Pretensioned single girder bridge

CONTENTS

1. GENERAL / MEASUREMENT

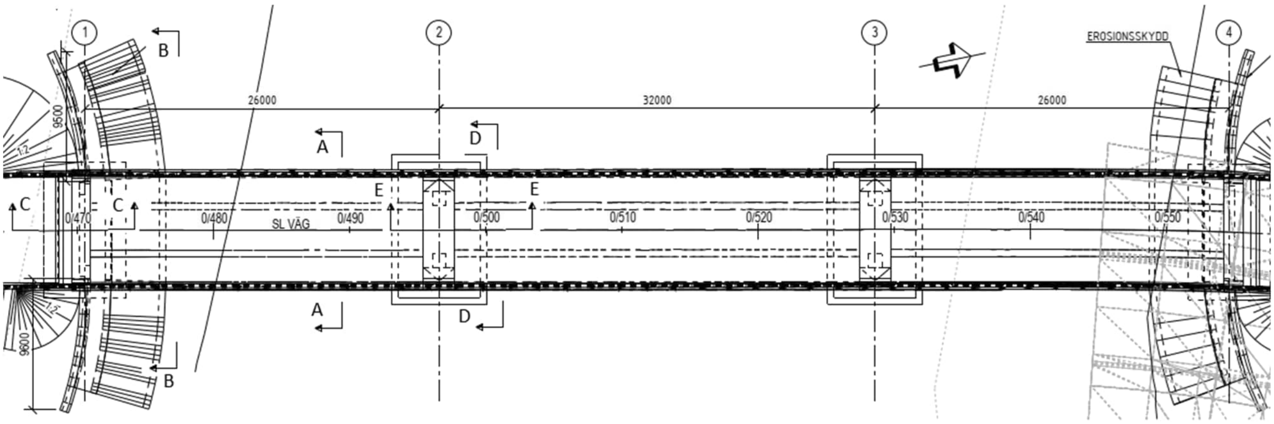
1.1 CONSTRUCTION TYPE

Bridge is constructed using reinforced concrete. Superstructure is modelled with one longitudinal beam that are pretensioned.

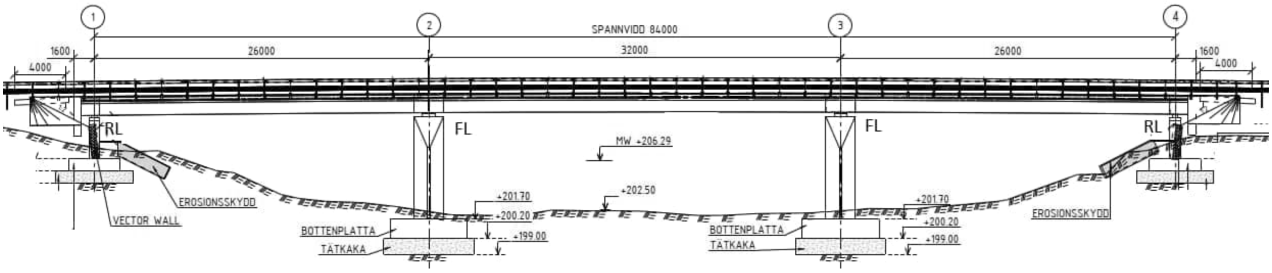
Bottom slabs are founded on underwater concrete slab (“tätkaka”) cast inside sheet pile box (“spontlåda”).

1.2 MEASURMENT

1.2.1 Overview

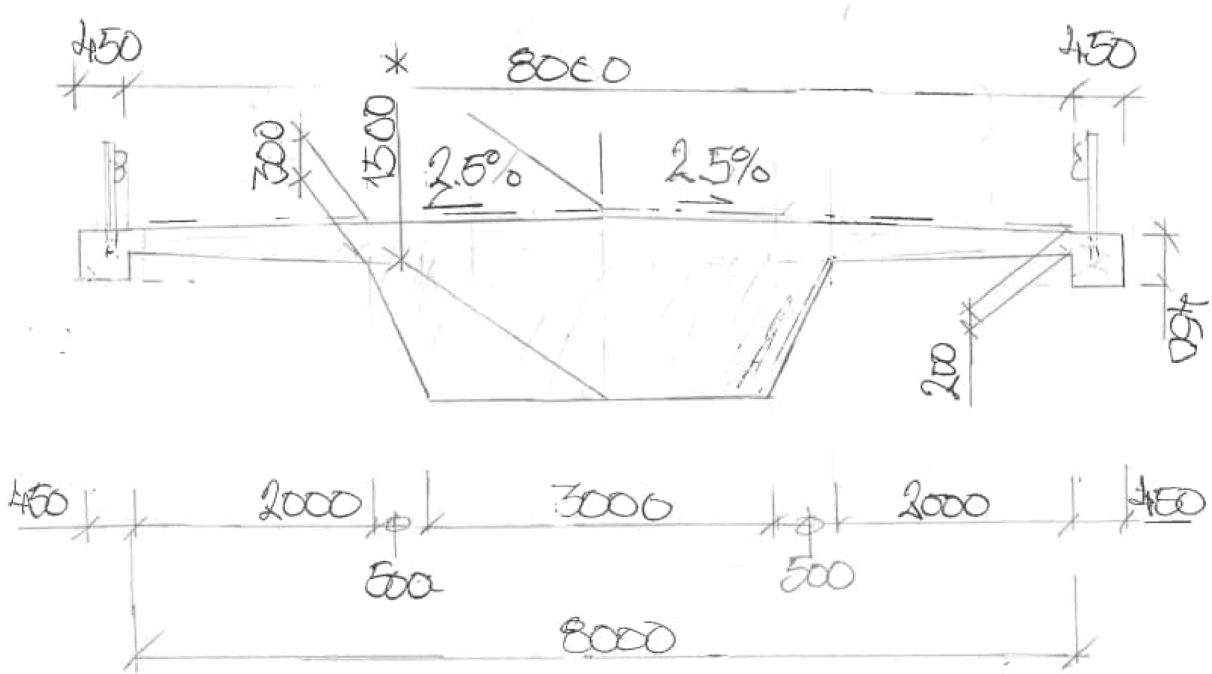


PLAN

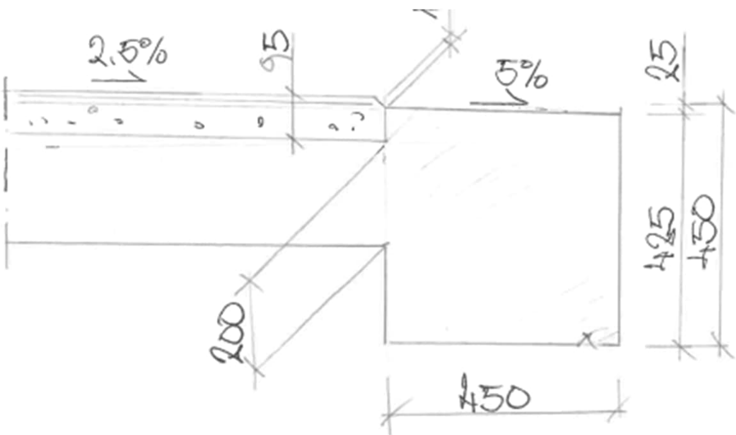


ELEVATION

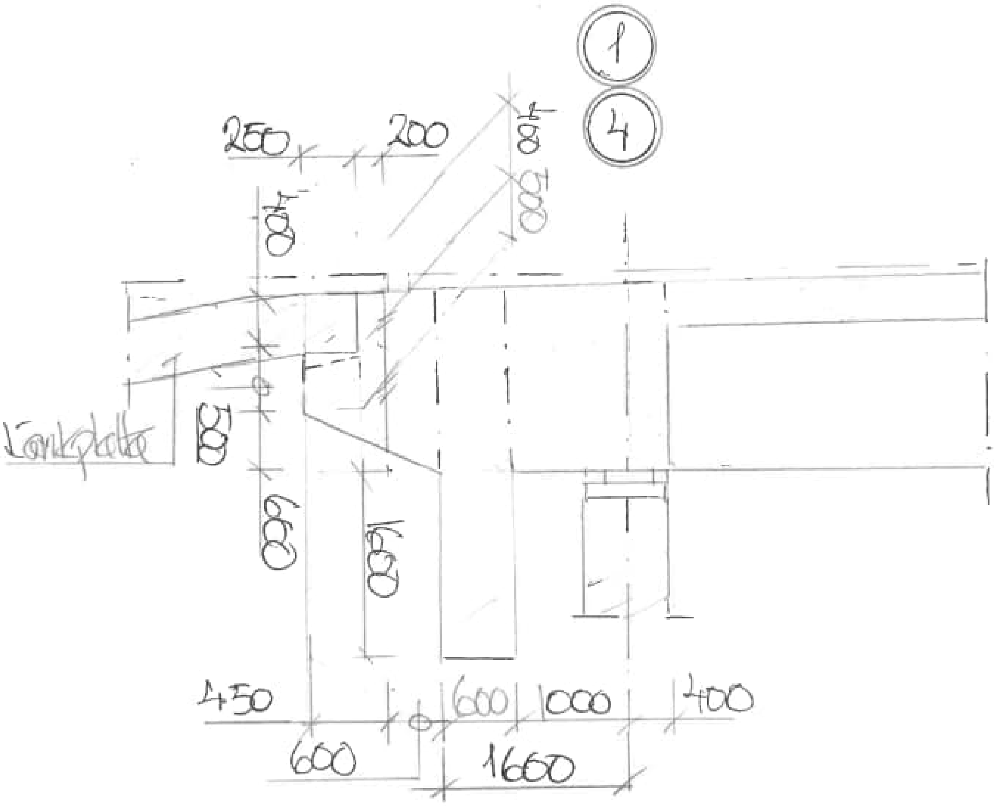
1.2.2 Superstructure



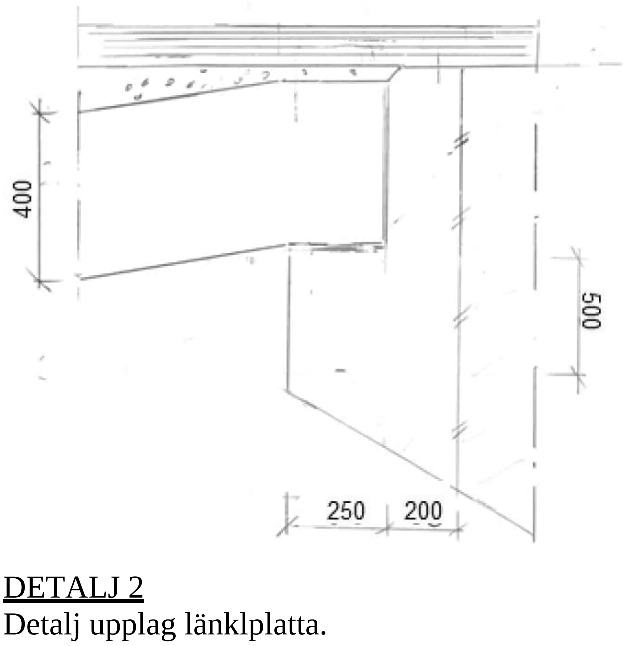
SECTION A-A



DETAIL 1
Edge beam.

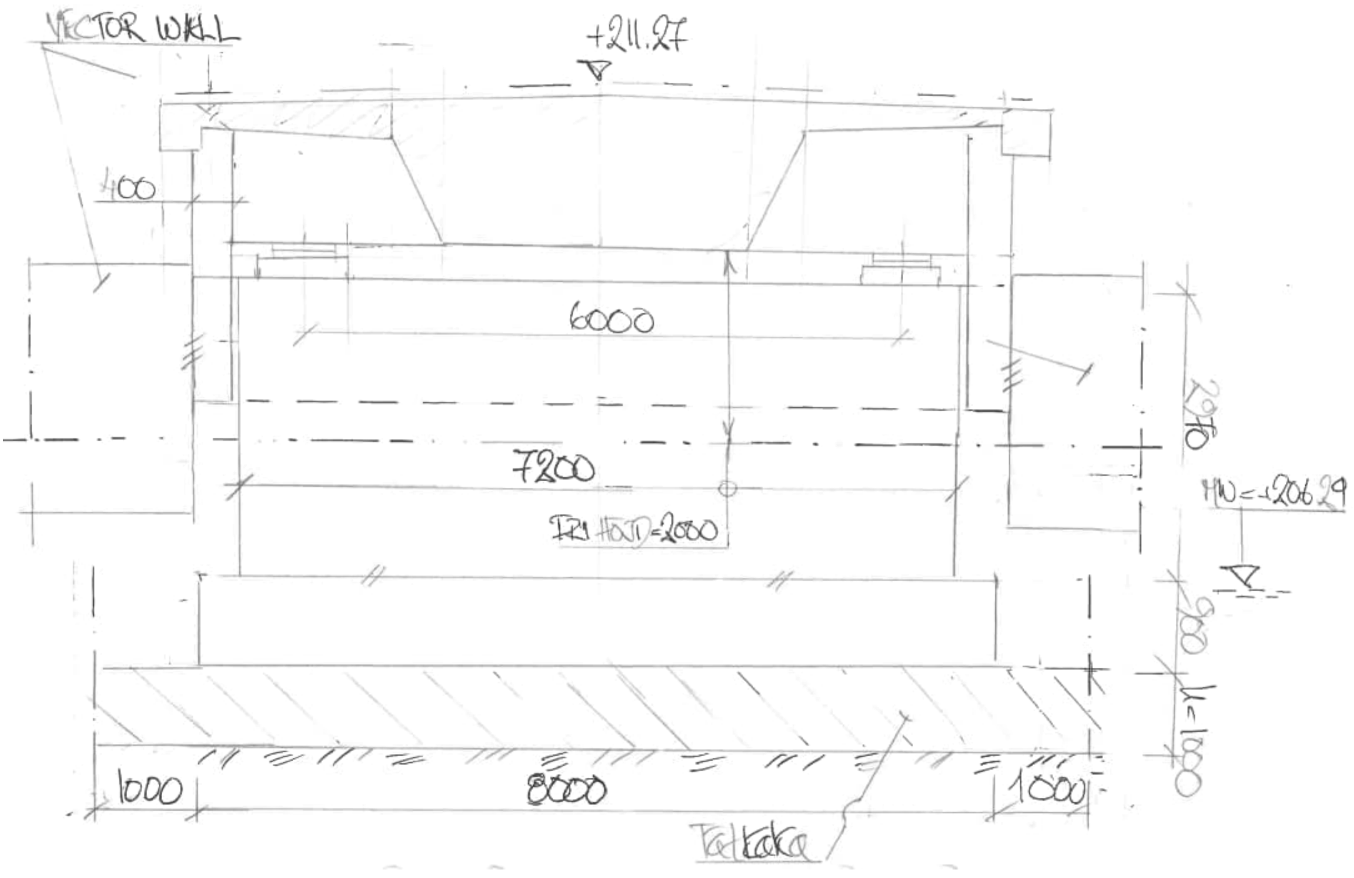


SEKTION D-D
Broände.

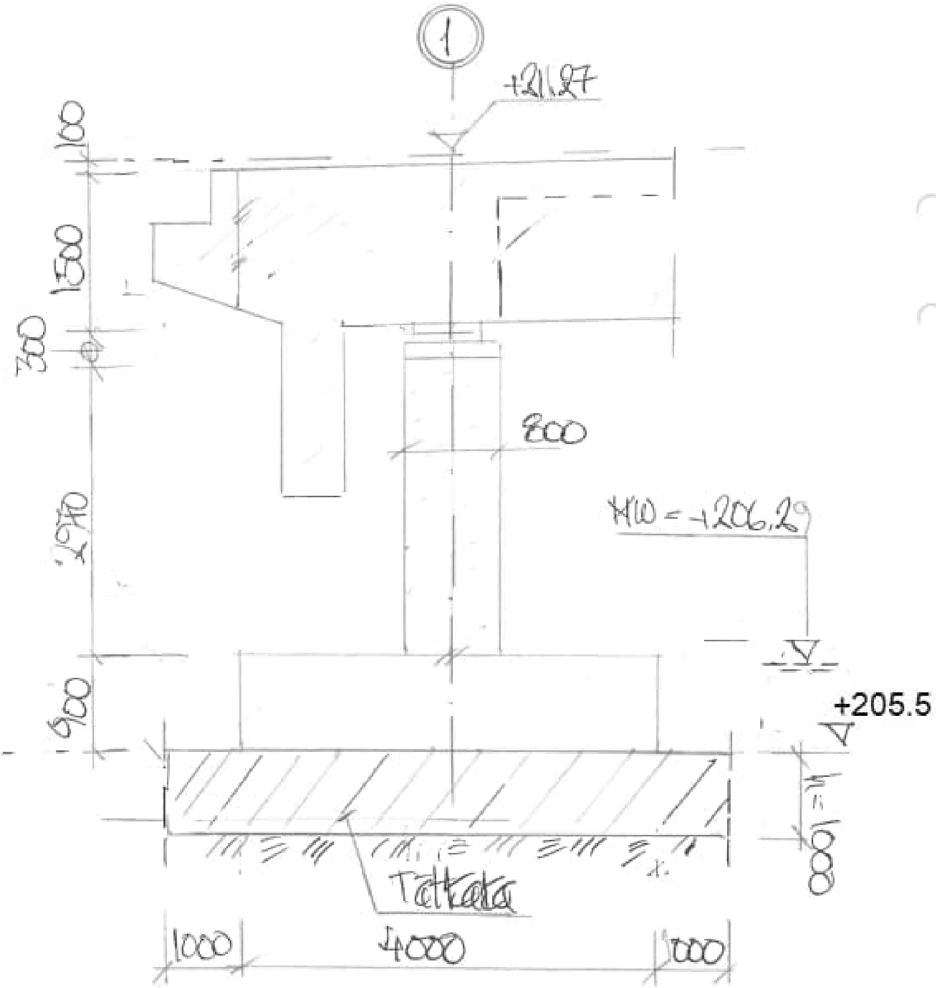


DETALJ 2
Detalj upplag länklplatta.

