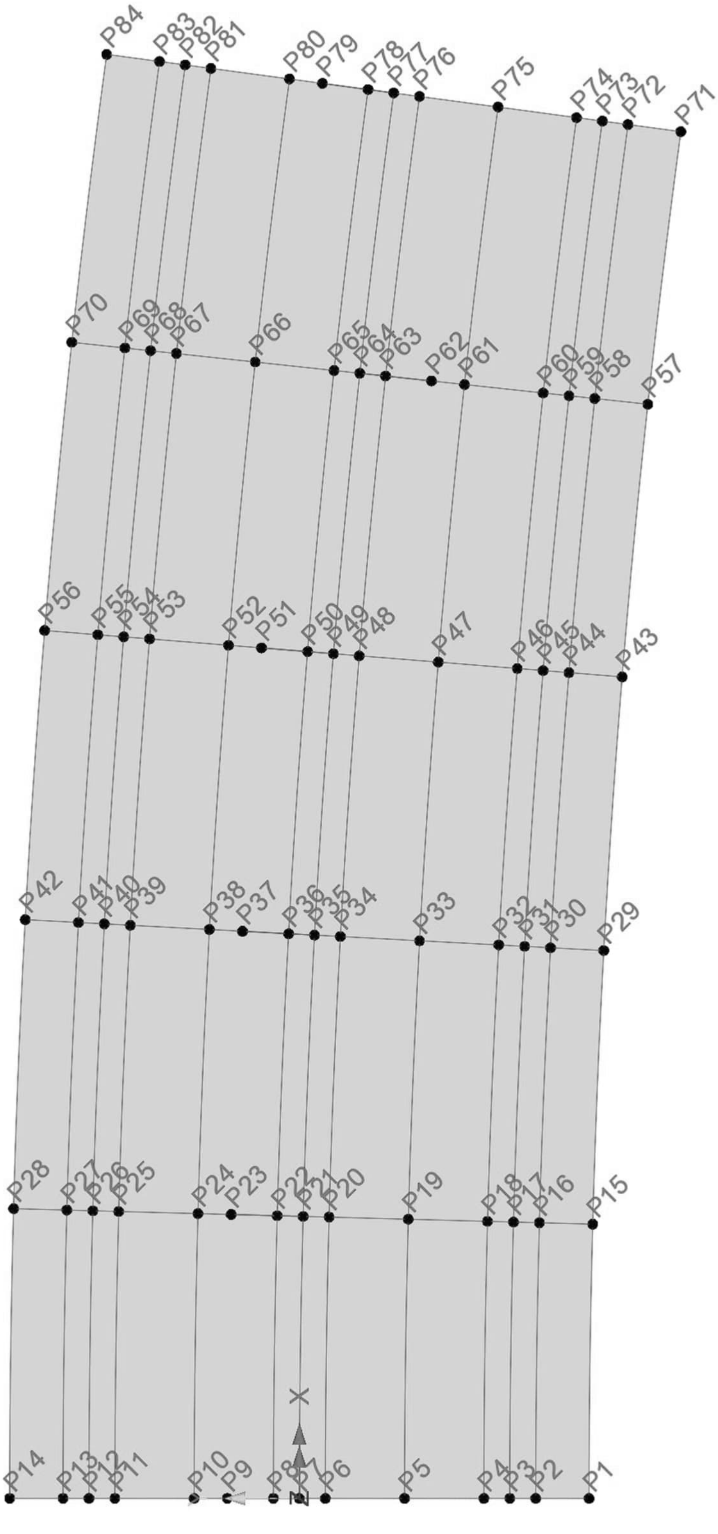


2.2.1 Geometry : POINTS

2.2.1.1 Deck



2D Overview



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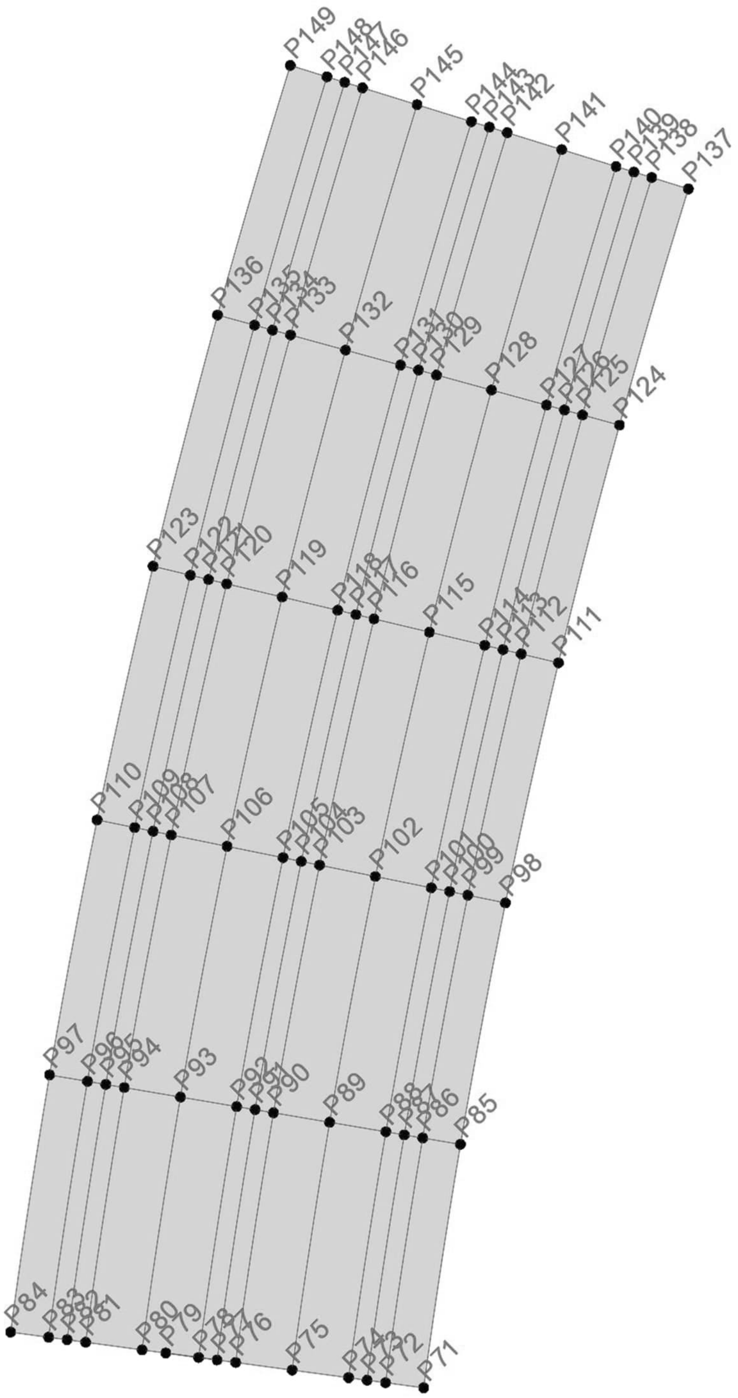
<u>Span 1</u>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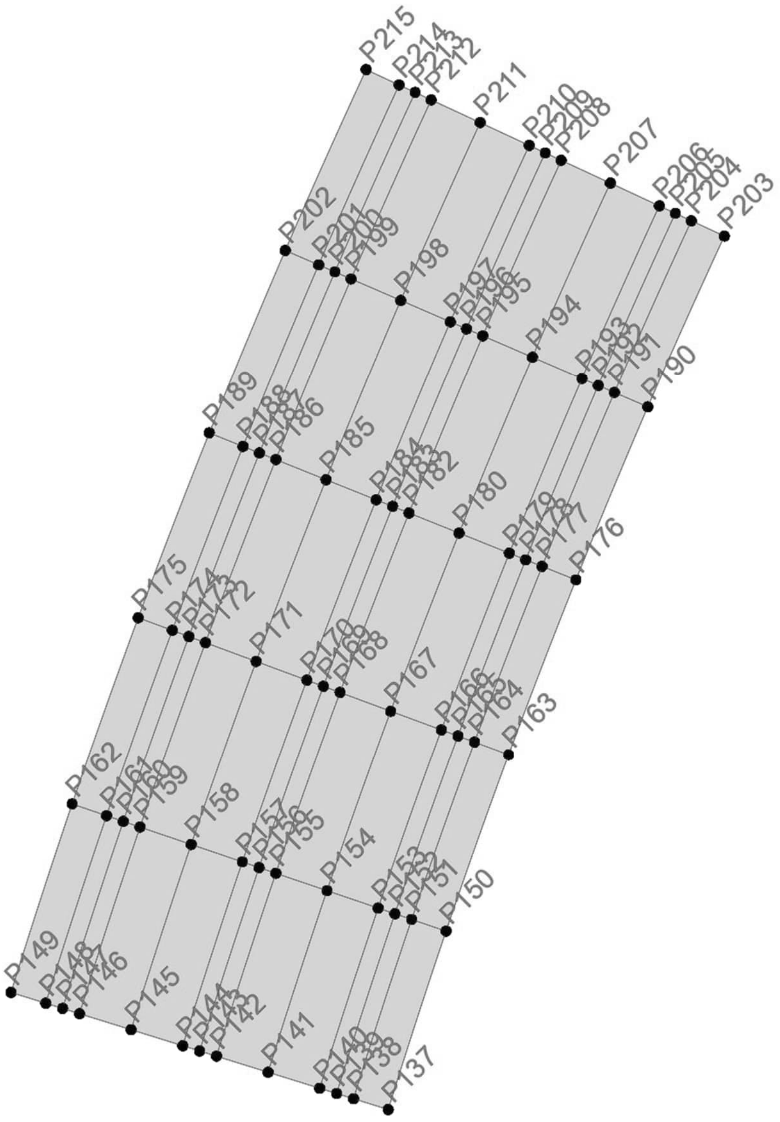
Span 2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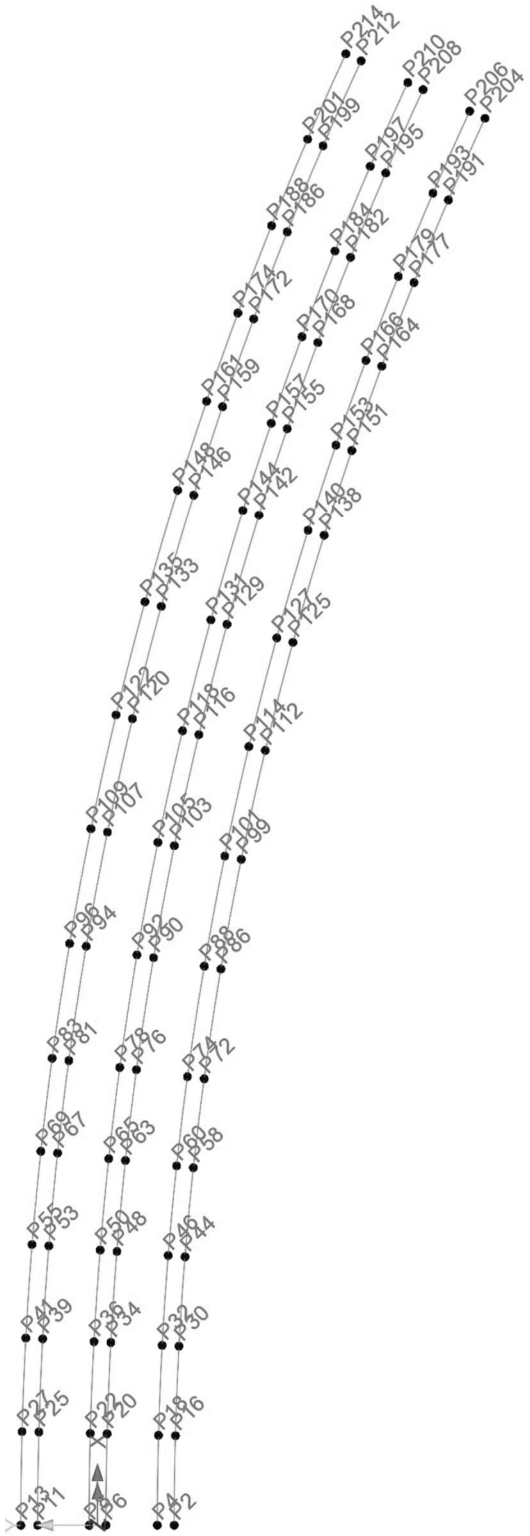
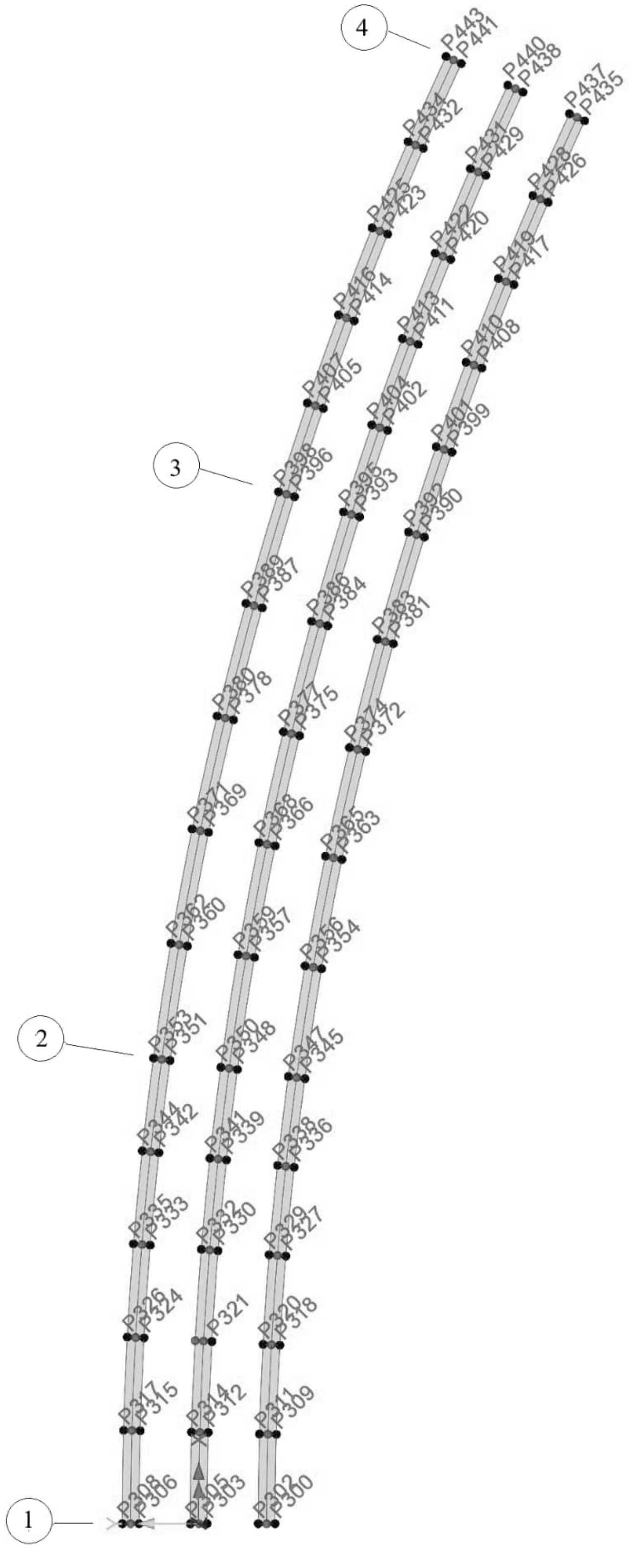
Span 3

2.2.1.2 Girder: top flange



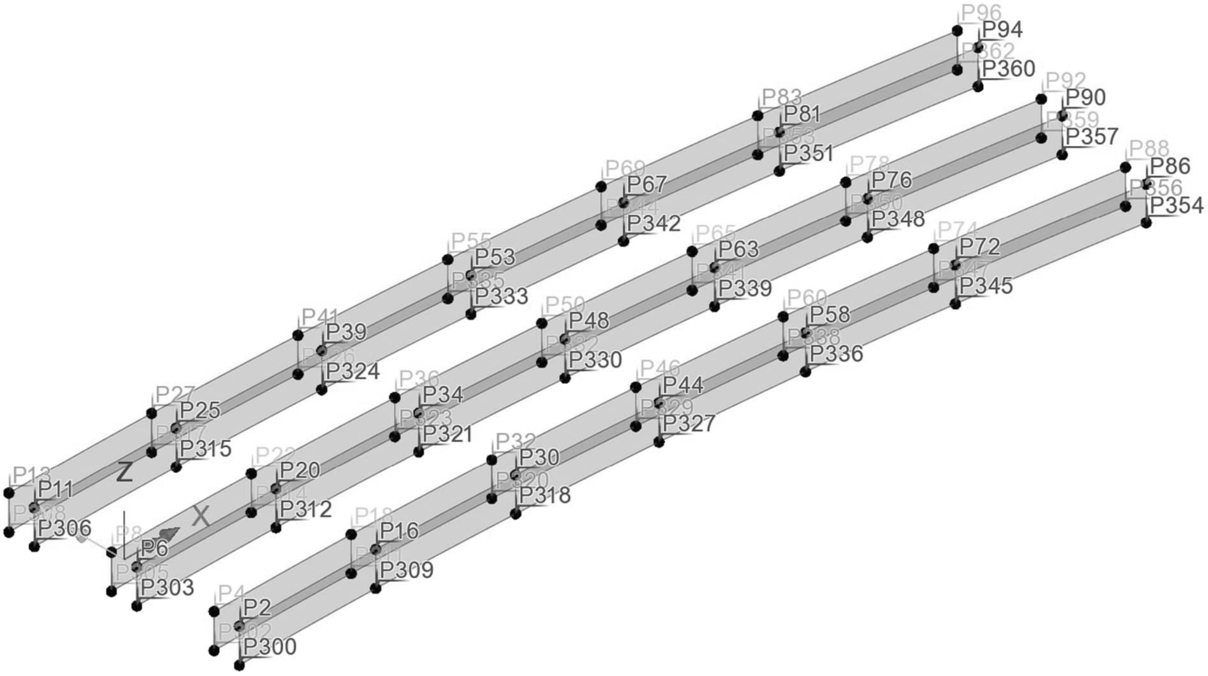
2D Overview

2.2.1.3 Girder: bottom flange



2D Overview

2.2.1.4 Web



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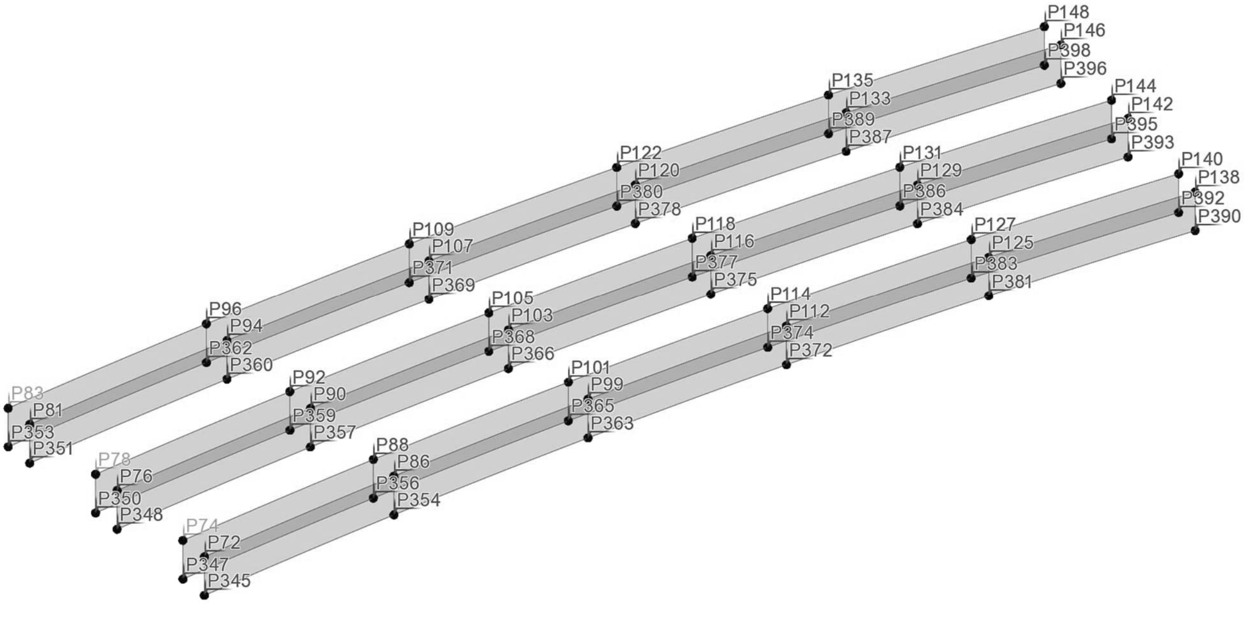

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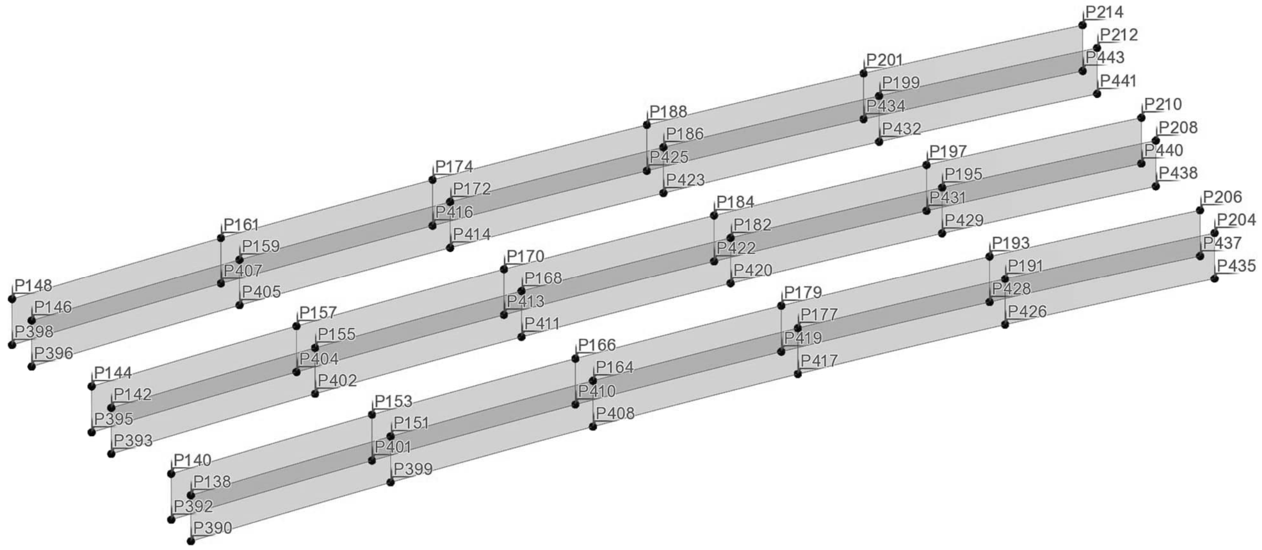
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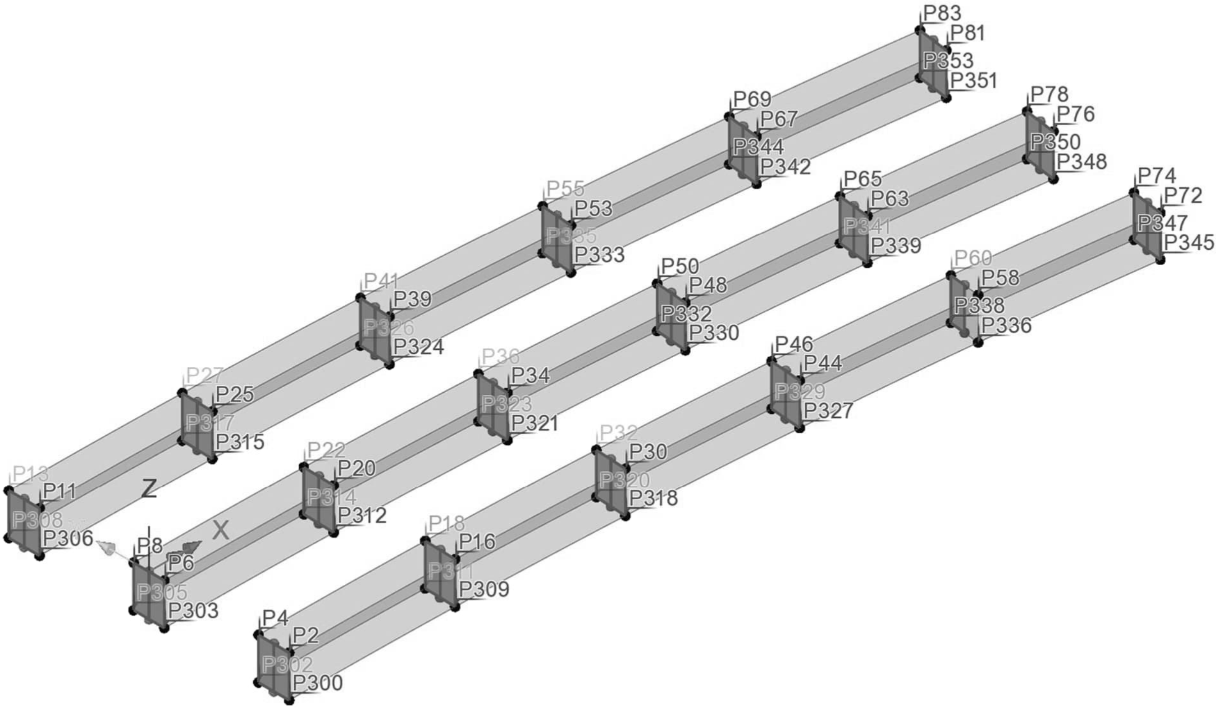
Span 3

2.2.1.5 Inner stiffners: S & F



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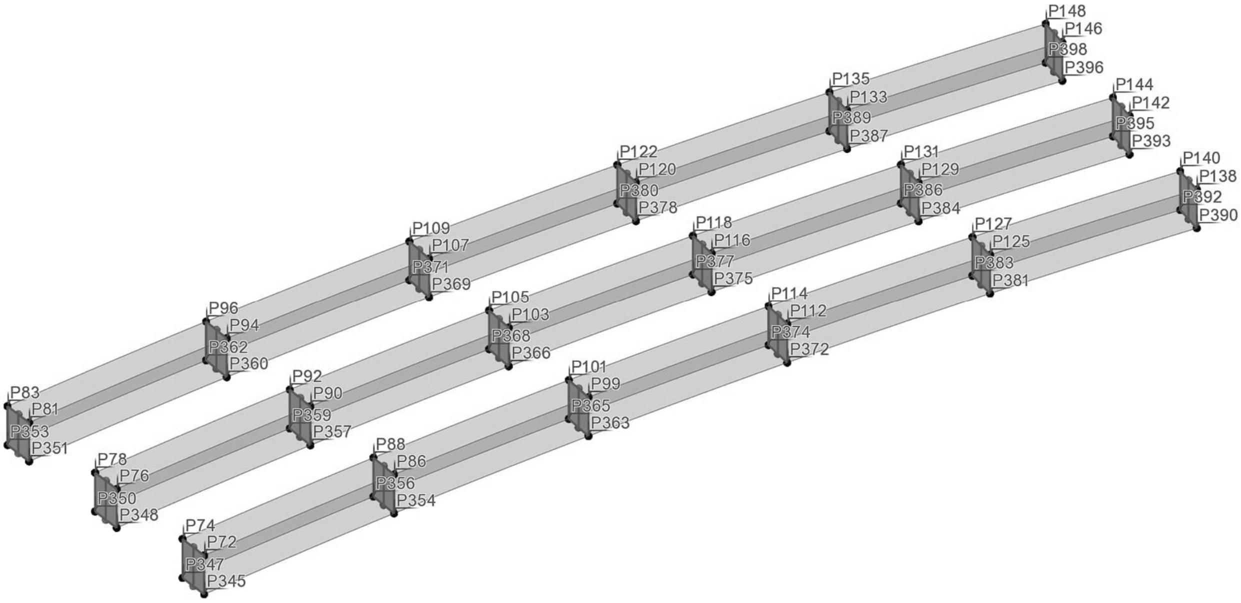

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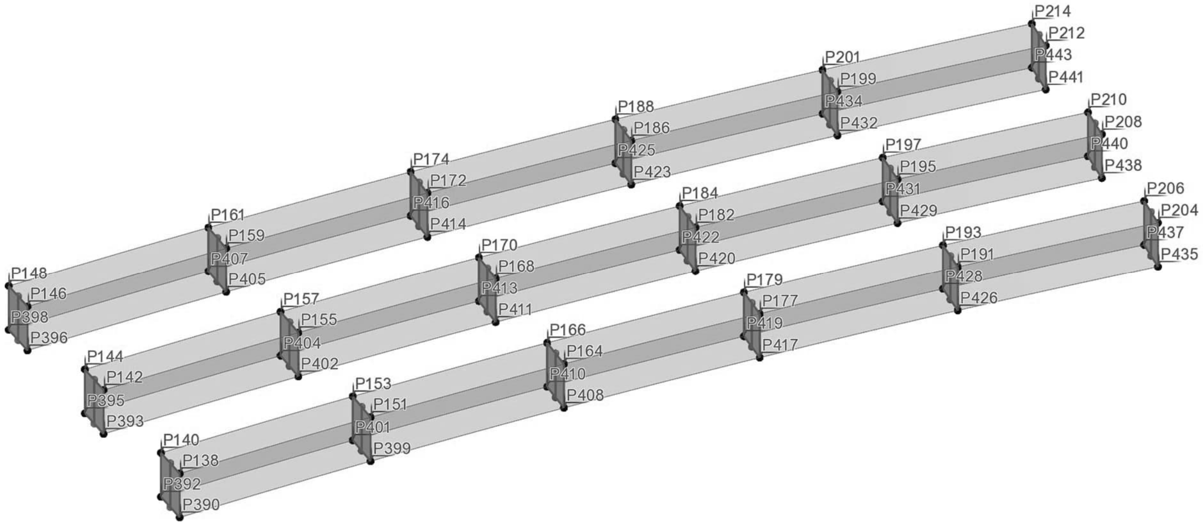
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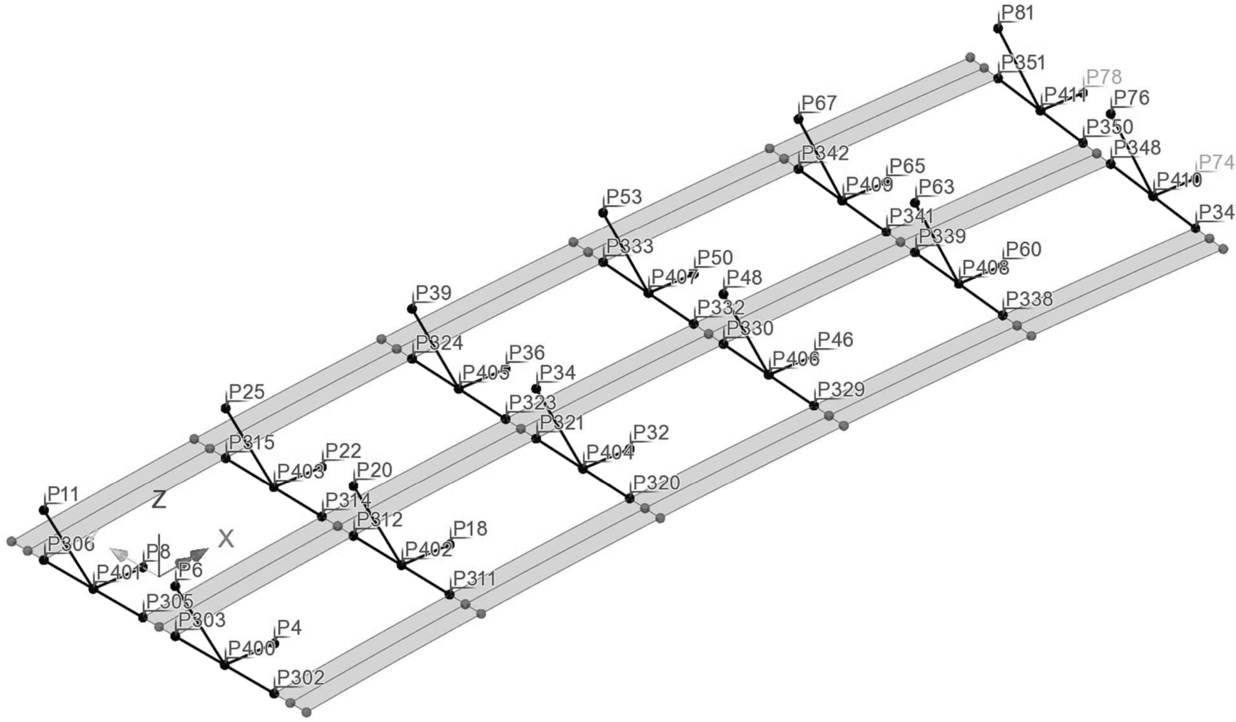
<u>Span 3</u>

2.2.1.6 Bracings



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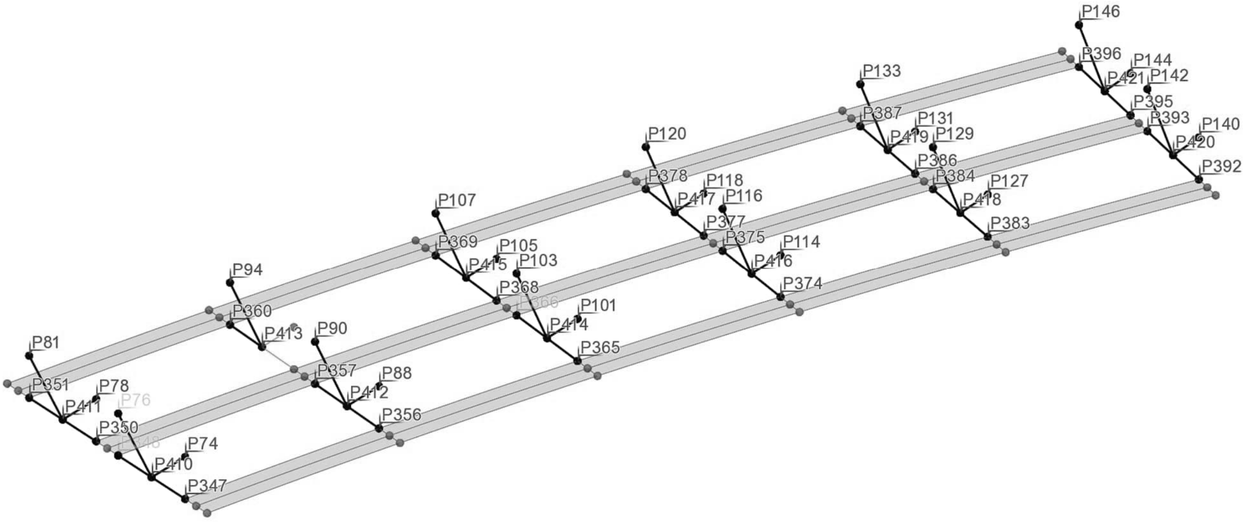

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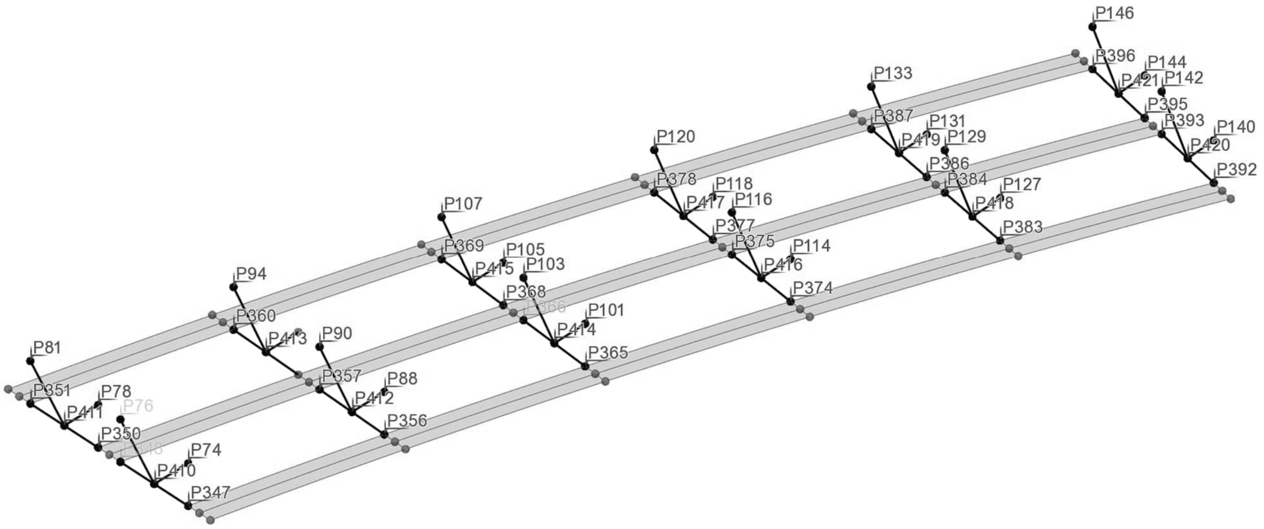
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Span 3

2.2.2 Geometry: LINES

LINES are defined by POINTS, see appendix 1.

2.2.3 Geometry : SURFACES

SURFACES are defined by LINES, see appendix 1.