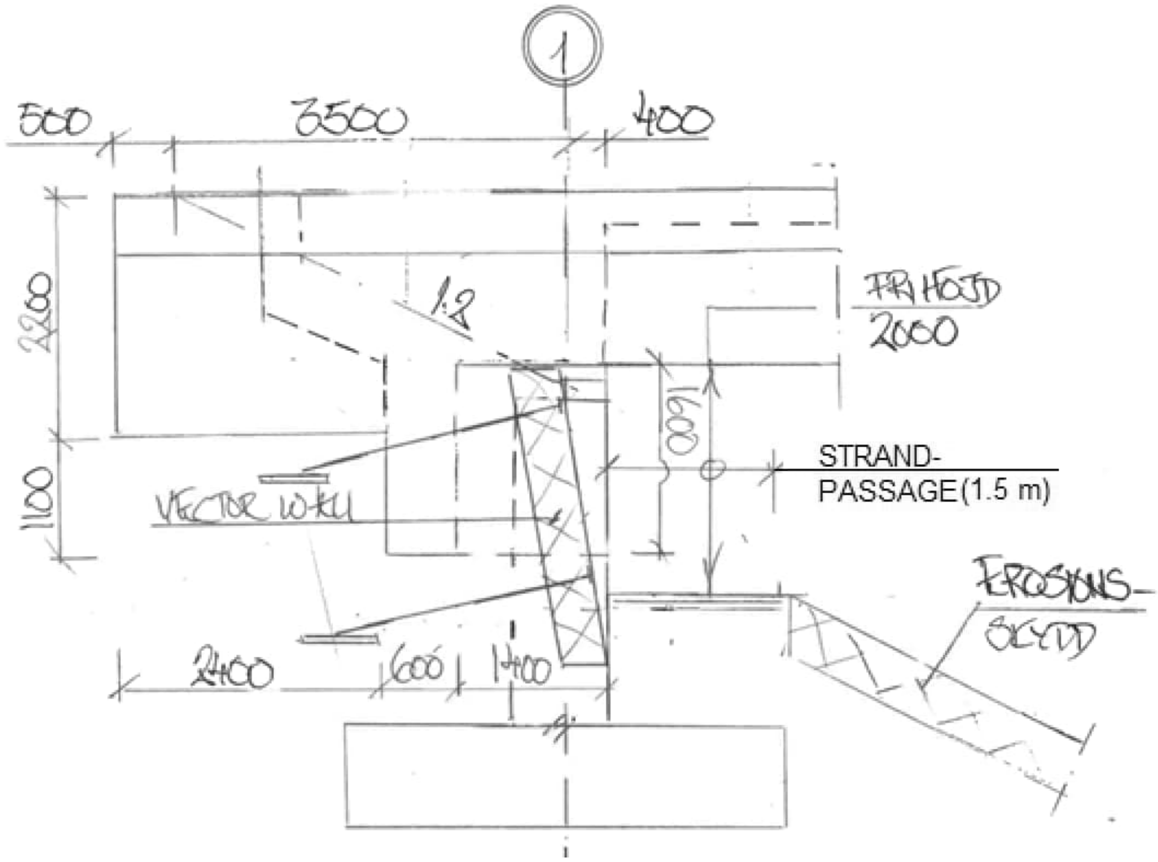
1.2.3 Substructure



SECTION B-B

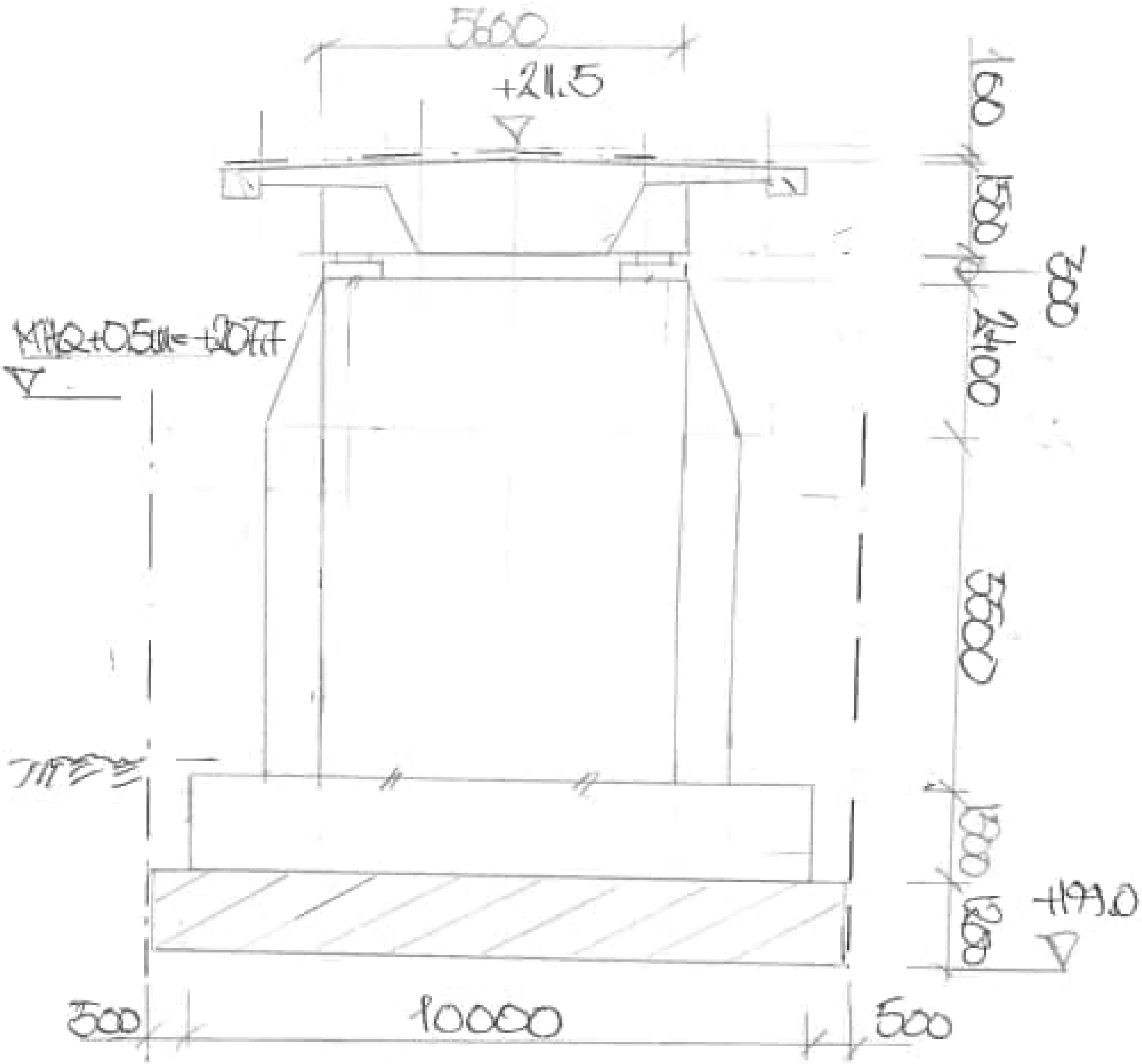


SECTION C-C

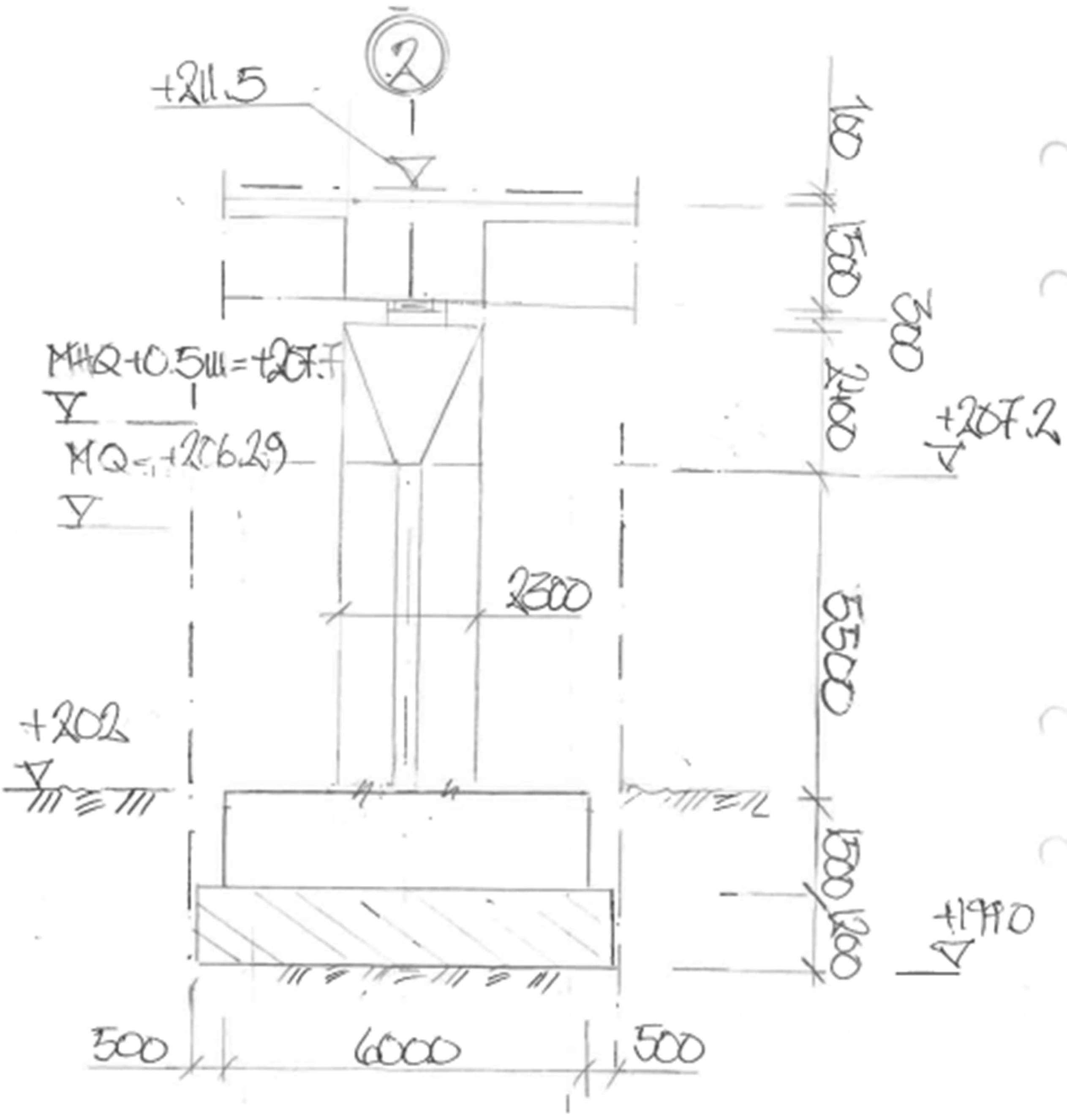


<u>VY F-F</u>

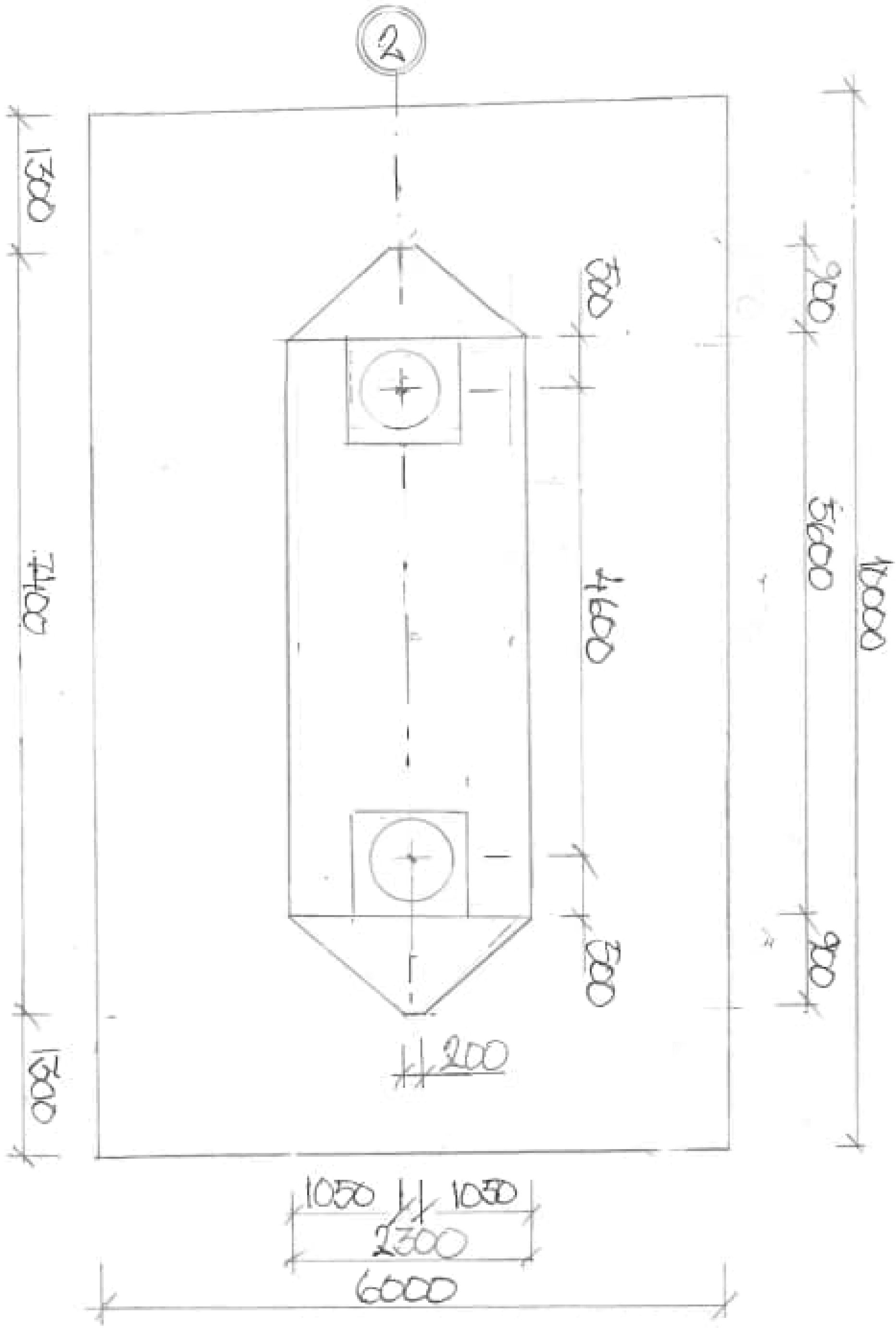
Stöd 1. Gäller även stöd 4.



SECTION D-D

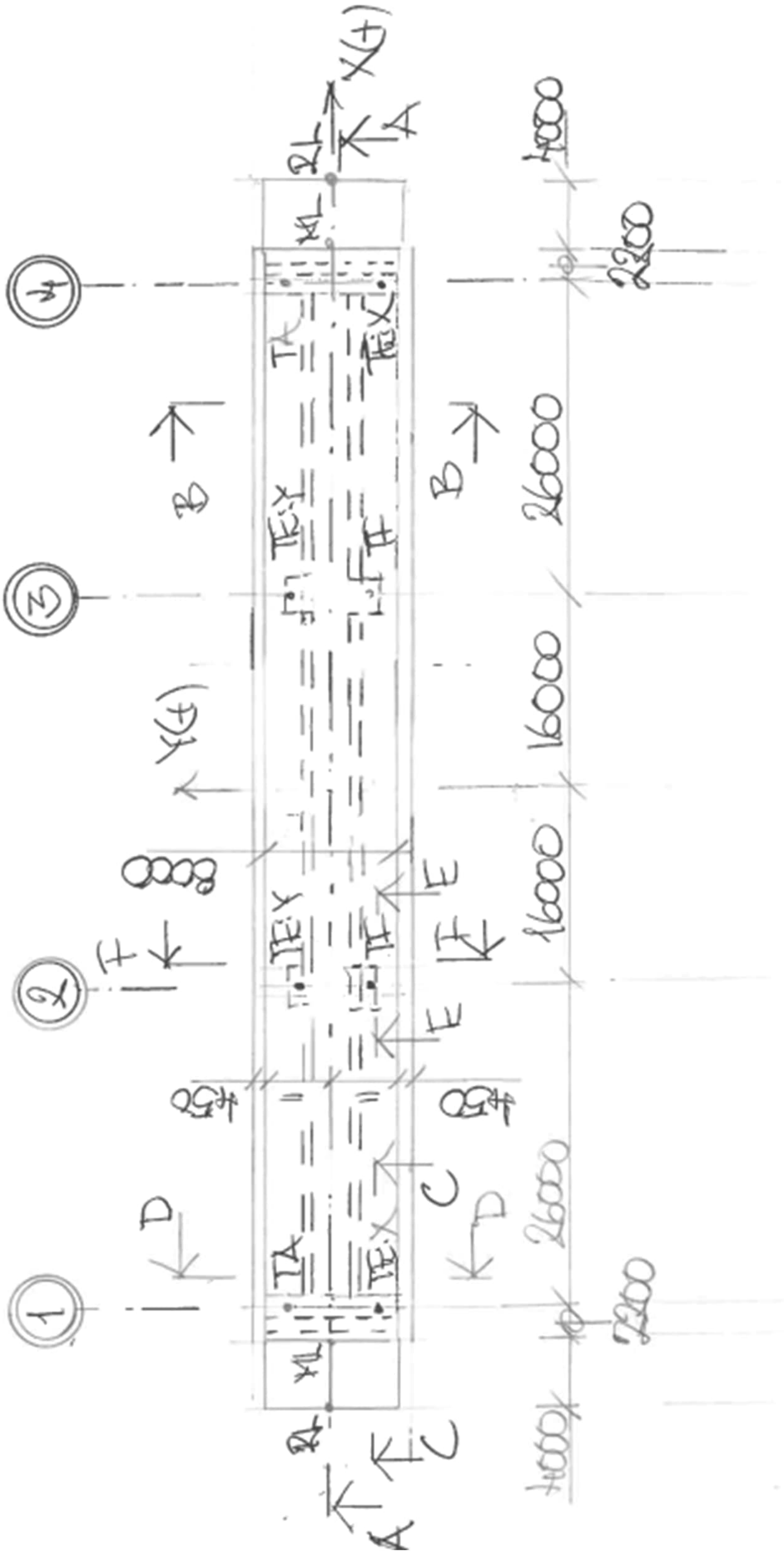

2
+211.5
MHQ+0.5m=+207.7
MQ=+206.29
+207.2
+202
+199.0
100
1500
2400
300
2300
5500
1500
1200
500
6000
500

VY E-E

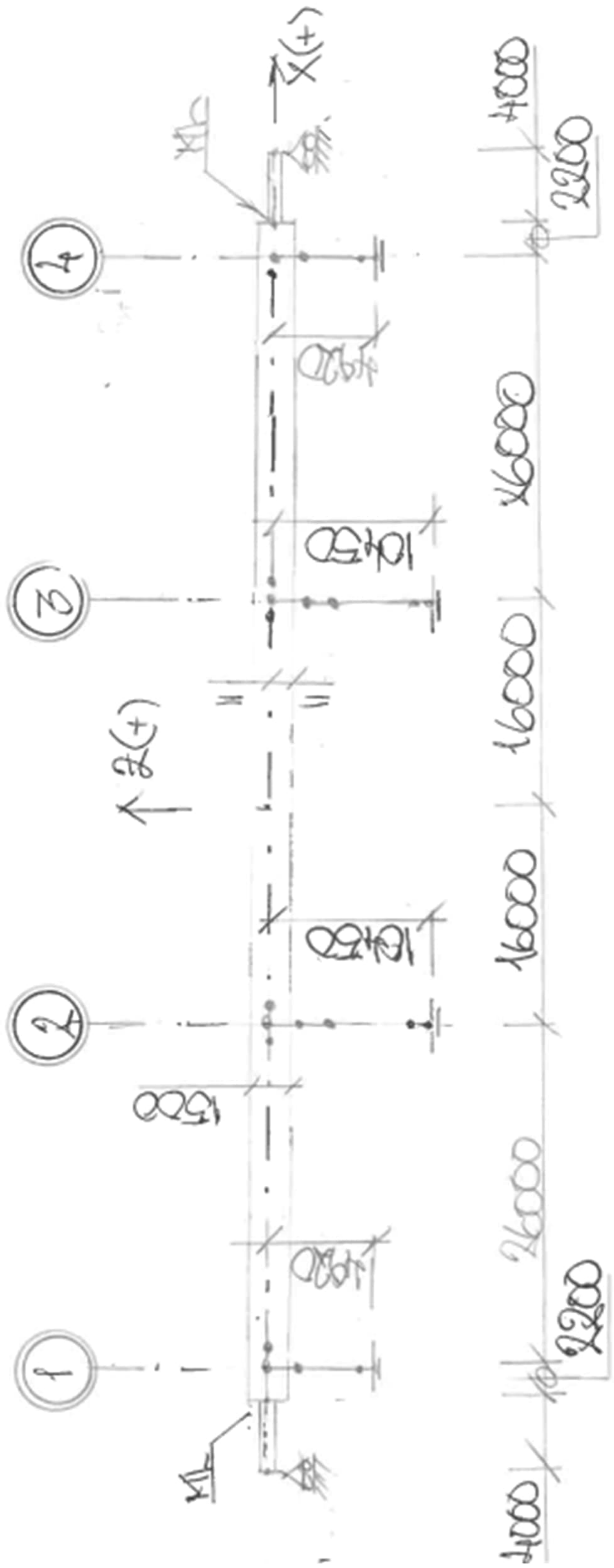


<u>PLAN</u>
Valid for support 3.

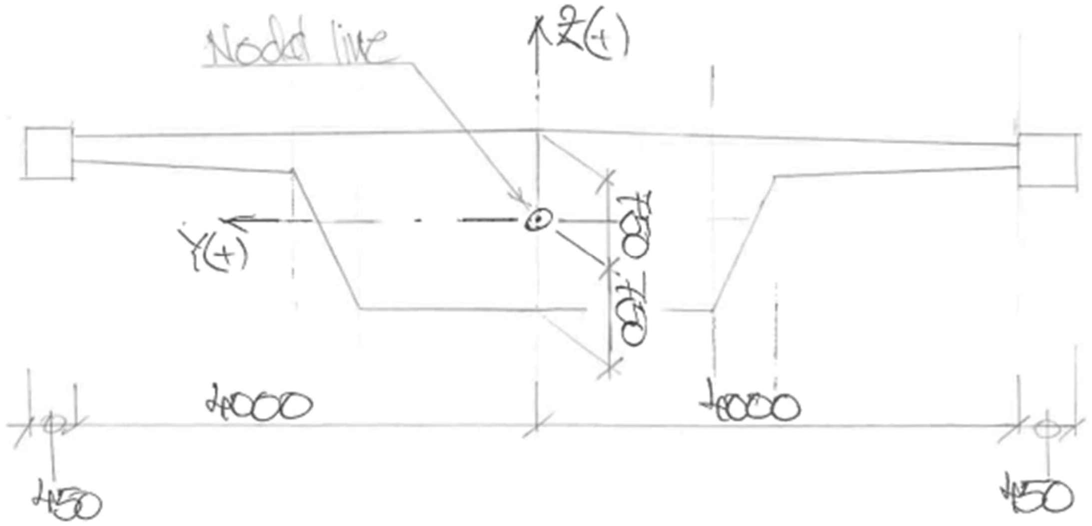
1.2.2 Simplified geometry system analysis



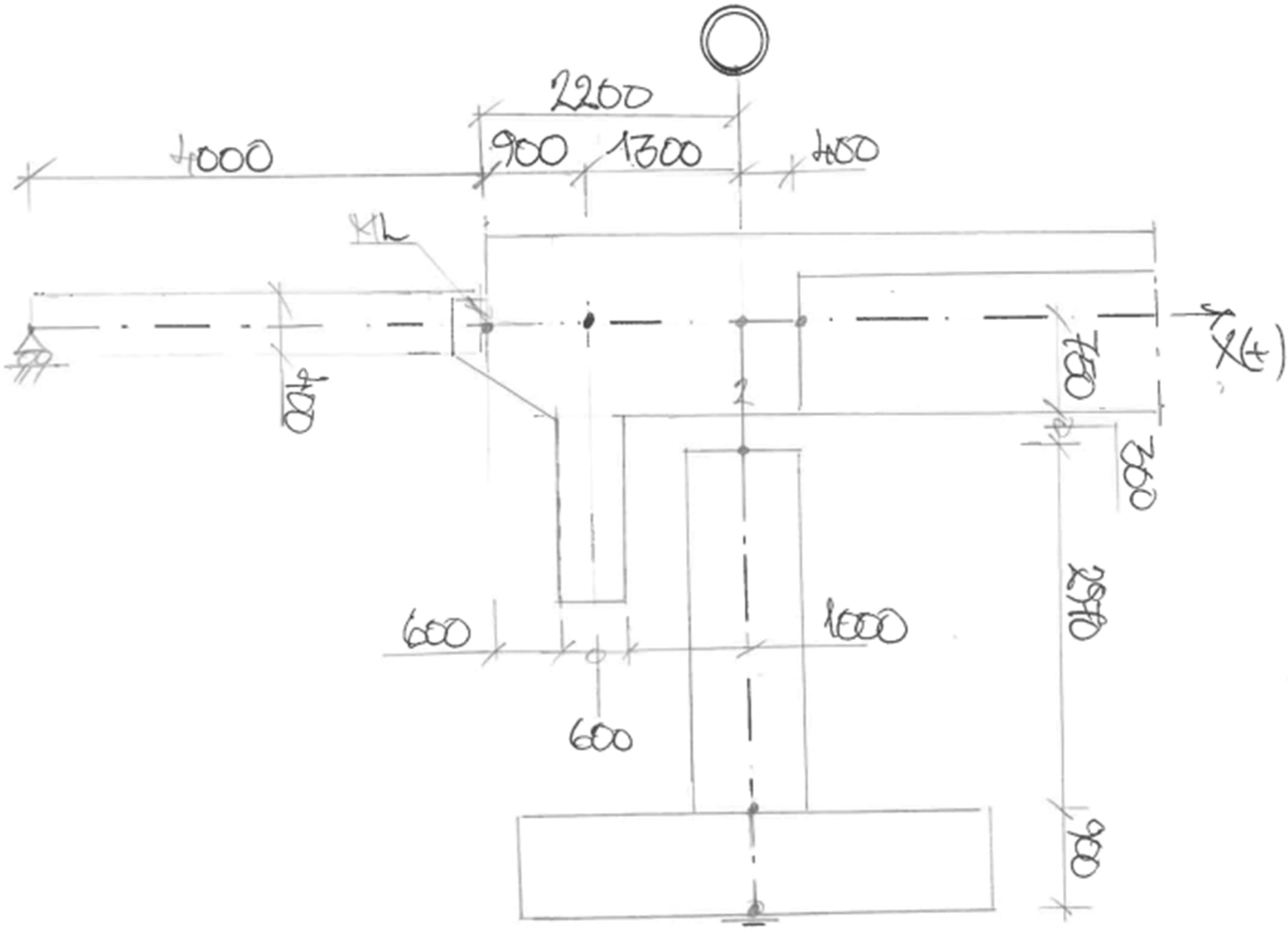
PLAN



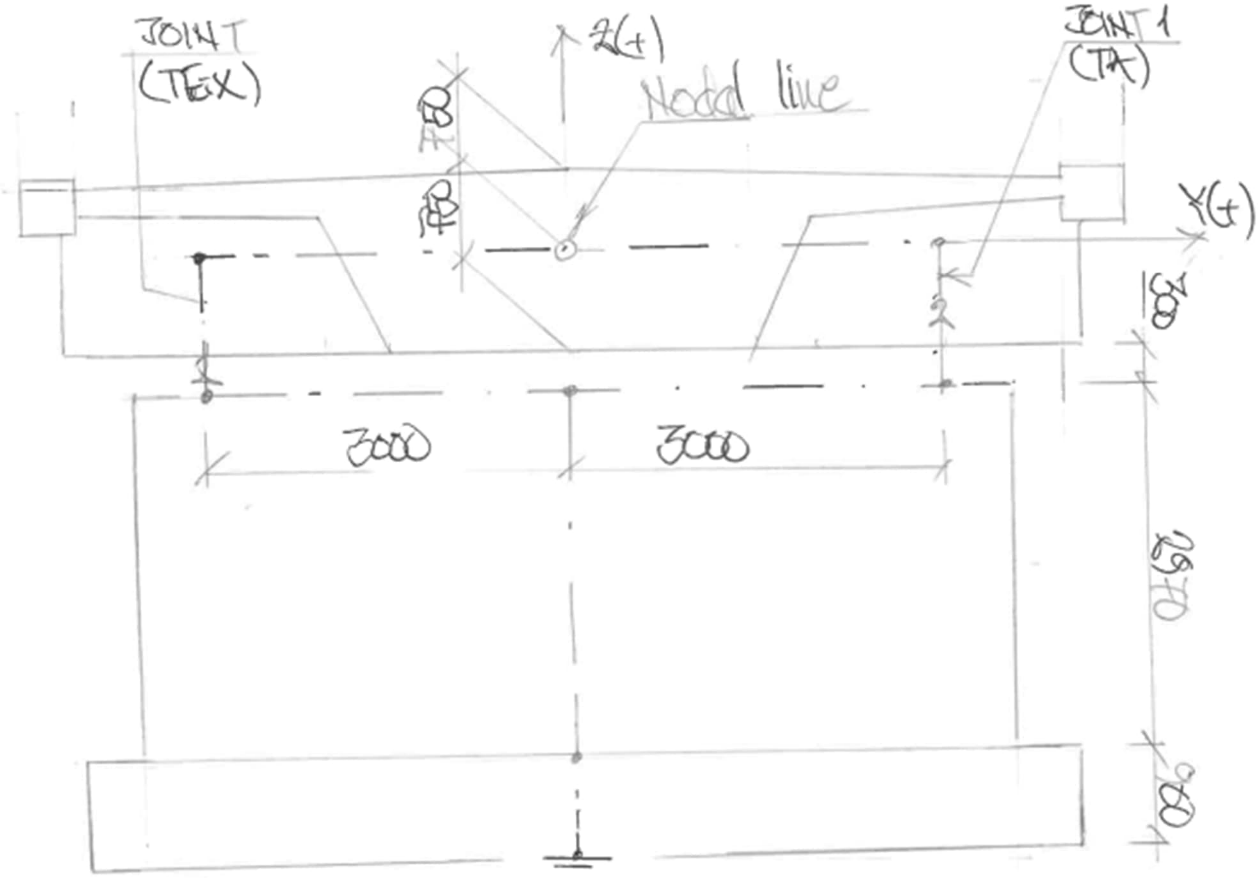
SECTION A-A



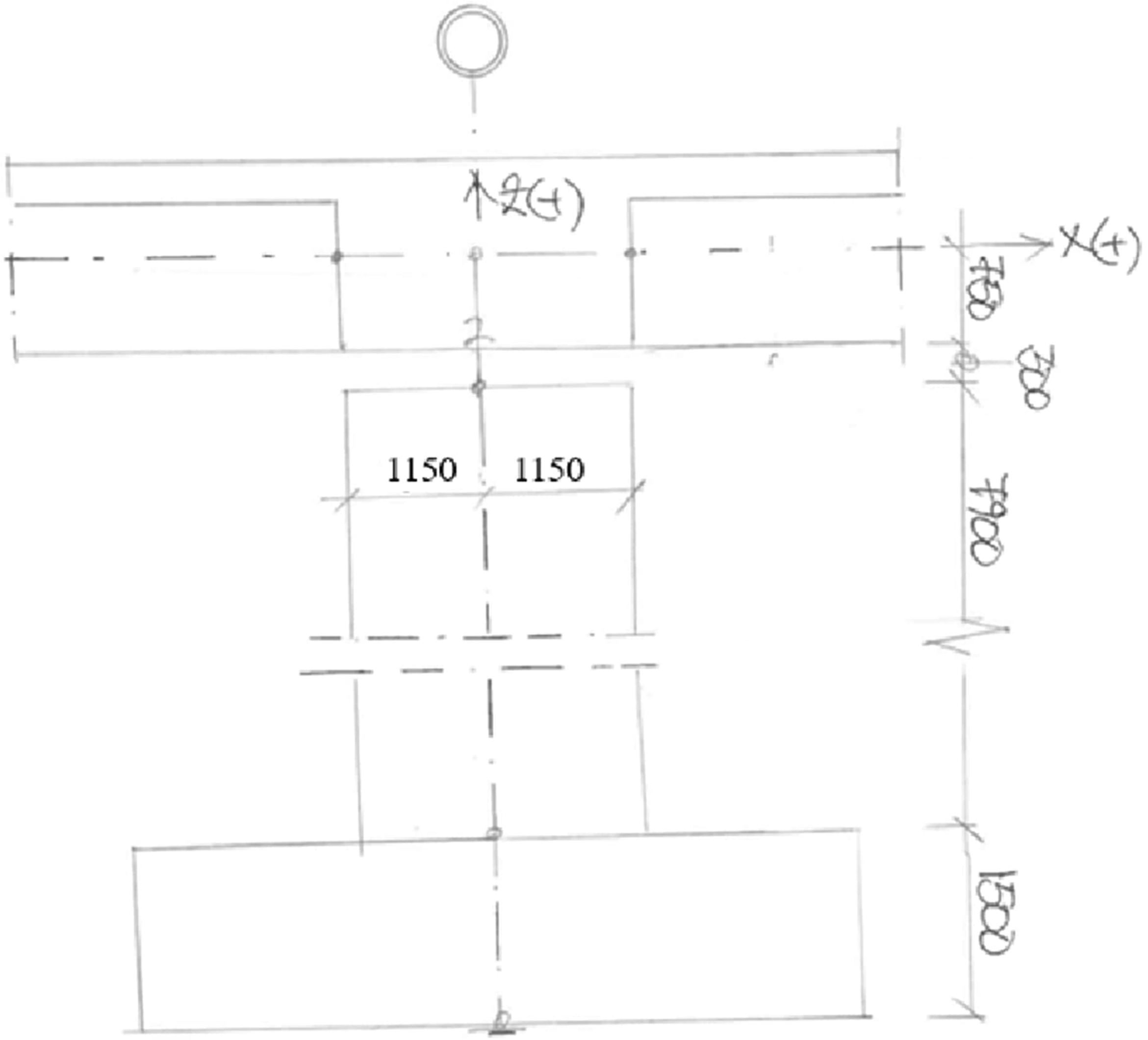
SECTION B-B



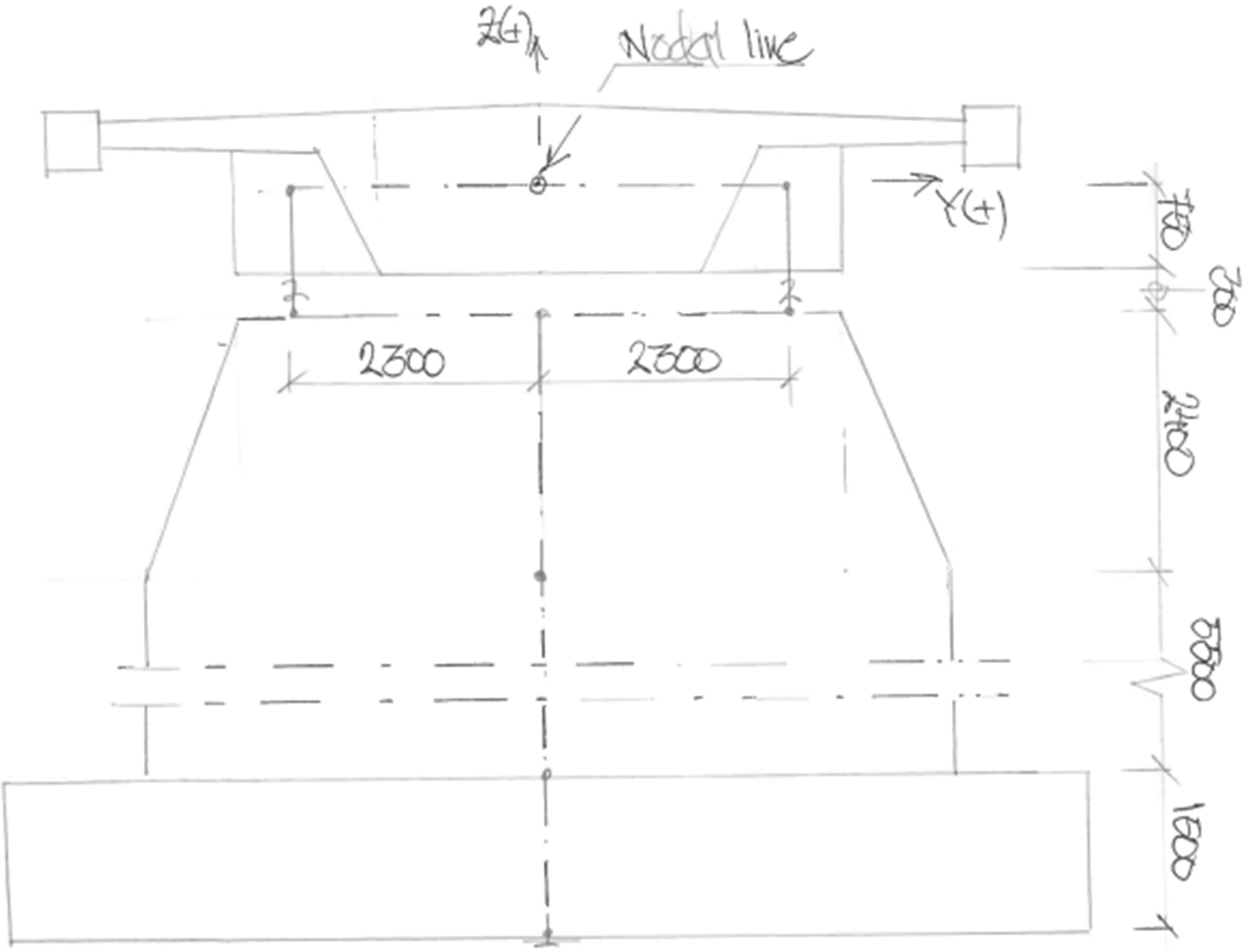
SECTION C-C



SECTION D-D



SECTION E-E



SECTION F-F

1.3 FOUNDATION

Bottom slabs are underwater cast concrete in side a sheet piled box.

Beneath glaciofluvial gravel on top of rock is found.

1.4 CODE OCH TENDER DOCUMENTS

- ”Bro och broliknande konstruktion allmänna krav” (TRVINFRA-00226 v5)
- ”Bro och broliknande konstruktion byggande” (TRVINFRA-0027 v6)
- ”TSFS 2018:57 med ändringar tom TSFS 2022:50”
- ”AMA Anläggning 23”
- ”TRV ändringar och tillägg till AMA 23” (TDOK 2023:0125 v3)
- ”Geokonstruktion dimensionering och utformning” (TRVINFRA-00230 v2)
- Document SS-EN 1990 to SS-EN 1999, see TRVINFRA section A.1.2.3.2

1.5 TECHNICAL SERVICE LIFE

Technical life span 120 years (L100).