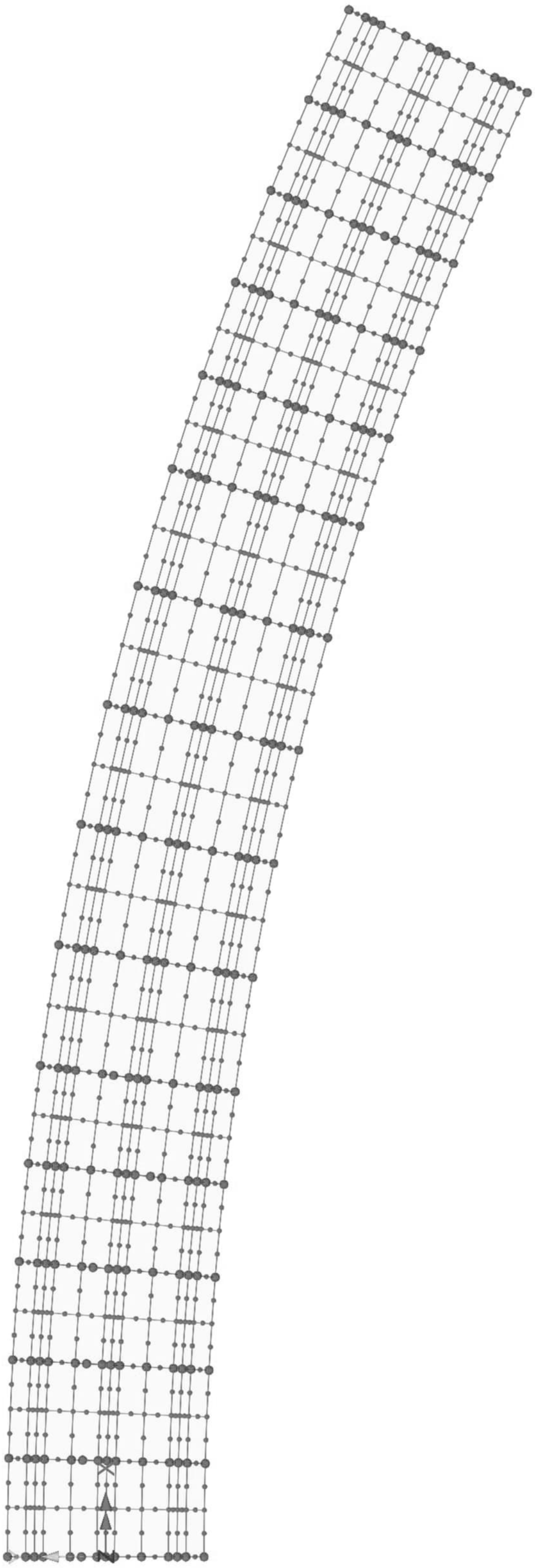
2.3 MESH

2.3.1 MESH: Shell element (QTS8)

Shell elements are used is webs and deck.

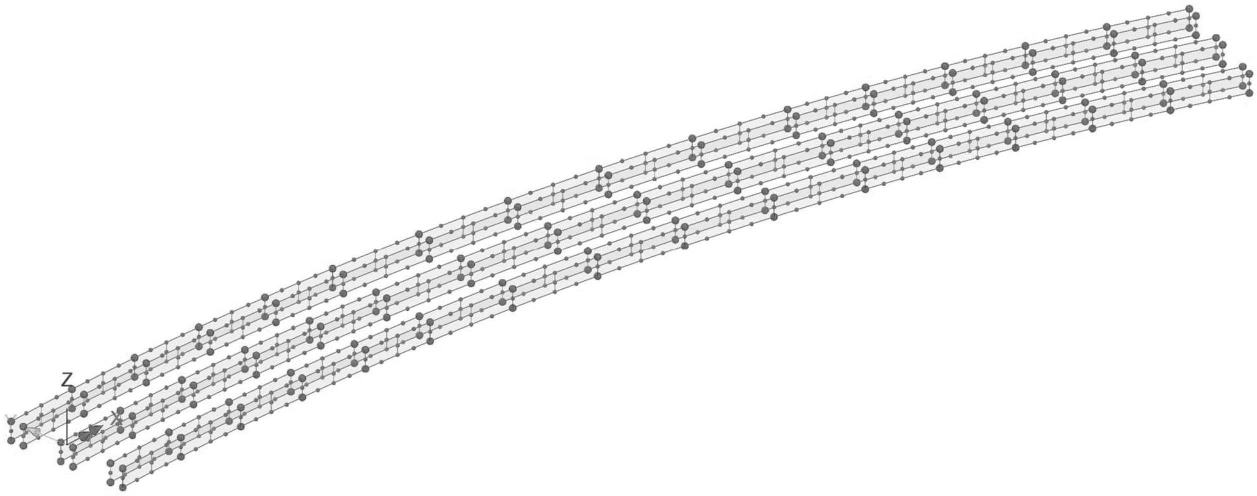
Type	x-divisions	y-divisions
Thick shell	2	1
Thick shell	1	1
-	-	-

Deck:



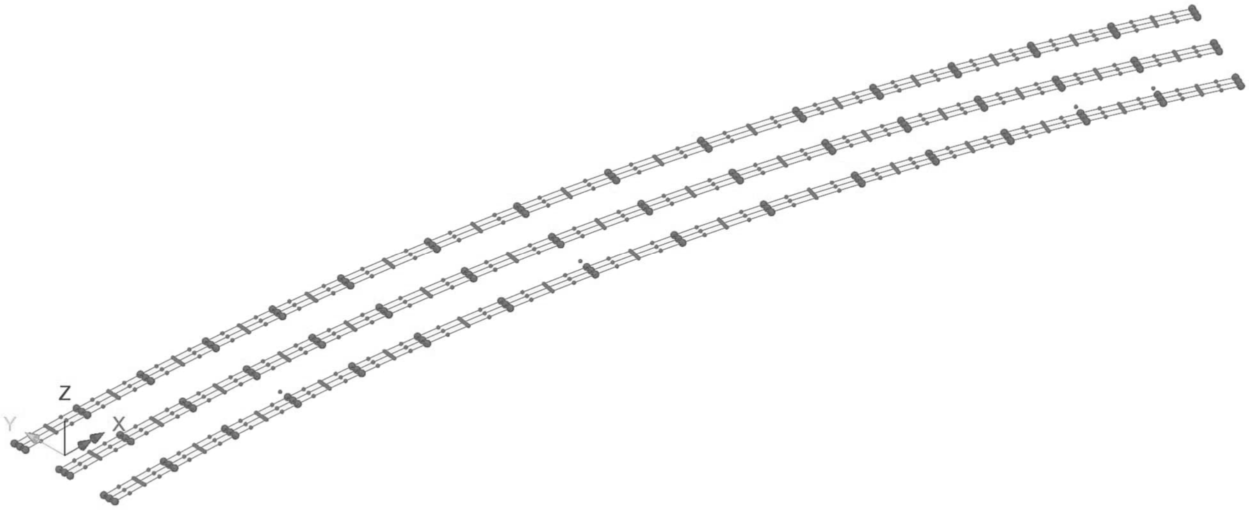
2D Overview

Webs:



3D Overview

Bottom flanges:



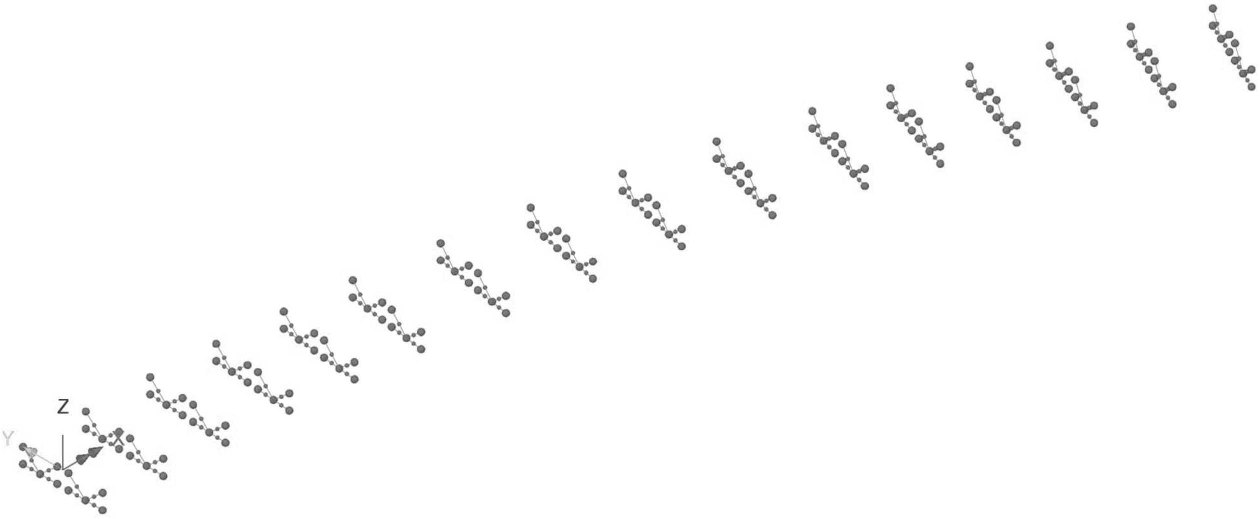
3D Overview

2.3.2 MESH: 3D-beam element (BMI31)

Beam elements are used for flanges and bracings, se table below.

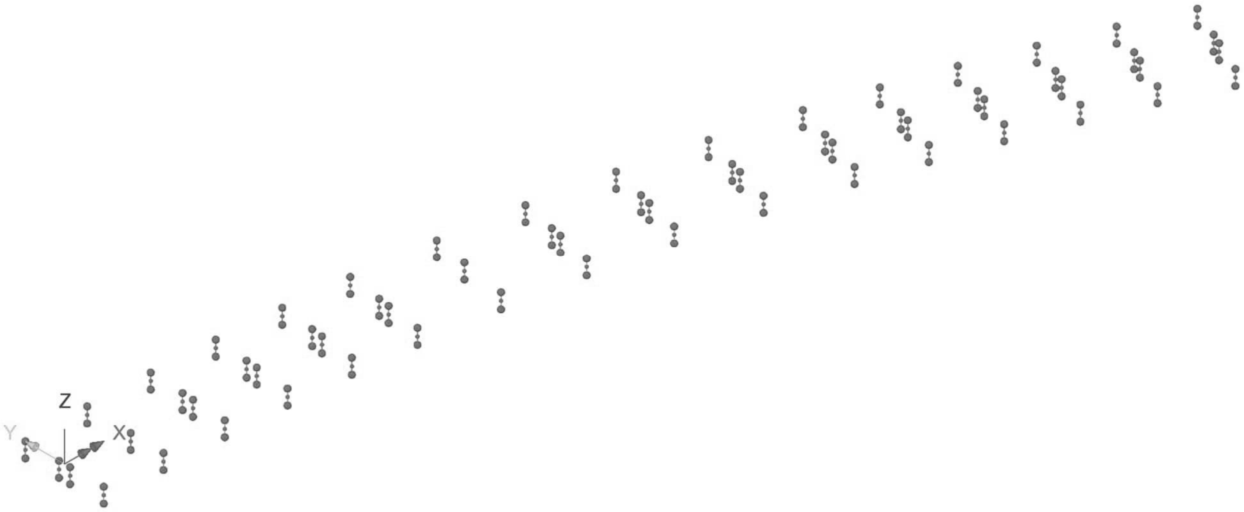
Type	Divisions	End release: Start	End release: End
Thick beam	1	None	None
Thick beam	2	None	None
	-	-	-

Bracings:



3D Overview

Outer stiffeners:

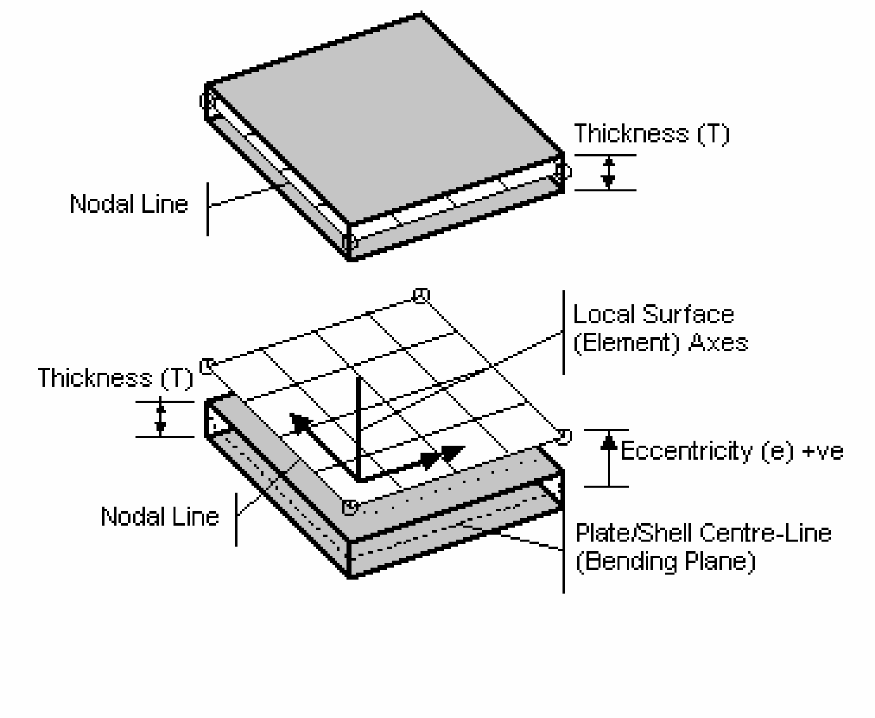


3D Overview

2.4 CROSS SECTION PROPERTIES

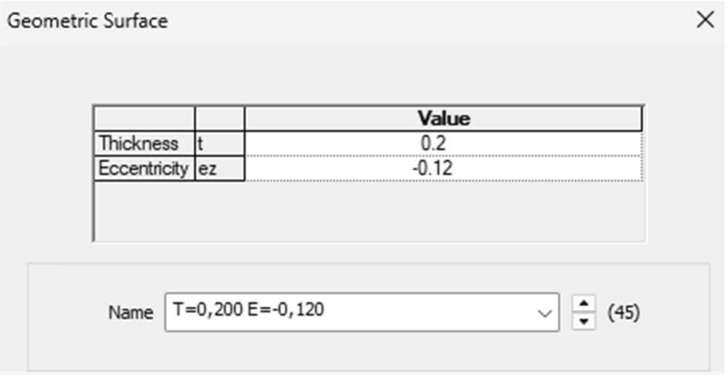
2.4.1 Shell elements

Web and deck are defined as shell elements. Principle figures of geometry is seen below.



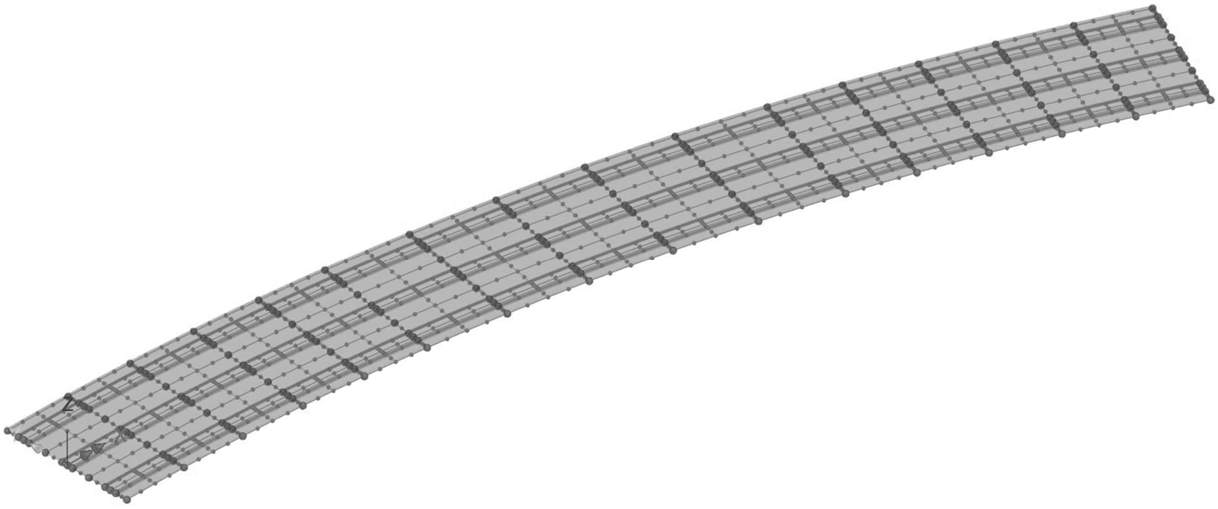
Deck :

Deck is given geometric properties seen below.



		Value
Thickness	t	0.2
Eccentricity	ez	-0.12

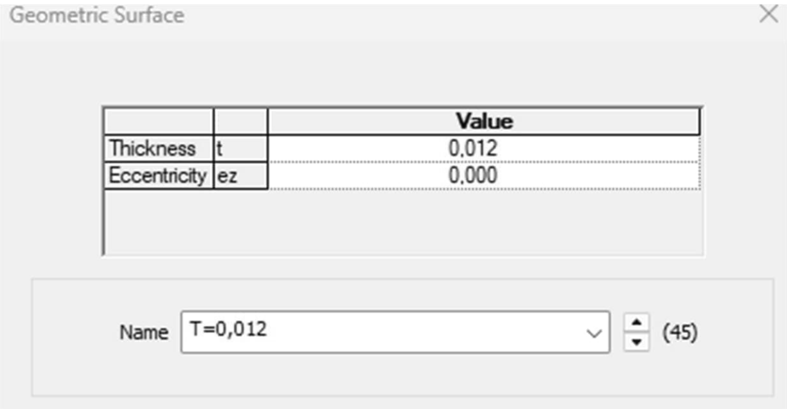
Name: T=0,200 E=-0,120 (45)



3D Overview

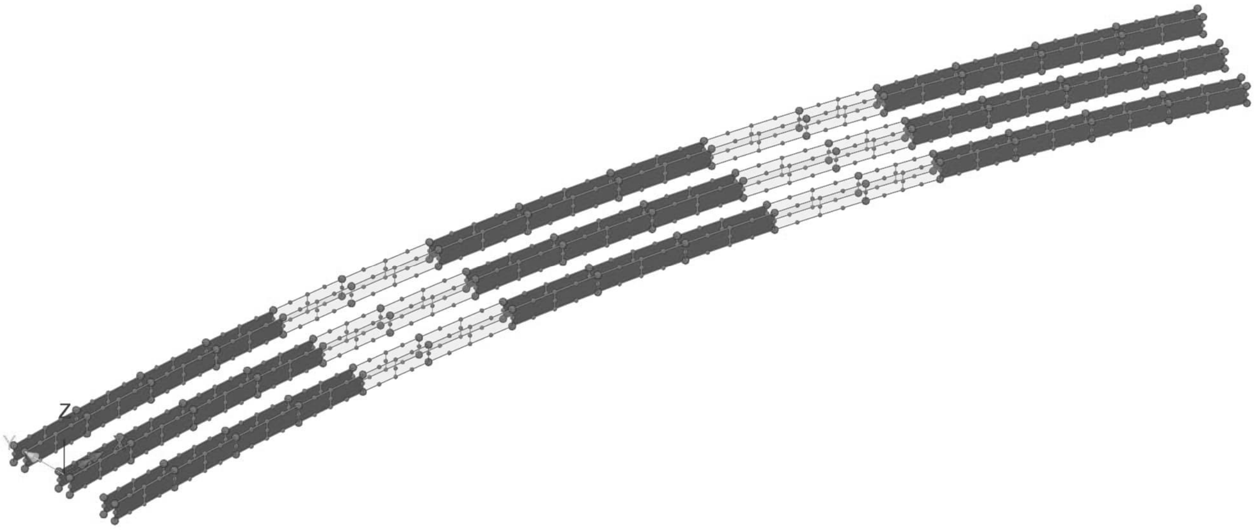
Web (BEAM 1, BEAM 3 & BEAM 5):

Deck is given geometric properties seen below.



		Value
Thickness	t	0,012
Eccentricity	ez	0,000

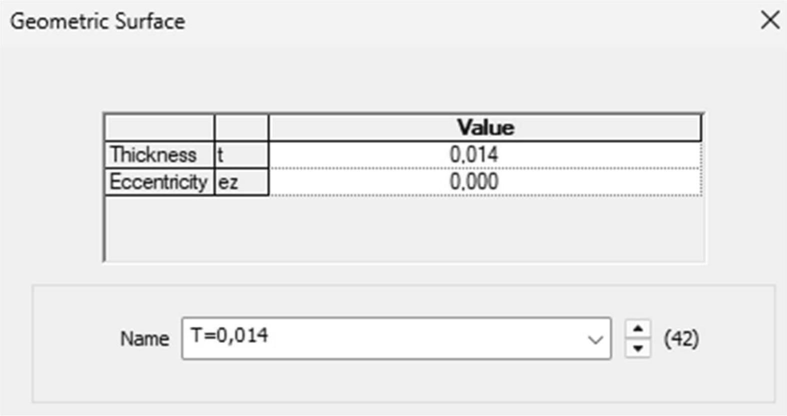
Name T=0,012 (45)



3D Overview

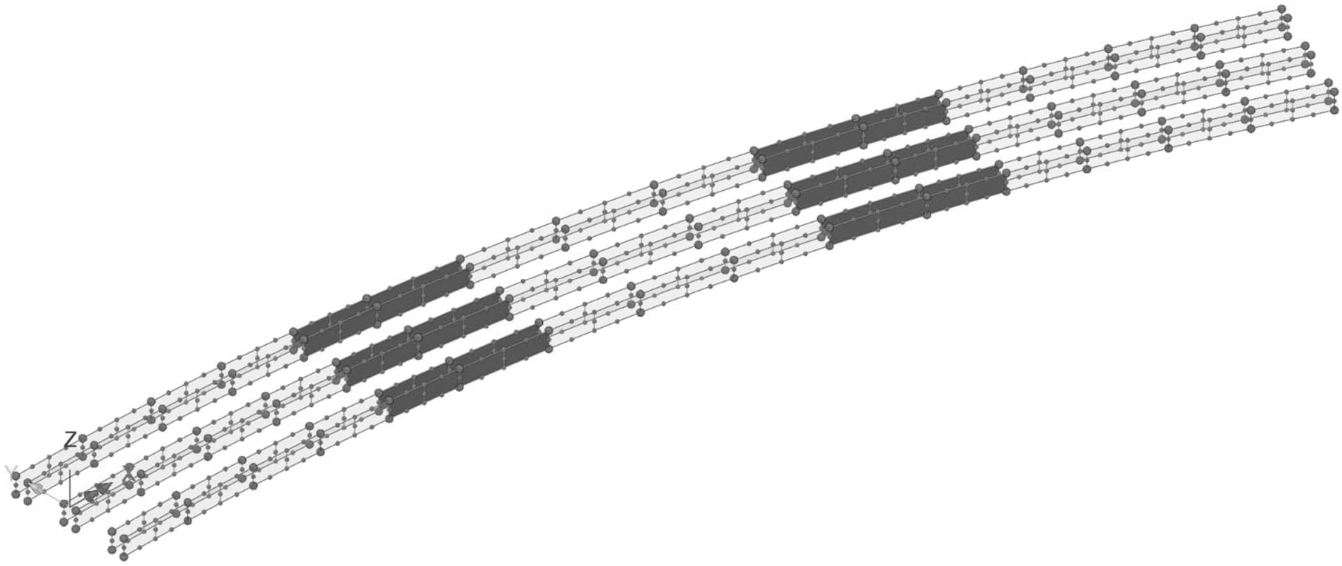
Web (BEAM 2 & BEAM 4):

Deck is given geometric properties seen below.



		Value
Thickness	t	0,014
Eccentricity	ez	0,000

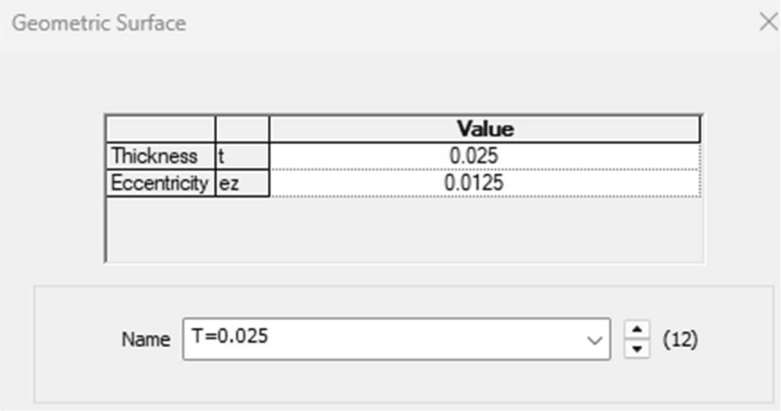
Name T=0,014 (42)



3D Overview

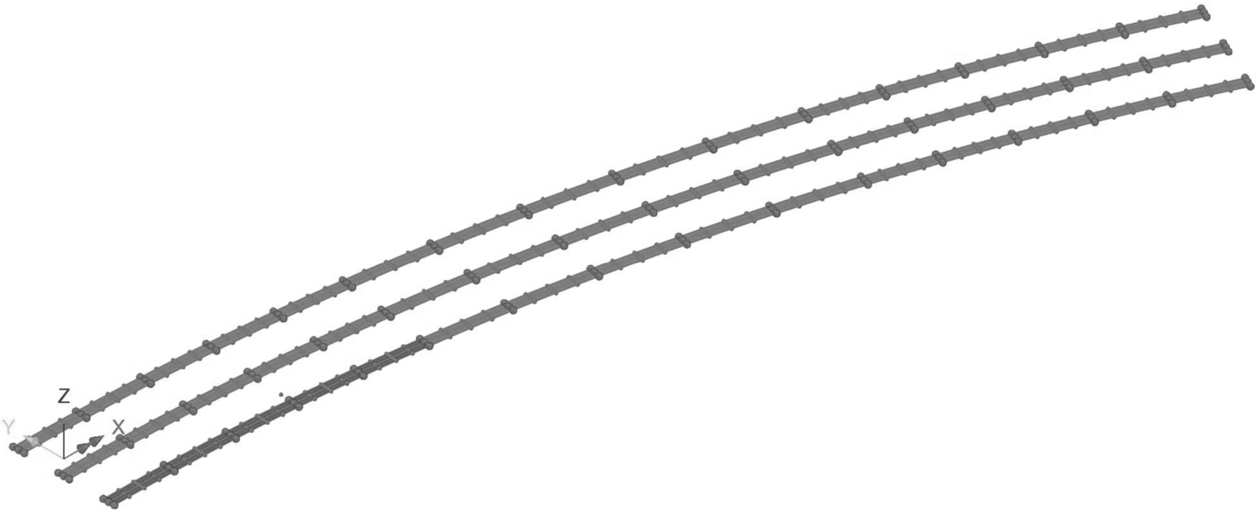
Bottom slab (BEAM 1, BEAM 2, BEAM 3, BEAM 4 & BEAM 5):

Deck is given geometric properties seen below.



		Value
Thickness	t	0.025
Eccentricity	ez	0.0125

Name T=0.025 (12)

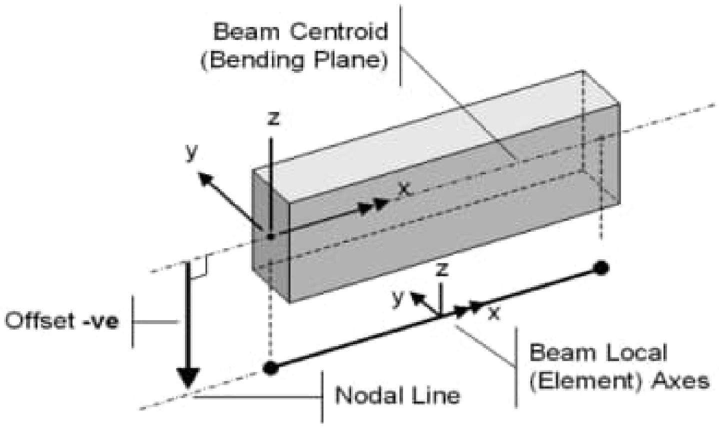


3D Overview

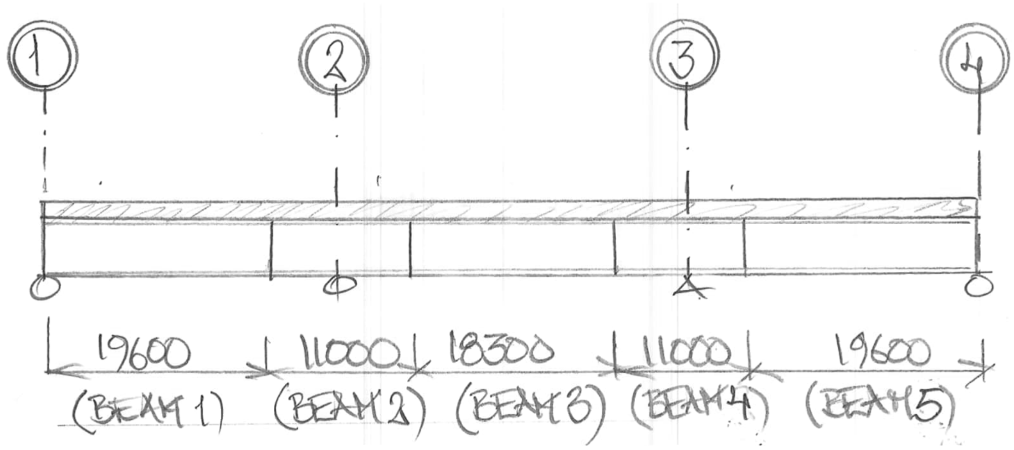
2.4.2 3D-beam elements

Flanges and bracing are as beam elements.

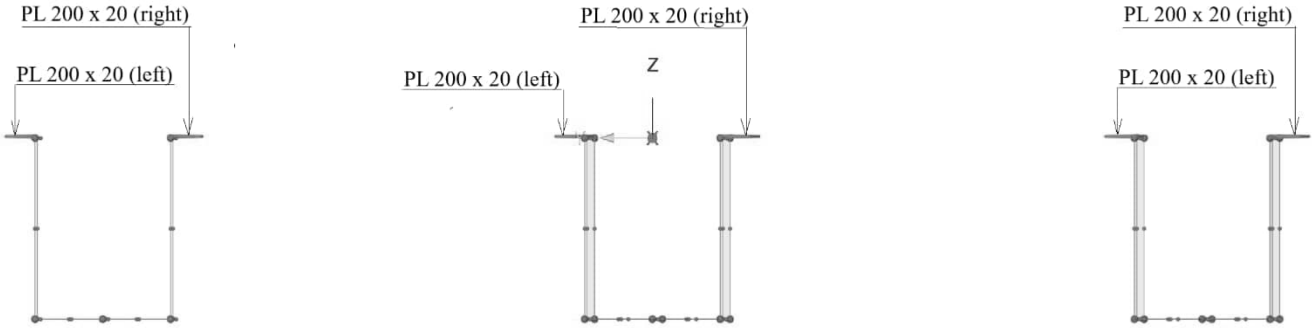
Principal sketch of geometry associated to 3D beam elements are seen below.



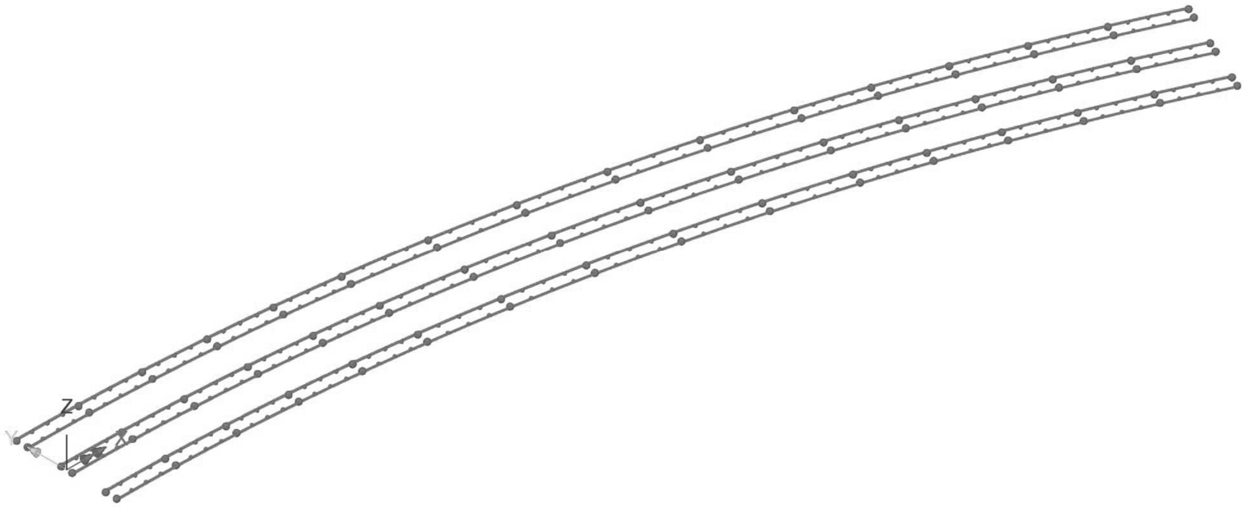
2.4.2.1 Flanges steel girders



Top flange (BEAM 1, BEAM 2, BEAM , BEAM 4 & BEAM 5):

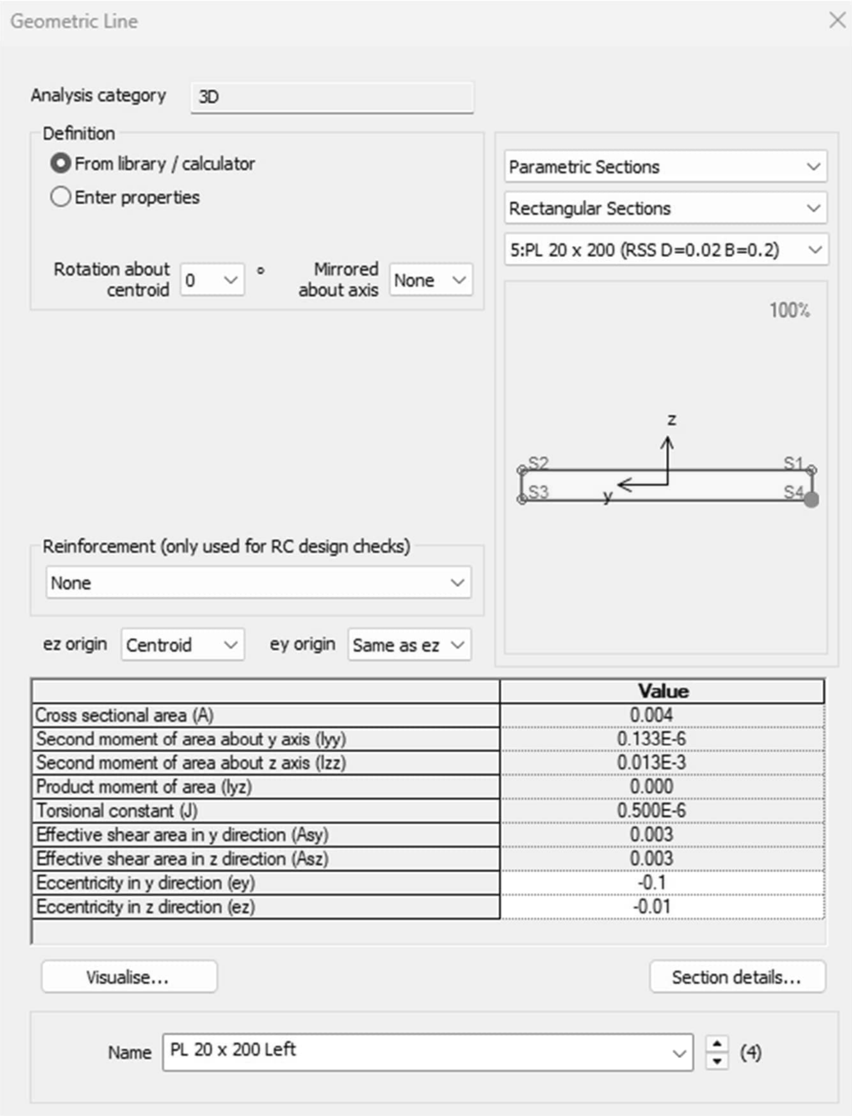


Cross section



3D Overview

Flange is given geometric properties seen below.