1.6 ENVIRONMENT

Road traffic enviroment (“vägmiljö”) is assumed for the overlying traffic road since salt is used at winter, see TB section B1.

1.7 MATERIAL

Concrete : C30/37 & C35/45 (CEM I 42.5 N, Anläggningscement klass N)

Reinforcement : B500B

Compacted fill : ”Förtärkningslagermaterial” according to AMA CEB.415

Backfill : ”Grovkrossad sprängsten” according to AMA CEB.524

Surfacing : See document RKFM

Pretension: VSL system or eqivalent

1.8 GEOTECHNICAL CLASS

Geotechnical class GK2

1.9 SAFETY CLASS

Geotechnical resistance: SK 2

Brigde structure : SK 3

Retaining walls: SK 3

1.10 CONCRETE COVER AND CRACK CRITERIA

Class identification bridge components :

Bridge components	Exposure class[1.)]	Life spann	max vct_{ekv}[2.)]	ζ [3.)]
Substructure incl. linkplate:				
▫ Wingwall towards filling	XD1/XF4	L100	0.45	1.5
▫ Wingwall from filling	XD1/XF4	L100	0.45	1.5
▫ Abutement below ground	XC2/XF3	L100	0.50	1.0
▫ Abutement in air	XC4/XF3	L100	0.50	1.2
▫ Bottom slab in general	XC2/XF3	L100	0.50	1.0
▫ Bottom slab underside	XC2/XF3	L100	0.50	1.0
▫ Link slab in general	XD3/XF2	L100	0.40	1.8
▫ Link slab underside	XD3/XF2	L100	0.40	1.8
Superstructure:				
▫ Edge beam	XD3/XF4	L100	0.40	1.8
▫ Bridge deck	XD1/XF4	L100	0.40	1.5
▫ End shield towards filling	XD1/XF4	L100	0.40	1.5
▫ End shield from filling	XC2/XF3	L100	0.50	1.0

Footnote:

1.) TRVINFRA-00227 section 5.3.2.3

2.) TSFS table 12.1

3.) TSFS table 12.3

Design parameters low corrosion sensitive reinforcement (rebars):

$c_{min.dur}$: minimum cover with regard to environmental impact

$c_{min.b}$: minimum cover with regard to adhesion requirements
Δc_{dev} : execution tolerance
$c_{min} = \max(c_{min.b}; c_{min.dur}; 10mm)$: SS-EN 1992-1-1 eq. 4.2
$c_{nom} = c_{min} + \Delta c_{dev}$: SS-EN 1992-1-1 eq. 4.1, noted as BM on the drawing

Construction part	$c_{min.dur}$ [1.)]	$c_{min.b}$ [2.)]	c_{min}	c_{dev} [3.)]	c_{nom}	$w_{k,till}$ [4.)]
Substructure incl. linkplate:						
▫ Wingwall towards filling	30	20	30	10	40	0.20
▫ Wingwall from filling	30	20	30	10	40	0.20
▫ Abutement below ground	20	20	20	10	30	0.40
▫ Abutement in air	25	20	25	10	35	0.30
▫ Bottom slab in general	20	20	20	10	30	0.40
▫ Bottom slab underside	20	20	20	10	30	0.40
▫ Link slab in general	45	20	45	10	55	0.15
▫ Link slab underside	45	20	45	10	60[5.)]	0.15
Superstructure:						
▫ Edge beam	45	20	45	10	55	0.15
▫ Bridge deck	25	20	25	10	35	0.20
▫ End shield towards filling	25	20	25	10	35	0.20
▫ End shield from filling	25	20	25	10	35	0.40

Footnotes:
1.) TSFS table 12.1
2.) SS-EN 1992-1-1 section 4.4.1.2 table 4.2
3.) SS-EN 1992-1-1 section 4.4.1.3
4.) TSFS tabele 12.2
5.) TSFS chapter 12 paragraph 3§ $k_1 = c_{min} + 15$ mm vhen casting against building foil.

Design parameters high corrosion sensitive reinforcement (pretension):

$c_{min.dur}$: minimum cover with regard to environmental impact

$c_{min.b}$: minimum cover with regard to adhesion requirements
Δc_{dev} : execution tolerance
$c_{min} = \max(c_{min.b}; c_{min.dur}; 10mm)$: SS-EN 1992-1-1 eq. 4.2
$c_{nom} = c_{min} + \Delta c_{dev}$: SS-EN 1992-1-1 eq. 4.1, noted as BM on the drawing

Construction part	$c_{min.dur}$ 1.)	$c_{min.b}$ 2.)	c_{min}	c_{dev} 3.)	c_{nom}	$w_{k,till}$ 4.)
Superstructure:						
▫ Top bridge deck	25	90	90	10	100	*
▫ Other part of bridge deck	25	90	90	10	100	*
	mm	mm	mm	mm	mm	mm

Footnotes:
1.) TSFS table 12.1
2.) SS-EN 1992-1-1 section 4.4.1.2 (3) specifies pretension tube ϕ90
3.) SS-EN 1992-1-1 section 4.4.1.3
4.) TSFS table 12.2 states that crack width is not needed when ”tensile stress” for SLS-F is less than $f_{ctk.0.05}/\zeta$

2. SYSTEM ANALYSIS

2.1 GENERAL

The bridge is built using reinforced concrete.

The superstructure is designed as single longitudinal T-beam .

A link slab is attached to superstructure using joint without moment (ML). This is done by introducing pined end-release in link slab. A fictious beam with length of 4 m and roller support is used in FEM-modell.

All concrete structures are modelled 3D-beam elements located at nodal lines.

At supports fictious transversal rigid beams (Rigid:T) are added to superstructure to transfer loads to bearings.

At supports fictious transversal rigid beams (Rigid:B) are addes top of abutments to transfer lo bearing load to substructure.

Between transversal rigid beams bearing are defined using joints.

Entire structure is modelled using isotropic material.

Bridge foundation consists of “tätkaka” on glaciofluvial gravel on top of rock.

Wingwalls are not modelled statically since considered inactive in vertical direction. This is due cracking and the use of only minimal reinforcement in this direction.

Edge beams are not modelled statically since considered inactive. This assumption is considered on safe side. The assumption will facilitate future replacement of edge beams.

In system analysis gross cross section may be used for longitudinal beams in superstructure, see SS-EN 1992-1-1 section 5.3.2.1 point (4).

In FEM-analysis constant cross section is used for longitudinal beams along entire span length, see SS-EN 1992-1-1 section 5.3.2.1 (4).

Attachments:

Attachment	Name
1	Input receipt
2	Results reactions
3	Results abutments
4	Results longitudinal beams

2.2 SKETCH SYSTEM ANALYSIS

2.2.1 Geometry

In order to describe geometry first POINTS are defined.

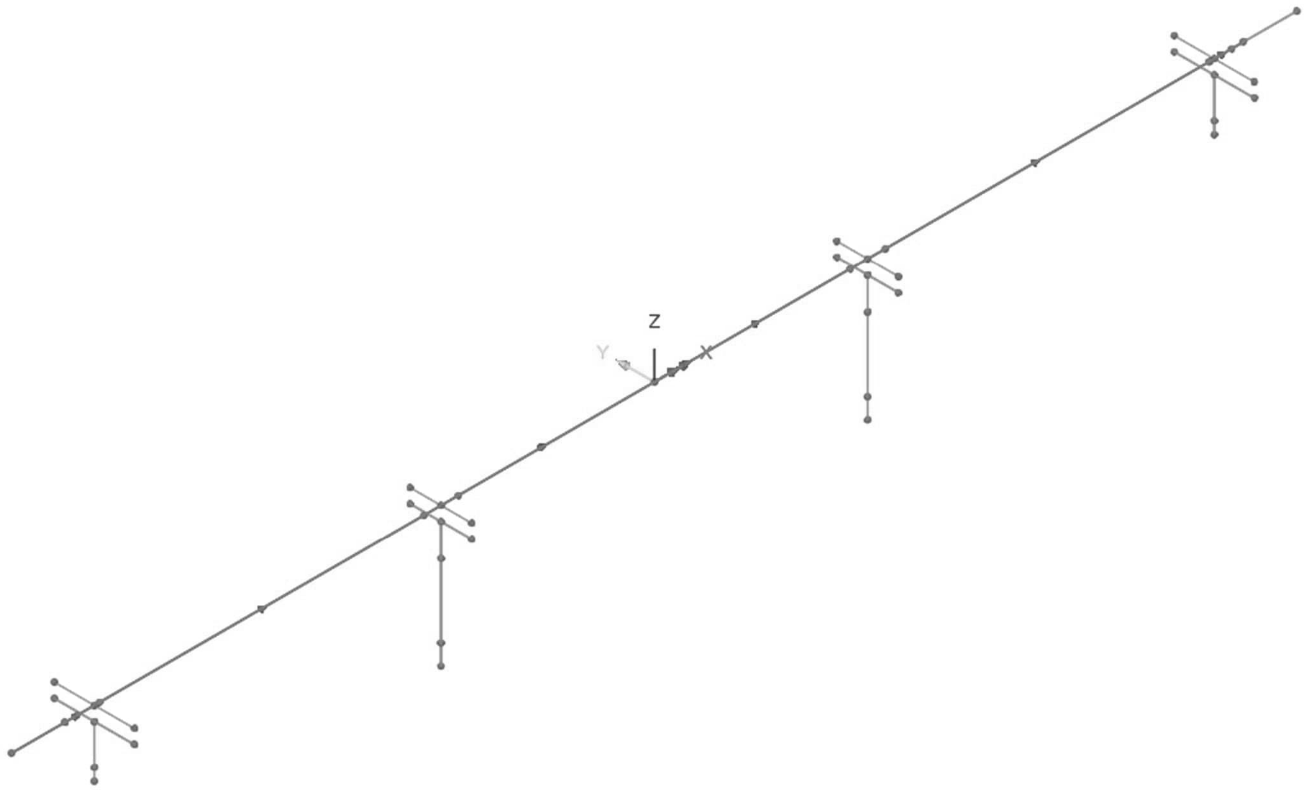
Beam elements are defined by applying attributes to LINES.

Attached pictures are retrieved from graphical sketches generated by FEM program of POINTS and LINES.

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

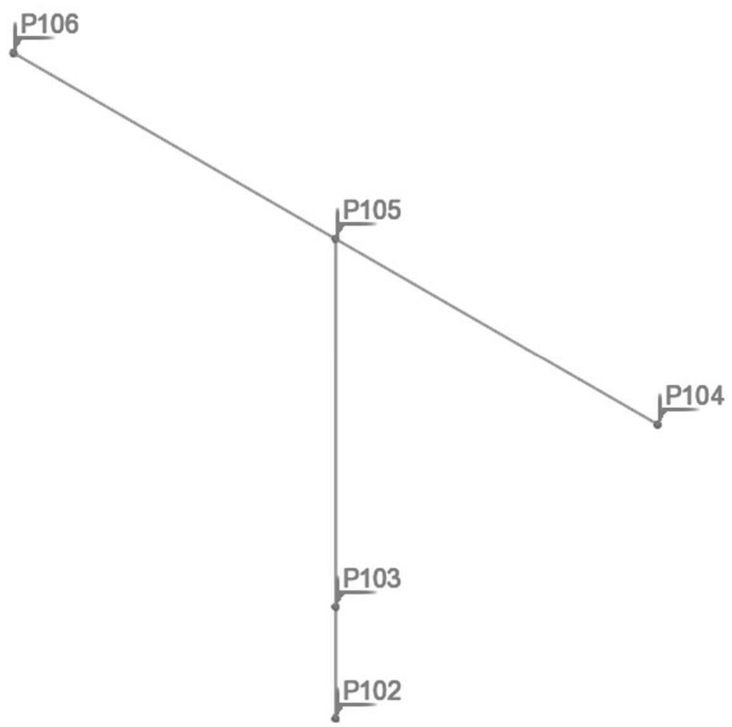
All POINTS needed to describe LINES are found in attachment 1.

Overview :

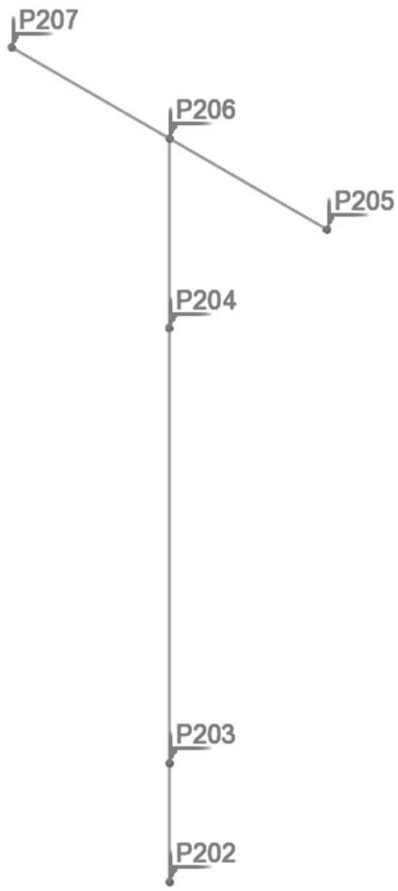


2.2.1.1 Geometry : POINTS

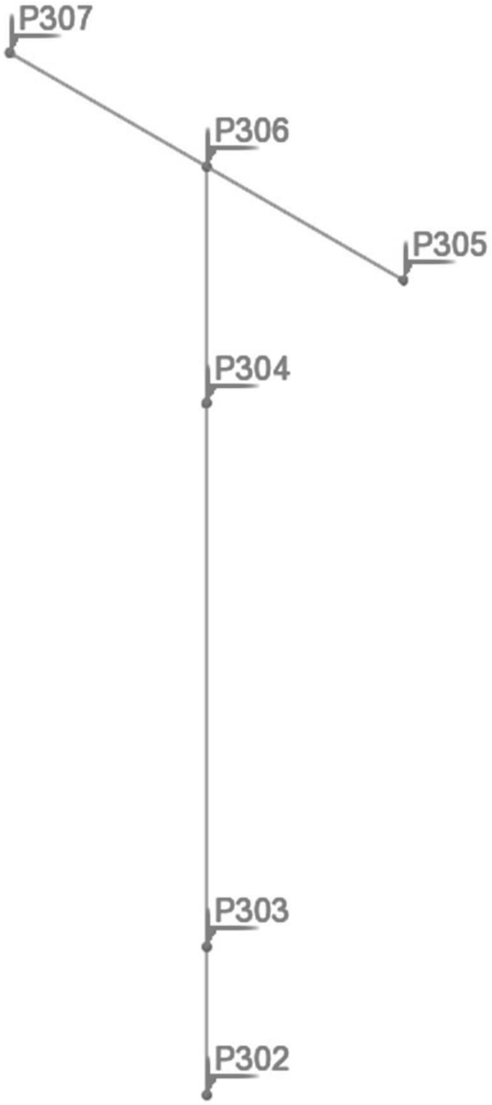
Abutment 1 (including Rigid:B) :



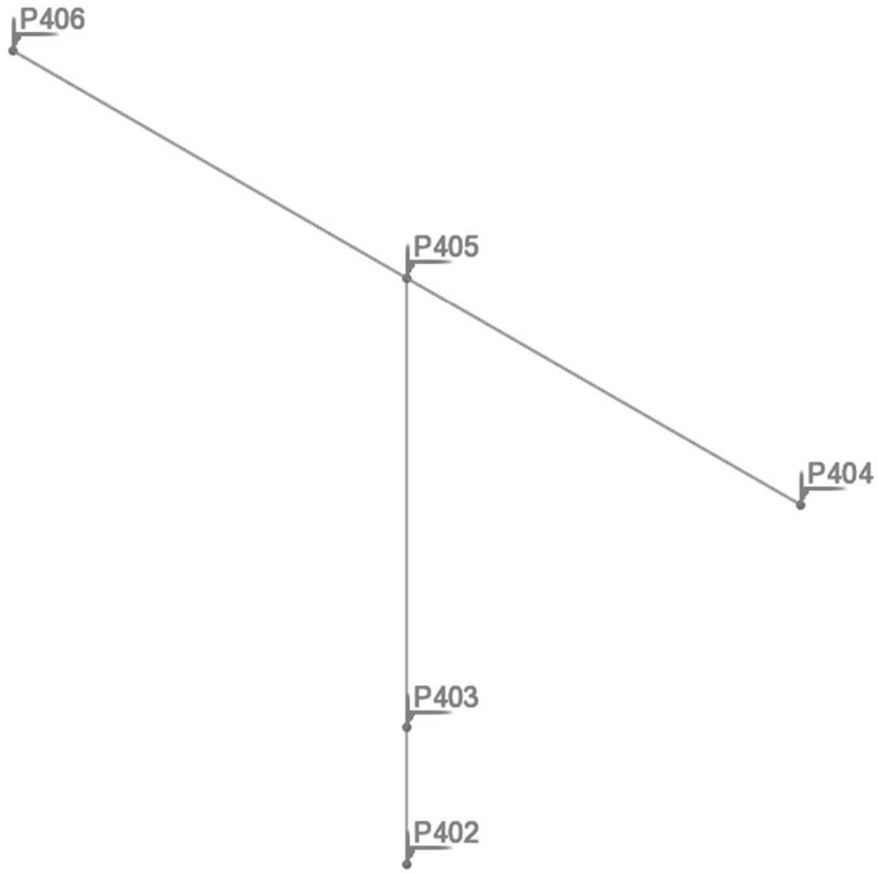
Abutment 2 (including Rigid:B) :



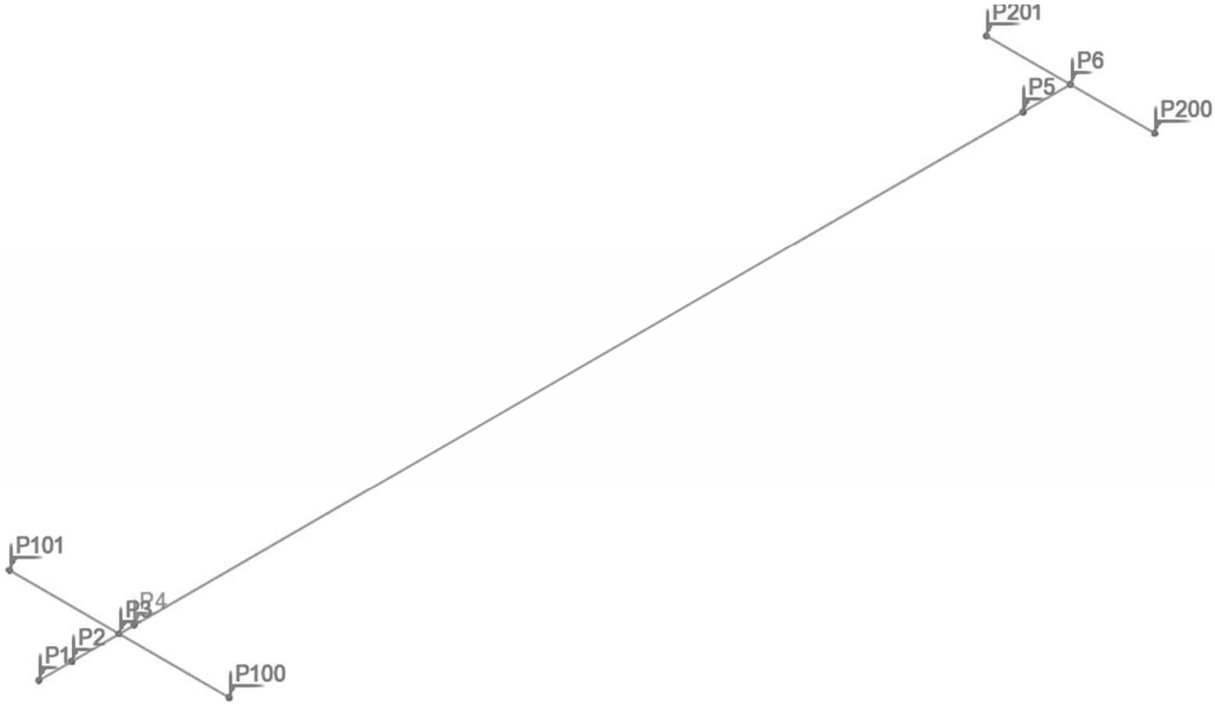
Abutment 3 (including Rigid:B) :



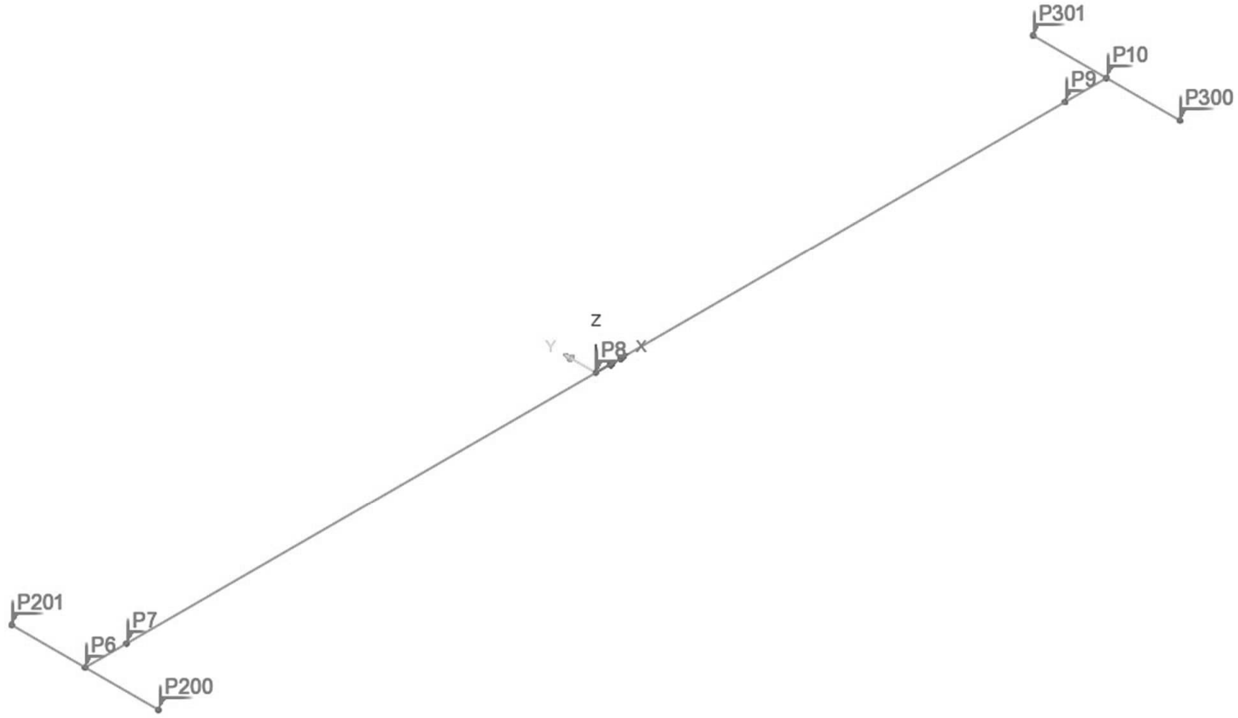
Abutment 4 (including Rigid:B) :



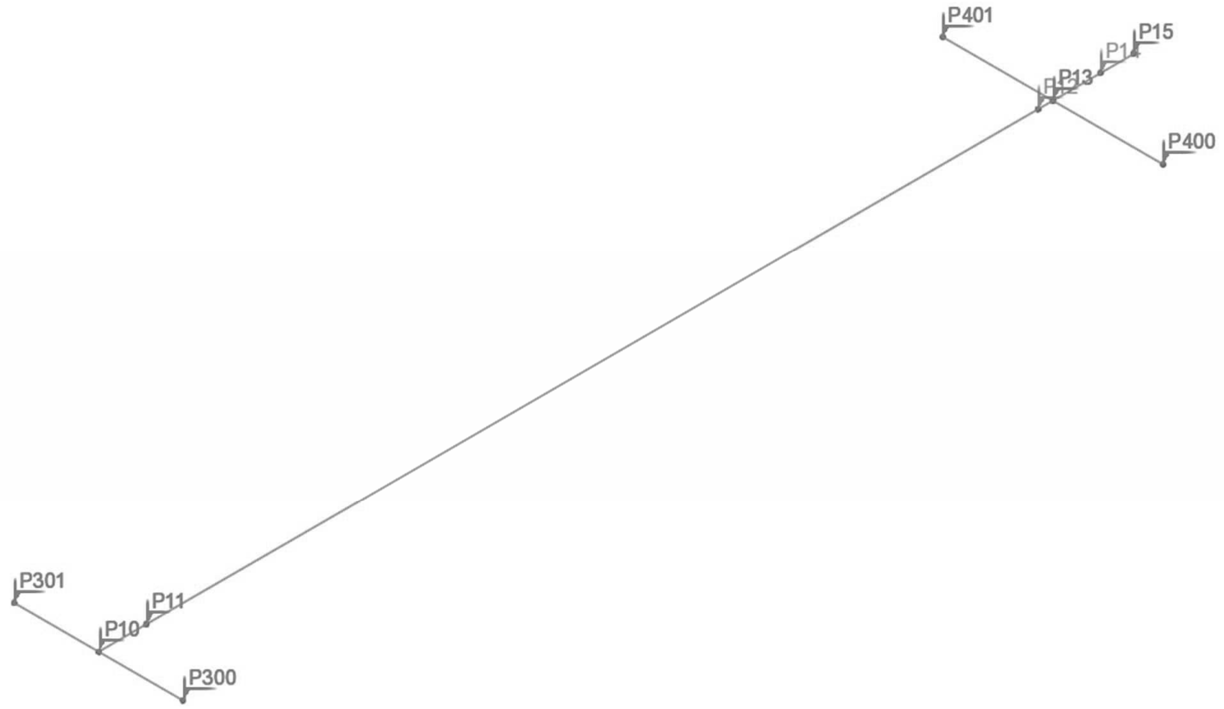
Superstructure – spann 1 (including Rigid:T) :



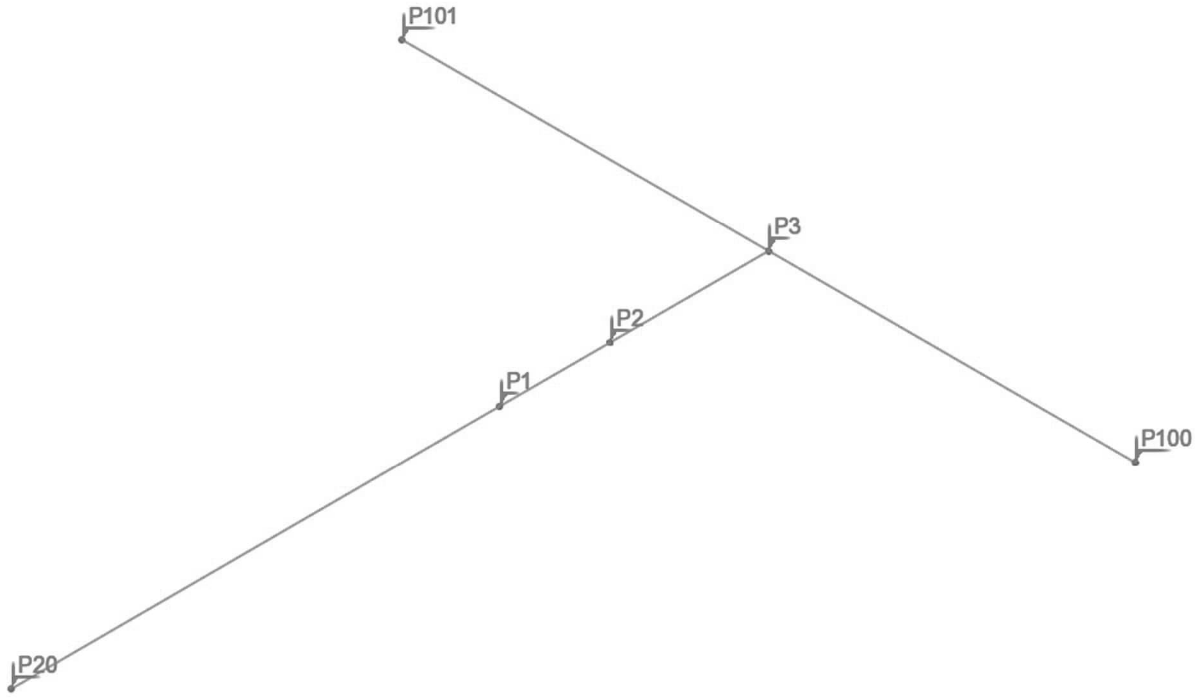
Superstructure – spann 2 (including Rigid:T) :



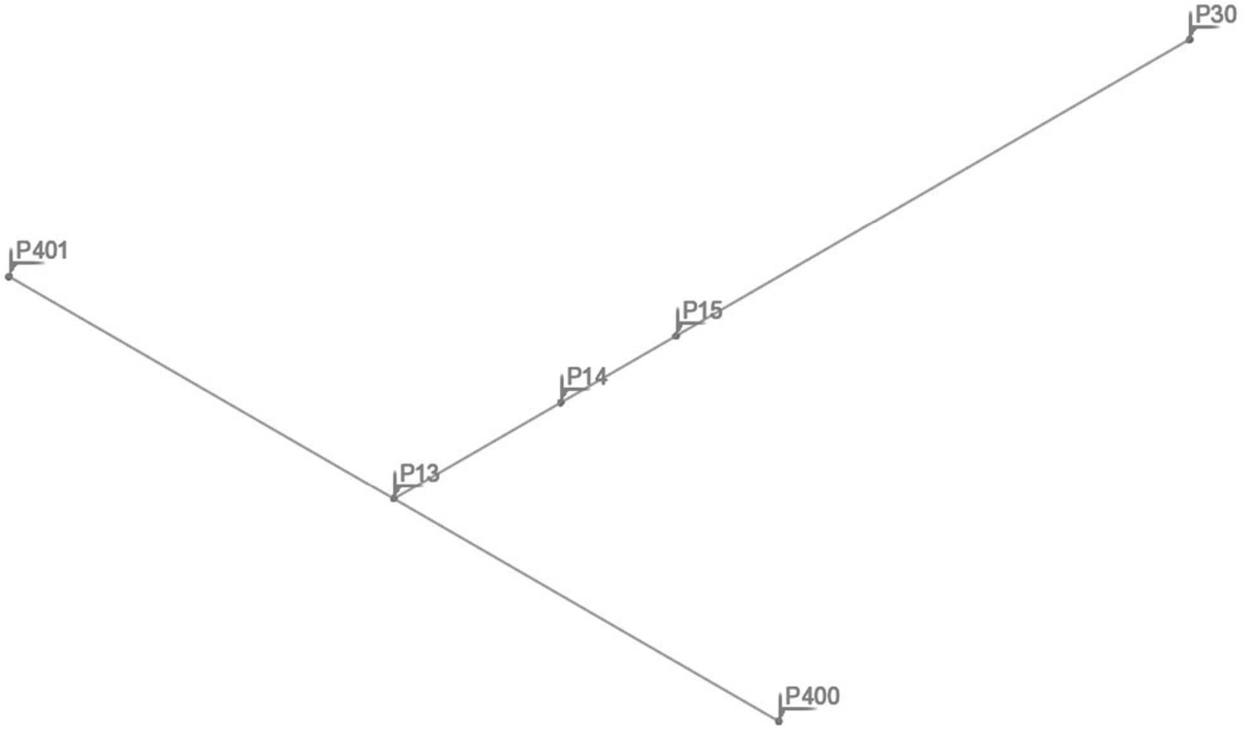
Superstructure – spann 3 (including Rigid:T) :



Link slab at support 1 :



Link slab at support 4 :



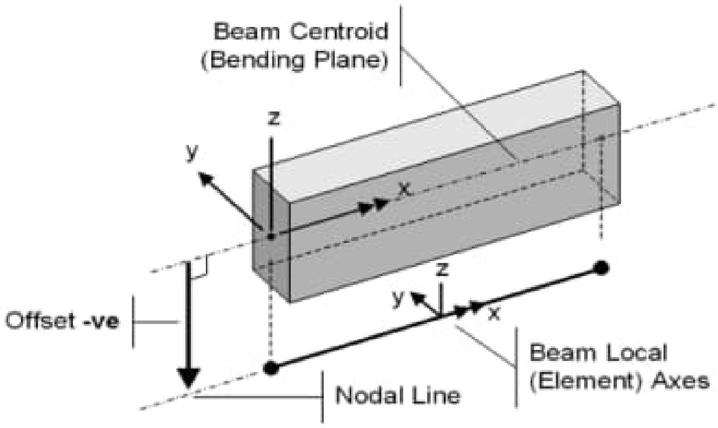
2.2.1.2 Geometry : LINES

See attachment 1.

2.3 CROSS SECTION PROPERTIES

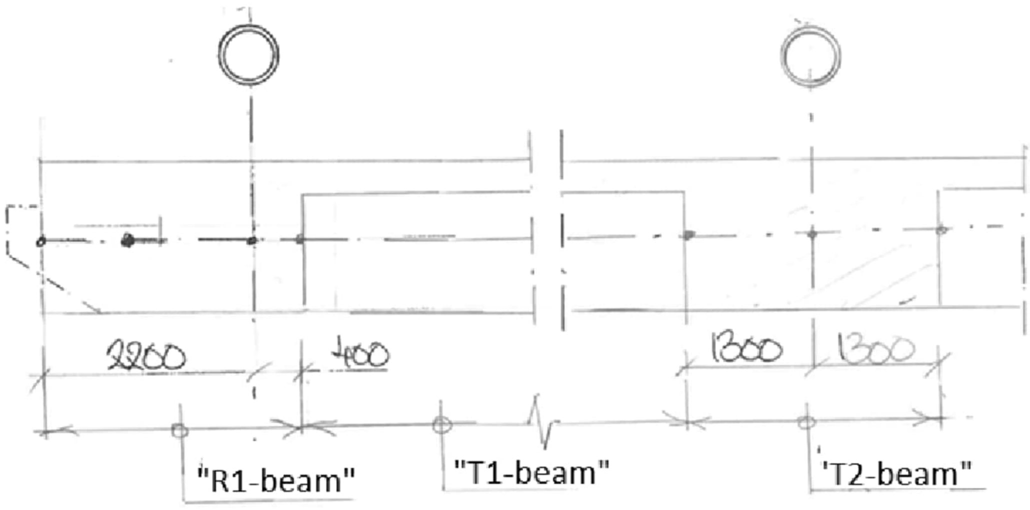
The structure only contain 3D-beams (”Thick beam” / BMS3).

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



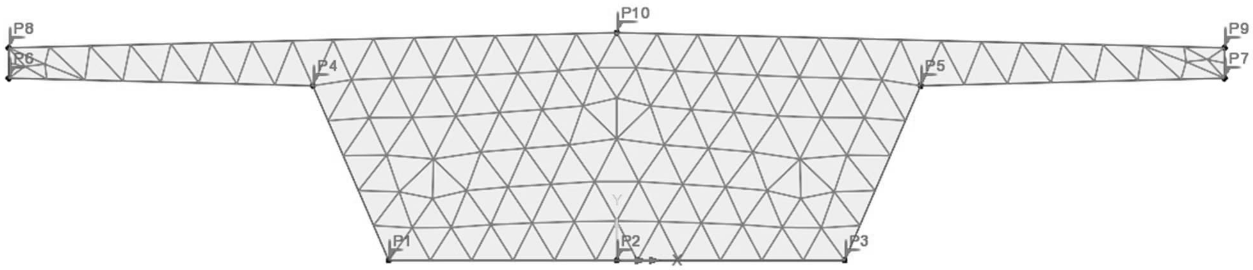
2.3.1 Longitudinal beam: T1-beam

The cross section is constant apart for areas at location supports, as seen in sketch below.



In order to determine exact rotational stiffness (Vlasov & St Venant) a FEM-anlaysis is performed. This is done using “Section Property Calculator” for an arbitrary section.