Geometric Line

Analysis category: 3D

Definition
● From library / calculator
○ Enter properties

Rotation about centroid: 0 °
Mirrored about axis: None

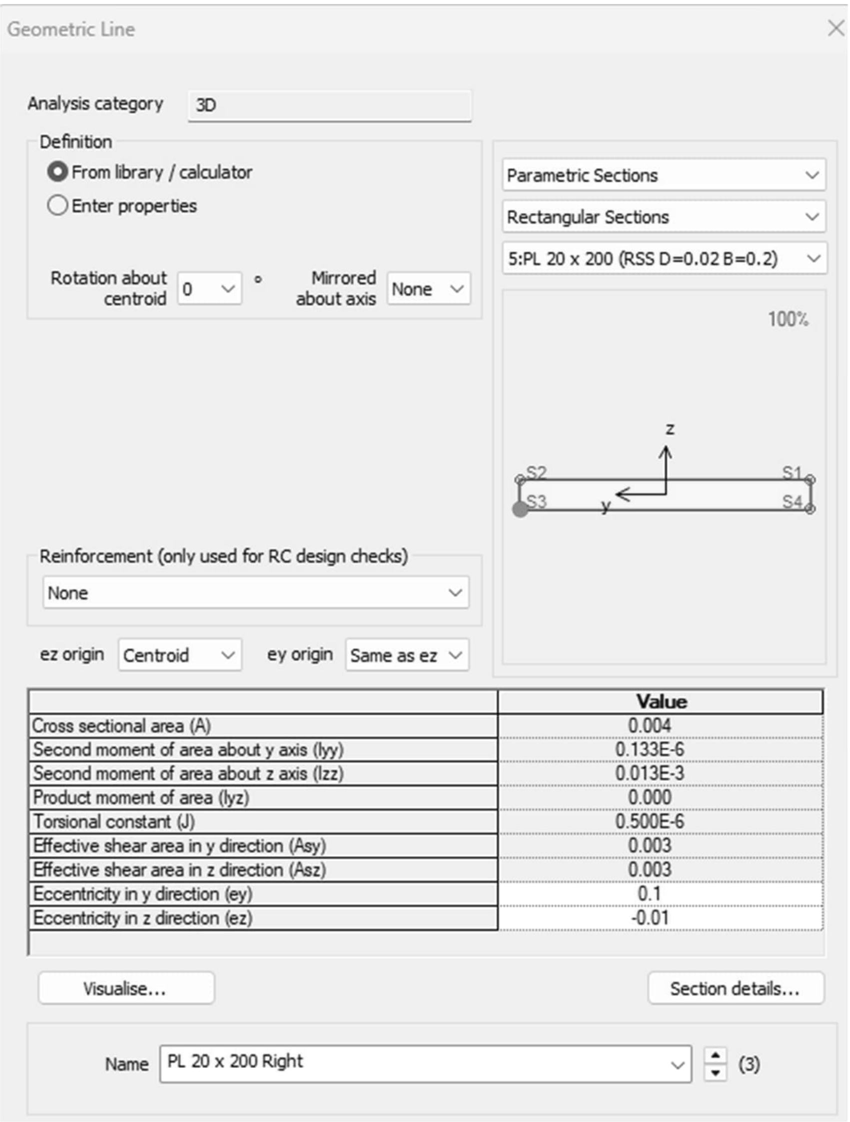
Parametric Sections
Rectangular Sections
5:PL 20 x 200 (RSS D=0.02 B=0.2)

Reinforcement (only used for RC design checks): None

ez origin: Centroid
ey origin: Same as ez

	Value
Cross sectional area (A)	0.004
Second moment of area about y axis (Iyy)	0.133E-6
Second moment of area about z axis (Izz)	0.013E-3
Product moment of area (Iyz)	0.000
Torsional constant (J)	0.500E-6
Effective shear area in y direction (Asy)	0.003
Effective shear area in z direction (Asz)	0.003
Eccentricity in y direction (ey)	-0.1
Eccentricity in z direction (ez)	-0.01

Name: PL 20 x 200 Left (4)



Analysis category: 3D

Definition

- ● From library / calculator
- ○ Enter properties

Rotation about centroid: 0 °

Mirrored about axis: None

Parametric Sections

Rectangular Sections

5:PL 20 x 200 (RSS D=0.02 B=0.2)

Reinforcement (only used for RC design checks): None

ez origin: Centroid

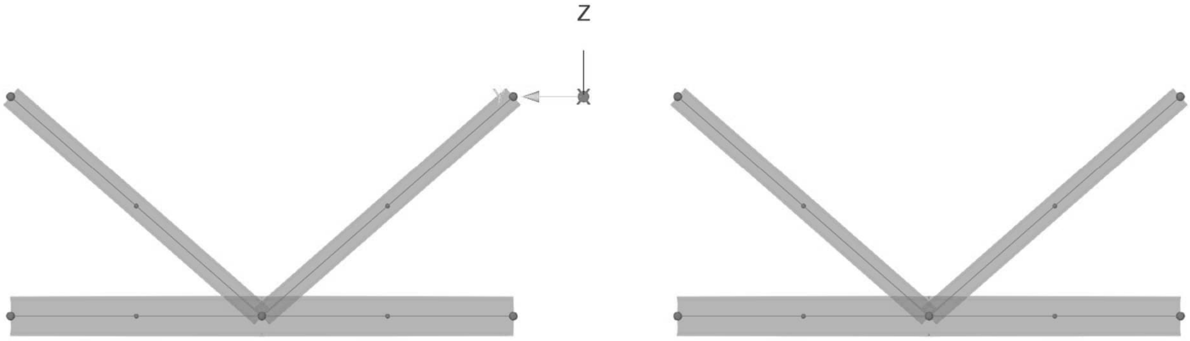
ey origin: Same as ez

	Value
Cross sectional area (A)	0.004
Second moment of area about y axis (Iyy)	0.133E-6
Second moment of area about z axis (Izz)	0.013E-3
Product moment of area (Iyz)	0.000
Torsional constant (J)	0.500E-6
Effective shear area in y direction (Asy)	0.003
Effective shear area in z direction (Asz)	0.003
Eccentricity in y direction (ey)	0.1
Eccentricity in z direction (ez)	-0.01

Name: PL 20 x 200 Right (3)

2.4.2.2 Intermediate bracing: type F

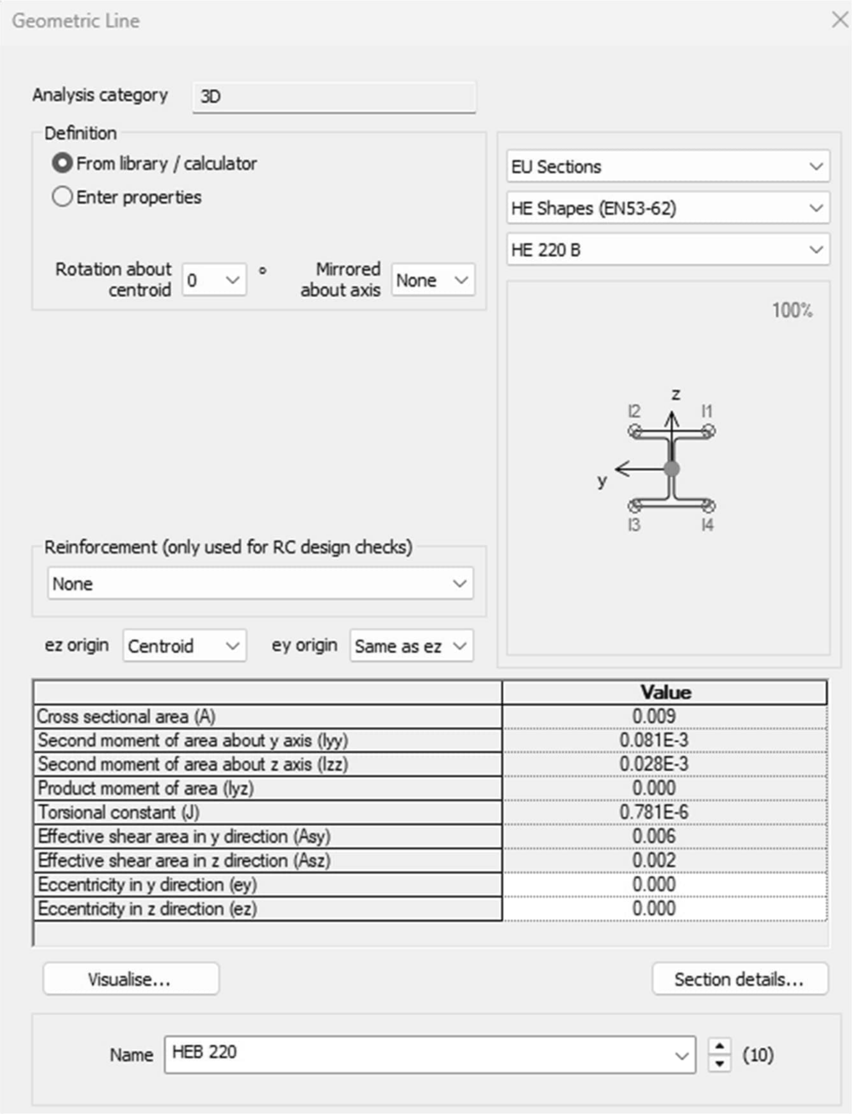
Each bracing consist of 3 parts and are identical at all bracings.



Typ F

Bracings intermediate (F)- horizontal beam (HEB 220):

Beam is given geometric properties seen below.



Analysis category: 3D

Definition

● From library / calculator

○ Enter properties

Rotation about centroid: 0 °

Mirrored about axis: None

EU Sections

HE Shapes (EN53-62)

HE 220 B

100%

Reinforcement (only used for RC design checks): None

ez origin: Centroid

ey origin: Same as ez

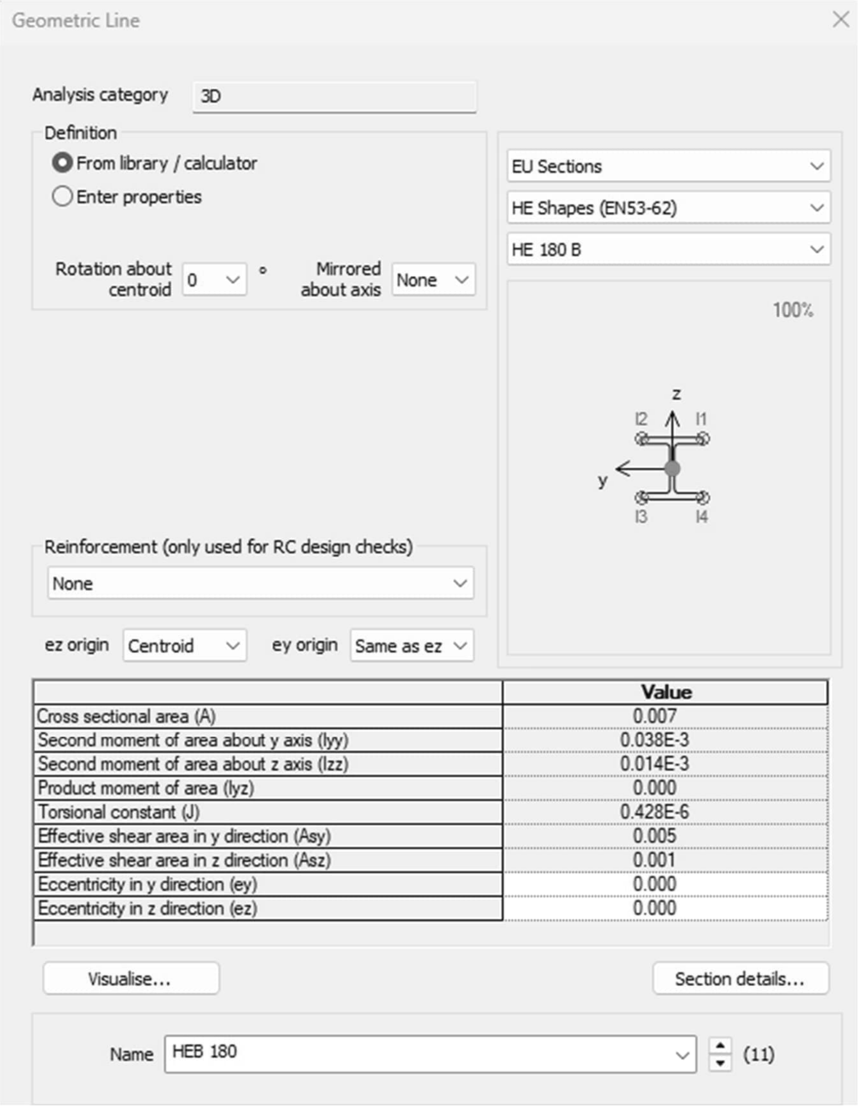
	Value
Cross sectional area (A)	0.009
Second moment of area about y axis (Iyy)	0.081E-3
Second moment of area about z axis (Izz)	0.028E-3
Product moment of area (Iyz)	0.000
Torsional constant (J)	0.781E-6
Effective shear area in y direction (Asy)	0.006
Effective shear area in z direction (Asz)	0.002
Eccentricity in y direction (ey)	0.000
Eccentricity in z direction (ez)	0.000

Name: HEB 220 (10)

3D Overview

Bracings intermediate (F)- inclined beam (HEB 180):

Beam is given geometric properties seen below.



Analysis category: 3D

● From library / calculator
○ Enter properties

Rotation about centroid: 0 °

Mirrored about axis: None

EU Sections

HE Shapes (EN53-62)

HE 180 B

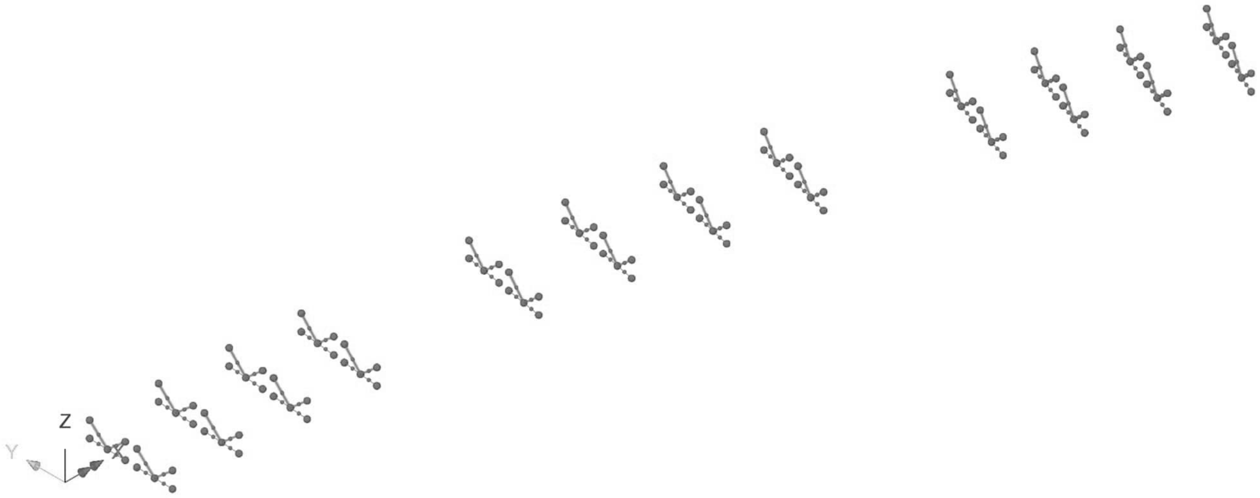
Reinforcement (only used for RC design checks): None

ez origin: Centroid

ey origin: Same as ez

	Value
Cross sectional area (A)	0.007
Second moment of area about y axis (Iyy)	0.038E-3
Second moment of area about z axis (Izz)	0.014E-3
Product moment of area (Iyz)	0.000
Torsional constant (J)	0.428E-6
Effective shear area in y direction (Asy)	0.005
Effective shear area in z direction (Asz)	0.001
Eccentricity in y direction (ey)	0.000
Eccentricity in z direction (ez)	0.000

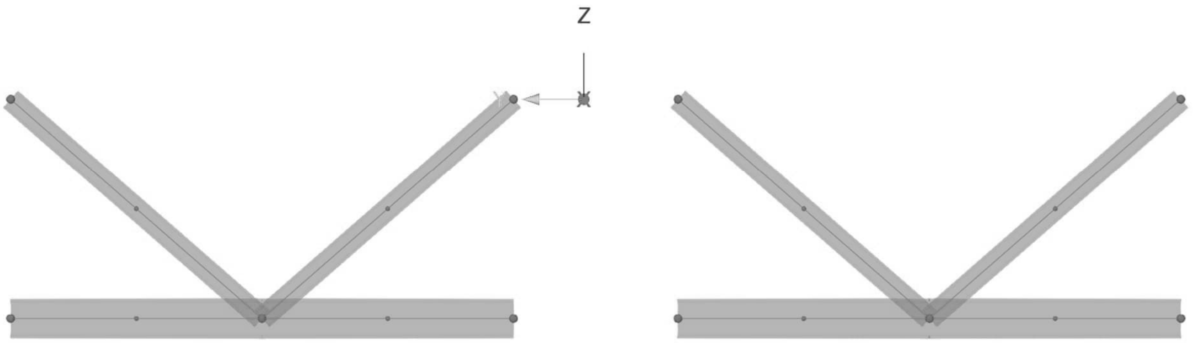
Name: HEB 180 (11)



3D Overview

2.4.2.3 Support bracing: type S

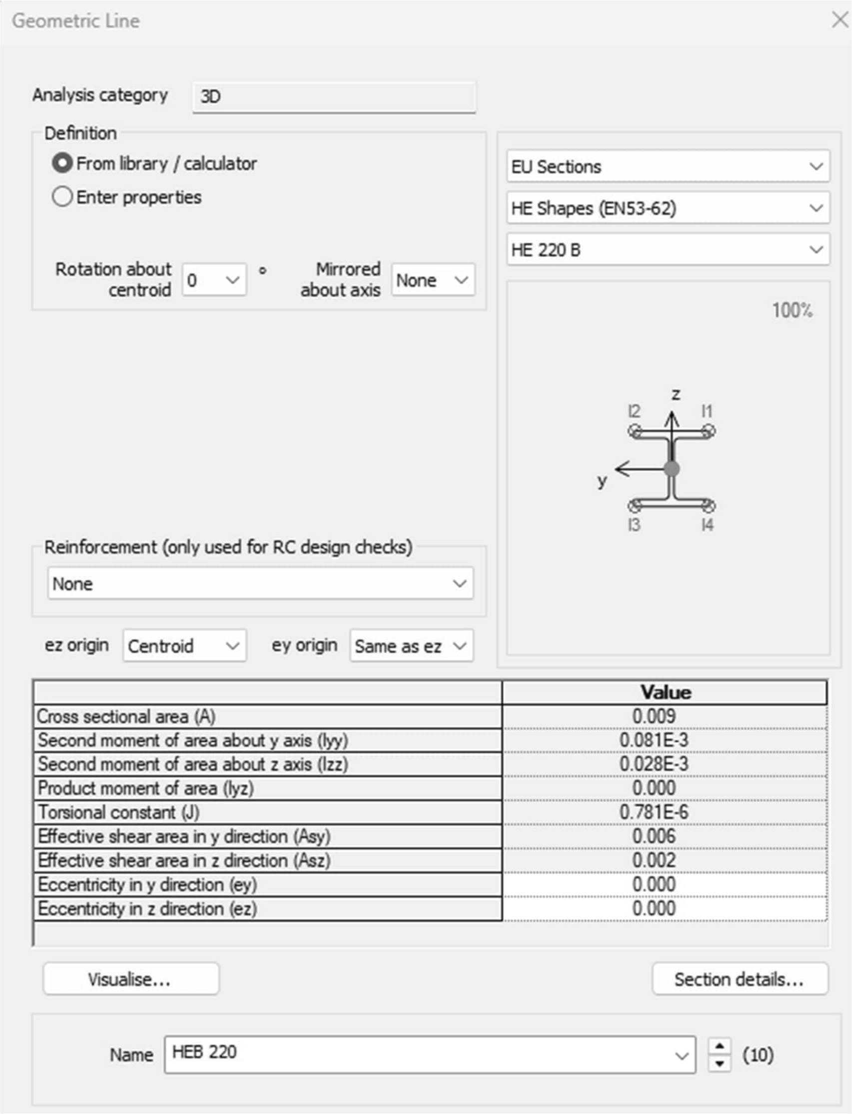
Each bracing consists of 3 part and are identical at all supports.



Typ S

Bracings supports (S)- horizontal beam bottom (HEB 220):

Beam is given geometric properties seen below.



Analysis category: 3D

● From library / calculator
○ Enter properties

Rotation about centroid: 0 °

Mirrored about axis: None

EU Sections

HE Shapes (EN53-62)

HE 220 B

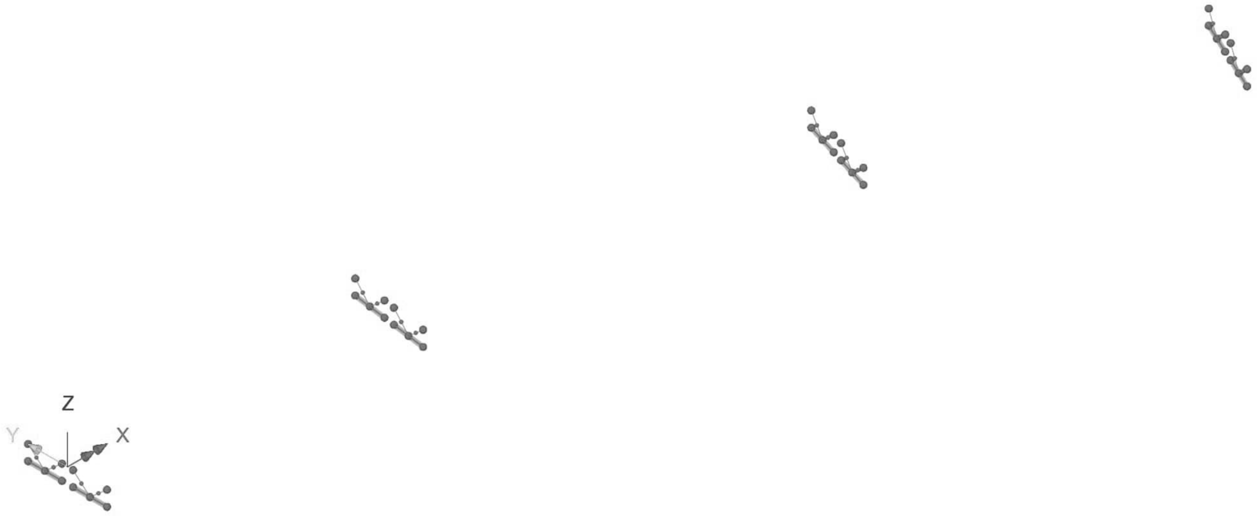
Reinforcement (only used for RC design checks): None

ez origin: Centroid

ey origin: Same as ez

	Value
Cross sectional area (A)	0.009
Second moment of area about y axis (Iyy)	0.081E-3
Second moment of area about z axis (Izz)	0.028E-3
Product moment of area (Iyz)	0.000
Torsional constant (J)	0.781E-6
Effective shear area in y direction (Asy)	0.006
Effective shear area in z direction (Asz)	0.002
Eccentricity in y direction (ey)	0.000
Eccentricity in z direction (ez)	0.000

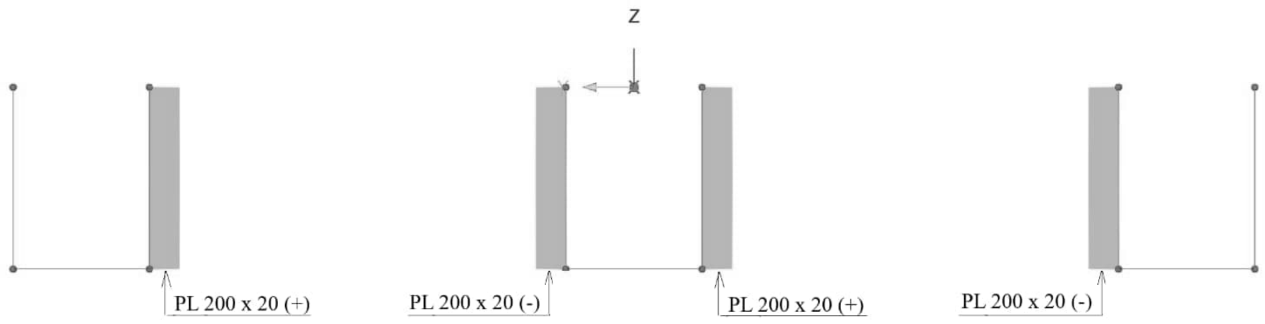
Name: HEB 220 (10)



3D Overview

2.4.2.4 Stiffeners (F)

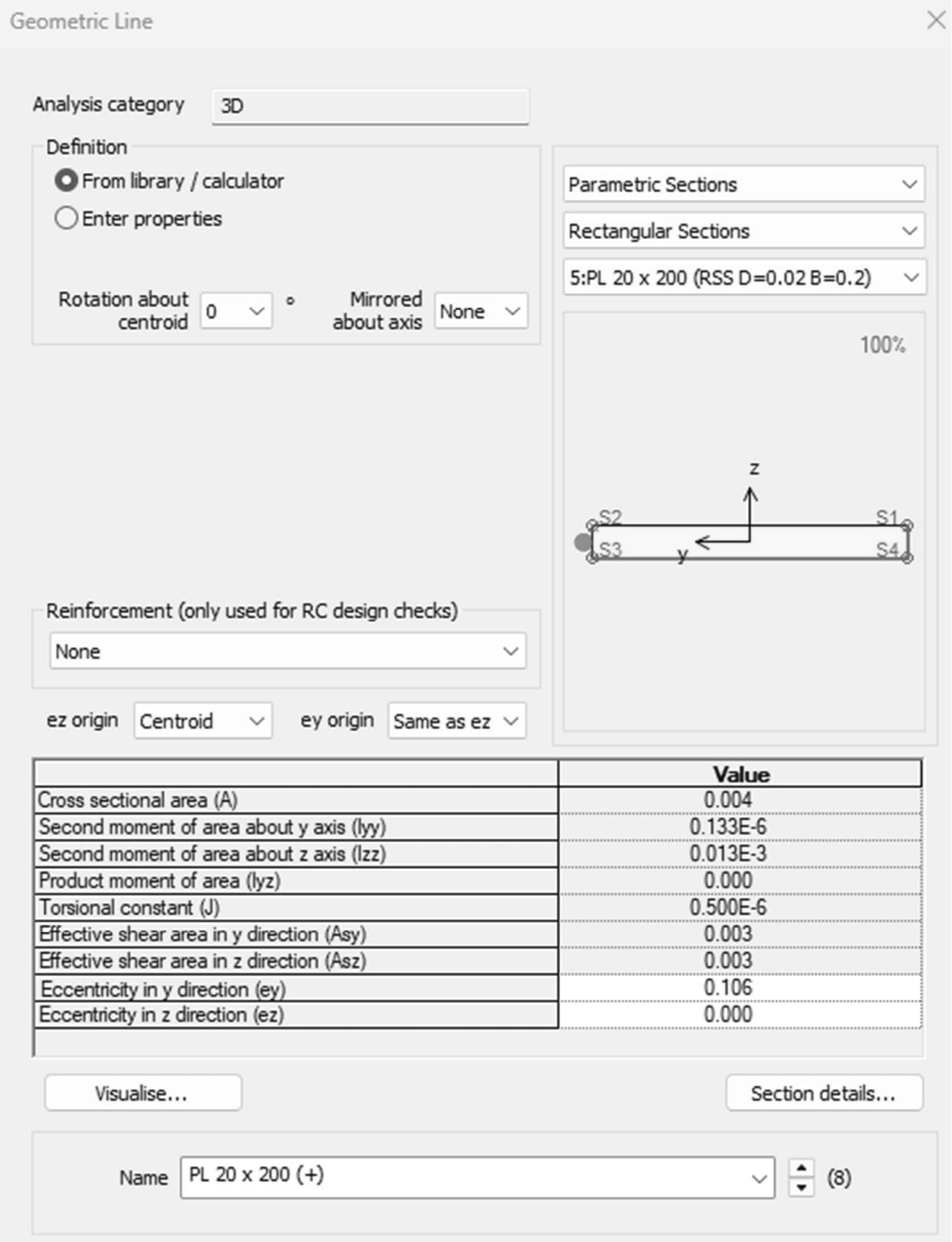
At locations of every bracing (F) stiffeners as seen below are applied.



Stiffener right – PL 200 x 20 (+):

A beam (PL 20 x 200) is placed eccentrically (e_y) as seen below.

$e_y = 0.5 \cdot (b + t_w) = 0.5 \cdot (200\ \text{mm} + 12\ \text{mm}) = +106\ \text{mm}$.



Analysis category: 3D

● From library / calculator
○ Enter properties

Rotation about centroid: 0 °

Mirrored about axis: None

Parametric Sections

Rectangular Sections

5:PL 20 x 200 (RSS D=0.02 B=0.2)

Reinforcement (only used for RC design checks): None

ez origin: Centroid

ey origin: Same as ez

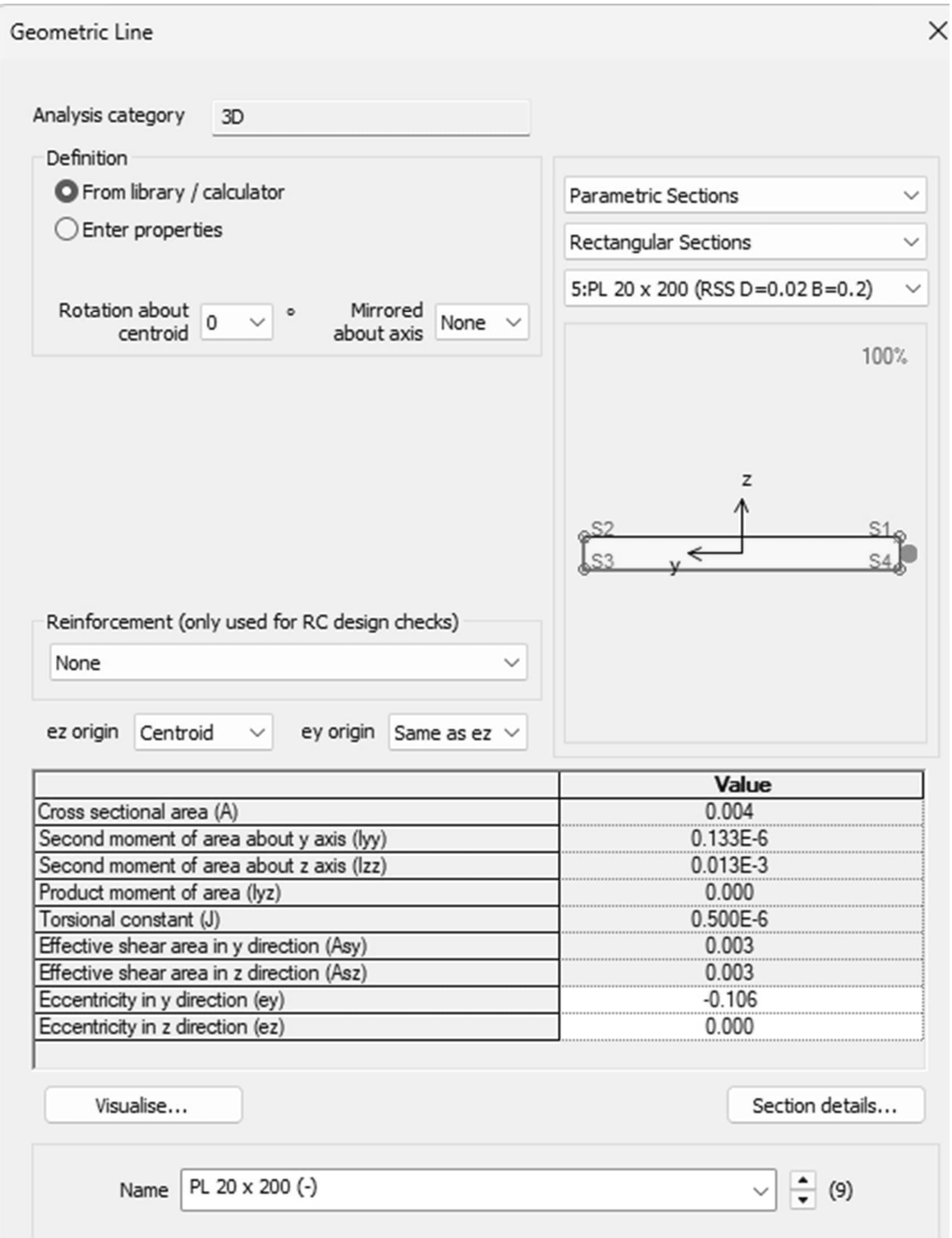
	Value
Cross sectional area (A)	0.004
Second moment of area about y axis (Iyy)	0.133E-6
Second moment of area about z axis (Izz)	0.013E-3
Product moment of area (Iyz)	0.000
Torsional constant (J)	0.500E-6
Effective shear area in y direction (Asy)	0.003
Effective shear area in z direction (Asz)	0.003
Eccentricity in y direction (ey)	0.106
Eccentricity in z direction (ez)	0.000

Name: PL 20 x 200 (+) (8)

Stiffener right – PL 200 x 20 (-):

A beam (PL 20 x 200) is placed eccentrically (e_y) as seen below.

$e_y = -0.5\cdot(b + t_w) = -0.5\cdot (200\text{ mm} + 12\text{ mm}) = -106\text{ mm}.$



Analysis category: 3D

Definition

● From library / calculator
○ Enter properties

Rotation about centroid: 0 °

Mirrored about axis: None

Parametric Sections

Rectangular Sections

5:PL 20 x 200 (RSS D=0.02 B=0.2)

Reinforcement (only used for RC design checks): None

ez origin: Centroid

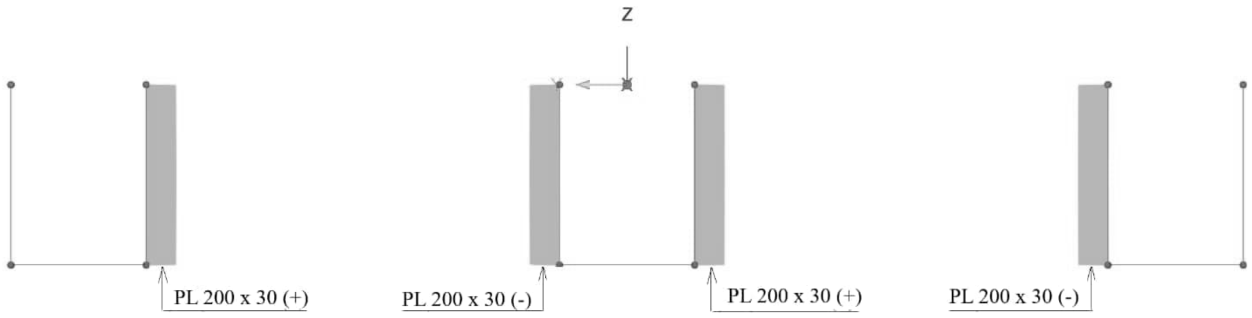
ey origin: Same as ez

	Value
Cross sectional area (A)	0.004
Second moment of area about y axis (Iyy)	0.133E-6
Second moment of area about z axis (Izz)	0.013E-3
Product moment of area (Iyz)	0.000
Torsional constant (J)	0.500E-6
Effective shear area in y direction (Asy)	0.003
Effective shear area in z direction (Asz)	0.003
Eccentricity in y direction (ey)	-0.106
Eccentricity in z direction (ez)	0.000

Name: PL 20 x 200 (-) (9)

2.4.2.6 Stiffeners (S)

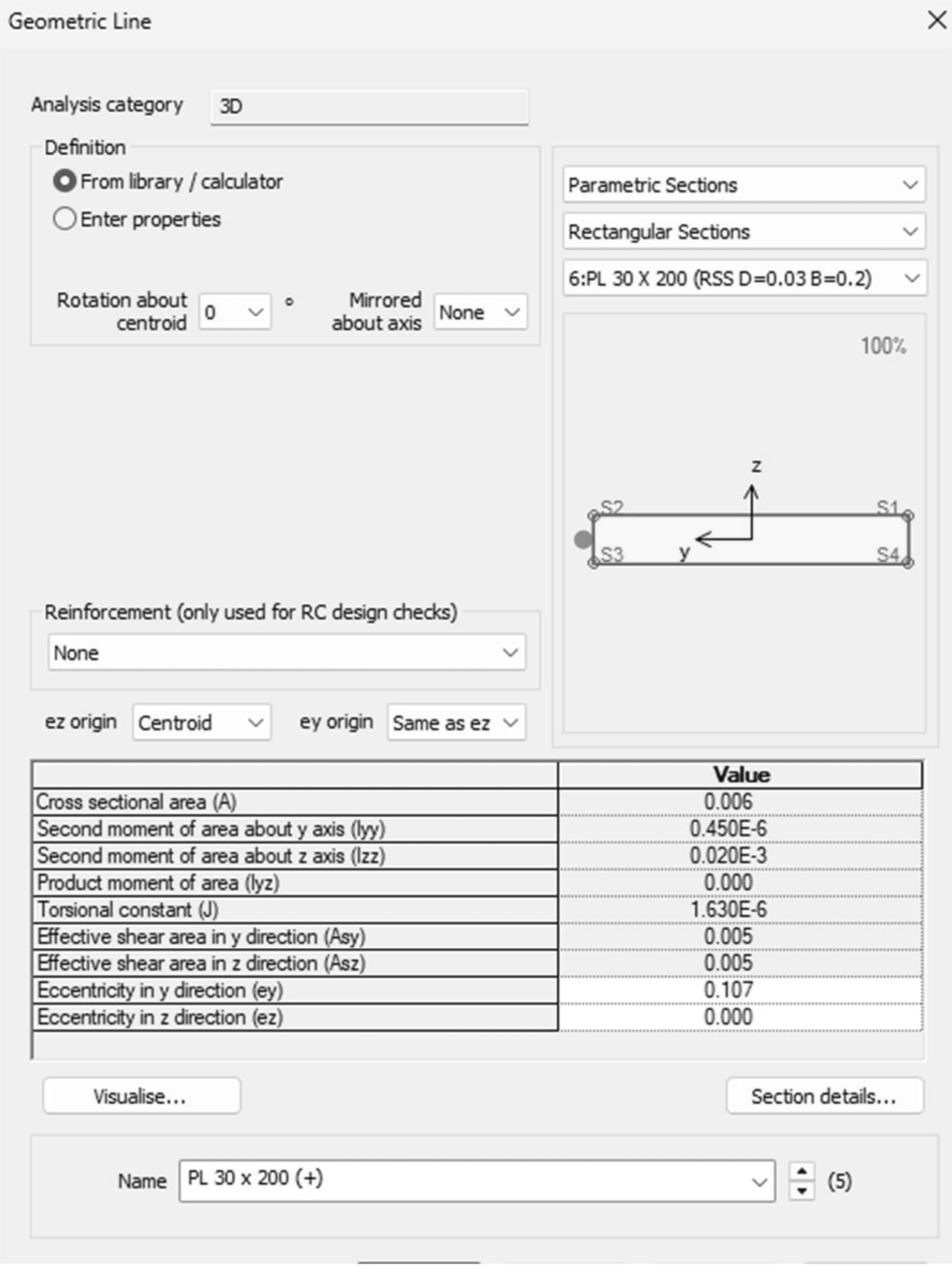
At locations of every bracing (F) stiffeners as seen below are applied.



Stiffener right – PL 200 x 30 (+):

A beam (PL 30 x 200) is placed eccentrically (e_y) as seen below.

$e_y = 0.5\cdot(b + t_w) = 0.5\cdot (200\text{ mm} + 14\text{ mm}) = +107\text{ mm}.$



Geometric Line

Analysis category: 3D

Definition

● From library / calculator

○ Enter properties

Rotation about centroid: 0 °

Mirrored about axis: None

Parametric Sections

Rectangular Sections

6:PL 30 X 200 (RSS D=0.03 B=0.2)

Reinforcement (only used for RC design checks): None

ez origin: Centroid

ey origin: Same as ez

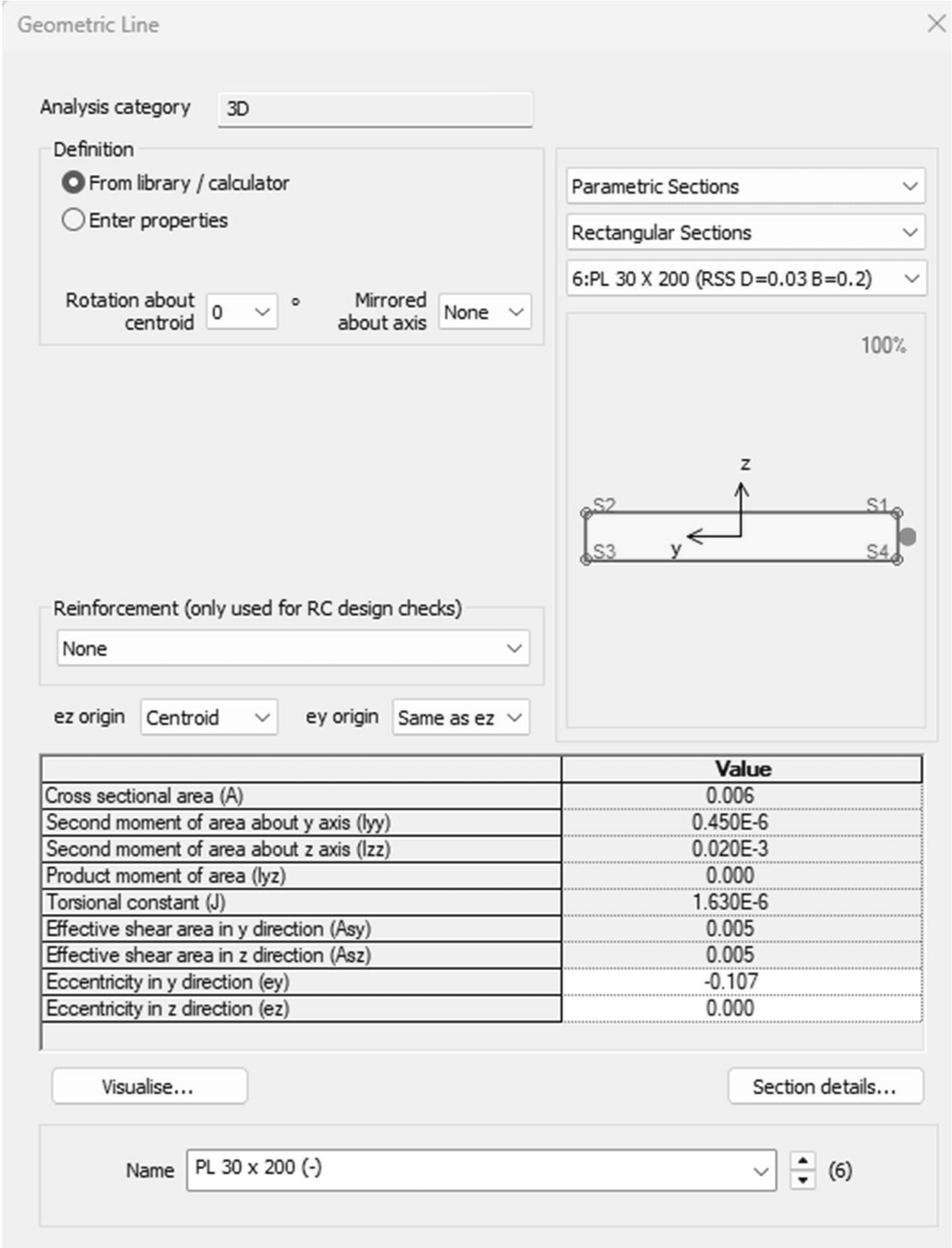
	Value
Cross sectional area (A)	0.006
Second moment of area about y axis (Iyy)	0.450E-6
Second moment of area about z axis (Izz)	0.020E-3
Product moment of area (Iyz)	0.000
Torsional constant (J)	1.630E-6
Effective shear area in y direction (Asy)	0.005
Effective shear area in z direction (Asz)	0.005
Eccentricity in y direction (ey)	0.107
Eccentricity in z direction (ez)	0.000

Name: PL 30 x 200 (+) (5)

Stiffener right – PL 200 x 30 (-):

A beam (PL 30 x 200) is placed eccentrically (e_y) as seen below.

$e_y = -0.5 \cdot (b + t_w) = -0.5 \cdot (200\ \text{mm} + 14\ \text{mm}) = -107\ \text{mm}.$



Analysis category: 3D

Definition: ● From library / calculator ○ Enter properties

Rotation about centroid: 0 °
Mirrored about axis: None

Parametric Sections
Rectangular Sections
6:PL 30 X 200 (RSS D=0.03 B=0.2)

Reinforcement (only used for RC design checks): None

ez origin: Centroid
ey origin: Same as ez

	Value
Cross sectional area (A)	0.006
Second moment of area about y axis (Iyy)	0.450E-6
Second moment of area about z axis (Izz)	0.020E-3
Product moment of area (Iyz)	0.000
Torsional constant (J)	1.630E-6
Effective shear area in y direction (Asy)	0.005
Effective shear area in z direction (Asz)	0.005
Eccentricity in y direction (ey)	-0.107
Eccentricity in z direction (ez)	0.000

Name: PL 30 x 200 (-) (6)

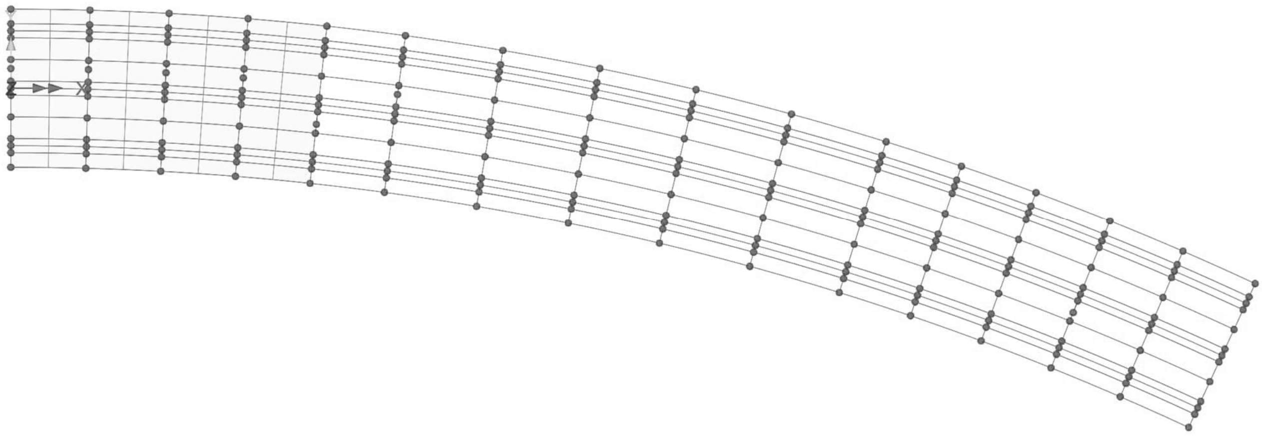
2.5 CASTING STAGES

There are a total of 5 construction and 2 operational stages. In the different phases the roadway is activated/deactivated. Changes are made in relation to system 7 (Base Analysis).

This is handled by applying “Deactivate” in the applicable phases. When applied to a static system, allocation must be made for each individual load case.

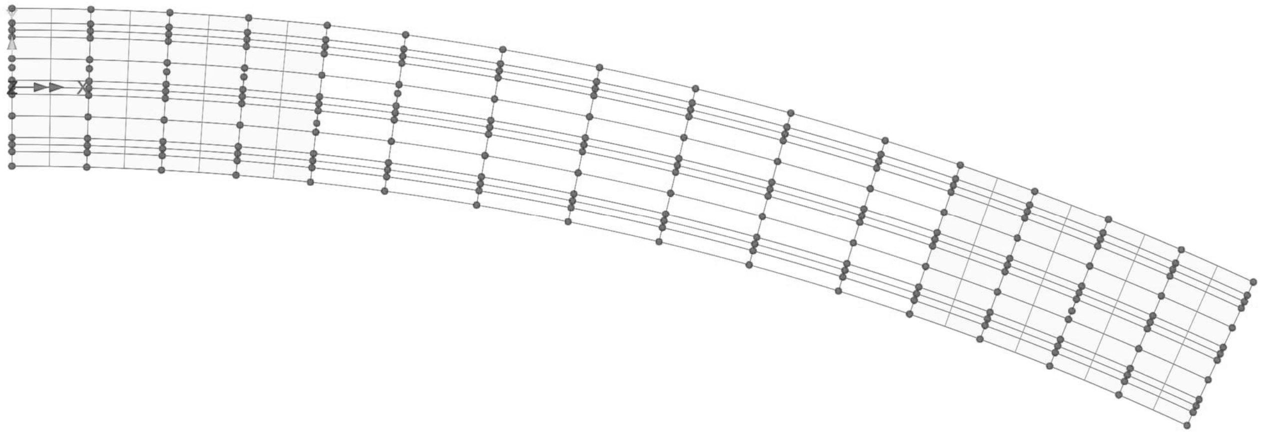
2.5.1 *Analysis 1 (Stage I)*

Deactivate : Stage II-V



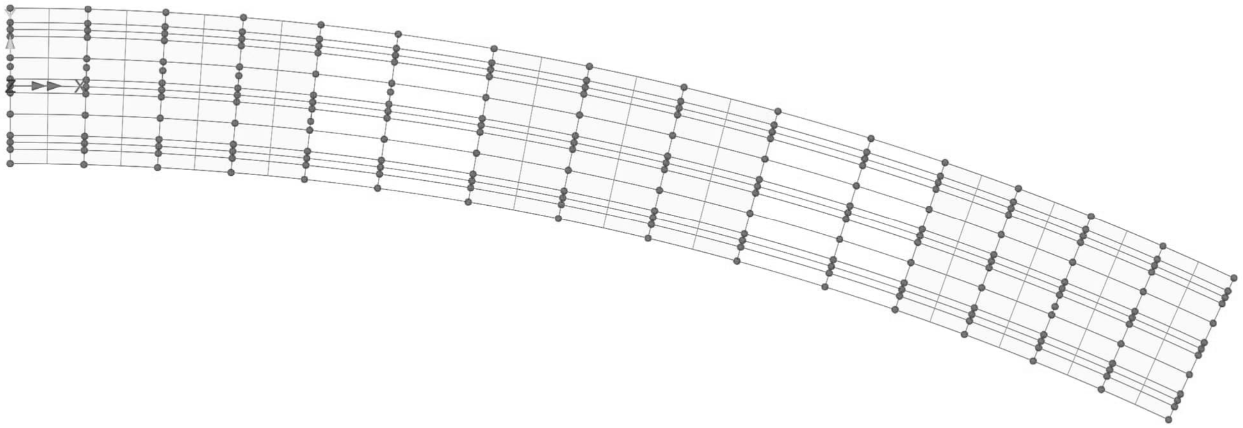
2.5.2 *Analysis 2 (Stage II)*

Deactivate : Stage III-V



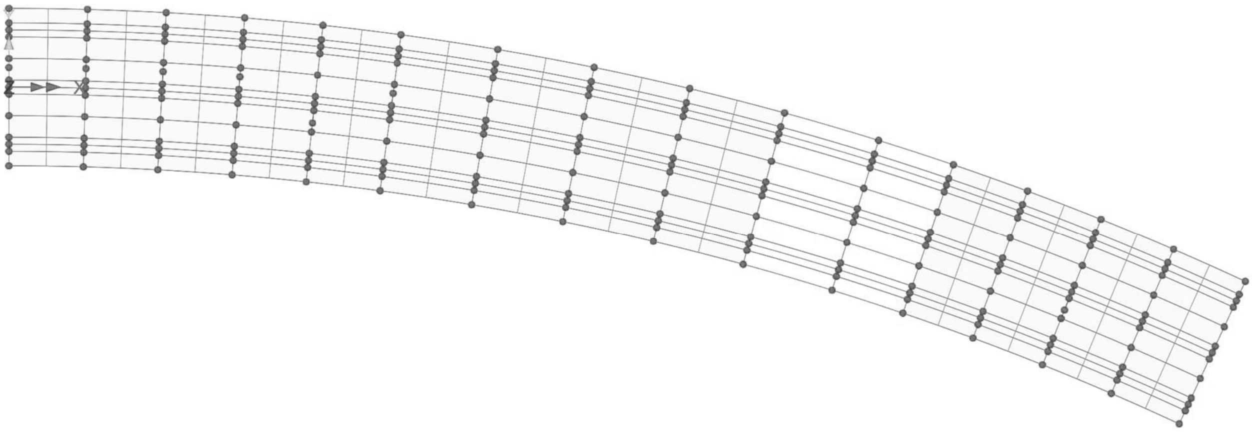
2.5.3 *Analysis 3 (Stage III)*

Deactivate : Stage IV-V



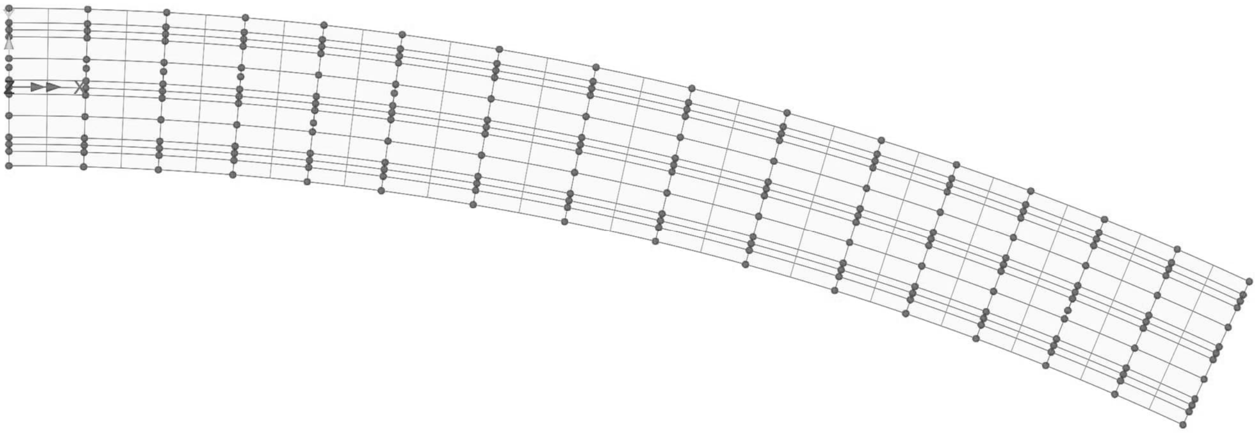
2.5.4 *Analysis 4 (Stage 4)*

Deactivate : Stage V



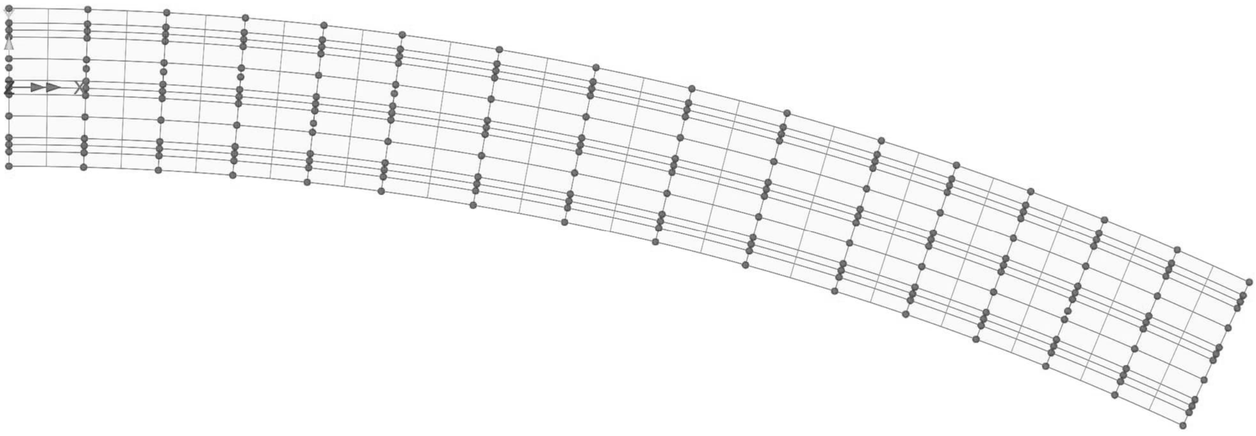
2.5.5 *Analysis 5 (Stage 5)*

Deactivate : None



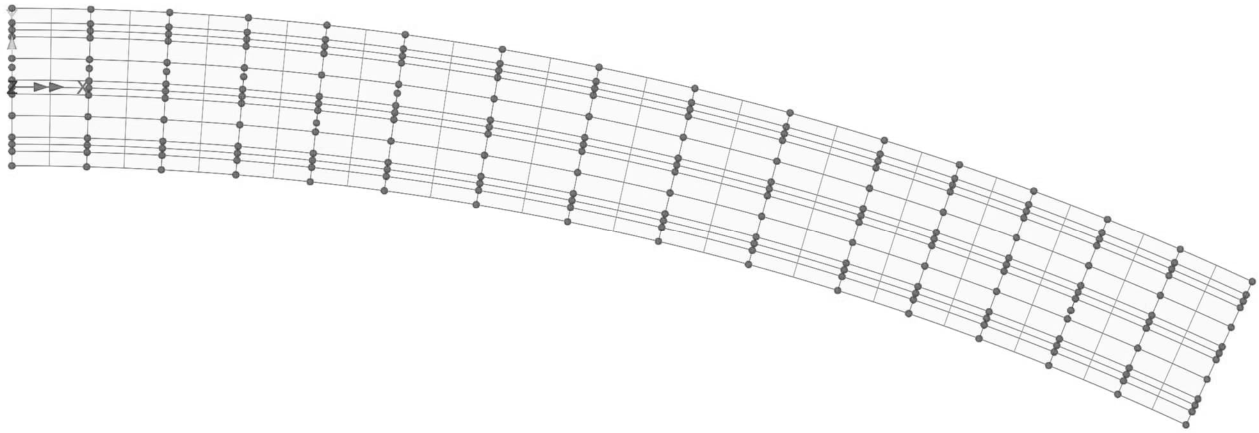
2.5.6 *Analysis 6 (O:PERM)*

Deactivate : None



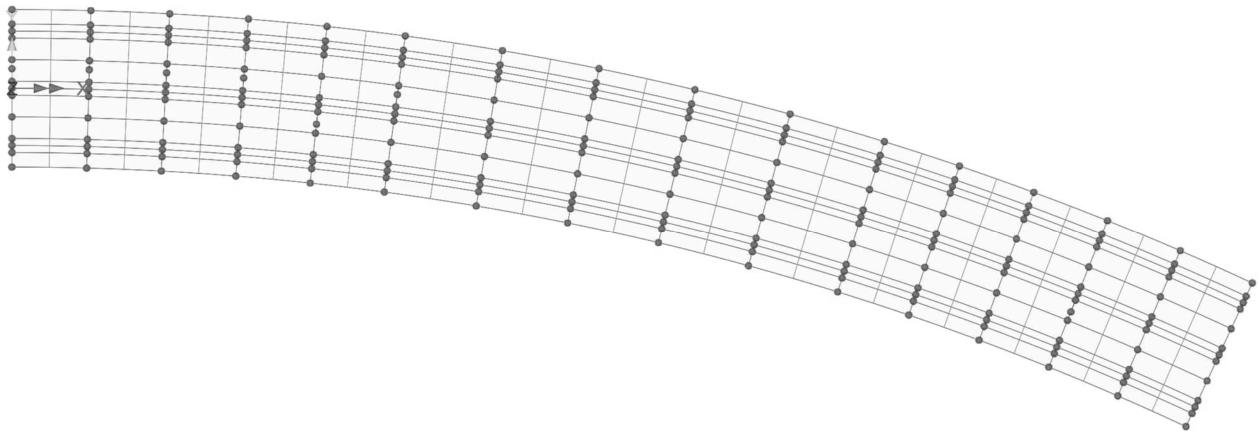
2.5.7 *Analysis 7 (O:VAR)*

Deactivate : None



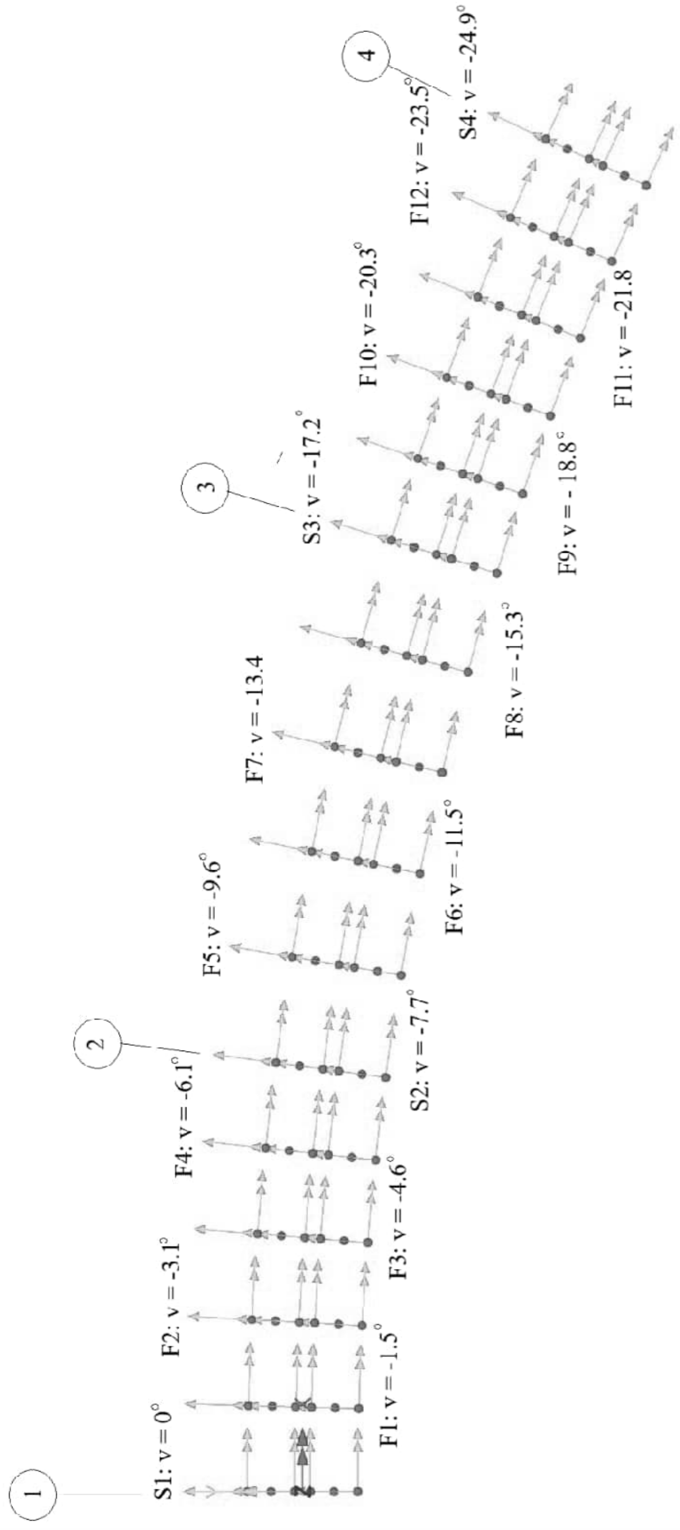
2.5.8 *Analysis 8 (O:TEMP)*

Deactivate : None



2.6 LOCAL COORDINATE SYTEM

When assigning loads and boundary conditions, local coordinate systems are used at each support line as described below.

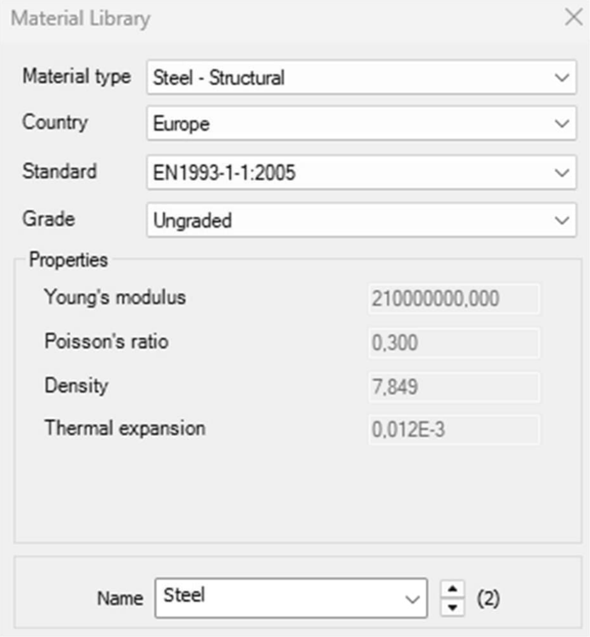


2D Overview

2.7 MATERIAL

2.7.1 Steel

Steel : E_s = 210 GPa



Material type: Steel - Structural

Country: Europe

Standard: EN1993-1-1:2005

Grade: Ungraded

Properties

Young's modulus: 210000000,000

Poisson's ratio: 0,300

Density: 7,849

Thermal expansion: 0,012E-3

Name: Steel (2)

2.7.2 Concrete

In total, there are 7 stages, of which 5 are construction and 2 are operational stages. Considering this, the material properties of concrete deck vary.

Used concrete C35/45: $E_{cm} = 34.0$ GPa

There several types of concrete as seen in table below. In system analysis to determine load effects only types 3, 5 & 7 are considered.

Type	E	Stage	ϕ	ψ_L	Cross section	Load
1	0[1.)]	Constructional	-	-	Wet	Permanent loads
2	34.0[2.)]	Constructional	0	1.0[3.)]	Uncracked	Permanent loads
3	11.3	Operational	2.0	1.0[3.)]	Uncracked	Permanent loads excl. shrinkage
4	11.3	Operational	2.0	1.0[3.)]	Uncracked	Shrinkage
5	34.0	Operational	0	1.0[3.)]	Uncracked	Variable loads excl. temperature
6	26.2	Operational	0.3	1.0[3.)]	Uncracked	Variable excl. temperature
7	0[1.)]	Operational	-	1.0[3.)]	Cracked	All loads
-	GPa	-	-	-	-	-

Footnote:

[1.)] Instead, a negligible stiffness is used $E_{cm}/1000$. The effect of reinforcement is not considered when determining load effects in system analysis.

[2.)] Loads associated to permanent load will also act during operational stage,
thus Young´s modulus associated to type 3 is used during system analysis.

[3.)] Used on safe side in example.

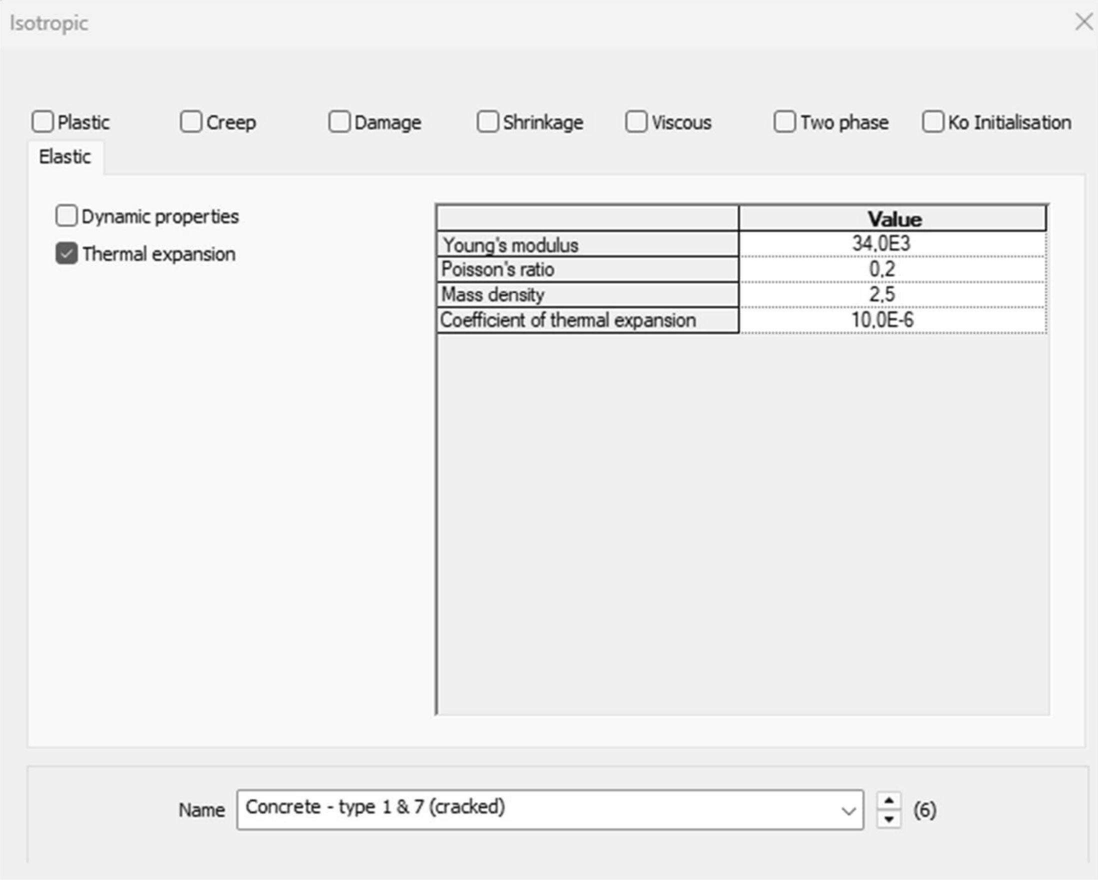
Remark

The effect of rebars and types 4 & 6 will only be considered when applying loads and determining resistance according SS-EN 1994-1.

2.7.2.1 Material : Wet & cracked concrete

The isotropic concrete has negligible stiffness (E_{cm}/1000), corresponding to material properties associated to concrete type 1& 7.

$E = E_{cm}/ 1000 = 34{\cdot}10^6$ kPa / 1000 = $34{\cdot}10^3$ kPa



☐ Plastic ☐ Creep ☐ Damage ☐ Shrinkage ☐ Viscous ☐ Two phase ☐ Ko Initialisation

☐ Dynamic properties
☑ Thermal expansion

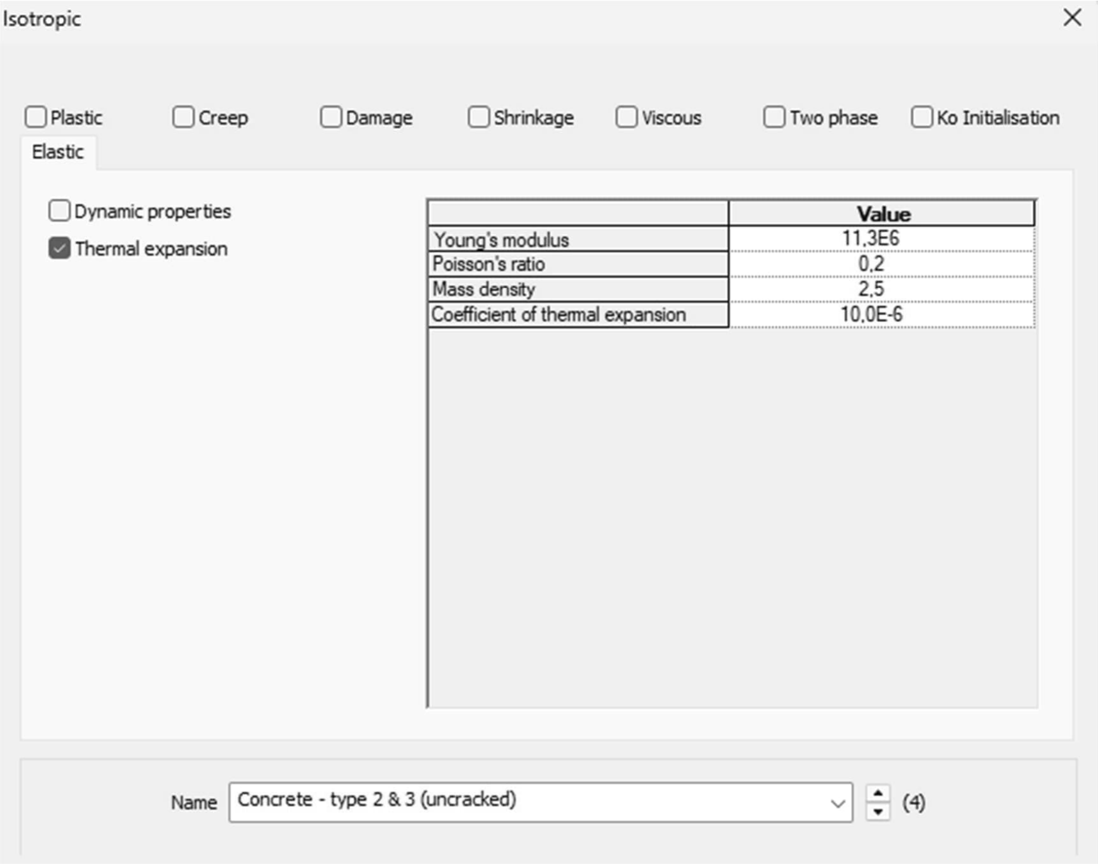
	Value
Young's modulus	34,0E3
Poisson's ratio	0,2
Mass density	2,5
Coefficient of thermal expansion	10,0E-6

Name: Concrete - type 1 & 7 (cracked) (6)

2.7.2.2 Material : Uncracked concrete - permanent loads

The isotropic concrete material properties associated to concrete type 2 & 3.

$$E = E_{cm}/\,(1+\psi_L\cdot\,\phi) = 34\cdot10^6\ \text{kPa} / (1+1.0\cdot2.0) = 11.3\cdot10^6\ \text{kPa}$$



☐ Plastic ☐ Creep ☐ Damage ☐ Shrinkage ☐ Viscous ☐ Two phase ☐ Ko Initialisation

☐ Dynamic properties
☑ Thermal expansion

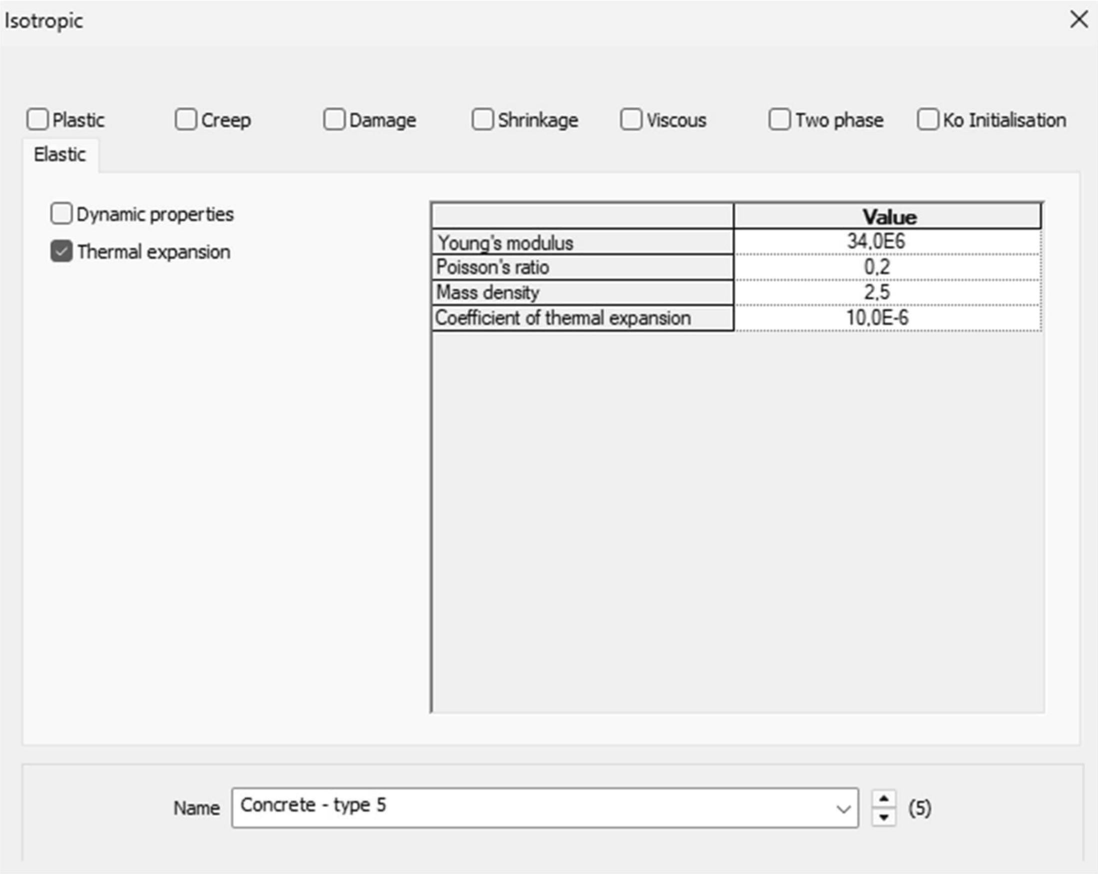
	Value
Young's modulus	11,3E6
Poisson's ratio	0,2
Mass density	2,5
Coefficient of thermal expansion	10,0E-6

Name: Concrete - type 2 & 3 (uncracked) (4)

2.7.2.3 Material : Uncracked concrete - variable loads excl. temperature

The isotropic concrete material properties associated to concrete type 5.