Definition of arbitrary section



Point	x	y
1	-1.5	0
2	0	0
3	1.5	0
4	-2.0	1.15
5	2.0	1.15
6	-4.0	1.20
7	4.0	1.20
8	-4.0	1.40
9	4.0	1.40
10	0	1.50
-	m	m

Cross section properties

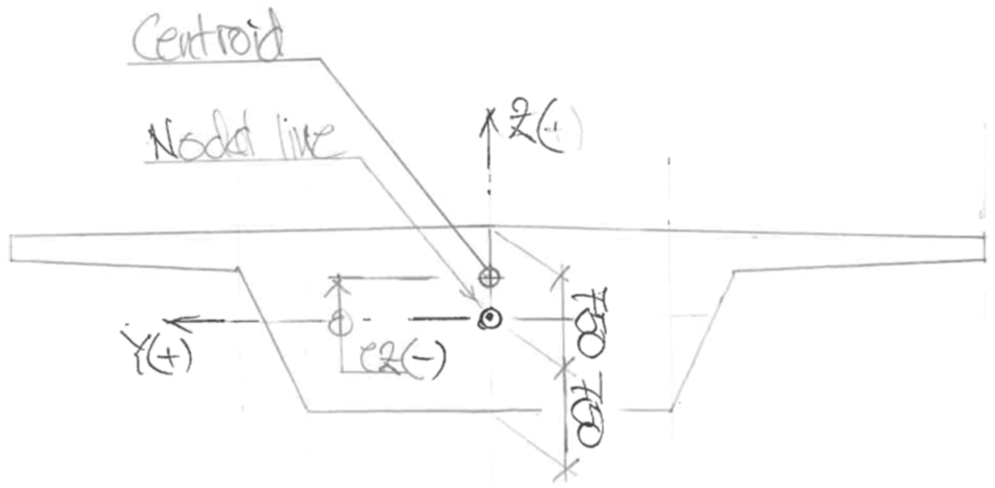
Section Details

Calculated properties

		Value
Cross sectional area	A	6.325
Second moment of area about x axis	Ixx	1.18484
Second moment of area about y axis	Iyy	14.7927
Product moment of area	Ixy	-1.89594E-15
Torsional constant	J	2.89917
Effective shear area in x direction	Asx	5.33467
Effective shear area in y direction	Asy	2.07906
Radius of gyration about x axis	kx	0.432813
Radius of gyration about y axis	ky	1.5293
Warping torsional constant about shear centre	Cw	0.642747
Shear centre x distance from centroid	xo	-2.57777E-6
Shear centre y distance from centroid	yo	-0.115161
Monosymmetry constant about x	betax	3.3089
Monosymmetry constant about y	betay	2.03617E-6
Wagner constant 1st moment of square radius about x	Ixr	3.64763
Wagner constant 1st moment of square radius about y	Iyr	4.99667E-12
Wagner constant 4th moment of area about origin	Irr	109.434
Wagner constant 2nd moment of warping about origin	Iwr	68.3524E-6
Plastic section modulus about x axis	Zpx	2.37684
Plastic section modulus about y axis	Zpy	7.74583
Plastic torsional section modulus	Zpt	4.77977
Plastic neutral axis, distance from centroid along x axis	xp	-26.8779E-18
Plastic neutral axis, distance from centroid along y axis	yp	0.0703815
Centroid X from geometry origin	Xc	-17.0044E-18
Centroid Y from geometry origin	Yc	-0.858696
Principal axes angle	theta	0.0

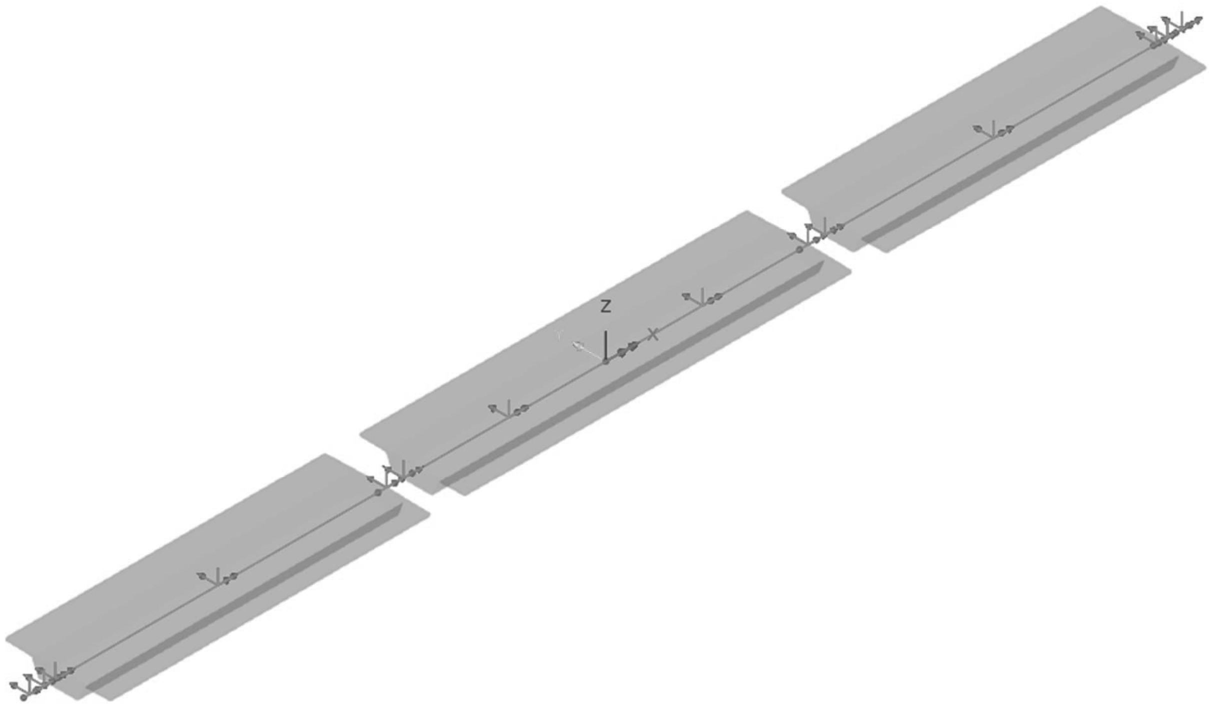
Results “T1-beam”

ez = 0.750 m + Y_c = 0.750 m - 0.858 m = -0.109 m



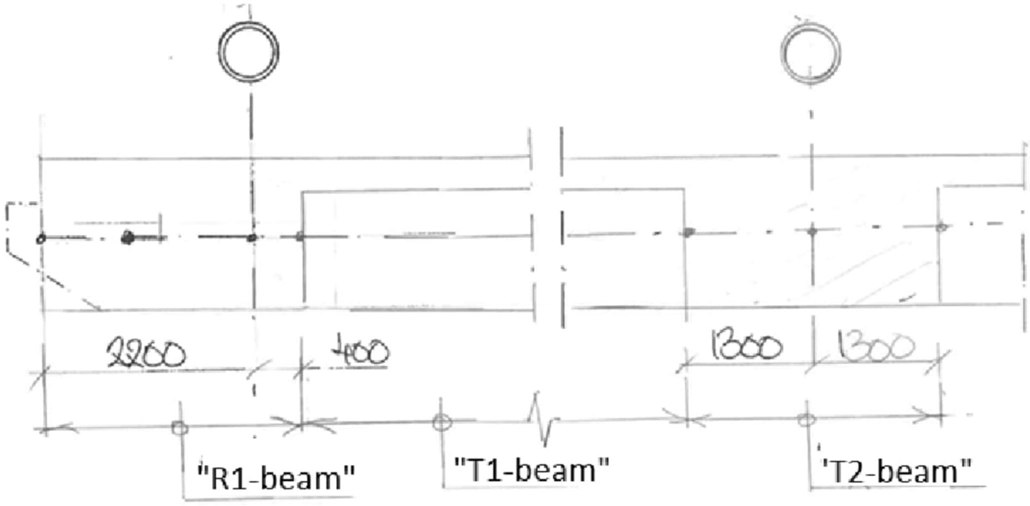
Data	“T1-beam”	Unit
A	6.325	m^2
Iyy	1.185	m^4
Izz	14.793	m^4
Iyz	0	m^4
J	2.899	m^4
ez	-0.109	m
-	m	-

Graphic visualization

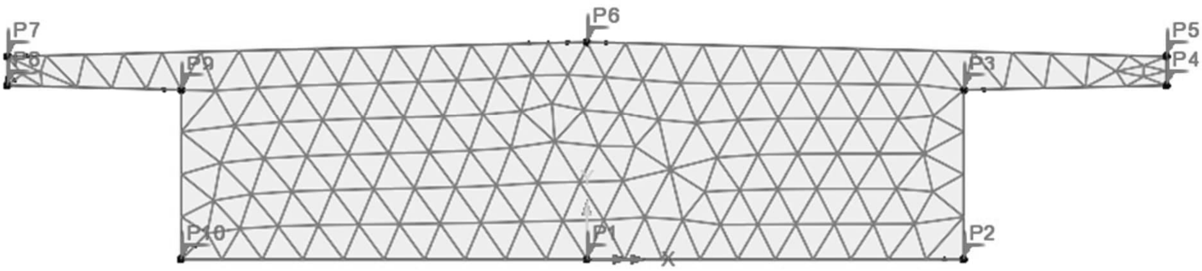


2.3.2 Longitudinal beam: T2-beam

The cross section is occurs locally at support 2 & 3, as seen in sketch below. Calculation is performed using “Section Property Calculator” for an arbitrary section.

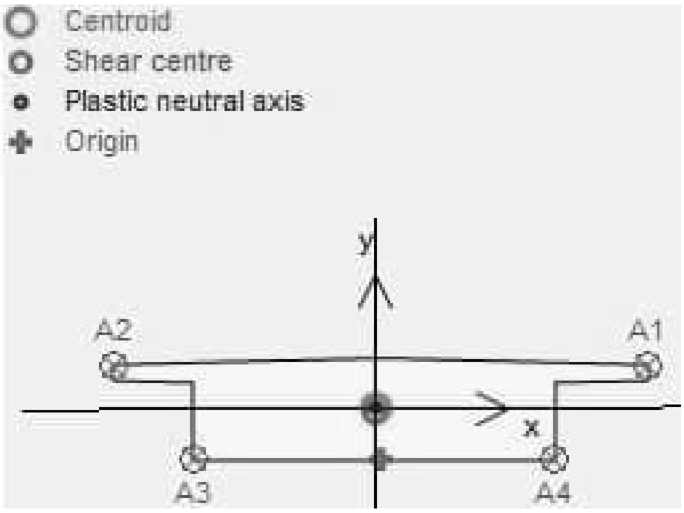


Definition of arbitrary section



Point	x	y
1	0	0
2	2.8	0
3	2.8	1.17
4	4.0	1.20
5	4.0	1.40
6	0	1.50
7	-4.0	1.40
8	-4.0	1.20
9	-2.8	1.17
10	-2.8	0
-	m	m

Cross section properties



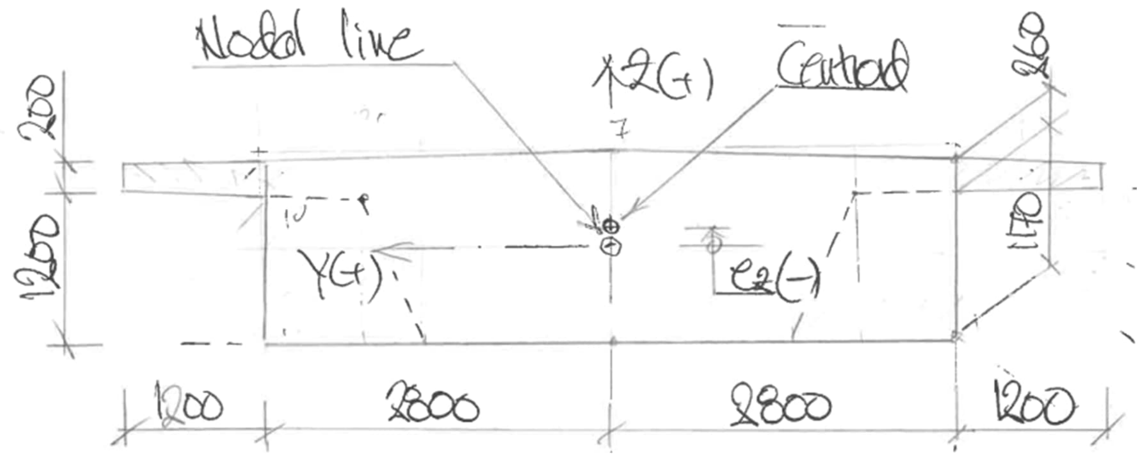
Section Details

Calculated properties

		Value
Cross sectional area	A	8.756
Second moment of area about x axis	Ixx	1.63794
Second moment of area about y axis	Iyy	27.5331
Product moment of area	Ixy	-2.78561E-15
Torsional constant	J	4.97776
Effective shear area in x direction	Asx	7.6109
Effective shear area in y direction	Asy	5.31414
Radius of gyration about x axis	kx	0.43251
Radius of gyration about y axis	ky	1.77327
Warping torsional constant about shear centre	Cw	3.12092
Shear centre x distance from centroid	xo	-7.14726E-6
Shear centre y distance from centroid	yo	-0.0730907
Monosymmetry constant about x	betax	1.58752
Monosymmetry constant about y	betay	16.6908E-6
Wagner constant 1st moment of square radius about x	Ixr	2.36075
Wagner constant 1st moment of square radius about y	Iyr	0.14466E-9
Wagner constant 4th moment of area about origin	Irr	186.978
Wagner constant 2nd moment of warping about origin	Iwr	0.114759E-3
Plastic section modulus about x axis	Zpx	3.30552
Plastic section modulus about y axis	Zpy	13.2565
Plastic torsional section modulus	Zpt	7.84241
Plastic neutral axis, distance from centroid along x axis	xp	-0.162061E-15
Plastic neutral axis, distance from centroid along y axis	yp	0.0133845
Centroid X from geometry origin	Xc	-0.206835E-15
Centroid Y from geometry origin	Yc	-0.768407
Principal axes angle	theta	0.0

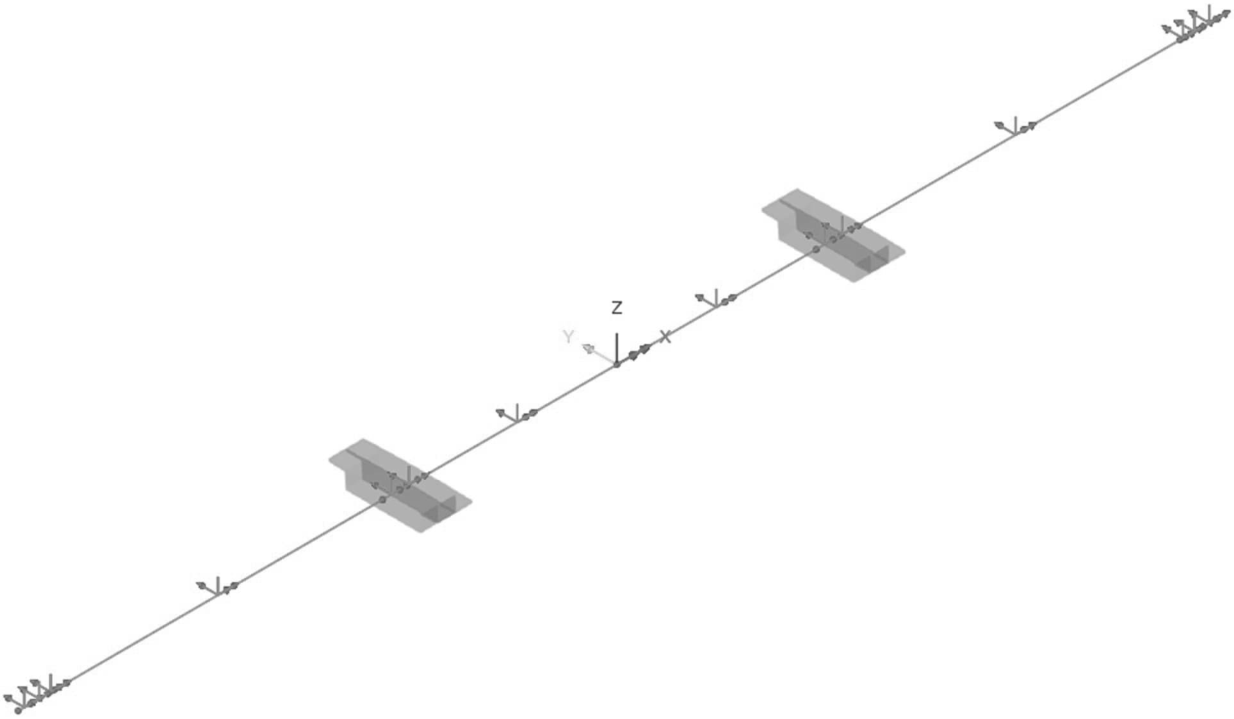
Results "T2-beam"

ez = 0.750 m + Y_c = 0.750 m - 0.768 m = -0.018 m



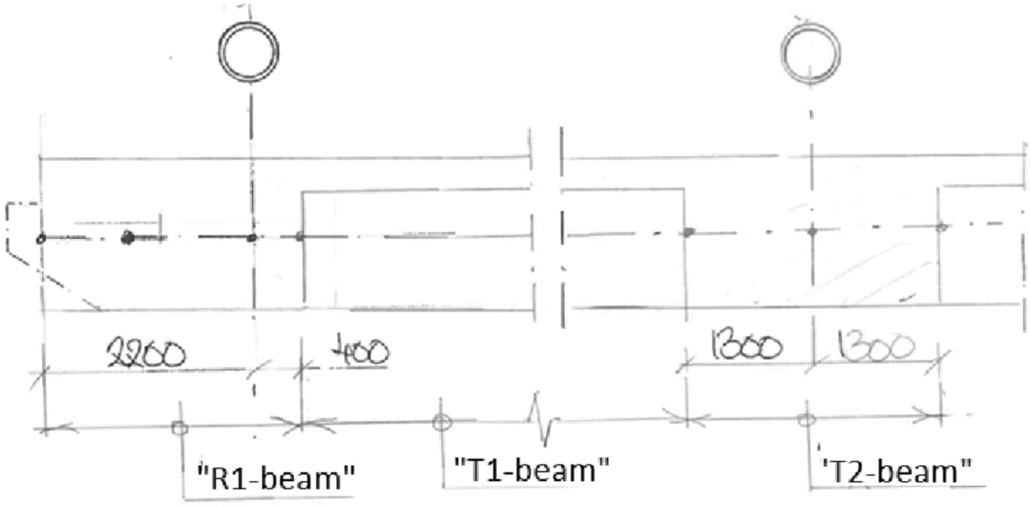
Data	"T2-beam"	Unit
A	8.756	m^2
Iyy	1.638	m^4
Izz	27.533	m^4
Iyz	0	m^4
J	4.978	m^4
ez	-0.023	m
-	m	-

Graphic visualization



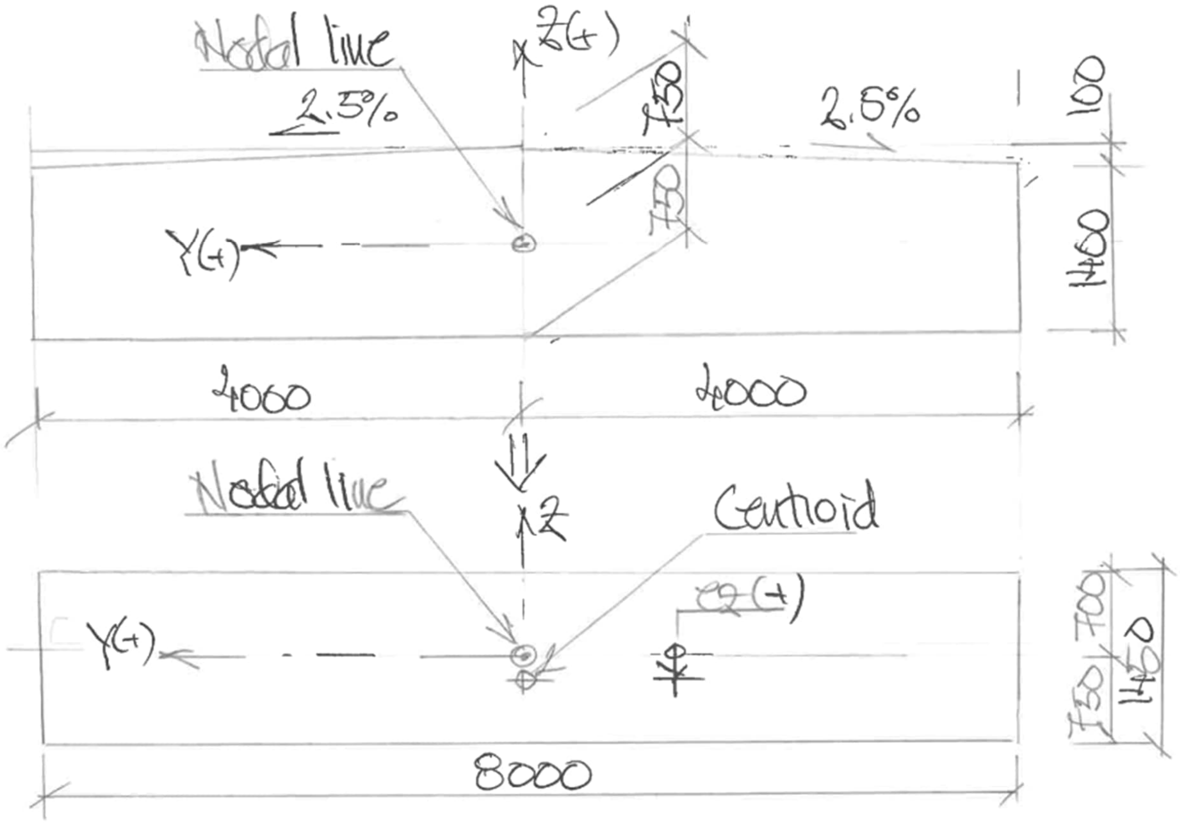
2.3.3 Longitudinal beam: Rectangular beam

The cross section is occurs locally at support 1 & 4, as seen in sketch below. Calculation is performed using “Section Property Calculator” for a parametric section type rectangular solid.