E = $E_{cm}/(1+\psi_L \cdot \phi) = 34 \cdot 10^6$ kPa / (1+ 0) = $34.0 \cdot 10^6$ kPa



☐ Plastic ☐ Creep ☐ Damage ☐ Shrinkage ☐ Viscous ☐ Two phase ☐ Ko Initialisation

☐ Dynamic properties

☑ Thermal expansion

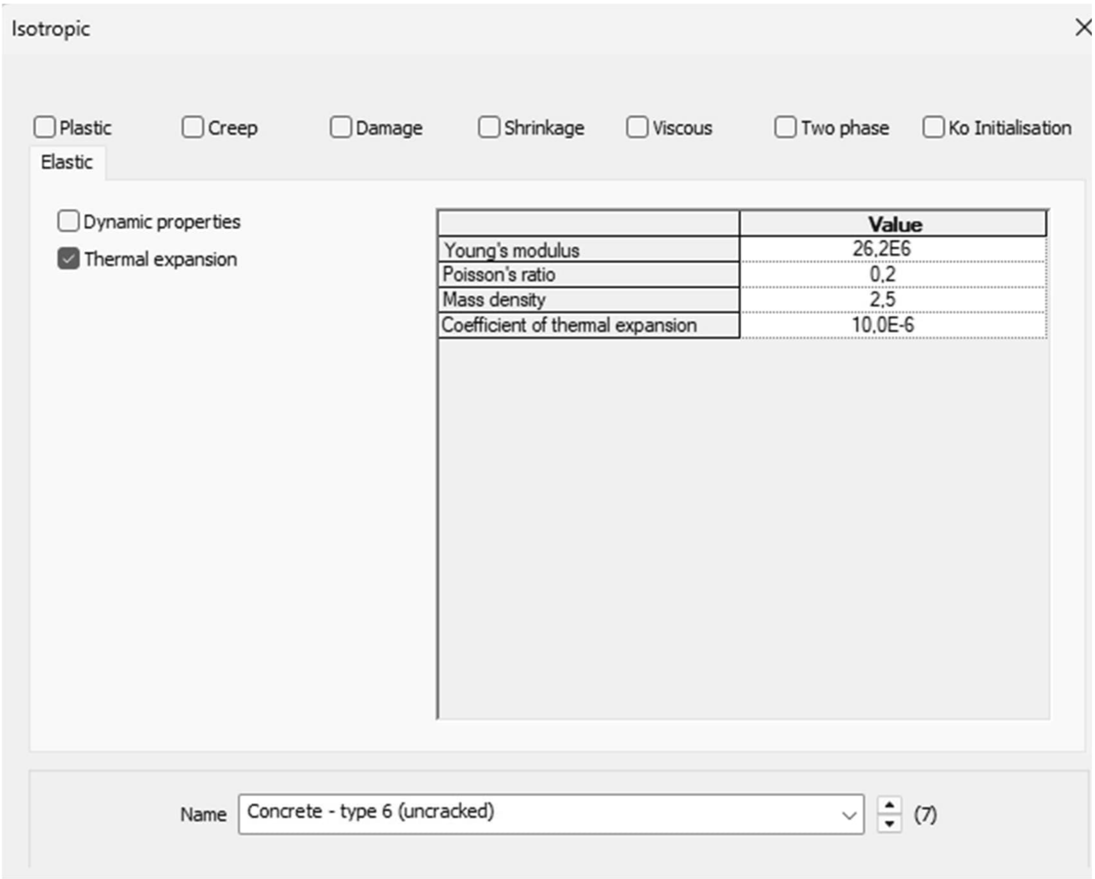
	Value
Young's modulus	34,0E6
Poisson's ratio	0,2
Mass density	2,5
Coefficient of thermal expansion	10,0E-6

Name: Concrete - type 5 (5)

2.7.2.4 Material : Uncracked concrete - temperature

The isotropic concrete material properties associated to concrete type 6.

$E = E_{cm} / (1+\psi_L \cdot \phi) = 34 \cdot 10^6$ kPa $/ (1+ 1.0 \cdot 0.3) = 26.2 \cdot 10^6$ kPa

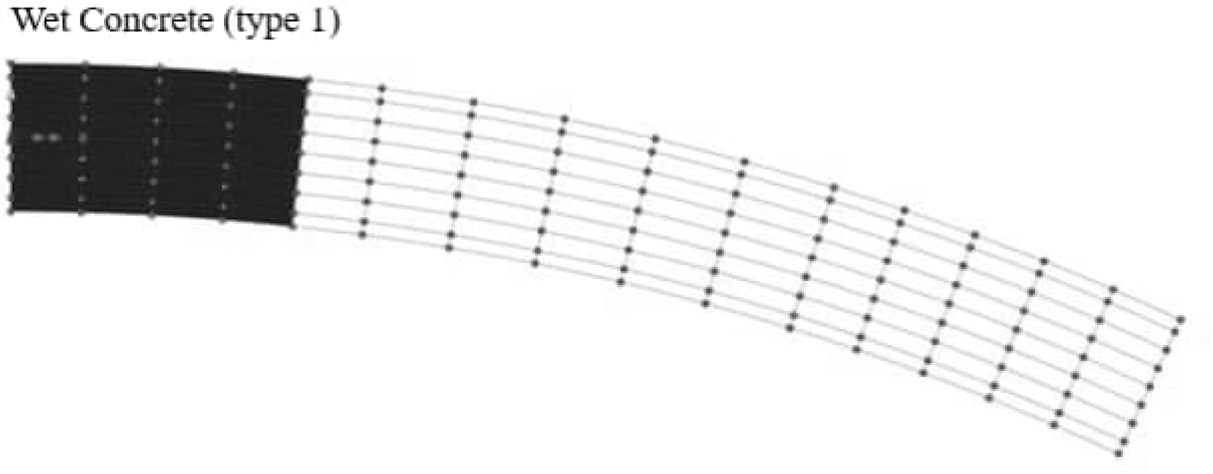


☐ Dynamic properties
☑ Thermal expansion

	Value
Young's modulus	26,2E6
Poisson's ratio	0,2
Mass density	2,5
Coefficient of thermal expansion	10,0E-6

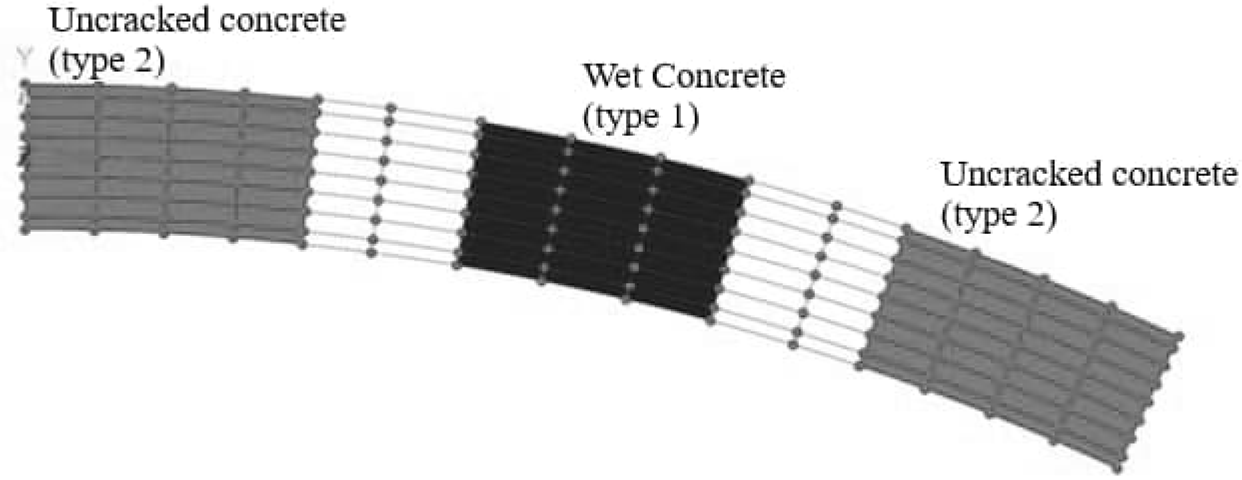
Name: Concrete - type 6 (uncracked) (7)

2.7.2.5 *Analysis 1 (Stage I)*

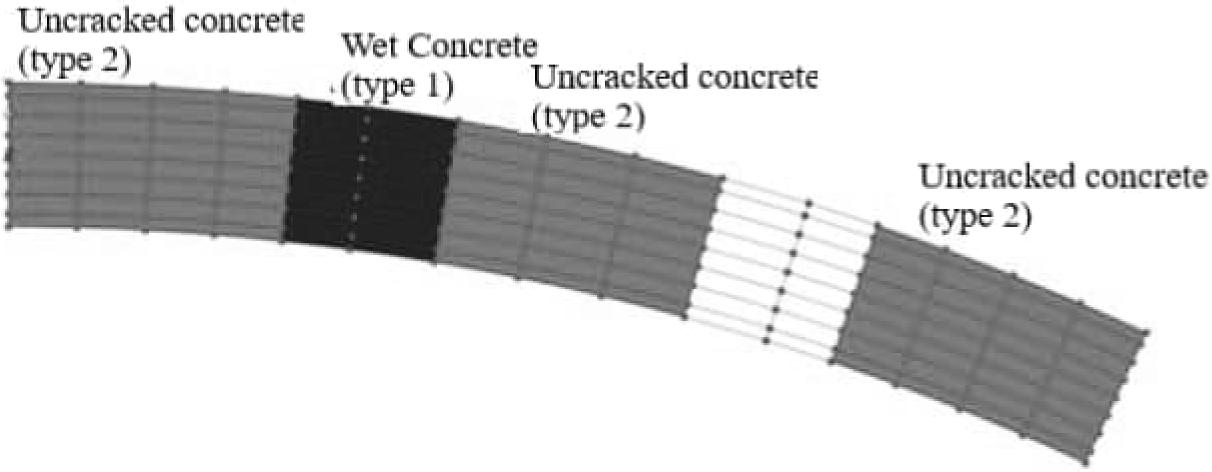


2.7.2.6 *Analysis 2 (Stage II)*

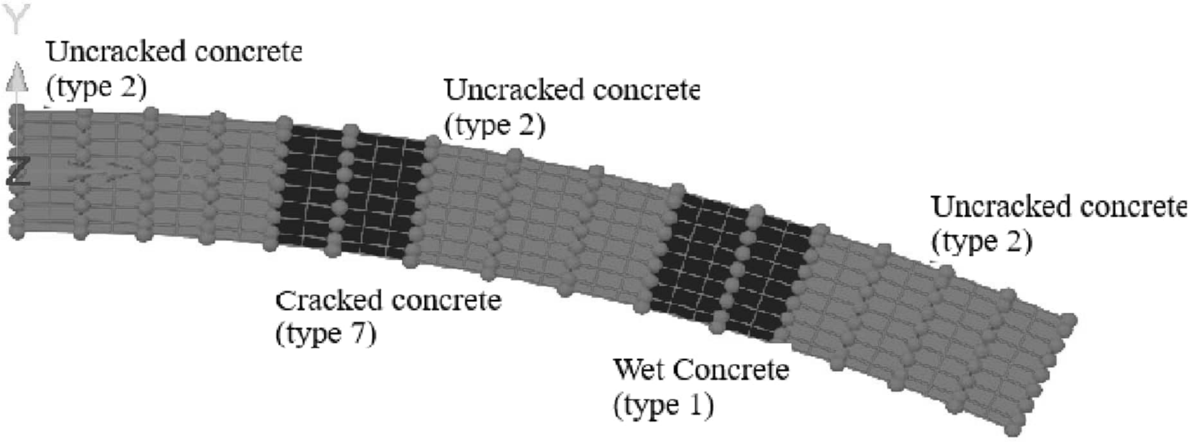
2.7.2.7 *Analysis 3 (Stage III)*



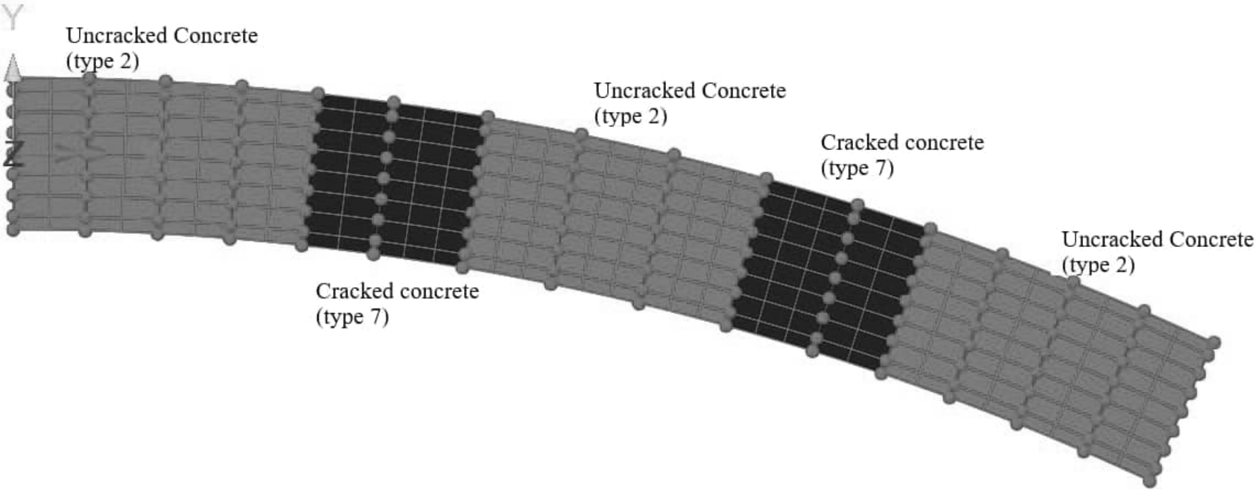
2.7.2.8 *Analysis 4 (Stage IV)*



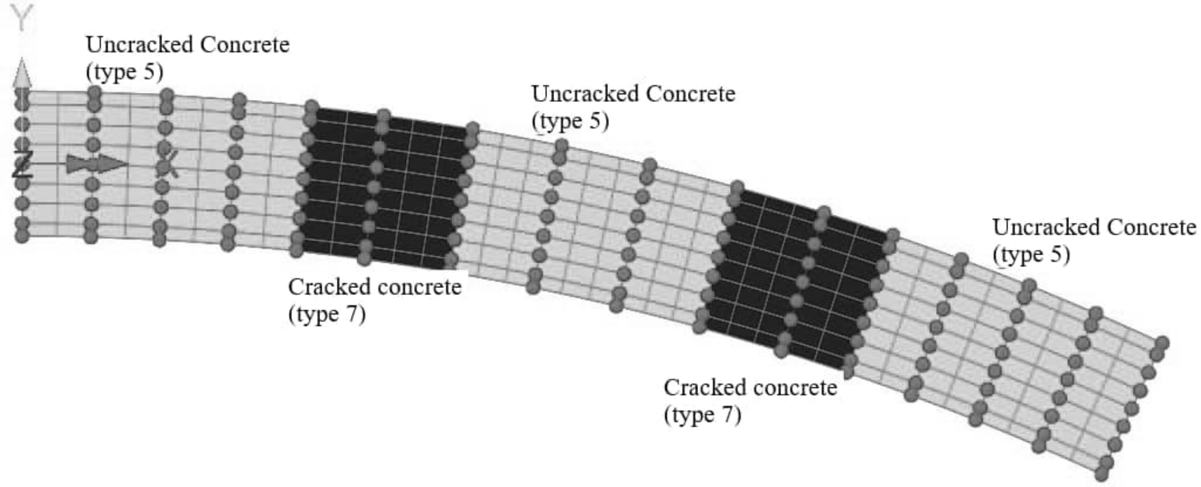
2.7.2.9 *Analysis 5 (Stage V)*



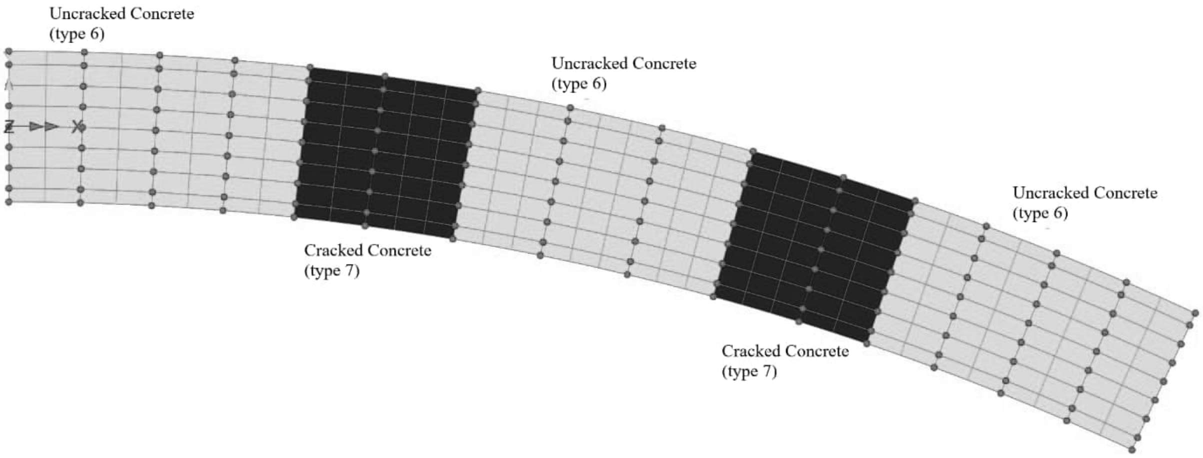
2.7.2.10 *Analysis 6 (O:PERM)*



2.7.2.11 *Analysis 7 (O:VAR)*

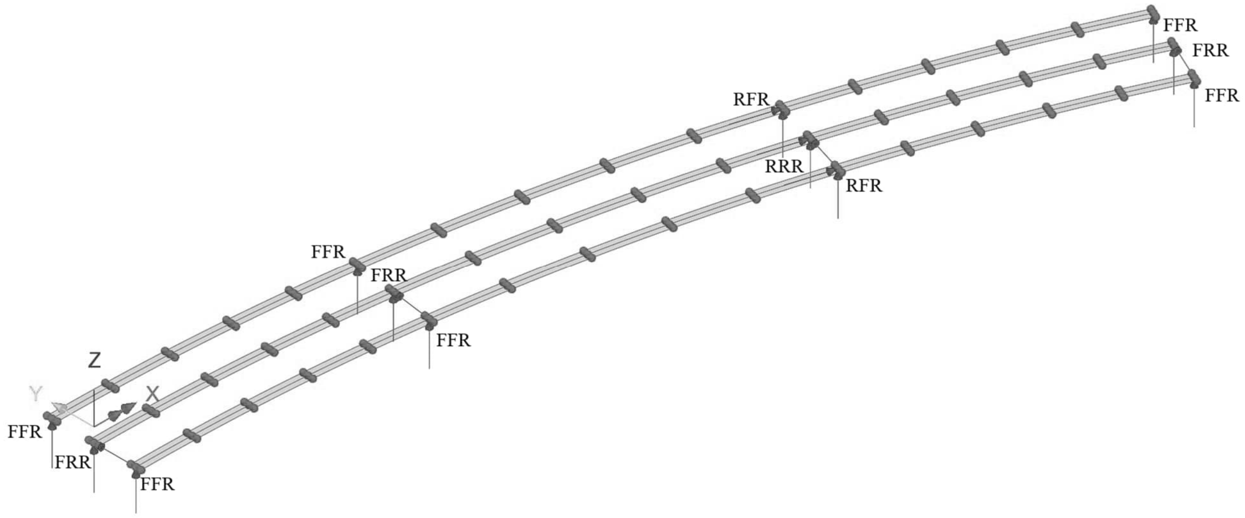


2.7.2.11 *Analysis 8 (O:TEMP)*



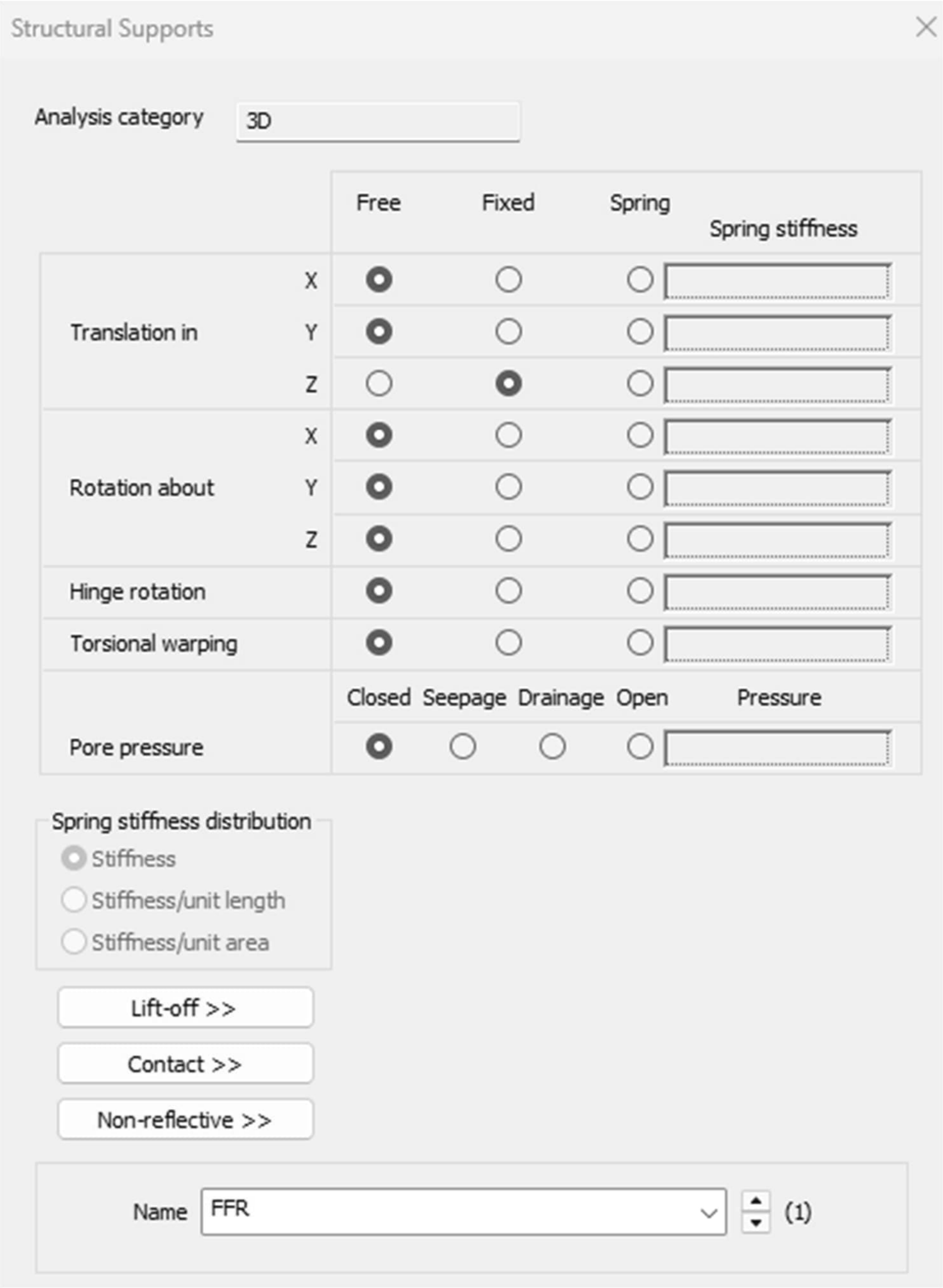
2.8 BOUNDARY CONDITIONS

At every support 4 bearings are defined as seen below. Support 3 is fixed in longitudinal direction.



Overview 3D

Bearings FFR :



Structural Supports

Analysis category: 3D

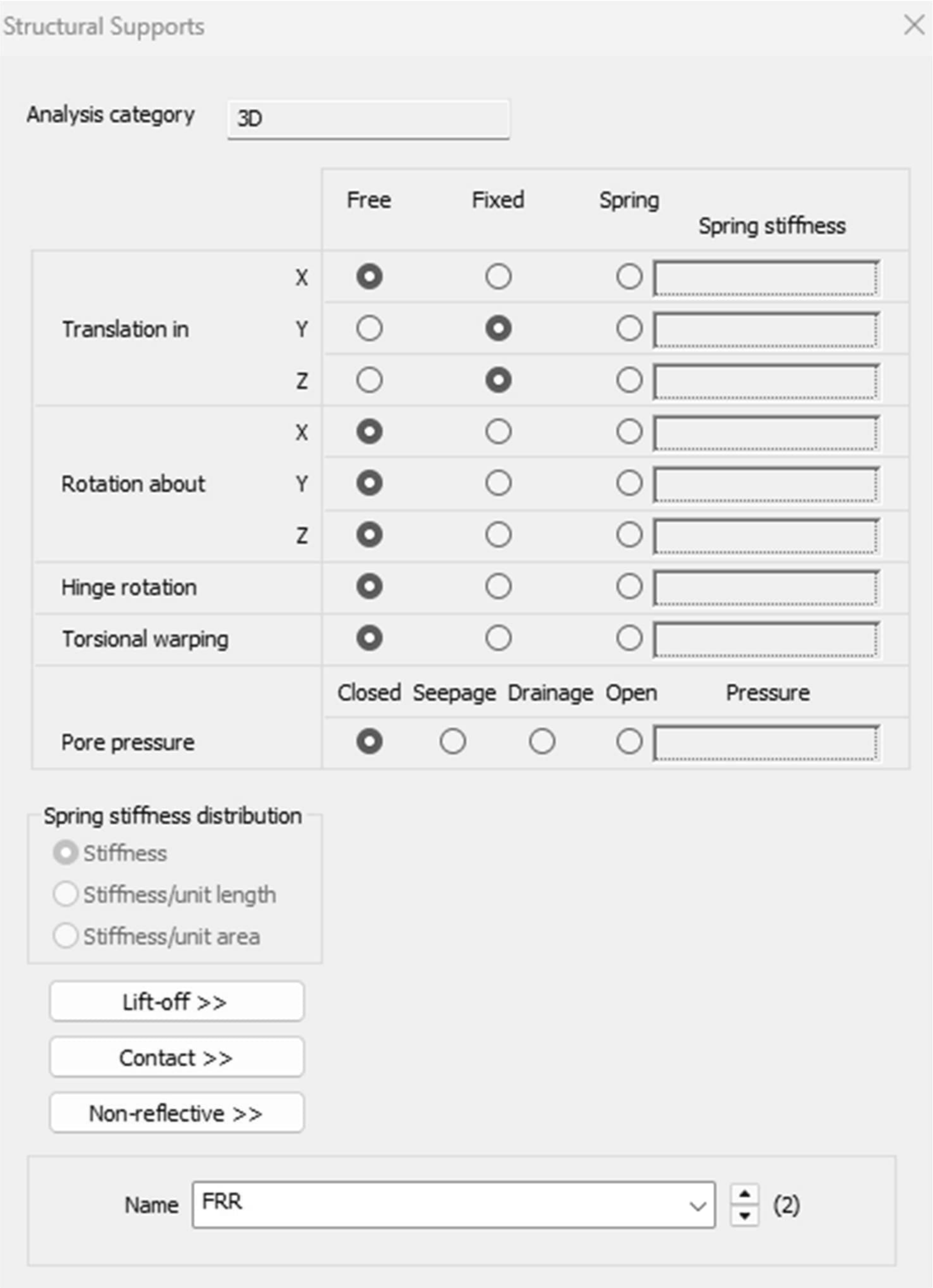
		Free	Fixed	Spring	Spring stiffness
Translation in	X	●	○	○	
	Y	●	○	○	
	Z	○	●	○	
Rotation about	X	●	○	○	
	Y	●	○	○	
	Z	●	○	○	
Hinge rotation		●	○	○	
Torsional warping		●	○	○	

	Closed	Seepage	Drainage	Open	Pressure
Pore pressure	●	○	○	○	

Spring stiffness distribution
- ● Stiffness
- ○ Stiffness/unit length
- ○ Stiffness/unit area

Name: FFR (1)

Bearings FRR :



Analysis category: 3D

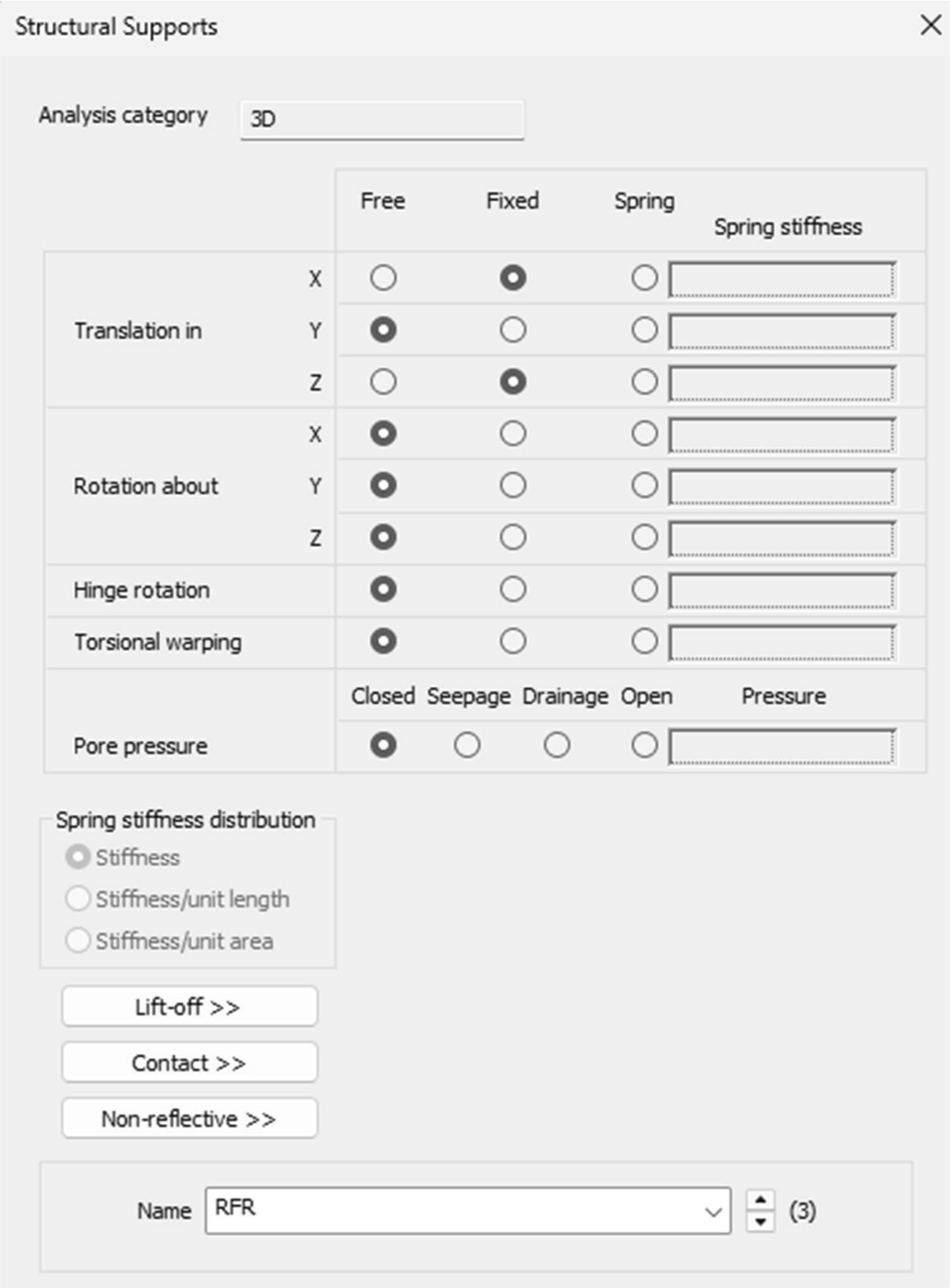
		Free	Fixed	Spring	Spring stiffness
Translation in	X	●	○	○	
	Y	○	●	○	
	Z	○	●	○	
Rotation about	X	●	○	○	
	Y	●	○	○	
	Z	●	○	○	
Hinge rotation		●	○	○	
Torsional warping		●	○	○	

	Closed	Seepage	Drainage	Open	Pressure
Pore pressure	●	○	○	○	

Spring stiffness distribution
- ● Stiffness
- ○ Stiffness/unit length
- ○ Stiffness/unit area

Name: FRR (2)

Bearings RFR :



Structural Supports

Analysis category: 3D

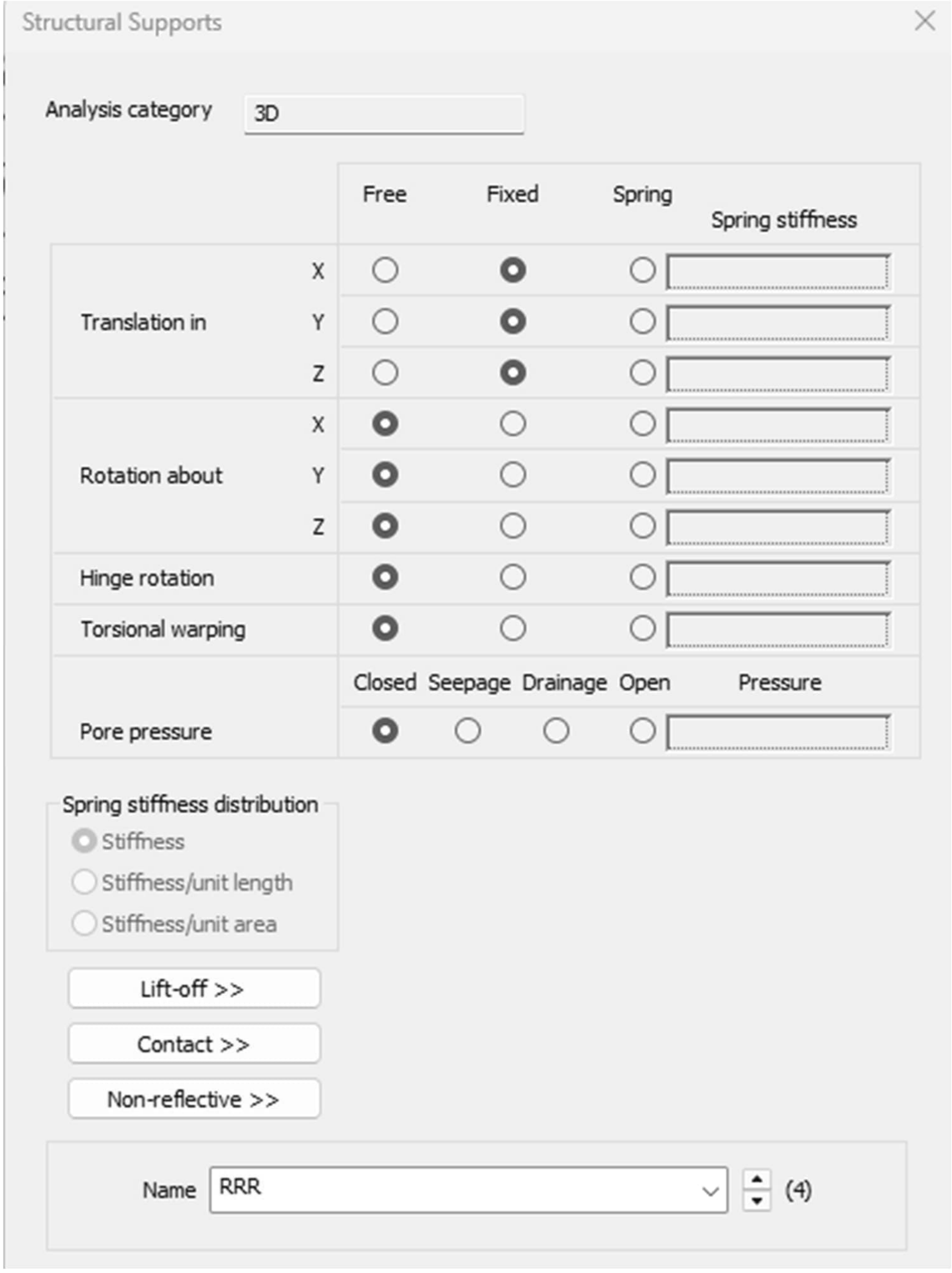
		Free	Fixed	Spring	Spring stiffness
Translation in	X	○	●	○	
	Y	●	○	○	
	Z	○	●	○	
Rotation about	X	●	○	○	
	Y	●	○	○	
	Z	●	○	○	
Hinge rotation		●	○	○	
Torsional warping		●	○	○	

	Closed	Seepage	Drainage	Open	Pressure
Pore pressure	●	○	○	○	

Spring stiffness distribution
- ● Stiffness
- ○ Stiffness/unit length
- ○ Stiffness/unit area

Name: RFR (3)

Bearings RRR :



Analysis category: 3D

		Free	Fixed	Spring	Spring stiffness
Translation in	X	○	●	○	
	Y	○	●	○	
	Z	○	●	○	
Rotation about	X	●	○	○	
	Y	●	○	○	
	Z	●	○	○	
Hinge rotation		●	○	○	
Torsional warping		●	○	○	
		Closed	Seepage	Drainage	Open / Pressure
Pore pressure		●	○	○	○

Spring stiffness distribution
- ● Stiffness
- ○ Stiffness/unit length
- ○ Stiffness/unit area

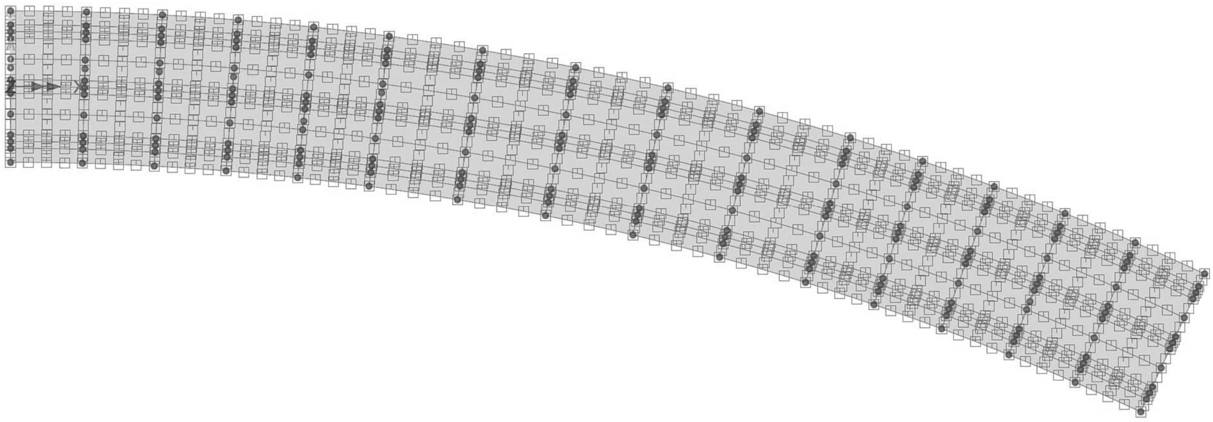
Name: RRR (4)

2.9 SEARCH AREA

Discrete load can be applied to structure as geometrical load areas. In static model load areas are termed *Search Area.*

Deck:

-

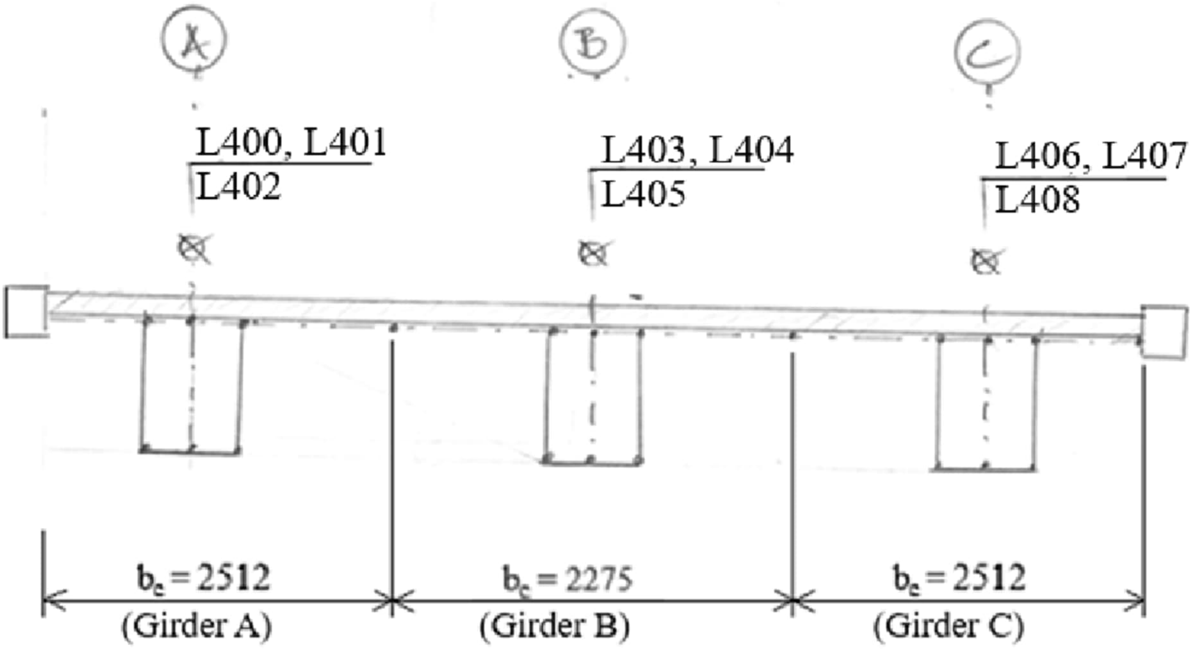


2.10 SLICE RESULTANTS BEAMS/SHELLS

Equivalent section forces will be determined at 4 sub-points for each main beam. This is done by studying load effects in the Nodal surface and Nodal line for the respective girder.

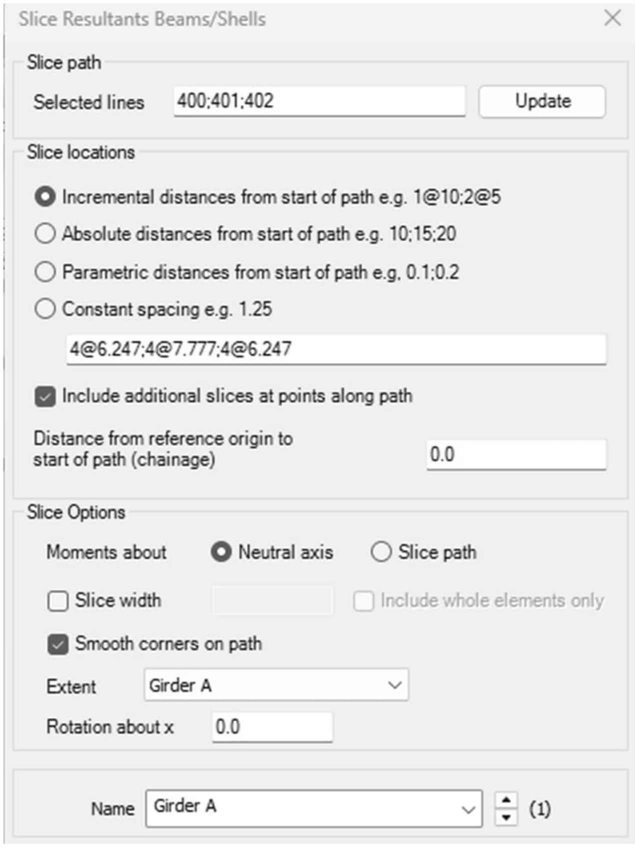
Static model has a script called "Slice Resultant Beams/Shells" to handle this, see the presentation below.

Grider	Path line	Width (b_c)	Extent
A	L400, L401, L402	2.512	Group ”Girder A”
B	L403, L404, L405	2.275	Group ”Girder B”
C	L406, L407, L408	2.512	Group ”Girder C”
-	-	m	-



2.10.1 Slice beam: Girder A

Span 1: 24.989 m = 4 x 6.247 m
Span 2: 31.108 m = 4 x 7.777 m
Span 3: 24.989 m = 4 x 6.247 m

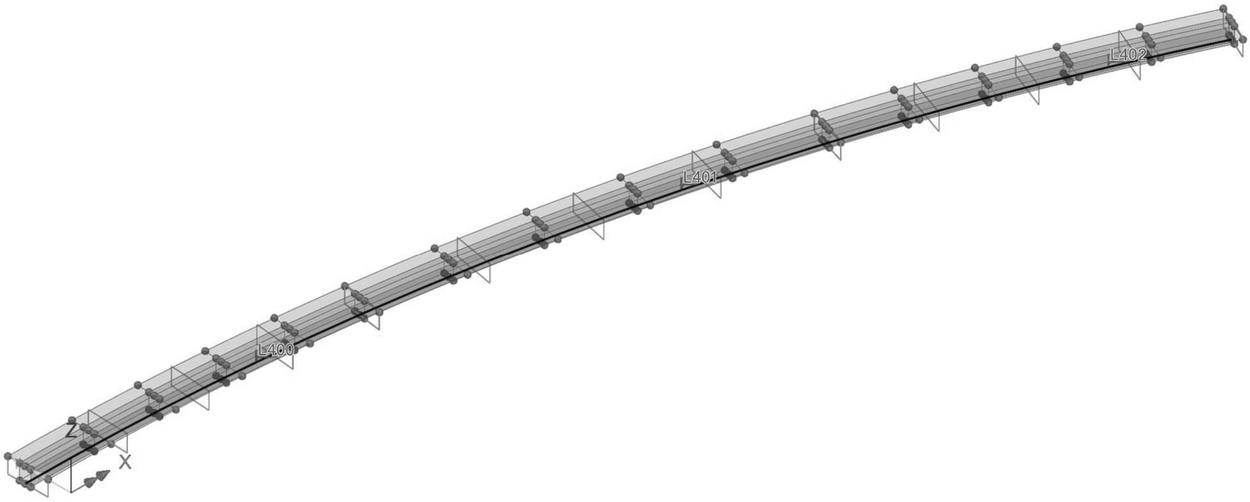

Slice Resultants Beams/Shells

Slice path
Selected lines: 400;401;402

Slice locations
● Incremental distances from start of path e.g. 1@10;2@5
○ Absolute distances from start of path e.g. 10;15;20
○ Parametric distances from start of path e.g. 0.1;0.2
○ Constant spacing e.g. 1.25
4@6.247;4@7.777;4@6.247
☑ Include additional slices at points along path
Distance from reference origin to start of path (chainage): 0.0

Slice Options
Moments about: ● Neutral axis ○ Slice path
☐ Slice width ☐ Include whole elements only
☑ Smooth corners on path
Extent: Girder A
Rotation about x: 0.0

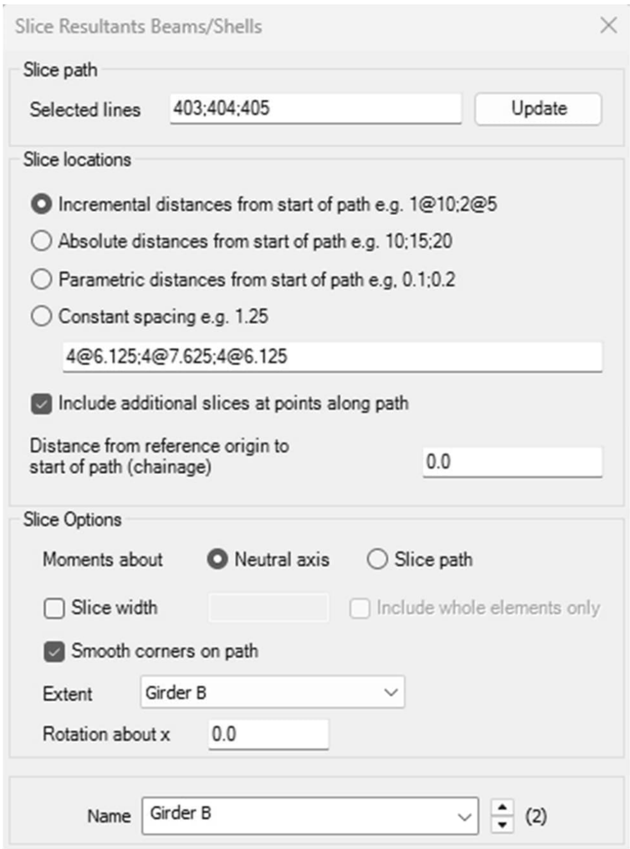
Name: Girder A (1)



OVERVIEW

2.10.2 Slice beam: Girder B

Span 1: 24.500 m = 4 x 6.125 m
Span 2: 30.500 m = 4 x 7.625 m
Span 3: 24.500 m = 4 x 6.125 m



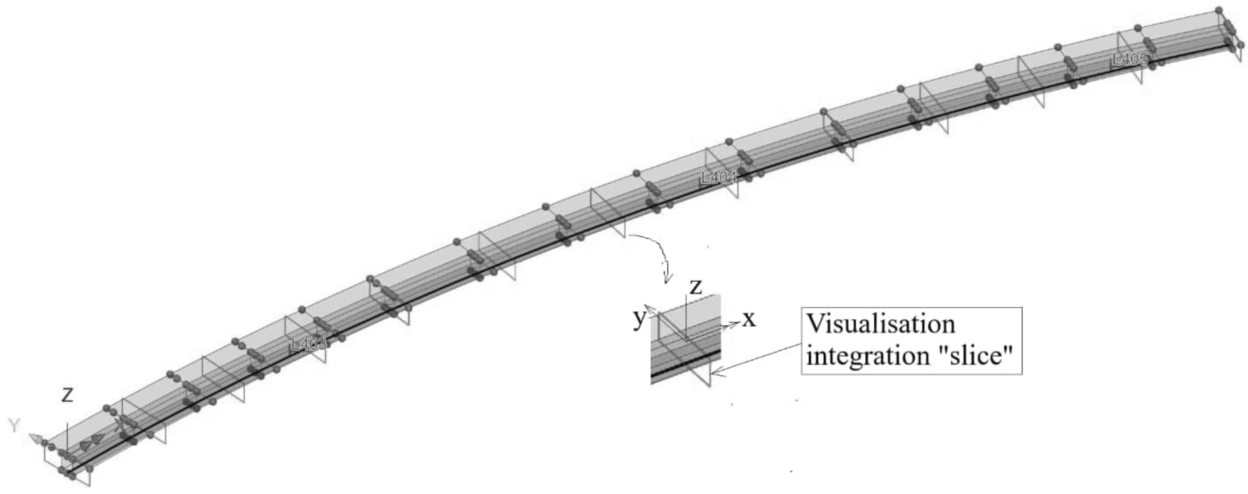
Slice Resultants Beams/Shells

Slice path
Selected lines: 403;404;405

Slice locations
● Incremental distances from start of path e.g. 1@10;2@5
○ Absolute distances from start of path e.g. 10;15;20
○ Parametric distances from start of path e.g. 0.1;0.2
○ Constant spacing e.g. 1.25
4@6.125;4@7.625;4@6.125
☑ Include additional slices at points along path
Distance from reference origin to start of path (chainage): 0.0

Slice Options
Moments about: ● Neutral axis ○ Slice path
☐ Slice width ☐ Include whole elements only
☑ Smooth corners on path
Extent: Girder B
Rotation about x: 0.0

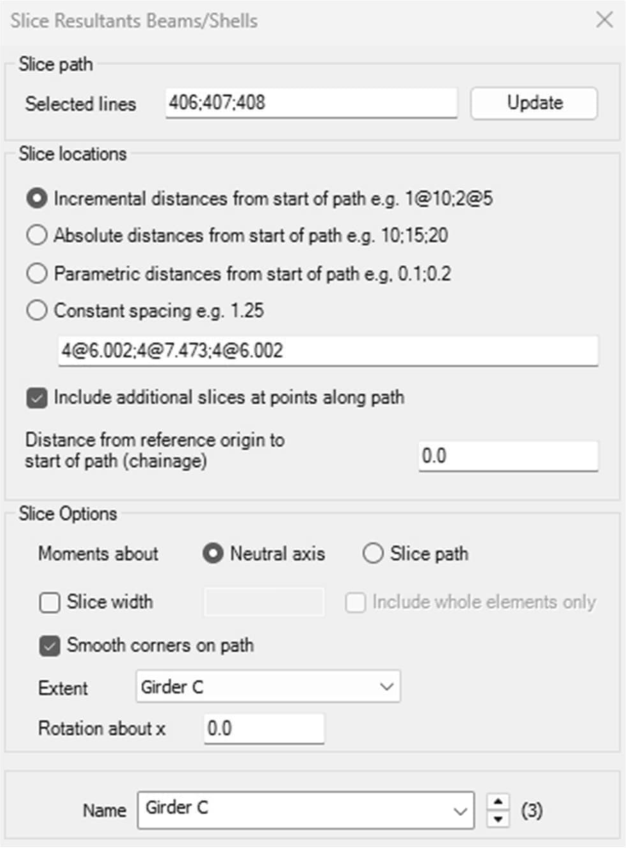
Name: Girder B (2)



OVERVIEW

2.10.3 Slice beam: Girder C

Span 1: 24.011 m = 4 x 6.002 m
Span 2: 29.892 m = 4 x 7.473 m
Span 3: 24.011 m = 4 x 6.002 m



Slice Resultants Beams/Shells

Slice path

Selected lines: 406;407;408

Slice locations

● Incremental distances from start of path e.g. 1@10;2@5
○ Absolute distances from start of path e.g. 10;15;20
○ Parametric distances from start of path e.g. 0.1;0.2
○ Constant spacing e.g. 1.25

4@6.002;4@7.473;4@6.002

☑ Include additional slices at points along path

Distance from reference origin to start of path (chainage): 0.0

Slice Options

Moments about: ● Neutral axis ○ Slice path

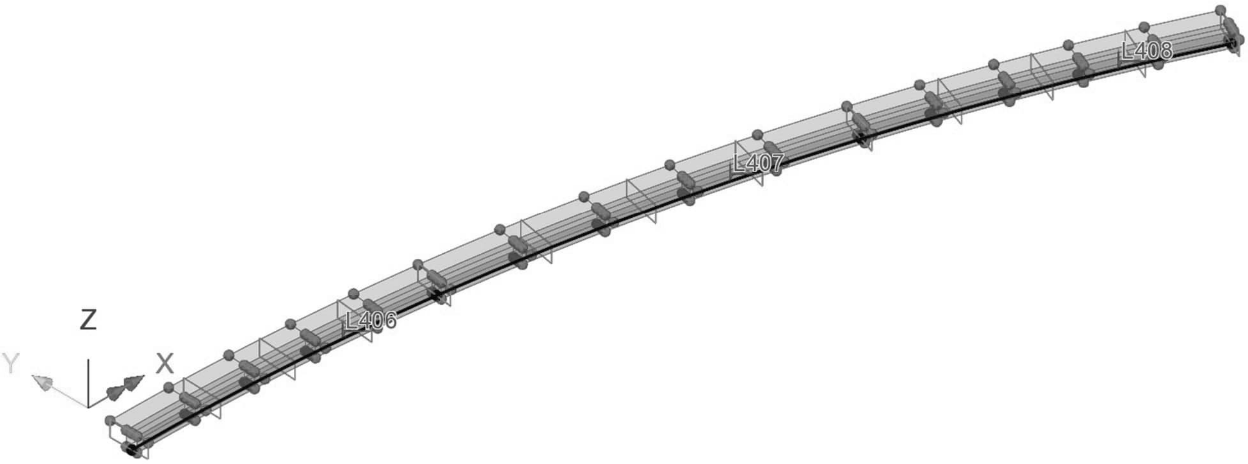
☐ Slice width ☐ Include whole elements only

☑ Smooth corners on path

Extent: Girder C

Rotation about x: 0.0

Name: Girder C (3)



OVERVIEW

2.11 FLANGE WIDTH

Flange width is determined by SS-EN 1992-1-1 section 5.3.2.1.

No reduction cross section is considered ($\therefore$ $b_{ef} \equiv b$).

3. LOADS

This worked example is only intended to illustrate software, thus the number of loads are simplified, thus only dead weight, surfacing, creep, shrinkage and traffic load is considered. (The effect of formwork is not considered in this example.)

3.1 DEAD WEIGHT

The dead weight is either steel structure or concrete deck. Densities below are applied.

$\gamma_c = 25 \cdot \frac{kN}{m^3}$: concrete

$\gamma_s = 77 \cdot \frac{kN}{m^3}$: steel

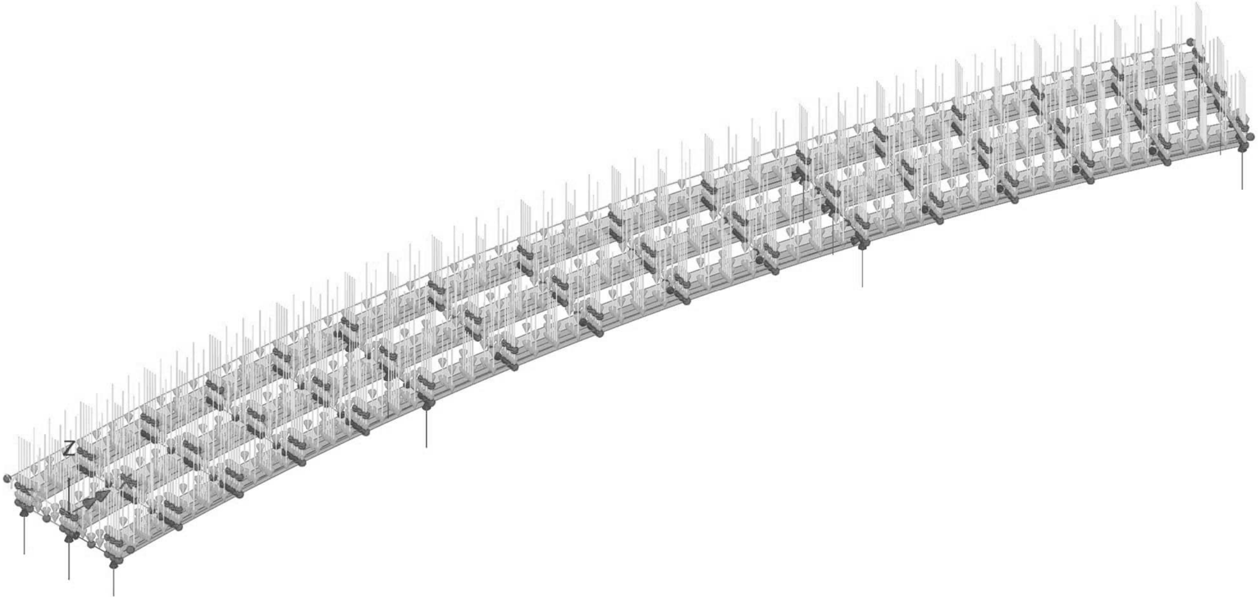
3.1.1 Steel structure (DEAD 1:S)

Load case : DEAD 1:1

Analysis: Analysis 1 (STAGE I)

Structural loading : Body force

Linear acceleration in Z (a_z) : -10 $\frac{m}{s^2}$



Overview 3D

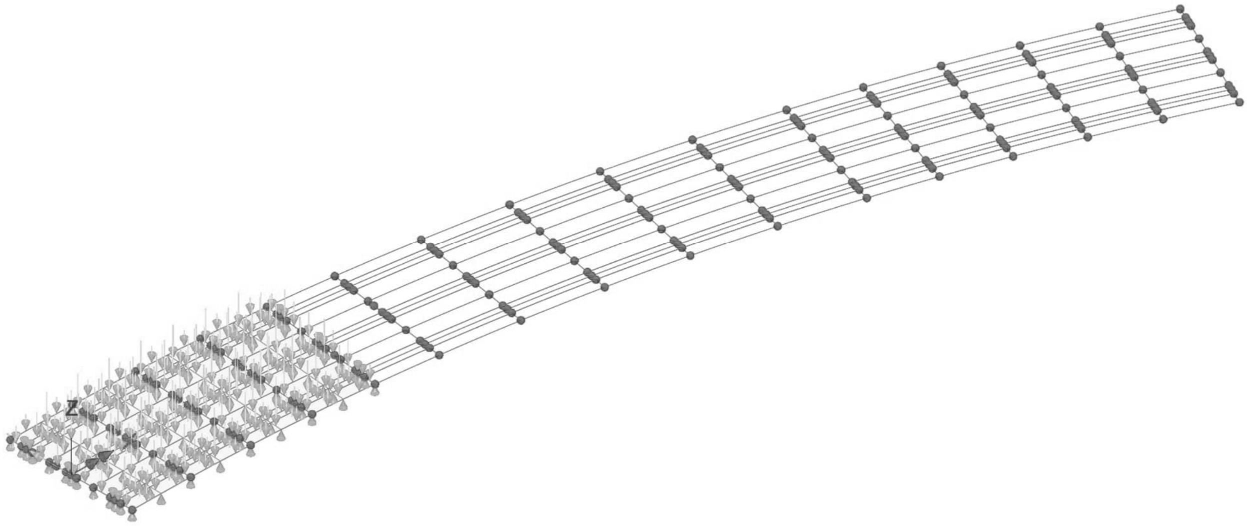
3.1.2 Concrete stage I (DEAD 1:C)

Load case : DEAD 1:C

Analysis: Analysis 1 (STAGE I)

Structural loading : Body force

Linear acceleration in Z (a_z) : -10 $\frac{m}{s^2}$



Overview 3D

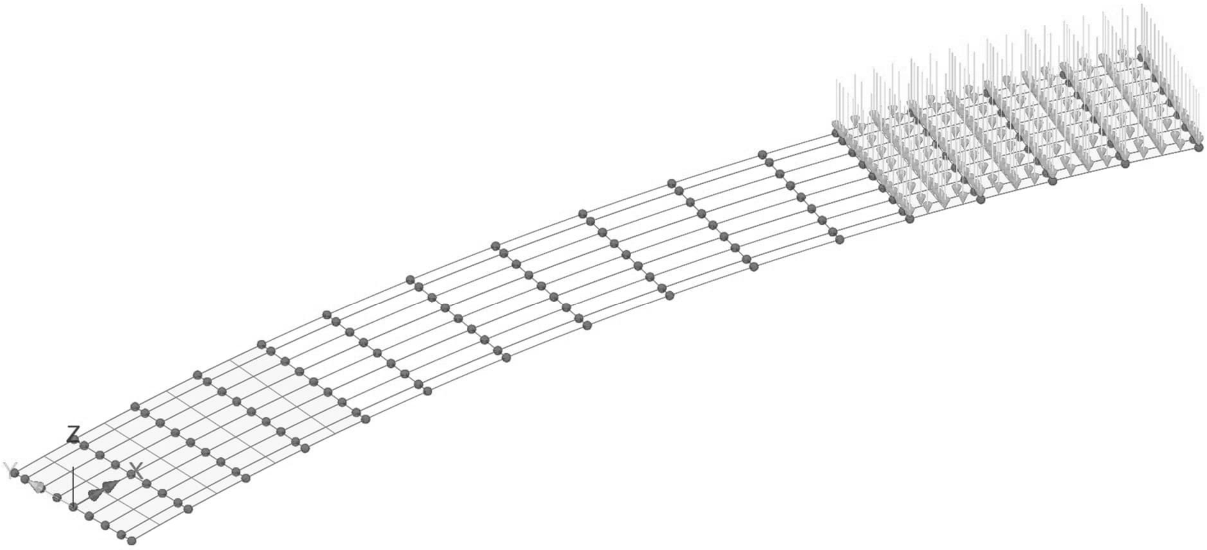
3.1.3 Concrete stage II (DEAD 2:C)

Load case : DEAD 2:C

Analysis: Analysis 2 (STAGE II)

Structural loading: Body force

Linear acceleration in Z (a_z) : -10 $\frac{m}{s^2}$



Overview 3D

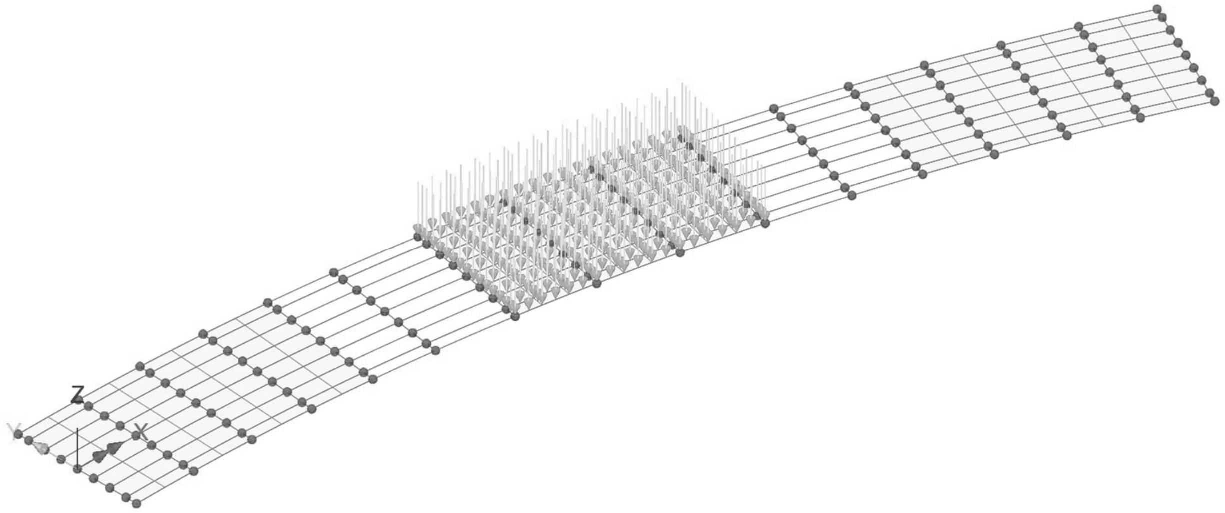
3.1.4 Concrete stage III (DEAD 3:C)

Load case : DEAD 3:C

Analysis: Analysis 3 (STAGE III)

Structural loading: Body force

Linear acceleration in Z (a_z) : -10 $\frac{m}{s^2}$



Overview 3D

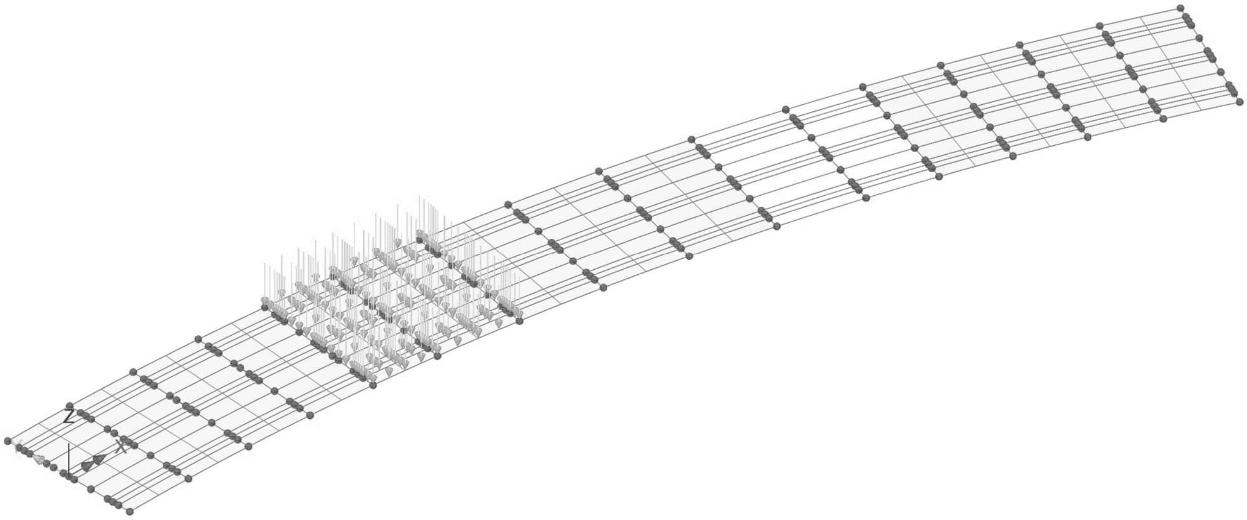
3.1.5 Concrete stage IV (DEAD 4:C)

Load case : DEAD 4:C

Analysis: Analysis 4 (STAGE IV)

Structural loading: Body force

Linear acceleration in Z (a_z) : -10 $\frac{m}{s^2}$



Overview 3D

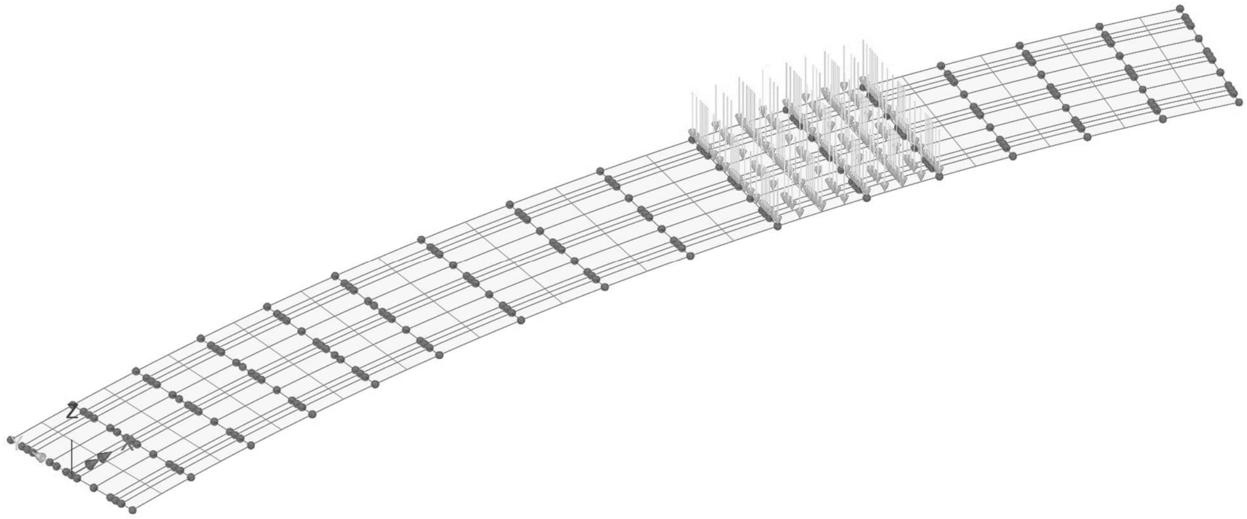
3.1.6 Concrete stage V (DEAD 5:C)

Load case : DEAD 5:C

Analysis: Analysis 5 (STAGE V)

Structural loading: Body force

Linear acceleration in Z (a_z) : -10 $\frac{m}{s^2}$



Overview 3D

3.1.7 Edge beams including railing (DEAD 6)

Along each edge bream a line load is introduced. The load includes weight of edge beam and railing. The edge beam is assumed to be cast after completion stage I-V, thus analysis 6.

$p_{railing} = 0.7\frac{kN}{m}$: weight railing

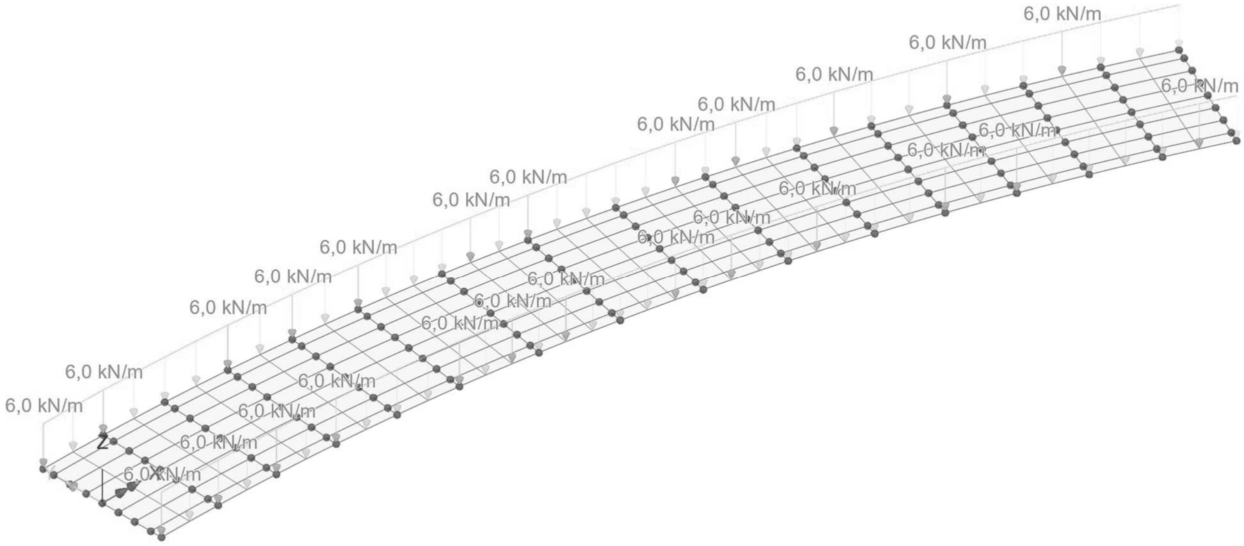
$\rightarrow p_z = p_{railing} + p_{EB} = 0.7\frac{kN}{m} + 0.40m \cdot 0.45m \cdot 25\frac{kN}{m^3} = -6\frac{kN}{m}$

Load case : DEAD 6

Analysis: Analysis 6 (O:PERM)

Structural loading : Global distributed

Line load per unit length in Z direction: -6 $\frac{kN}{m}$



Overview 3D

3.1.8 Load combination deadweight (DEAD)

Basic load combination DEAD:

Loadcase	Factor
DEAD 1:S	1.00
DEAD 1:C	1.00
DEAD 2:C	1.00
DEAD 3:C	1.00
DEAD 4:C	1.00
DEAD 5:C	1.00
DEAD 6	1.00

3.2 SURFACING

Thickness pavement with a thickness of 95 mm built as follows:

- Wearing course ABS 11	40 mm
- Combined protective and binder course PGJA	50 mm
- Waterproofing layer	5 mm

$\gamma = 23\frac{kN}{m^3}$: course

$q_{mat} = 0.11kPa$: waterproofing

$$\rightarrow q_{surf} = \gamma \cdot t + q_{matta} = 23\frac{kN}{m^3} \cdot 0.09m + 0.11kPa = 2.2kPa$$

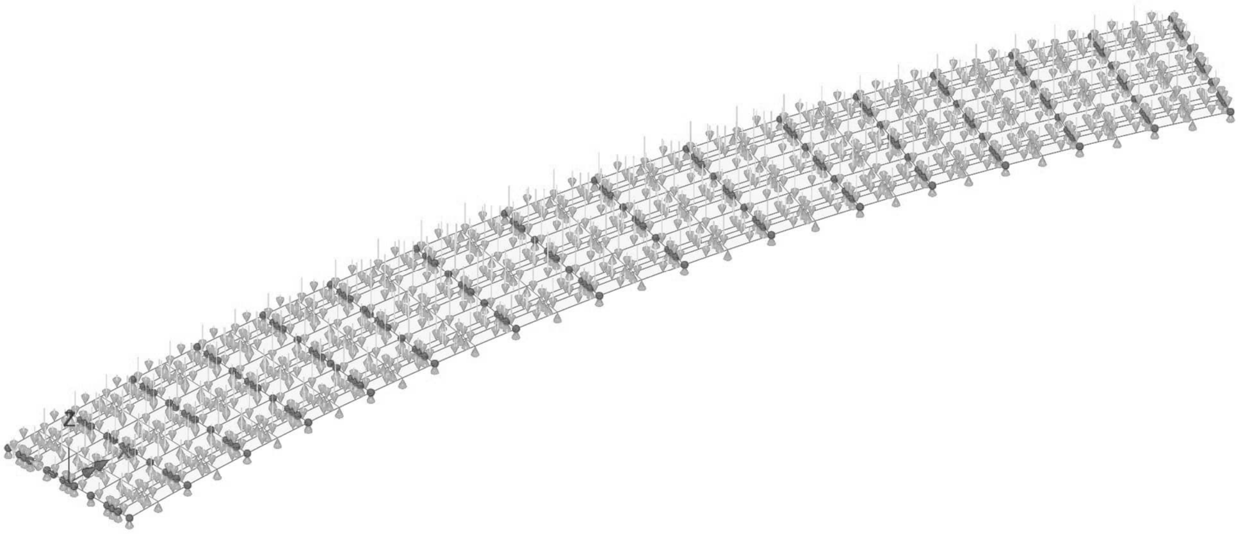
Load : SURF

Analysis: Analysis 6 (O:PERM)

Structural loading : Global distributed

Load per unit area in Z direction (q_z) : -2.2 kPa

Loadcase : SURF



Overview 3D

3.3 CREEP

Total creep is determined according to SS-EN 1992-1-1 §3.1.4 and TRVINFRA-00227 section 7.1.6.4 for RH 80% at time t_1.

Time for first loading (= time when formwork was removed) is termed t_0.

$$t_0 = 5\ days$$

$$t_1 = 120\ years$$

On safe side $\phi(t_1, t_0) = 2.0$ is applied.

$$\varepsilon_{cc}(t_1, t_0) = \varphi(t_1, t_0) \cdot \frac{\sigma_c}{E_c}$$

To study the effect concrete stiffness according to SS-EN 1992-1-1 5.8.7 creep values seen below are used.