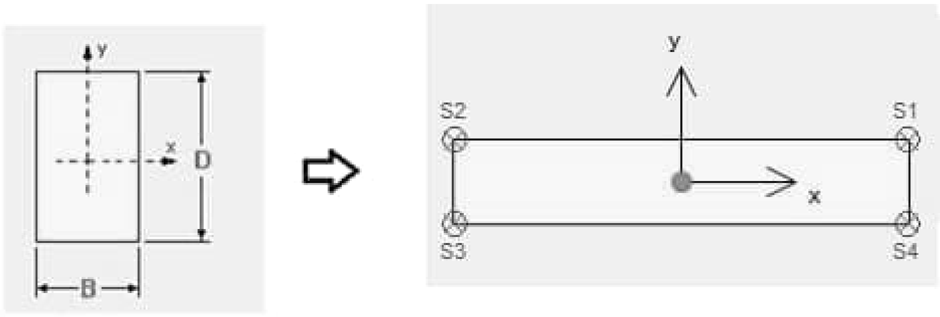
In these areas exact cross section is simplified to equivalent rectangular cross sections.

<u>Equivalent "R1-beam"</u>



ez = 0.750 m + Y_c = 0.750 m - 0.725 m = +0.025 m :

Input rectangular cross section

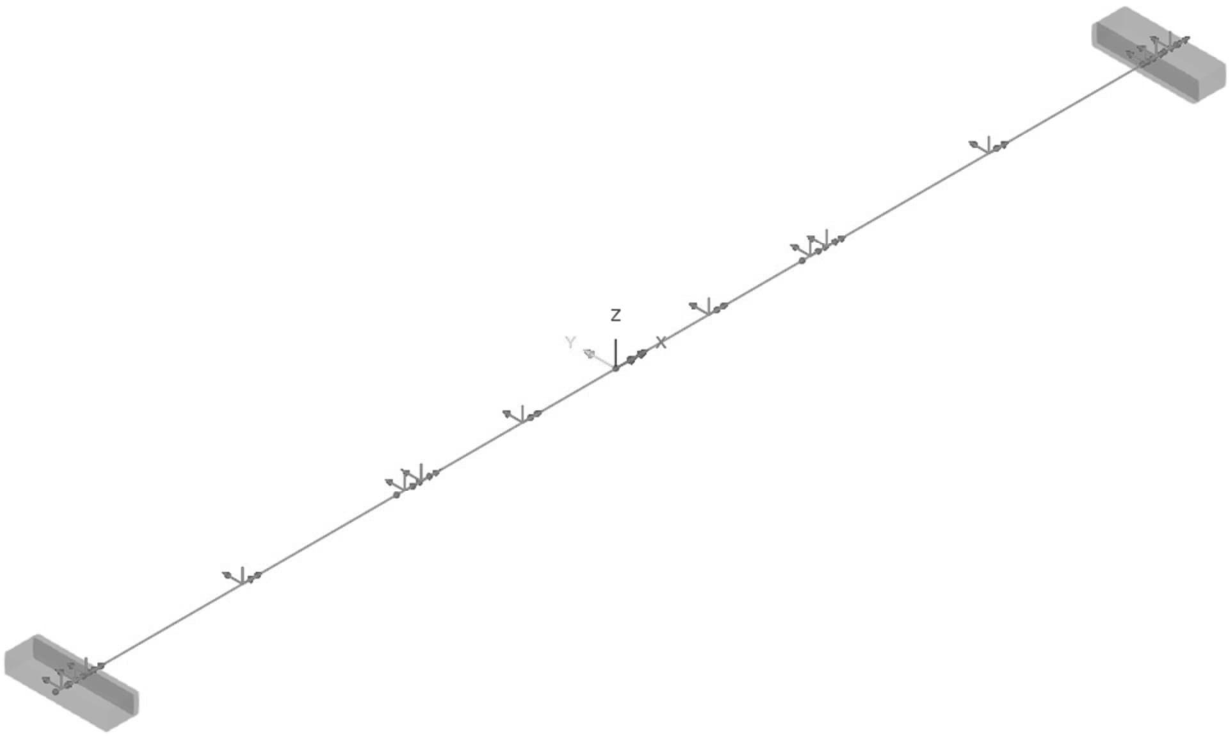


Data	"R2-beam"
D	1.465
B	5.600
-	m

Results

Data	"R1-beam"	Unit
A	11.600	m^2
Iyy	2.034	m^4
Izz	61.867	m^4
Iyz	0	m^4
J	7.202	m^4
ez	+0.025	m

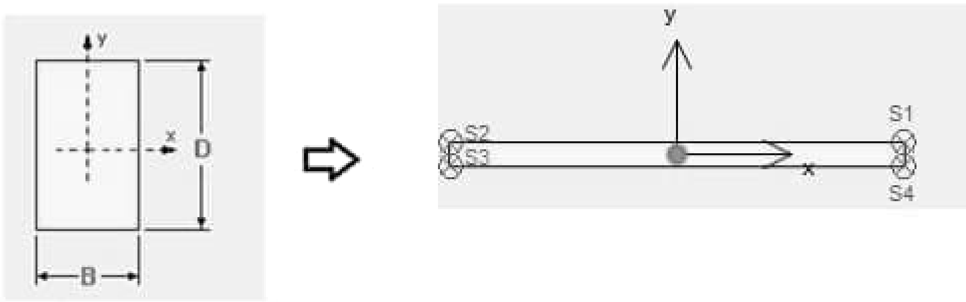
Graphic visualization



2.3.4 Link slabs: Rectangular beams

This link slabs are modelled using “Section Property Calculator” for parametric section type rectangular solid.

Input rectangular cross section

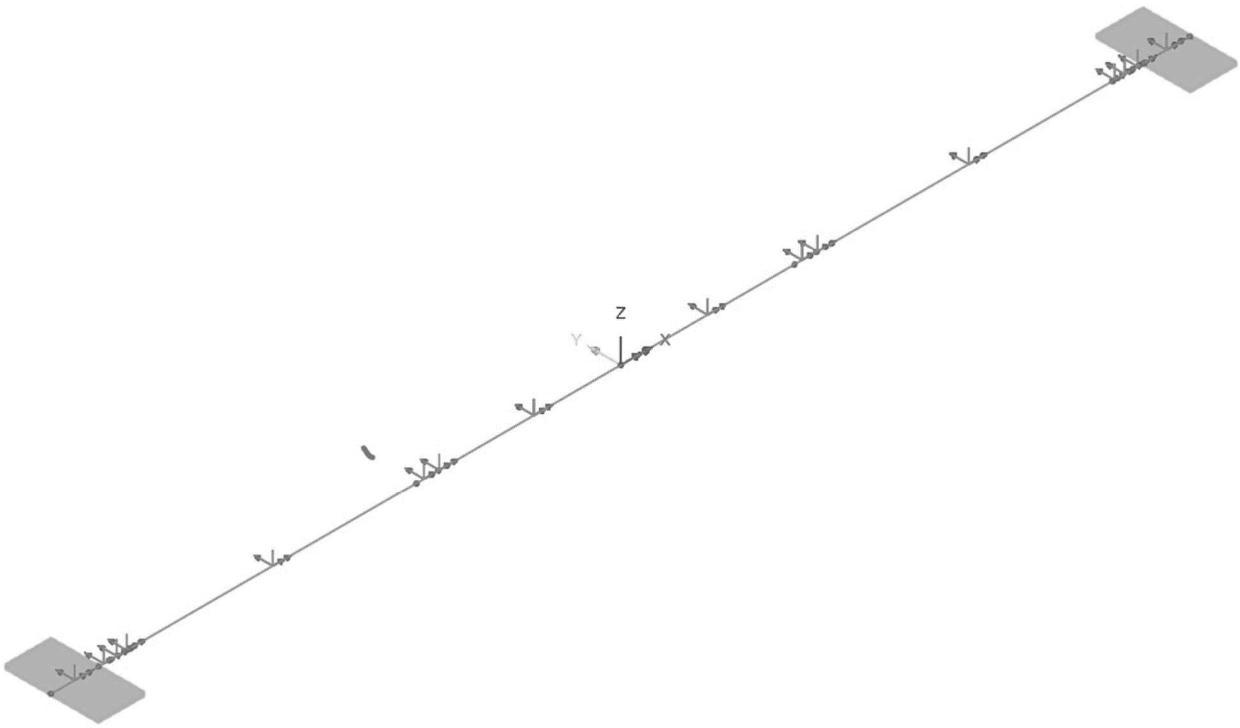


Data	“R2-beam”
D	0.400
B	8.000
-	m

Results

Data	“R2-beam”	Unit
A	3.200	m^2
Iyy	0.043	m^4
Izz	17.067	m^4
Iyz	0	m^4
J	0.165	m^4
ez	0	m

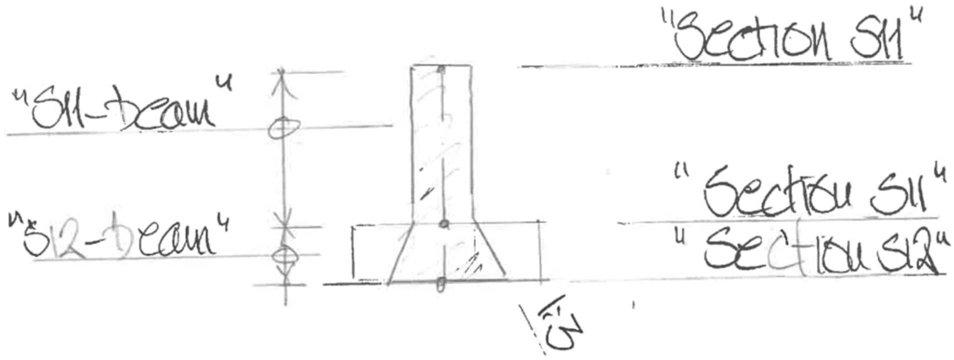
Graphic visualization



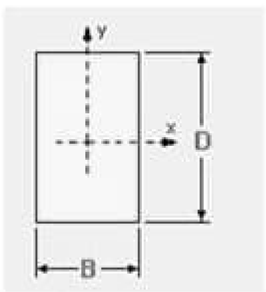
2.3.5 Support 1 & 4: Rectangular beams

This link slabs are modelled using “Section Property Calculator” for parametric section type rectangular solid.

In areas where beam vary the function “Multiple varying section” is applied.



Input rectangular cross sections



Data	“Section S11”	“Section S12”
D	0.800	1.400
B	7.200	8.000
-	m	m

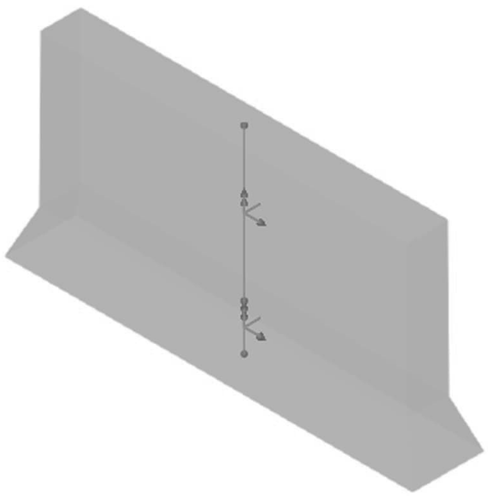
Results

Data	"Section S11"	"Section S12"	Unit
A	5.760	11.200	m^2
Iyy	0.3072	1.829	m^4
Izz	24.883	59.733	m^4
Iyz	0	0	m^4
J	1.143	6.510	m^4
ez	0	0	m

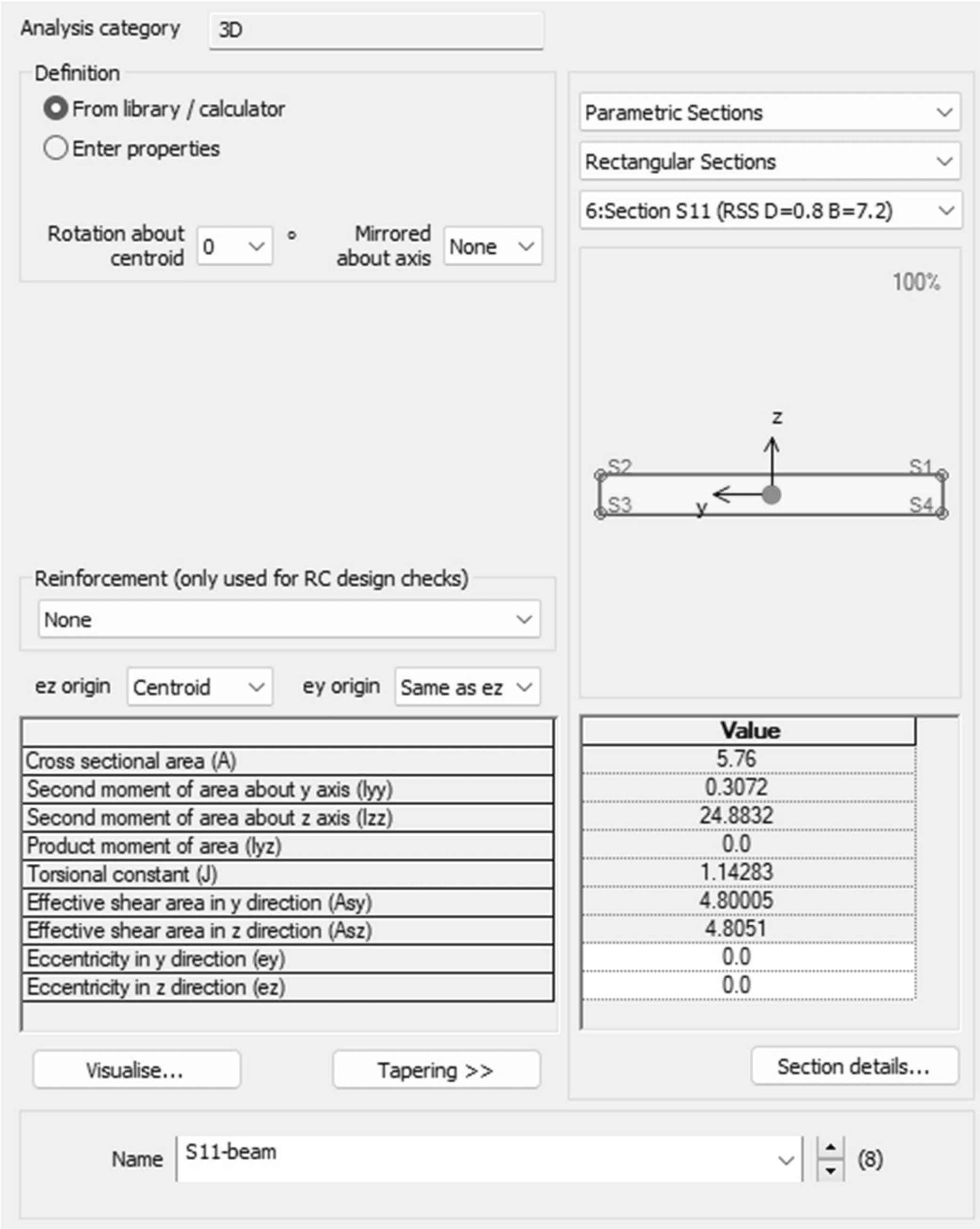
Remark

Chosen cross section are simplified thus with regard to cross section areas, thus a weightless material needs is applied.