Load cases	φ
Permanent	2.0
Variable excluding temperature	0
Temperature	0.3*

* = According to Swedish work practice

$$E^{system} = \frac{E_{cm}}{1+\varphi}$$

Instead of adjusting E-modulus the load coefficients are adjusted.

$$f_{shrinkage} = \frac{1}{1+\varphi_{ef}} = \frac{1}{1+2.0} = 0.33$$

$$f_{temp} = \frac{1}{1+\varphi_{ef}} = \frac{1}{1+0.3} = 0.77$$

Note:
According to TRVINFRA-00227 section 7.2.1.1.2.4, no reduction is permitted for uneven temperature across the cross-section. This is because this temperature variation is considered to have a very short duration (only over the day).

3.4 SHRINKAGE

Load applied to Analysis : *Analysis 6*

Total shrinkage according to SS-EN 1992-1-1 §3.1.4 and TRVINFRA-00227 section 7.1.6.4 for RH 80% at time t_1.

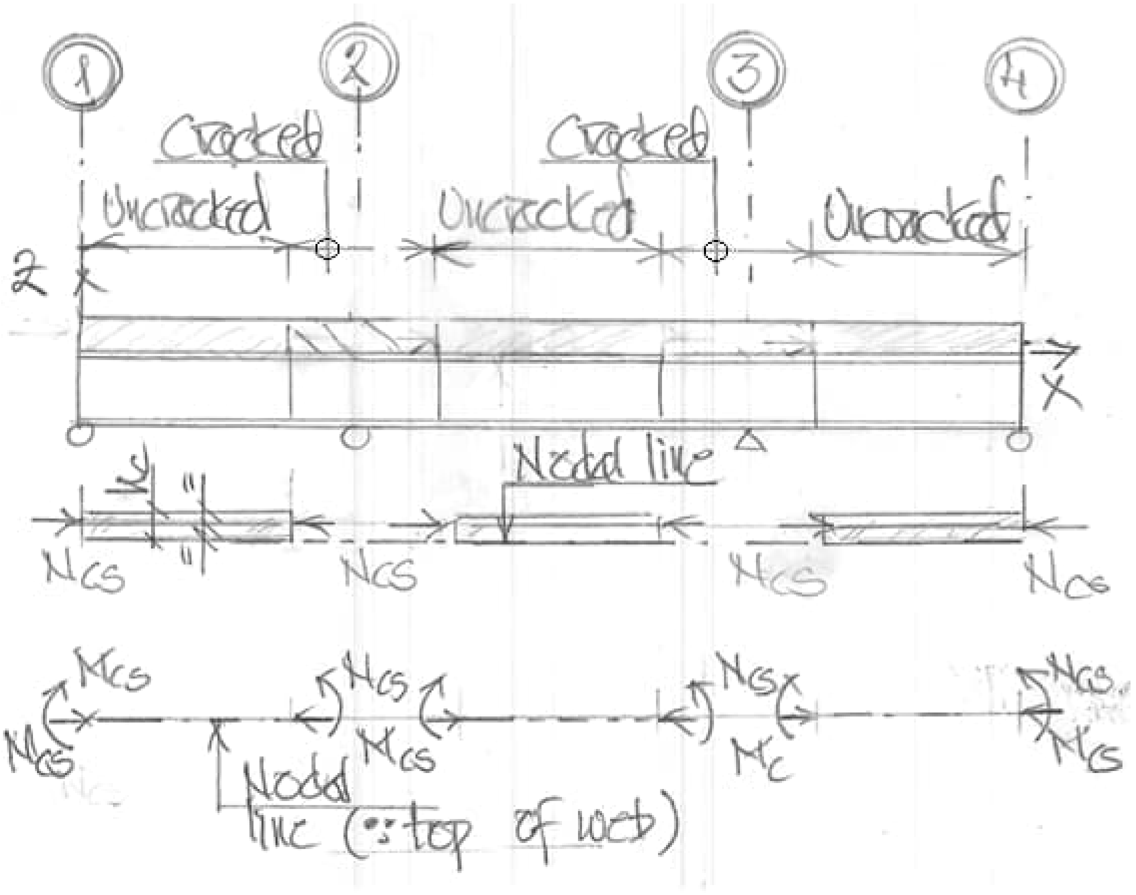
Determination of load effect from shrinkage should consider the reduced concrete stiffness from creep.

$t_s = 0\ days$

$t_1 = 120\ years$

On safe side $\varepsilon_{cs}\ (t_1) = 0.025\%$ is applied.

Shrinkage corresponds to movement due to an imaginary temperature load ∴ T = -25°C but a normal force (N_{cs}) is instead inserted at centre of deck at location of uncracked concrete. These force arises due to prevented movement by steel girder.



Uncracked concrete (girder A & C):

$$0.5N_{cs.1} = \frac{\varepsilon_{cs}}{2} \cdot \frac{E_{cm}}{1 + \psi_L \cdot \phi_{t1}} \cdot h_c \cdot b_c = \frac{0.25 \cdot 10^{-3}}{2} \cdot \frac{34 \cdot 10^6 kPa}{1 + 0.55 \cdot 2.0} \cdot 0.20m \cdot 2.512m = 1017kN$$

$$0.5M_{cs.1} = 0.5N_{cs.1} \cdot (t_c + 0.5h_c) = 1017kN \cdot (0m + 0.5 \cdot 0.20m) = 102kNm$$

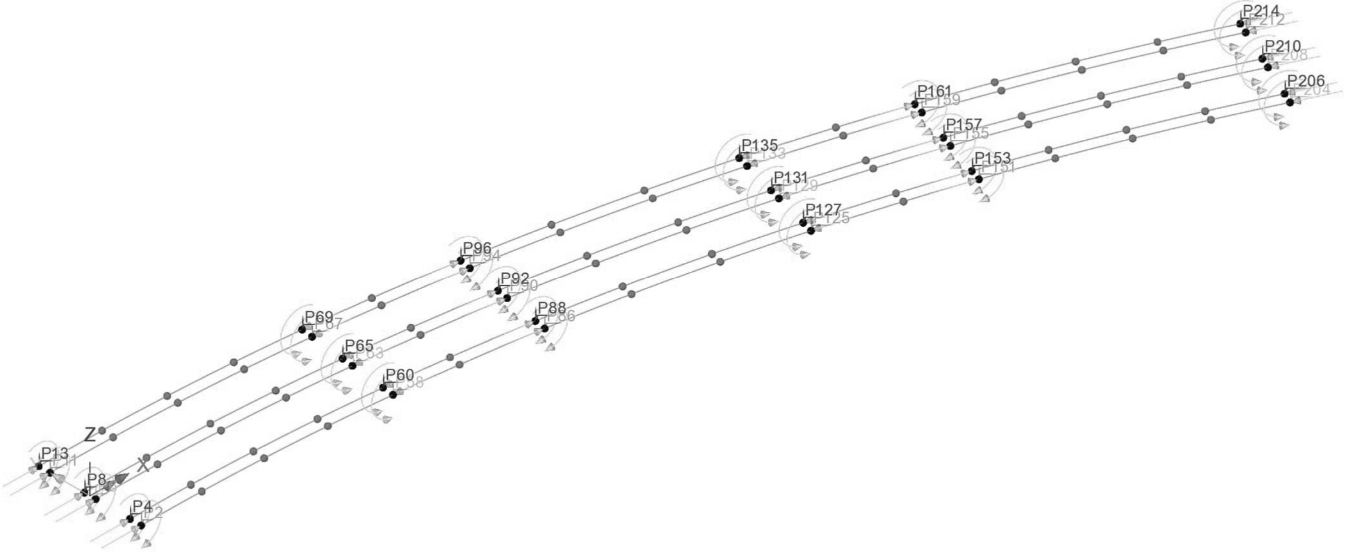
Uncracked concrete (girder B):

$$0.5N_{cs.2} = \frac{\varepsilon_{cs}}{2} \cdot \frac{E_{cm}}{1 + \psi_L \cdot \phi_{t1}} \cdot h_c \cdot b_c = \frac{0.25 \cdot 10^{-3}}{2} \cdot \frac{34 \cdot 10^6 kPa}{1 + 0.55 \cdot 2.0} \cdot 0.20m \cdot 2.275m = 921kN$$

$$0.5M_{cs.2} = 0.5N_{cs.2} \cdot (t_c + 0.5h_c) = 0.5 \cdot 1842kN \cdot (0\,m + 0.5 \cdot 0.20m) = 92kNm$$

Cracked concrete :

$$0.5N_{cs} = 0kN$$



3D Overview

Load : Ncs:1+

Analysis : Analysis 6 (O:PERM)

Structural loading : Internal beam point

Point load in X direction (P_x) : 1017 kN

Point moment around Y direction (M_y) : 102 kNm

Distance along local element (parametric) : 0

Load direction : Element local

Load position : About nodal line

Points: P2, P4, P11, P13, P86, P88, P94, P96, P151, P153, P159 & P161

Load case : SHRINKAGE

Load : Ncs:1-

Analysis : Analysis 6 (O:PERM)

Structural loading : Internal beam point

Point load in X direction (P_x) : -1017 kN

Point moment around Y direction (M_y) : -102 kNm

Distance along local element (parametric) : 1.0

Load direction : Element local

Load position : About nodal line

Points: P58, P60, P67, P69, P125, P127, P133, P135, P204, P206, P212 & P214

Load case : SHRINKAGE

Load : Ncs:2+

Analysis : Analysis 6 (O:PERM)

Structural loading : Internal beam point

Point load in X direction (P_x) : 921 kN

Point moment around Y direction (M_y) : 92 kNm

Distance along local element (parametric) : 0

Load direction : Element local

Load position : About nodal line

Points: P6, P8, P90, P92, P155 & P157

Load case : SHRINKAGE

Load : Ncs:2-

Analysis : Analysis 6 (O:PERM)

Structural loading : Internal beam point

Point load in X direction (P_x) : -921 kN

Point moment around Y direction (M_y) : -92 kNm

Distance along local element (parametric) : 1.0

Load direction : Element local

Load position : About nodal line

Points: P63, P65, P129, P131, P208 & P210

Load case : SHRINKAGE

3.5 TEMPERATURE

Temperature effect bridges according to TSFS section B.3.2.5 and EN 1991-1-5 chapter 6.

Effect in service state see SS-EN 1992-1-1 §2.3.1.2. If used then apply effect of gradual cracking according to SS-EN 1992-1-1 §5.4(3).

Effect in ultimate state is not required according to SS-EN 1992-1-1 §2.3.1.2. If used apply reduced stiffness according to SS-EN 1992-1-1 §5.4(3).

Casting temperature, $T_{mont} = +10° C$: EN 1991-1-5A.1(3)

Expansion coefficient, $\alpha = 12 \cdot 10^{-6}$

Concrete slab ⇒ typ 2

Location : Skellefteå

$T_{max} = +34℃$: TSFS chapter 8 sketch 8.1
$T_{min} = -42℃$: TSFS chapter 8 sketch 8.2

Duration coefficients :

Coefficients according to SS-EN 1990/A1 table A2.3

$\psi_0 = 0.60$
$\psi_1 = 0.60$
$\psi_2 = 0.50$

System superstructure:
Analysis 8 is used (see page A2:6).

3.5.1 Even temperature over entire bridge

Even temperature over entire bridge according to EN 1991-1-5 section 6.1.3.3. This temperature variation is seasonal and mainly gives rise to translation relative centre of movement located at support 3 where bearings are fixed.

Function according to SS-EN 1991-1-5 sketch 6.1 (bridge type 2):

$$T_e(T) = \mathrm{linterp}\left[(-50 \quad 0 \quad 30 \quad 50)^T \cdot {}^\circ C, (-46 \quad 5 \quad 34 \quad 54)^T \cdot {}^\circ C, T\right]$$

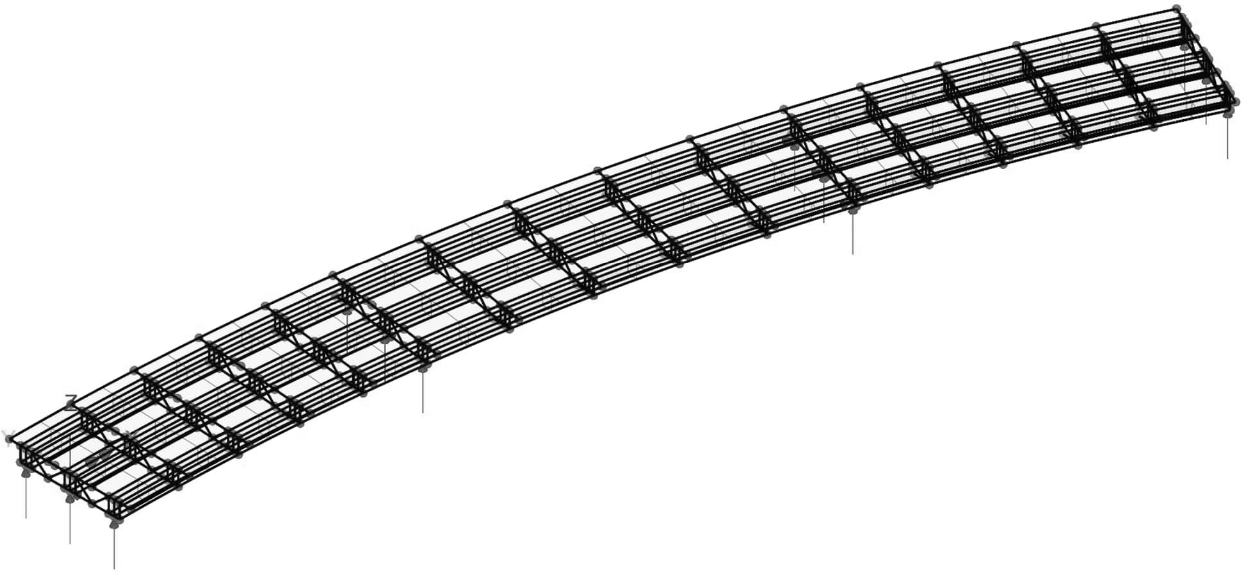
$$T_{e.max} = T_e\left(T_{max}\right) = 38\,{}^\circ C$$

$$T_{e.min} = T_e\left(T_{min}\right) = -38\,{}^\circ C$$

$$T^+ = T_{e.max} - T_0 = +38℃ - 10℃ = +28℃$$

$$T^- = T_{e.min} - T_0 = -38℃ - 10℃ = -48℃$$

Since temperature only gives rise to movement it is not added to this design report.



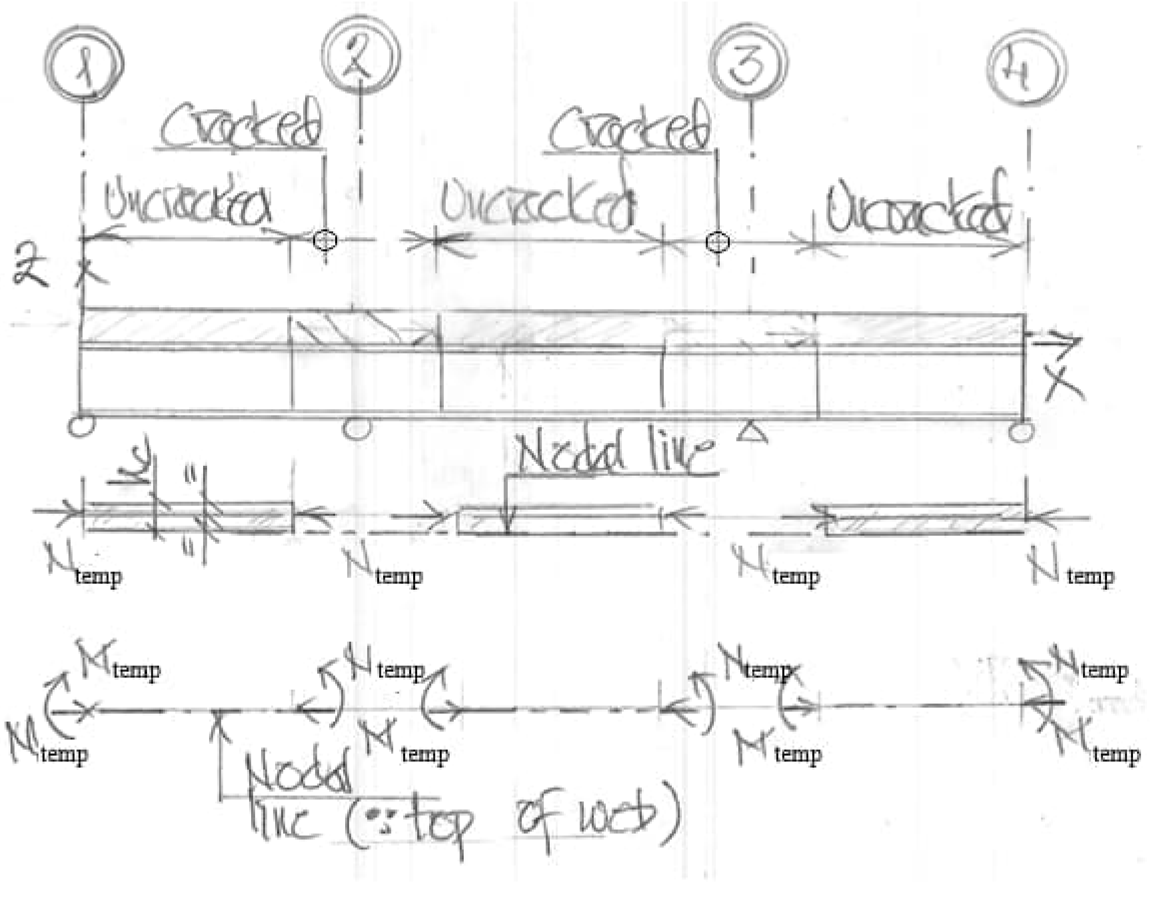
3.5.2 Uneven temperature between parts of cross section (UTEMP)

The linear temperature difference across the cross-section is determined according to the simplified procedure in EN 1991-1-5, clause 6.1.4.2 (method 2). Bridge superstructure type 2 (composite

$\Delta T_{\max} = +10°C$: top surface warmer

$\Delta T_{\min} = -10°C$: bottom surface warmer

The effect of temperature is disregarded in cracked areas while it is considered in uncracked areas as seen in stech below.



Uncracked concrete (girder A & C):

$$0.5N_{temp.1} = \pm\frac{\alpha}{2}\cdot\frac{E_{cm}}{1+\psi_L\cdot\phi_{t1}}\cdot \mathit{\Delta} T\cdot h_c\cdot b_c = \pm\frac{10^{-5}}{2}\cdot\frac{34\cdot 10^6 kPa}{1+1.0\cdot 0.3}\cdot 10°C\cdot 0.20m\cdot 2.512m \ldots$$

$$= \pm 656kN$$

$$0.5M_{temp.1} = 0.5N_{temp.1}\cdot(t_c + 0.5h_c) = \pm 656kN\cdot(0\,m + 0.5\cdot 0.20m) = \pm 66kNm$$

Uncracked concrete (girder B):

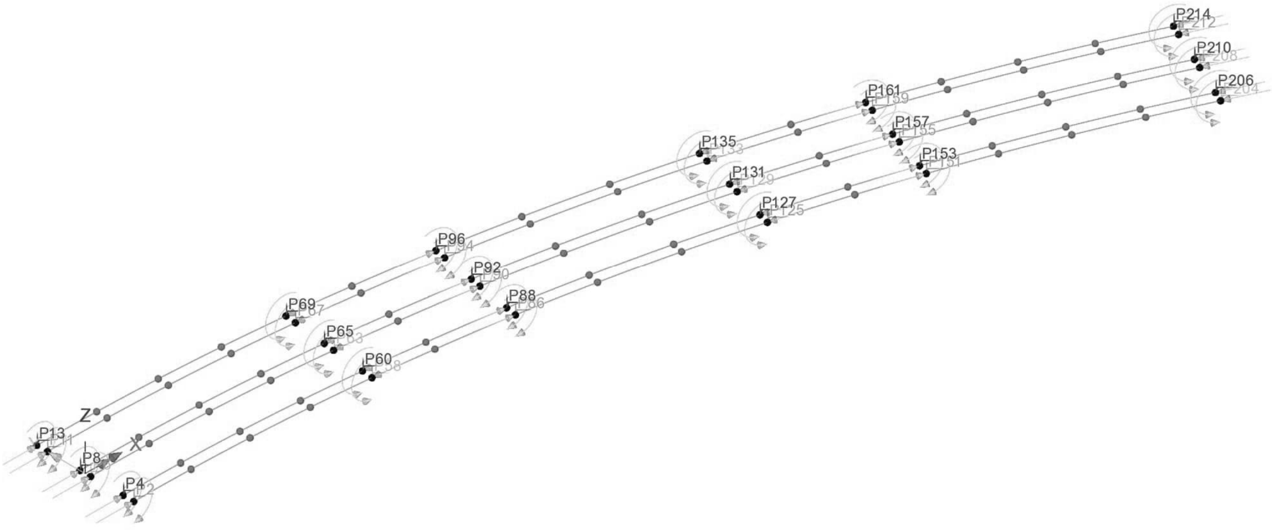
$$0.5N_{temp.2} = \pm\frac{\alpha}{2}\cdot\frac{E_{cm}}{1+\psi_L\cdot\phi_{t1}}\cdot \mathit{\Delta} T\cdot h_c\cdot b_c = \pm\frac{10^{-5}}{2}\cdot\frac{34\cdot 10^6 kPa}{1+1.0\cdot 0.3}\cdot 10°C\cdot 0.20m\cdot 2.275m \ldots$$

$$= \pm 596kN$$

$$0.5M_{temp.2} = 0.5N_{temp.1}\cdot(t_c + 0.5h_c) = \pm 596kN\cdot(0\,m + 0.5\cdot 0.20m) = \pm 60kNm$$

Cracked concrete :

$$0.5N_{temp} = 0kN$$



3D Overview

Load : Ntemp:1+

Analysis : Analysis 8 (O:TEMP)

Structural loading : Internal beam point

Point load in X direction (P_x) : 656 kN

Point moment around Y direction (M_y) : 66 kNm

Distance along local element (parametric) : 0

Load direction : Element local

Load position : About nodal line

Points: P2, P4, P11, P13, P86, P88, P94, P96, P151, P153, P159 & P161

Load case : UTEMP+

Load : Ntemp:1-

Analysis : Analysis 8 (O:TEMP)

Structural loading : Internal beam point

Point load in X direction (P_x) : -656 kN

Point moment around Y direction (M_y) : -66 kNm

Distance along local element (parametric) : 1.0

Load direction : Element local

Load position : About nodal line

Points: P2, P4, P11, P13, P86, P88, P94, P96, P151, P153, P159 & P161

Load case : UTEMP+

Load : Ntemp:2+

Analysis : Analysis 8 (O:TEMP)

Structural loading : Internal beam point

Point load in X direction (P_x) : 596 kN

Point moment around Y direction (M_y) : 60 kNm

Distance along local element (parametric) : 0

Load direction : Element local

Load position : About nodal line

Points: P63, P65, P129, P131, P208 & P210

Load case : UTEMP+

Load : Ntemp:2-

Analysis : Analysis 8 (O:TEMP)

Structural loading : Internal beam point

Point load in X direction (P_x) : -596 kN

Point moment around Y direction (M_y) : -60 kNm

Distance along local element (parametric) : 1.0

Load direction : Element local

Load position : About nodal line

Points: P63, P65, P129, P131, P208 & P210

Load case : UTEMP+

3.5.3 Uneven temperature across the cross section

The linear temperature difference across the cross-section is determined according to EN 1991-1-5 § 6.1.4.1 for a deck thickness of 100 mm and type 2 (composite bridge).

$$k_{1.sur} = 1.00$$

$$k_{2.sur} = 1.00$$

$\Delta T_{\max} = +15°C \cdot k_{1.sur} = +15°C$: top surface warmer

$\Delta T_{\min} = -18°C \cdot k_{2.sur} = -18°C$: bottom surface warmer

Remark

The described uneven temperature across the cross-section is considered to produce a lower load effect than between parts of cross section (UTEMP). For this read the load is not added to design report.

3.5.4 Combination of uniform and uneven temperature

Combination is done according to SS-EN 1991-1-5 section 6.1.5.

For design, however, the safe side is applied, which gives the load combination as shown below.

3.5.4 Kombination av jämn och ojämn temperatur

Kombinering sker enligt SS-EN 1991-1-5 avsnitt 6.1.5.

During design, however $\omega_M = 1.0$ and $\omega_N = 1.0$ are applied on safe side.

Smart Load combination *TEMP :*

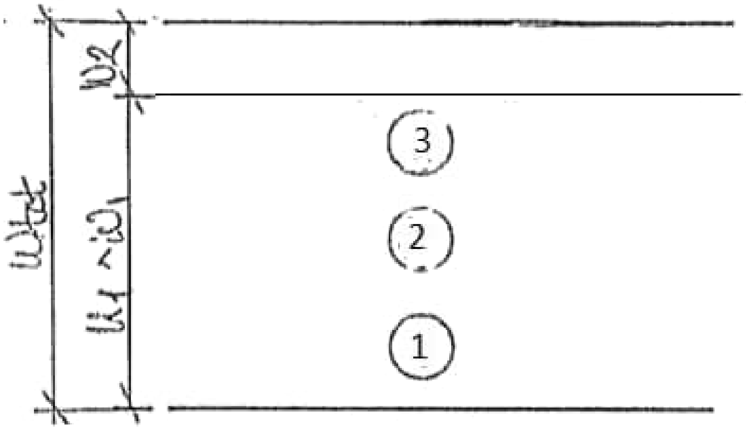
Load case	Permanent factor	Variable factor
UTEMP+	0	+1.00
UTEMP+	0	-1.00

3.6 TRAFFIC

Load applied to Analysis : Analysis 7 (O:VAR)

Evaluation of vertical traffic is performed for LM 1 and LM 2 according to SS-EN 1991-2 section 4.3.

3.6.1 Traffic lane division



Total traffic width : $w_{tot} = 10.05\ m$

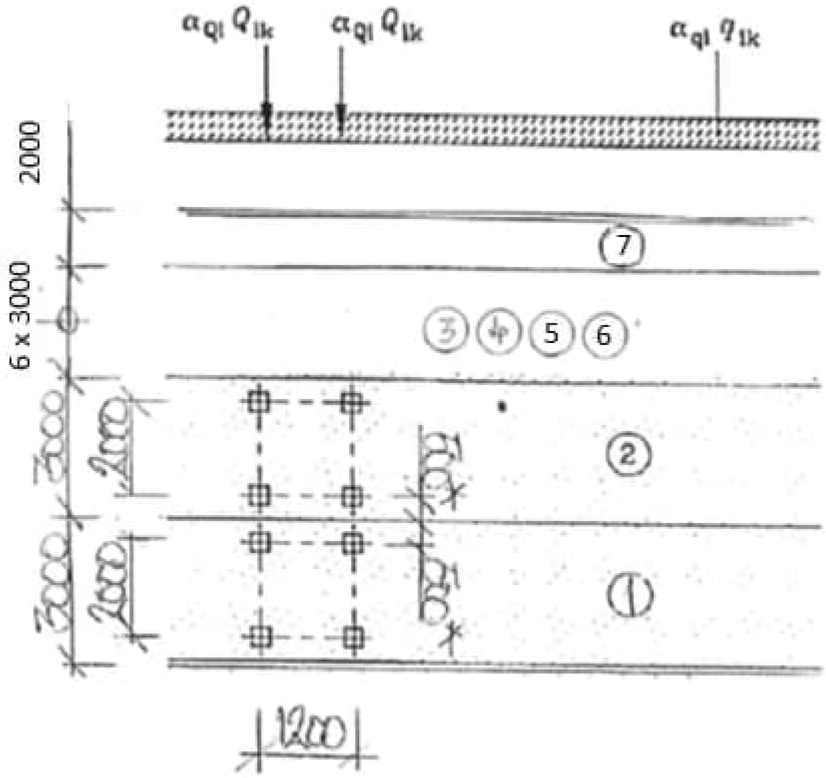
Number of traffic lanes : $n_1 = Integer\left[\frac{w_{tot}}{3.0m}\right] = 3\ lanes$

Full traffic width : $w_1 = 3.0m$

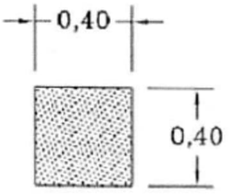
Remaining width : $w_2 = 1.05m$

3.6.2 Load model 1 (LM 1)

Characteristic values according to SS-EN 1991-2 §4.3.2.



* = When studying local effects 250 mm is to be assumed.



Axle loads:

α_Q : national adaptation factor according to TRVFS 2011:12 table 7.1

$Q'_k = \alpha_Q \cdot Q_k$: characteristic value including national adaptation factor

Traffic lane	Q_k	α_Q	Q'_k	Remark
1	300	0,9	270	LM1- 2 x 270 kN
2	200	0,9	180	LM1- 2 x 180 kN
3	100	0	0	No load
-	kN	-	kN	-

Surface loads:

α_q : national adaptation factor according to TRVFS 2011:12 table 7.1

$q'_k = \alpha_q \cdot q_k$: characteristic value including national adaptation factor

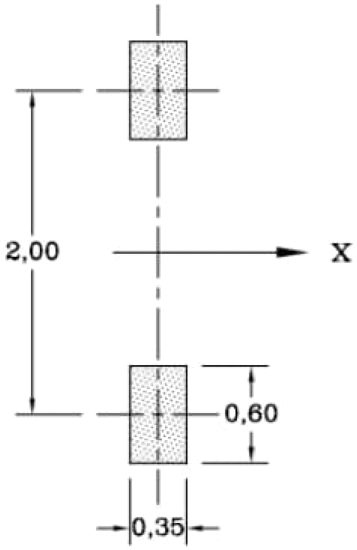
Traffic lane	q_k	α_q	q'_k
1	9.0	0.8	7.2
2-3	2.5	1.0	2.5
-	kPa	-	kPa

Remark

Evaluation is performed using Vehicle Load Optimisation (VLO), see section 3.7.4.

3.6.3 Load model 2 (LM 2)

Characteristic vertical load according to SS-EN 1991-2 §4.3.3.



$\beta_Q = \alpha_Q = 0.90$: national adaptation factor

$Q_k = 400$ kN : characteristic value

$Q'_k = \beta_k \cdot Q_k = 360$ kN : characteristic value including national adaptation factor

Tire pressure

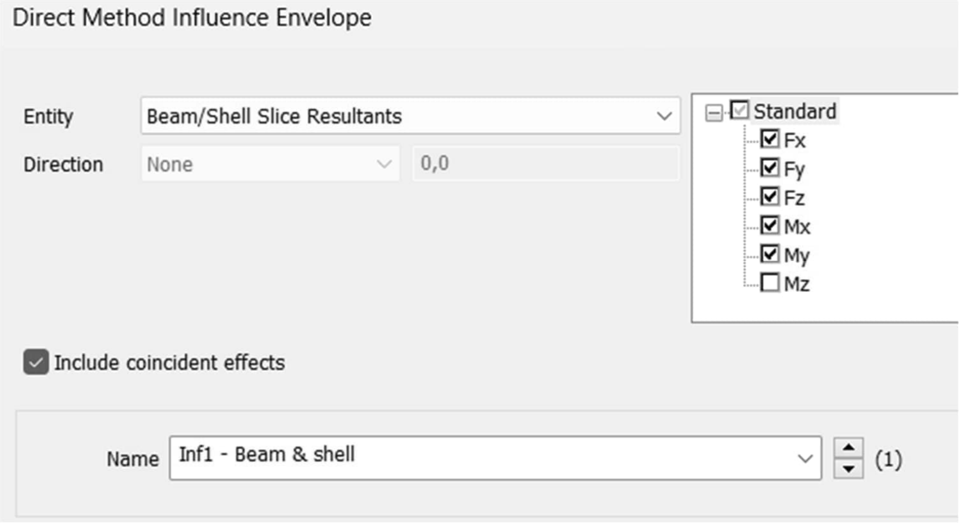
TSFS Chapter 11 Section 4 states that the same contact surface as LM 1 may be used.

3.6.4 Vehicle Load Optimization (VLO)

3.6.4.1 Influence components

Influence surfaces are created using *Direct Method Influence Envelope.* This is done by applying *Influence components* seen below.

Inf1 – Beam & shells :



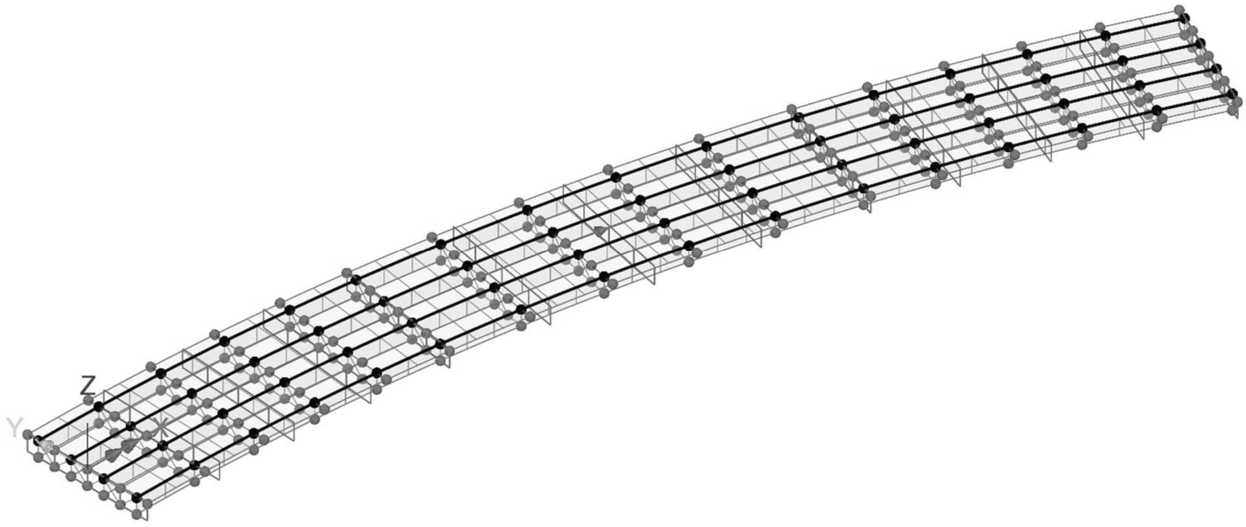
Direct Method Influence Envelope

Entity: Beam/Shell Slice Resultants
Direction: None 0,0

☑ Standard
- ☑ Fx
- ☑ Fy
- ☑ Fz
- ☑ Mx
- ☑ My
- ☐ Mz

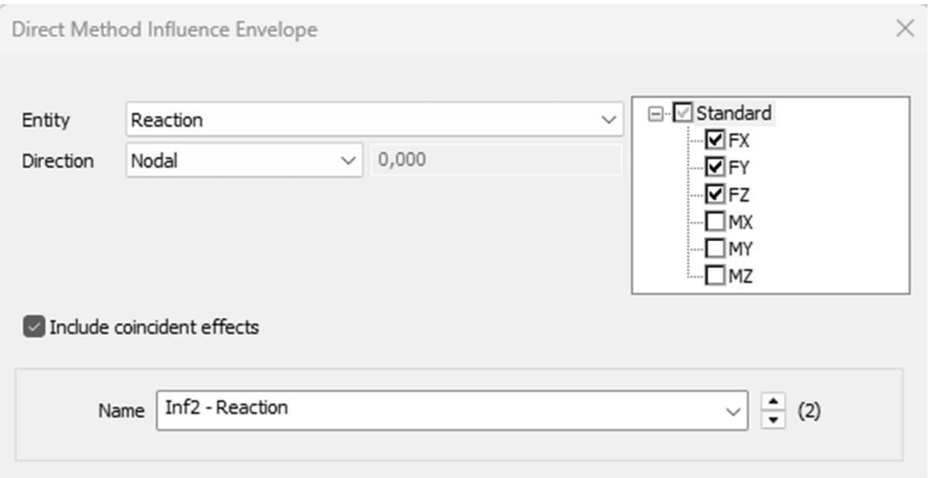
☑ Include coincident effects

Name: Inf1 - Beam & shell (1)



Overview 3D

Inf2 – Reactions :



Direct Method Influence Envelope

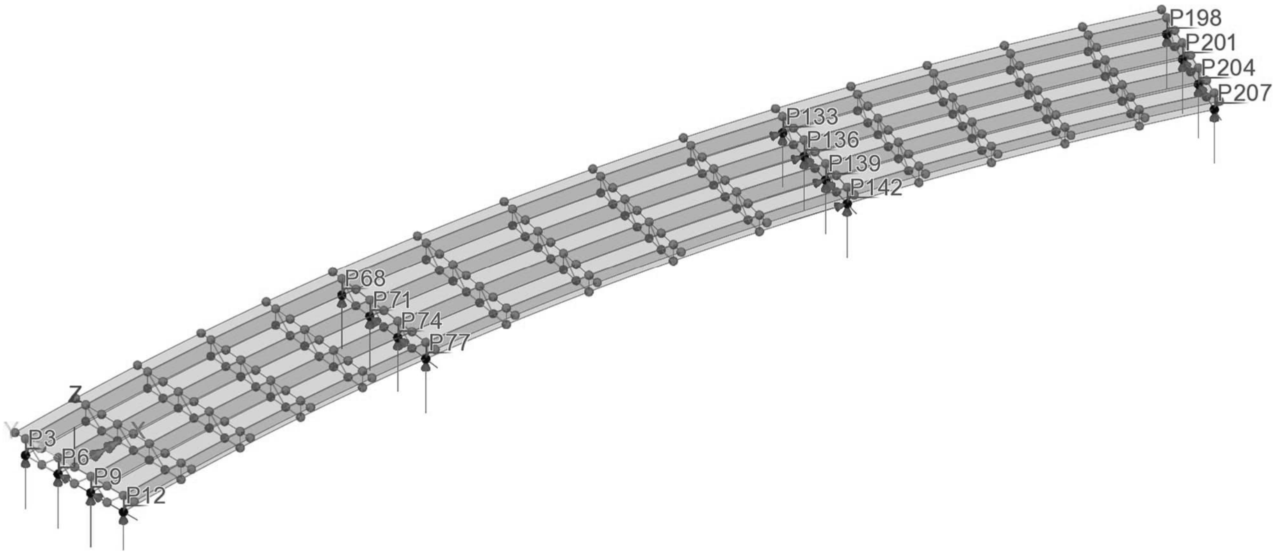
Entity: Reaction

Direction: Nodal 0,000

☑ Standard
- ☑ FX
- ☑ FY
- ☑ FZ
- ☐ MX
- ☐ MY
- ☐ MZ

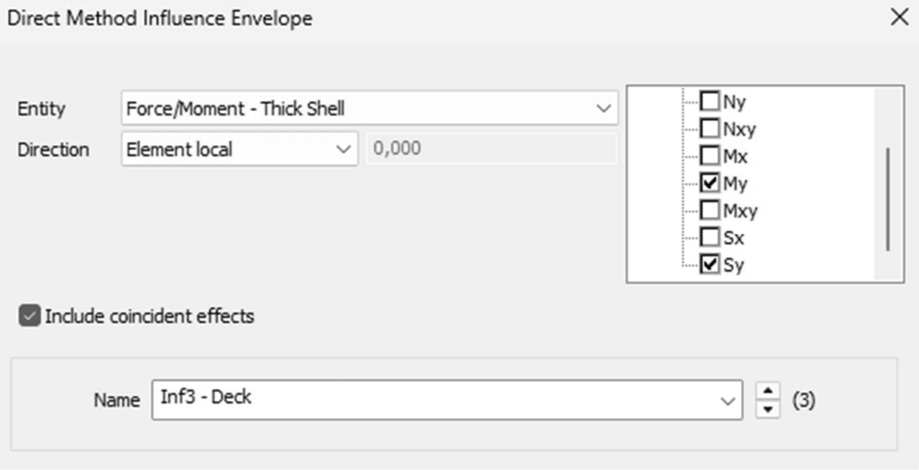
☑ Include coincident effects

Name: Inf2 - Reaction (2)



Overview 3D

Inf3 – Deck :



Direct Method Influence Envelope

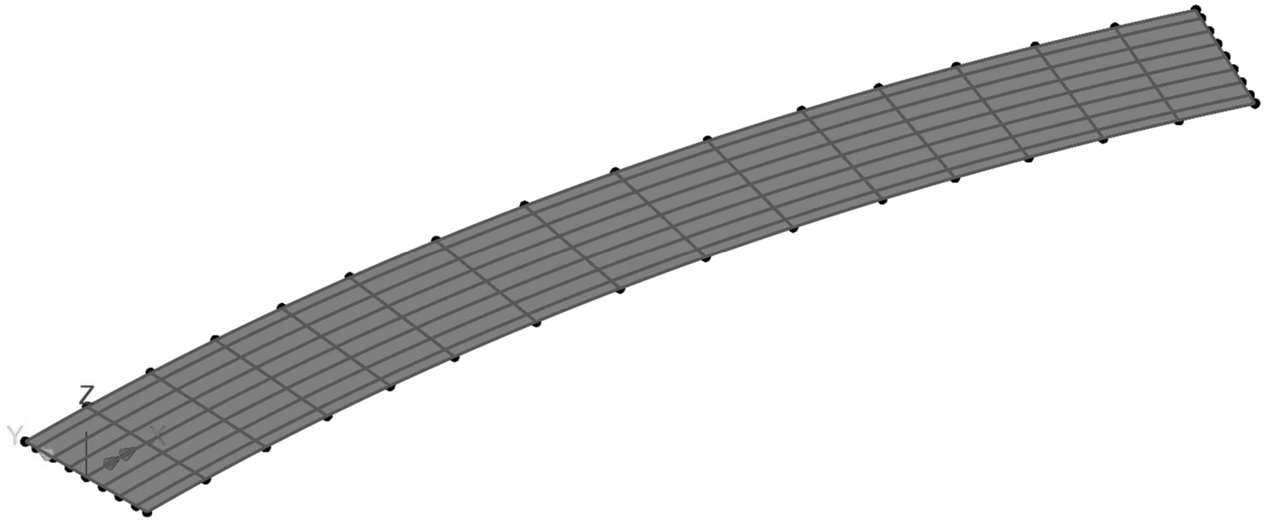
Entity: Force/Moment - Thick Shell

Direction: Element local 0,000

☐ Ny
☐ Nxy
☐ Mx
☑ My
☐ Mxy
☐ Sx
☑ Sy

☑ Include coincident effects

Name: Inf3 - Deck (3)



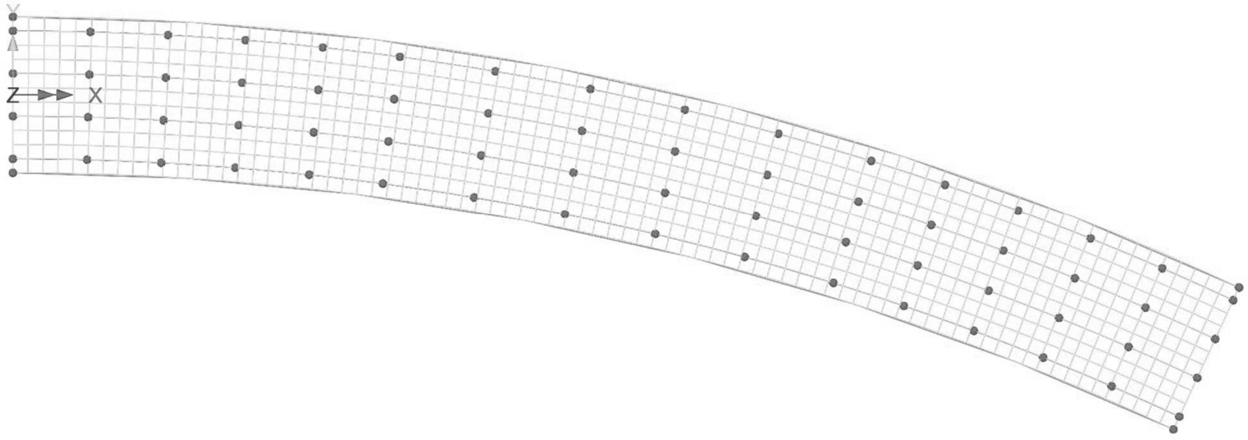
Overview 3D

3.6.4.2 Influence surface analysis

A influence surface is generated for every node grid. Below are the used settings.

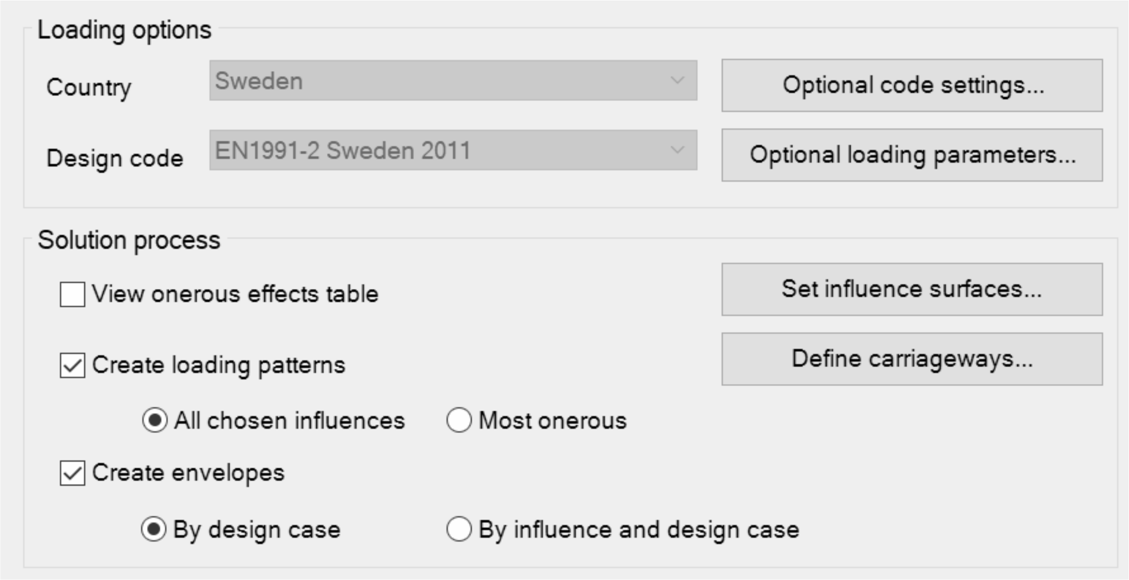
Influence surfaces :

Search area:	Superstructure
Definition type:	Grid
Path:	Centerline X
Transverse width:	10.05 m
Longitudinal spacing (ΔL_x) :	1.0 m
Transversal spacing: (ΔL_y) :	1.0 m



PLAN

3.6.4.3 Traffic load analysis (VLO)



Loading options

Country: Sweden

Design code: EN1991-2 Sweden 2011

Solution process

☐ View onerous effects table

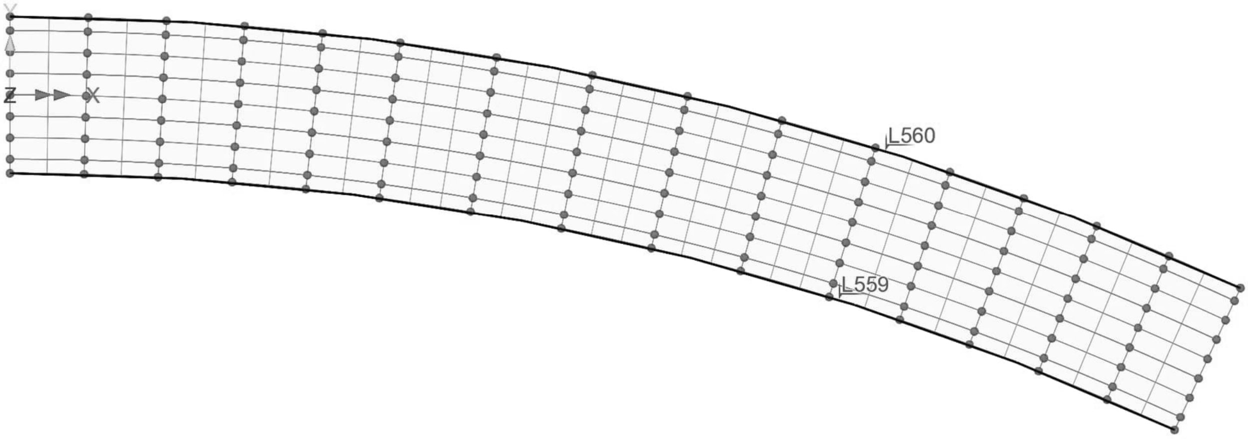
☑ Create loading patterns

● All chosen influences ○ Most onerous

☑ Create envelopes

● By design case ○ By influence and design case

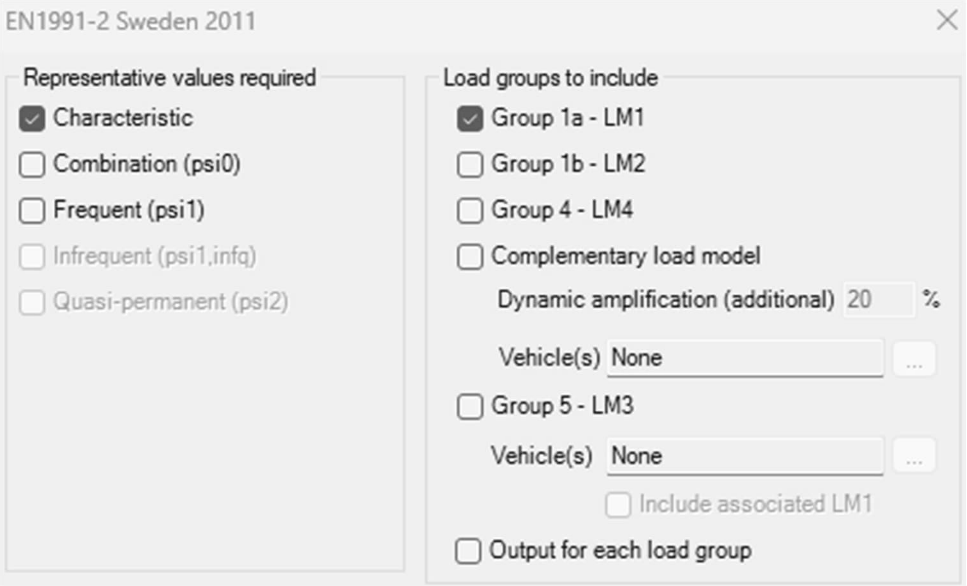
Vehicle longitudinal incremental movement:	0.25 m
Vehicle transverse incremental movement:	0.50 m
Vehicle direction:	both
Definition of carriageway (kerbs):	L559 & L560
Influence surfaces:	Include all (positive & negative)



PLAN

3.6.4.4 Envelope : LM 1

Load model 1 (LM1) defined in SS-EN 1991-2 section 4.3.2.

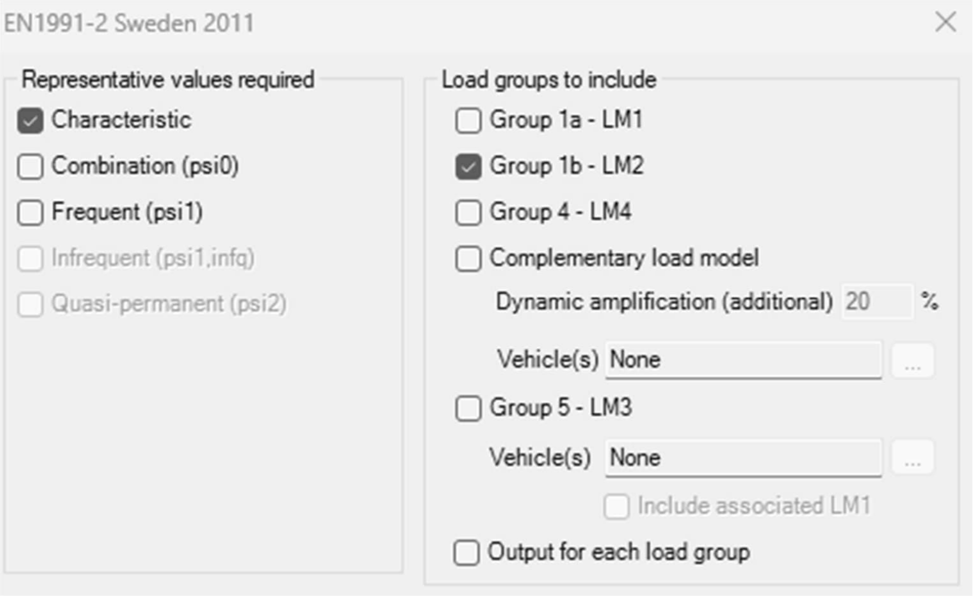

EN1991-2 Sweden 2011

Representative values required
☑ Characteristic
☐ Combination (psi0)
☐ Frequent (psi1)
☐ Infrequent (psi1,infq)
☐ Quasi-permanent (psi2)

Load groups to include
☑ Group 1a - LM1
☐ Group 1b - LM2
☐ Group 4 - LM4
☐ Complementary load model
Dynamic amplification (additional) 20 %
Vehicle(s) None
☐ Group 5 - LM3
Vehicle(s) None
☐ Include associated LM1
☐ Output for each load group

3.6.4.5 Envelope : LM 2

Load model 2 (LM2) defined in SS-EN 1991-2 section 4.3.3.


EN1991-2 Sweden 2011

Representative values required
☑ Characteristic
☐ Combination (psi0)
☐ Frequent (psi1)
☐ Infrequent (psi1,infq)
☐ Quasi-permanent (psi2)

Load groups to include
☐ Group 1a - LM1
☑ Group 1b - LM2
☐ Group 4 - LM4
☐ Complementary load model
Dynamic amplification (additional) 20 %
Vehicle(s) None
☐ Group 5 - LM3
Vehicle(s) None
☐ Include associated LM1
☐ Output for each load group

3.6.4.6 Combined traffic load (TRAFFIC)

There are a total 2 different traffic loads termed LM 1 and LM 2.

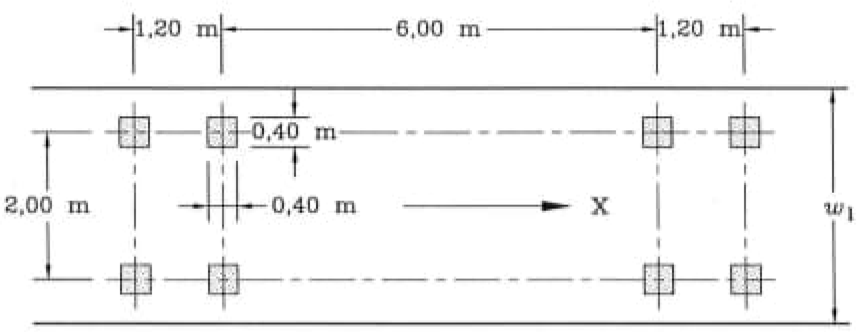
The envelope is used to identify the most onerous load effect.

Envelope TRAFFIC :

Envelope
LM 1
LM 2

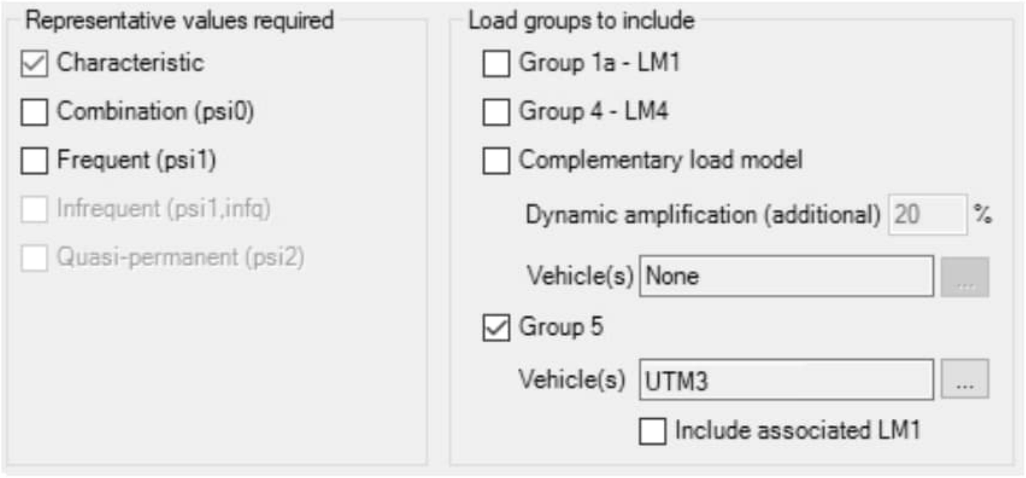
3.6.4.7 Fatigue model

Fatigue model 3 (UTM3) defined in SS-EN 1991-2 section 4.6.4. The load is defined in Group 5 (special vehicle) in present version of software.



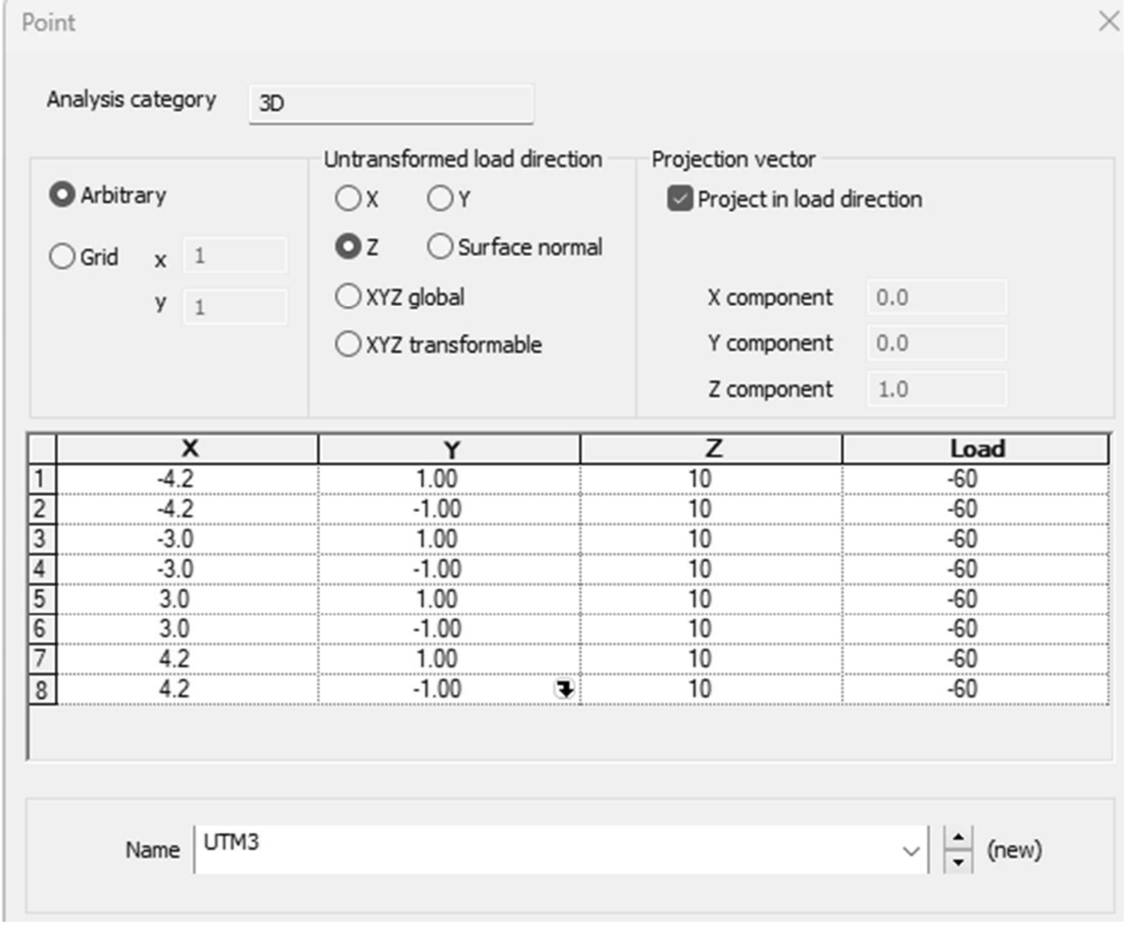
Q_k = 120 kN : characteristic value including nation adaptation factors.

The load definition:
The load UTM3 is defined as a special vehicle in "load group 5."



Representative values required
☑ Characteristic
☐ Combination (psi0)
☐ Frequent (psi1)
☐ Infrequent (psi1,infq)
☐ Quasi-permanent (psi2)

Load groups to include
☐ Group 1a - LM1
☐ Group 4 - LM4
☐ Complementary load model
Dynamic amplification (additional) 20 %
Vehicle(s) None
☑ Group 5
Vehicle(s) UTM3
☐ Include associated LM1



Analysis category: 3D

● Arbitrary

○ Grid x 1 y 1

Untransformed load direction

○ X ○ Y

● Z ○ Surface normal

○ XYZ global

○ XYZ transformable

Projection vector

☑ Project in load direction

X component 0.0

Y component 0.0

Z component 1.0

	X	Y	Z	Load
1	-4.2	1.00	10	-60
2	-4.2	-1.00	10	-60
3	-3.0	1.00	10	-60
4	-3.0	-1.00	10	-60
5	3.0	1.00	10	-60
6	3.0	-1.00	10	-60
7	4.2	1.00	10	-60
8	4.2	-1.00	10	-60

Name UTM3 (new)

3.7 LOAD COMBINATIONS

Verification of load capacity shall be carried out for several limit states as detailed in this section.

Fatigue Limit State:
The risk of fatigue according to the partial factor method is checked using equation 6.69 provided in document SS-EN 1992-1-1.

Other Limit States:
For other limit states, section 6.4.3 of EN-1990 is applied.

Verification of load capacity shall be carried out for several limit states as detailed in this section.

Fatigue Limit State:
The risk of fatigue according to the partial factor method is checked using equation 6.69 provided in document SS-EN 1992-1-1.

Other Limit States:
For other limit states, section 6.4.3 of EN-1990 is applied.

3.7.1 Ultimate Limit States (ULS)

When checking the ultimate limit state, the load factors vary depending on the type of failure as detailed below:

STR: Verification of structural bearing capacity

GEO: Verification of geotechnical bearing capacity

For checking the ultimate limit state, TRVNFRA-00227 section 7.1.6.3 specifies requirements for load combinations as follows.

Design Method D2 (Set B):
Design Method D2 (Set B) according to TSFS 2018:57 Table 4.4 shall be applied for the structural bearing capacity of the construction (STR; SK 3).

Design Method is defined according to EN-1990 equations 6.10a and 6.10b as detailed below.

$$E_{Sd}^{10a} = \sum_{j\geq 1} \gamma_{G.j} \cdot G_{k,j} + \gamma_{Q.1} \cdot \psi_{0,1} \cdot Q_{k.1} + \sum_{i>1} \gamma_{Q.i} \cdot \psi_{0,i} \cdot Q_{k,i} = \psi\gamma_{ULS-A} \cdot (\sum_{j>1} G_{k,j} + \sum_{i>1} Q_{k,i})$$

$$E_{Sd}^{10b} = \sum_{j\geq 1} \xi_j \cdot \gamma_{G.j} \cdot G_{k,j} + \gamma_{Q.1} \cdot Q_{k.1} + \sum_{i>1} \gamma_{Q.i} \cdot \psi_{0,i} \cdot Q_{k,i} = \psi\gamma_{ULS-B} \cdot (\sum_{j>1} G_{k,j} + \sum_{i>1} Q_{k,i})$$

Equation 6.10a refers to the (ULS-A) case where the permanent loads are dominant, usually during the construction phase.

Equation 6.10b refers to the (ULS-B) case where the variable loads are dominant.
Design method 2 (set B) according to TSFS 2018:57 table 4.4 shall be applied for the structural capacity (STR; SK3).

A1 (construction loads)
All load factors are greater than set C.

A2 (geotechnical loads)

- Load coefficient earth pressure:
  $\psi\gamma_{\mathrm{ULS-A}} = \gamma_{\mathrm{d}} \cdot 1.35 \cdot \eta_{\mathrm{sup.G}} = 1.0 \cdot 0.89 \cdot 1.35 \cdot 1.1 = 1.49$ ← dimensioning
  $\psi\gamma_{\mathrm{ULS-B}} = \gamma_{\mathrm{d}} \cdot 0.89 \cdot 1.35 \cdot \eta_{\mathrm{sup.G}} = 1.0 \cdot 0.89 \cdot 1.35 \cdot 1.1 = 1.33$

- Load coefficient surcharge:
  $\psi\gamma_{\mathrm{ULS-A}} = \gamma_{\mathrm{d}} \cdot \psi_0 \cdot 1.50 = 1.0 \cdot 0.75 \cdot 1.50 = 1.13$
  $\psi\gamma_{\mathrm{ULS-B}} = \gamma_{\mathrm{d}} \cdot 1.50 = 1.0 \cdot 1.50 = 1.50$ ← dimensioning

Design method D3 (set C) according to TSFS 2018:57 table 4.5 shall be applied for determining geotechnical bearing capacity (GEO; SK 2).

The design method is defined according to EN-1990 equation 6.10a and 6.10b as presented below.

$$E_{Sd}^{10a} = \sum_{j\geq1} \gamma_{G.j} \cdot G_{k,j} + \gamma_{Q.1} \cdot \psi_{0,1} \cdot Q_{k.1} + \sum_{i>1} \gamma_{Q.i} \cdot \psi_{0,i} \cdot Q_{k,i} = \psi\gamma_{ULS-GA} \cdot (\sum_{j>1} G_{k,j} + \sum_{i>1} Q_{k,i})$$

$$E_{sd}^{10b} = \sum_{j\geq1} \xi_j \cdot \gamma_{G.j} \cdot G_{k,j} + \gamma_{Q.1} \cdot Q_{k.1} + \sum_{i>1} \gamma_{Q.i} \cdot \psi_{0,i} \cdot Q_{k,i} = \psi\gamma_{ULS-GB} \cdot (\sum_{j>1} G_{k,j} + \sum_{i>1} Q_{k,i})$$

Equation 6.10a refers to the (ULS-A) case where the permanent loads are dominant, usually during the construction phase.

Equation 6.10b (ULS-B) refers to the case where the variable loads are dominant.

Design method 3 (set C) according to TSFS 2018:57 table 4.5 shall be applied for determining geotechnical bearing capacity (GEO).

A1 (construction loads)
All load factors are less than set B.

A2 (geotechnical loads)

- Load coefficient earth pressure: $\psi\gamma_{jord} = \gamma_d \cdot 1.1 \cdot \eta_{sup.G} = 0.91 \cdot 1.1 \cdot 1.1 = 1.10$

- Load coefficient surcharge: $\psi\gamma_{\text{över}} = \gamma_\text{d} \cdot 1.40 = 0.91 \cdot 1.40 = 1.27$

Simplified Design Method ULS:

To limit the number of load combinations, design method D2 (STR) is also applied for checking geotechnical bearing capacity (GEO). This is done by adjusting load coefficients associated with the geotechnical loads.
When applying the geotechnical loads, the earth pressure coefficient corresponding to D2 is applied.

Permanent loads:

Nr	Load		$\psi\gamma_{ULS-A}$	$\psi\gamma_{ULS-B}$
1	Dead weight	max	1.35	1.20
		min	1.00	1.00
2	Surfacing	max	1.45	1.35
		min	0.90	0.90
3	Fillling	max	1.45	1.35
		min	0.90	0.90
4	Earth pressure	max	1.49	1.35
		min	0.90	0.90
5	Water pressure	max	1.35	1.10
		min	1.00	1.00
6	Support settlement	max	1.35	1.20
		min	1.00	1.00
7	Shrinkage	max	1.35	1.20
		min	1.00	1.00

Remark
Equation ULS-B is considered dominant; thus ULS-A is not considered.

Variable loads:

Nr	Load	$\psi\gamma_{ULS-A}$	$\psi\gamma_{ULS-B}$
	Load model LM 1 :		
9	Tandem axel	1.13	1.03/1.50
10	Surface load	0.60	0.60/1.50
11	Braking force	0.84	0.84/1.13
12	Lateral force	0.84	0.84/1.13
13	Centrifugal force	0.84	0.84/1.13
	Load model LM 2 :		
14	Single axel	0	0/1.50
	Complementary load EG A/B :		
15	Vehicle EG A/B	1.13	1.13/1.50
16	Braking force	0.84	0.84/1.13
17	Lateral force	0.84	0.84/1.13
18	Centrifugal force	0.84	0.84/1.13
19	Temperature	0.90	0.90/1.50
	Wind load:		
20	Wind against bridge	0.45	0.45/1.50
21	Wind against vehicles	0.45	0.45/1.50
22	Surcharge	1.13	1.13/1.50

Remark

Equation ULS-B is considered dominant; thus ULS-A is not considered.

Load combination smart *ULS-PERM :*

Load case	Permanent factor	Variable factor
DEAD	1.00	0.20
SURF	0.90	0.45
SHRINKAGE	0	1.20

Load combination smart *ULS-VAR :*
(Load cases to consider : 2 / Variable load cases : 1)

Load case	Permanent factor	Variable factor
TRAFIK	1.03	0.47
TEMP	0.90	0.60

Load combination smart *ULS :*

Load case	Permanent factor	Variable factor
ULS-PERM	1	0
ULS-VAR	0	1

3.14.2 Service limit state (SLS)

The service limit state is divided into 3 load combinations based on their duration. The load combinations are presented below.

Load combination	Duration
SLS:K	Characteristic
SLS:F	Frequent
SLS:Q	Quasi-permanent

Load Combination SLS:K according to EN 1990 equation 6.14b is presented below.

$$E_{Sd} = \sum_{j\geq 1} G_{k,j} + Q_{k.1} + \sum_{i>1} \psi_{0,i} \cdot Q_{k,i} = \psi\gamma_{SLS.K} \cdot \left(\sum_{j>1} G_{k,j} + \sum_{i>1} Q_{k,i}\right)$$

Load Combination SLS:F according to EN 1990 equation 6.15b is presented below.

$$E_{Sd} = \sum_{j\geq 1} G_{k,j} + \psi_1 \cdot Q_{k.1} + \sum_{i>1} \psi_{2,i} \cdot Q_{k,i} = \psi\gamma_{SLS.2} \cdot \left(\sum_{j>1} G_{k,j} + \sum_{i>1} Q_{k,i}\right)$$

Load Combination SLS:Q according to EN 1990 equation 6.16b is presented below.

$$E_{Sd} = \textstyle\sum_{j\geq 1} G_{k,j} + \sum_{i>0} \psi_{2,i} \cdot Q_{k,i} = \psi\gamma_{SLS.Q} \cdot \left(\sum_{j>1} G_{k,j} + \sum_{i>1} Q_{k,i}\right)$$

When designing, load coefficients according to equations 6.14a, 6.15b, and 6.16b are applied.

Permanent loads:

Nr	Load		$\psi\gamma_{SLS-K}$	$\psi\gamma_{SLS-F}$	$\psi\gamma_{SLS-Q}$
1	Dead weight	max	1.00	1.00	1.00
		min	1.00	1.00	1.00
2	Surfacing	max	1.10	1.10	1.00
		min	0.90	0.90	1.00
3	Fillling	max	1.10	1.10	1.00
		min	0.90	0.90	1.00
4	Earth pressure	max	1.35	1.35	1.35
		min	0.90	0.90	1.00
5	Water pressure	max	1.00	1.00	1,00
		min	1.00	1.00	1.00
6	Support settlement	max	1.00	1.00	1.00
		min	1.00	1.00	1.00
7	Shrinkage	max	1.00	1.00	1.00
		min	1.00	1.00	1.00

Variable loads:

Nr	Load	$\psi\gamma_{SLS-K}$	$\psi\gamma_{SLS-F}$	$\psi\gamma_{SLS-Q}$
	Load model LM 1 :			
9	Tandem axel	0.75/1.00	0/0.75	0
10	Surface load	0.40/1.00	0/0.40	0
11	Braking force	0.56/0.75	0/0.56	0
12	Lateral force	0.56/0.75	0/0.56	0
13	Centrifugal force	0.56/0.75	0/0.56	0
	Load model LM 2 :			
14	Single axel	0.75/1.00	0/0.75	0
	Complementary load EG A/B :			
15	Vehicle EG A/B	0.75/1.00	0/0.75	0
16	Braking force	0.56/0.75	0/0.56	0
17	Lateral force	0.56/0.75	0/0.56	0
18	Centrifugal force	0.56/0.75	0/0.56	0
19	Temperature	0.60/1.00	0.50/0.60	0.50
	Wind load:			
20	Wind against bridge	0.30/1.00	0/0.30	0
21	Wind against vehicles	0.30/1.00	0/0.30	0
22	Surcharge	0.75/1.35	0/0.75	0

Load combination smart *SLS-PERM :*

Load case	Permanent factor	Variable factor
DEAD	1.00	0
SURF	0.90	0.20
SHRINKAGE	0	1.00

Load combination smart *SLS-K-VAR :*
(Load cases to consider : 2 / Variable load cases : 1)

Load case	Permanent factor	Variable factor
TRAFIK	0.75	0.25
TEMP	0.60	0.40

Load combination smart *SLS-F-VAR :*

Load case	Permanent factor	Variable factor
TRAFIK	0	0.75
TEMP	0	0.60

Load combination smart *SLS-K :*

Load case	Permanent factor	Variable factor
SLS-PERM	1	0
SLS-K-VAR	0	1

Load combination smart *SLS-F :*

Load case	Permanent factor	Variable factor
SLS-PERM	1	0
SLS-F-VAR	0	1

Load combination smart *SLS-Q :*

Load case	Permanent factor	Variable factor
DEAD	1.00	0
SURF	0.90	0.20
SHRINKAGE	0	1.00
TEMP	0	0.50

3.14.4 Fatigue load combination

Fatigue is considered according to SS EN 1992-1-1, 6.8.4 and 6.8.6, and SS EN 1992-2, 6.8 and Appendix NN.

The risk of fatigue is checked using a simplified method, denoted as the λ-method.
Load combination according to equation SS-EN 1992-1-1 section 6.8.3 equation 6.69.

In this load combination, the traffic load is considered to consist of UTM, whereby other traffic loads are excluded.

$$E_{Sd} = \sum_{j\geq 1} G_{k,j} + P + \psi_{1,1}\cdot Q_{k,1} + \sum_{i>1}\psi_{2,i}\cdot Q_{k,i} + Q_{fat} = \psi\gamma_{UTM}\cdot\left(\sum_{j\geq 1} G_{k,j} + P + \sum_{i\geq 1} Q_{k,i} + Q_{fat}\right)$$

Permanent loads:

Nr	Load		$\psi\gamma_{UTM}$
1	Dead weight	max	1.00
		min	1.00
2	Surfacing	max	1.10
		min	0.90
3	Fillling	max	1.10
		min	0.90
4	Earth pressure	max	1.48
		min	0.90
5	Water pressure	max	1.00
		min	1.00
6	Support settlement	max	1.00
		min	1.00
7	Shrinkage	max	1.00
		min	1.00

Variable loads:

Nr	Load	$\psi\gamma_{UTM}$
	Load model LM 1 :	
9	Tandem axel	-
10	Surface load	-
11	Braking force	-
12	Lateral force	-
13	Centrifugal force	-
	Load model LM 2 :	
14	Single axel	-
	Complementary load EG A/B :	
15	Vehicle EG A/B	-
16	Braking force	-
17	Lateral force	-
18	Centrifugal force	-
19	Temperature	0.60
	Wind load:	
20	Wind against bridge	0.30
21	Wind against vehicles	0.30
22	Surcharge	1.01
23	UTM3	1.00

Load combination smart FAT :

Load case	Permanent factor	Variable factor
DEAD	1.00	0
SURF	1.00	0
SHRINKAGE	-	-
UTM 3	-	1.00
TEMP	-	-

Load cases DEAD, SURF and SHRINKAGE are not fatigue loads, thus load coefficient 1.0 is applied.

Load case TEMP is not a fatigue loads, thus load is not considered.