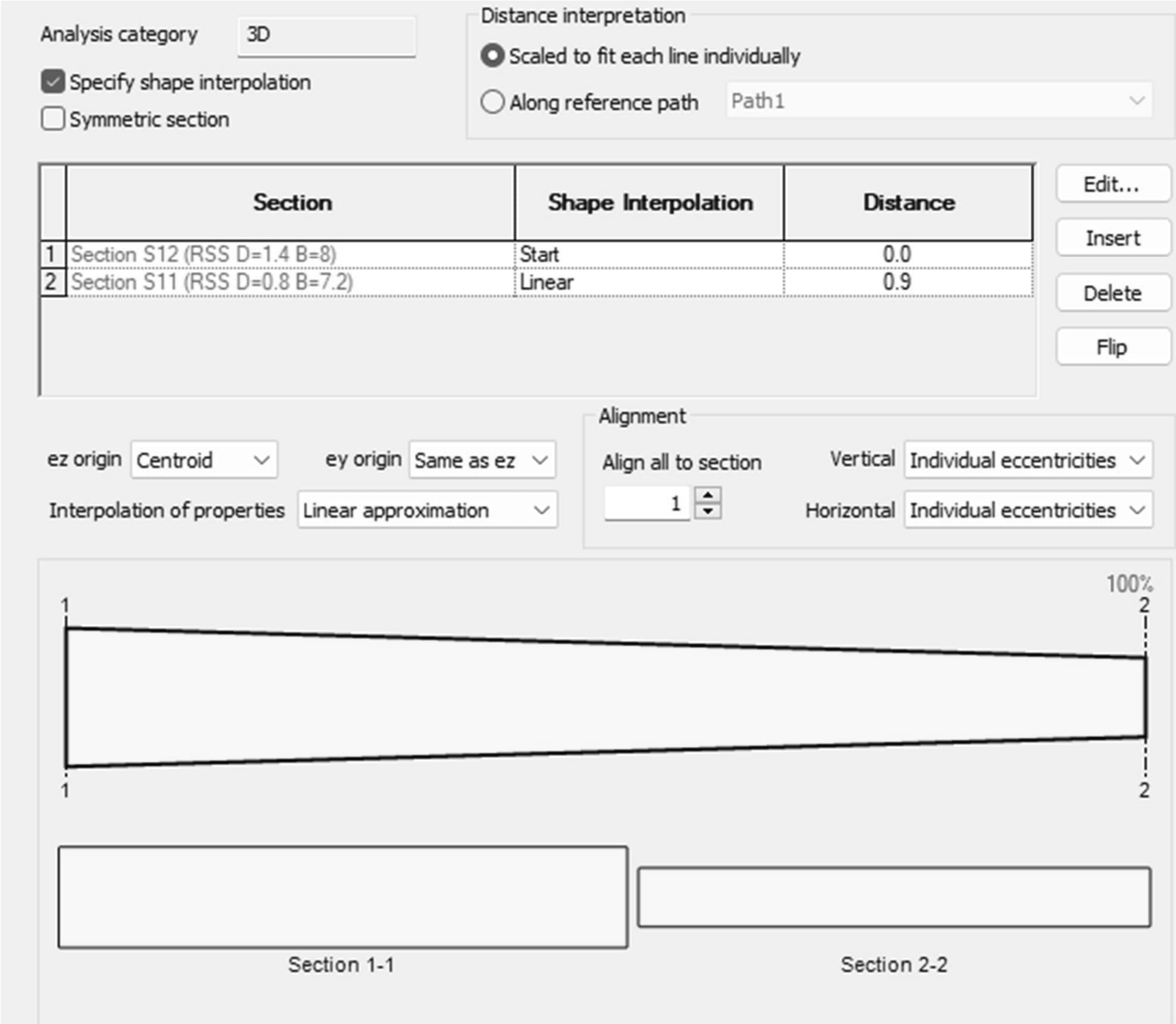
Graphic visualization



Definition of “ S11-beam”



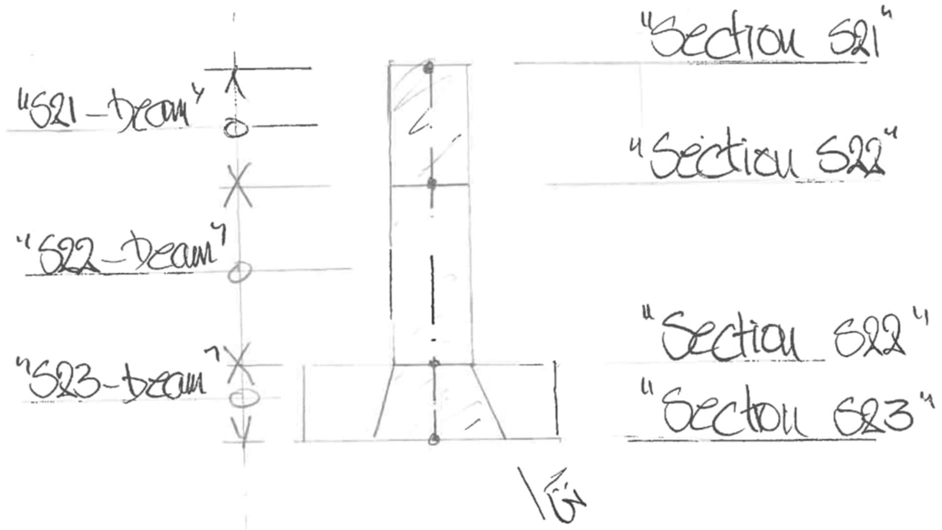
Definition of " S12-beam"



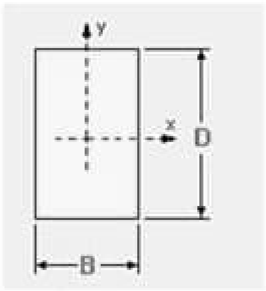
2.3.6 Support 2 & 3: Rectangular beams

This link slabs are modelled using "Section Property Calculator" for parametric section type rectangular solid.

In areas where beam vary the function "Multiple varying section" is applied.



Input rectangular cross sections

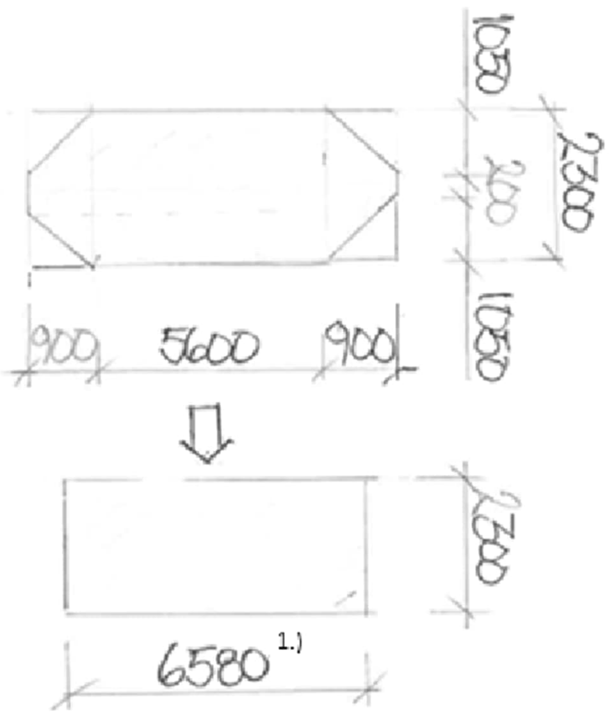


Data	"Section S21"	"Section S22"	"Section S23"
D	2.30	2.30	3.00
B	5.60	6.58[1.)]	7.28[2.)]
-	m	m	m

Footnote

[1.)] $B = 5.60m + 2 \cdot \frac{2.3m \cdot 0.9m - 0.9m \cdot 1.05m}{2.3m} = 6.58\text{m}$

[2.)] $B = 6.58m + 2 \cdot \frac{1.05m}{3} = 7.58\text{m}$



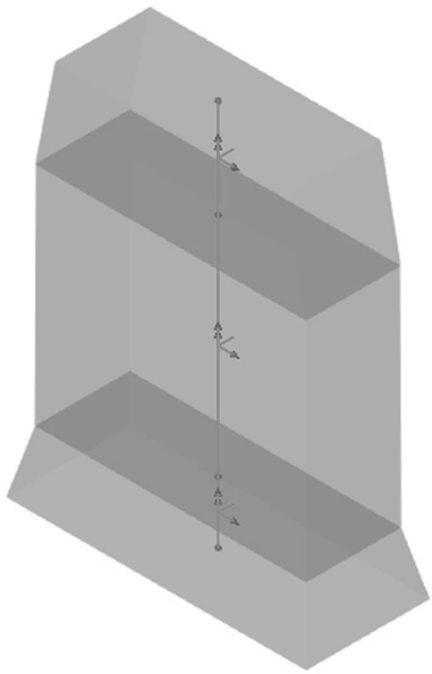
Results

Data	“Section S21”	“Section S22”	“Section S34”	Unit
A	12.880	15.134	21.840	m^2
Iyy	5.678	6.672	16.380	m^4
Izz	33.660	54.064	48.524	m^4
Iyz	0	0	0	m^4
J	16.840	20.811	48.524	m^4
ez	0	0	0	m

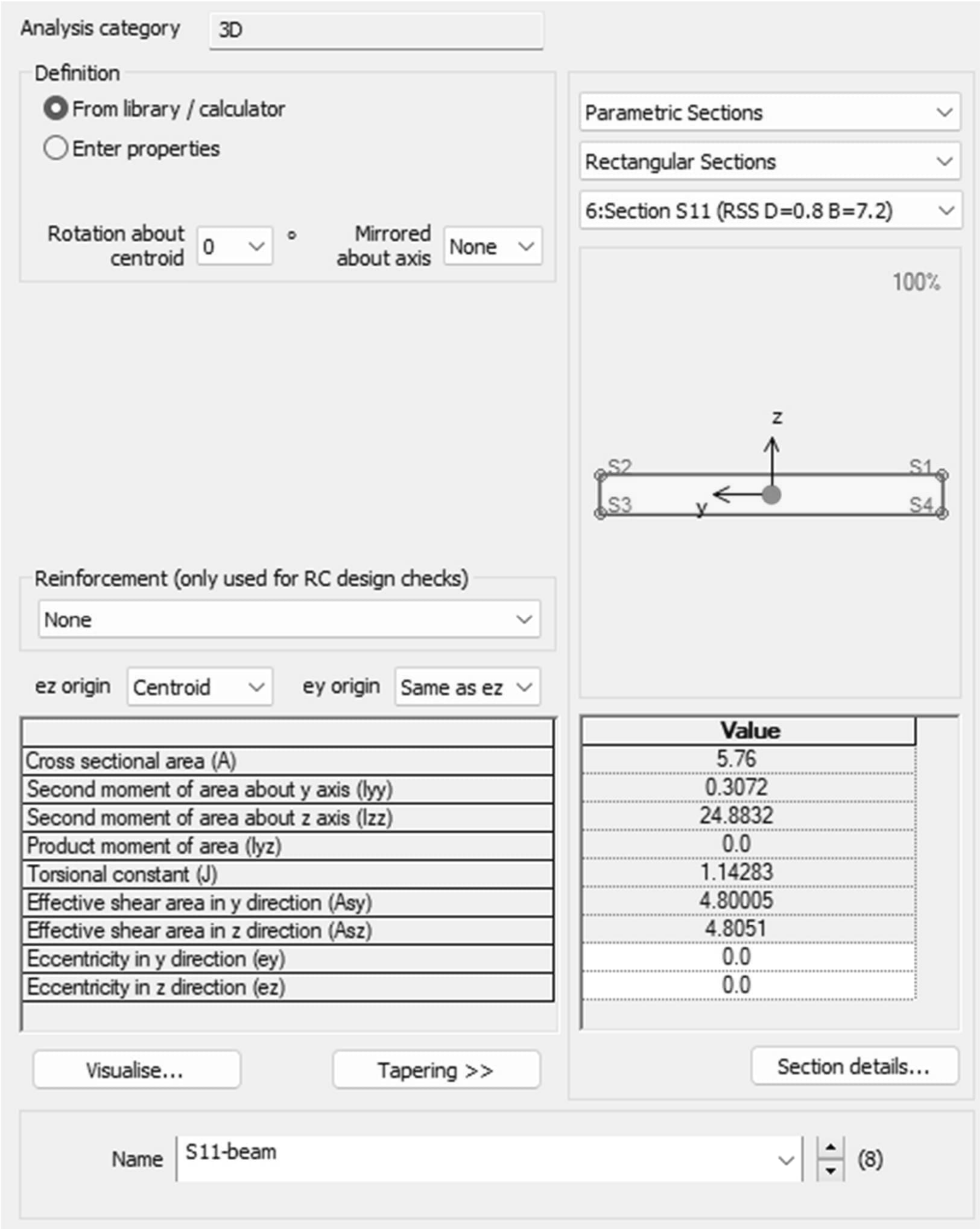
Remark

Chosen cross section are simplified thus with regard to cross section areas, thus a weightless material needs is applied.

Graphic visualization



Definition of " S11-beam"


Analysis category 3D

Definition
From library / calculator
Enter properties

Rotation about centroid 0 ° Mirrored about axis None

Parametric Sections
Rectangular Sections
6:Section S11 (RSS D=0.8 B=7.2)

Reinforcement (only used for RC design checks)
None

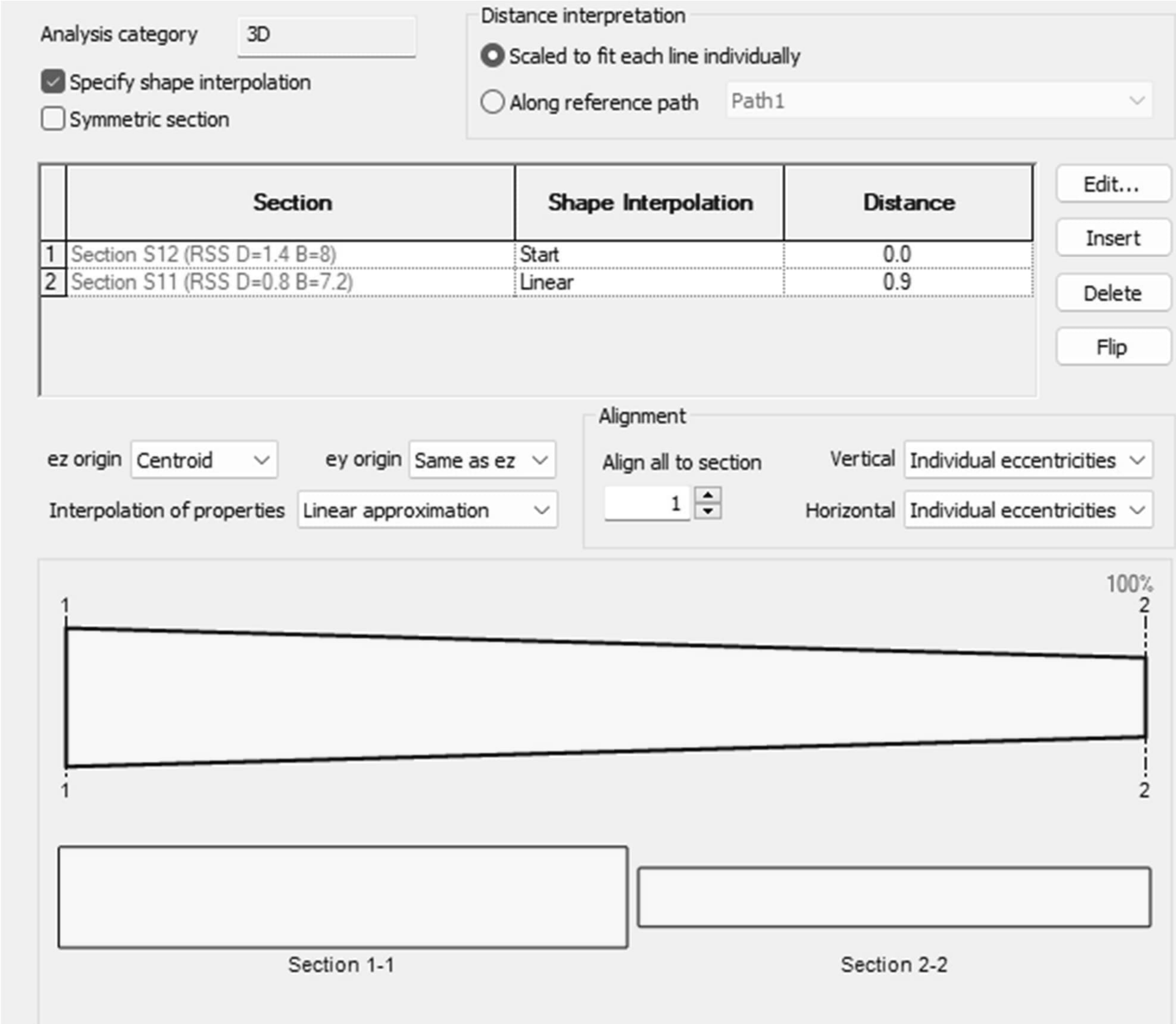
ez origin Centroid ey origin Same as ez

	Value
Cross sectional area (A)	5.76
Second moment of area about y axis (Iyy)	0.3072
Second moment of area about z axis (Izz)	24.8832
Product moment of area (Iyz)	0.0
Torsional constant (J)	1.14283
Effective shear area in y direction (Asy)	4.80005
Effective shear area in z direction (Asz)	4.8051
Eccentricity in y direction (ey)	0.0
Eccentricity in z direction (ez)	0.0

Visualise... Tapering >> Section details...

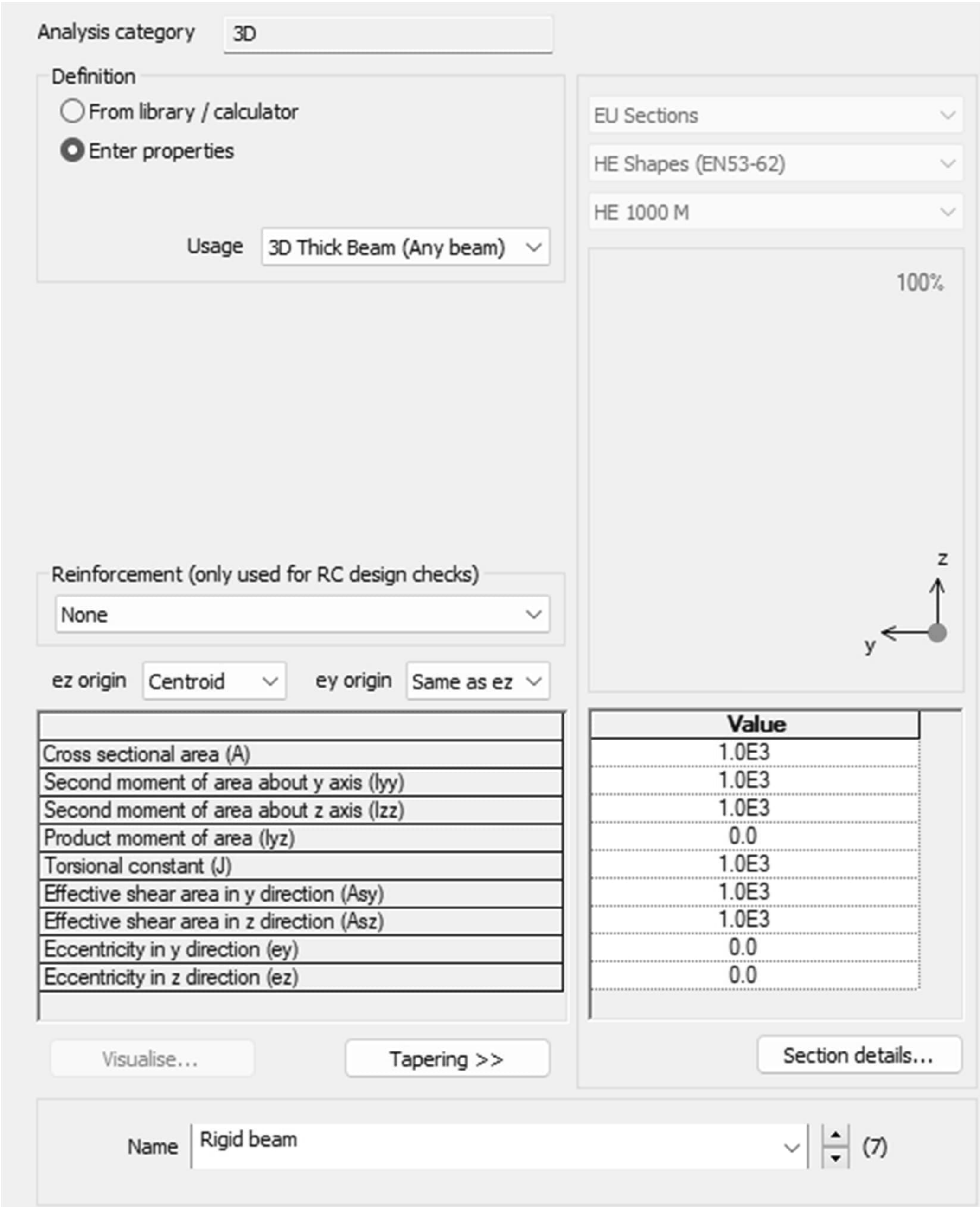
Name S11-beam (8)

Definition of " S12-beam"



2.3.7 Rigid beams

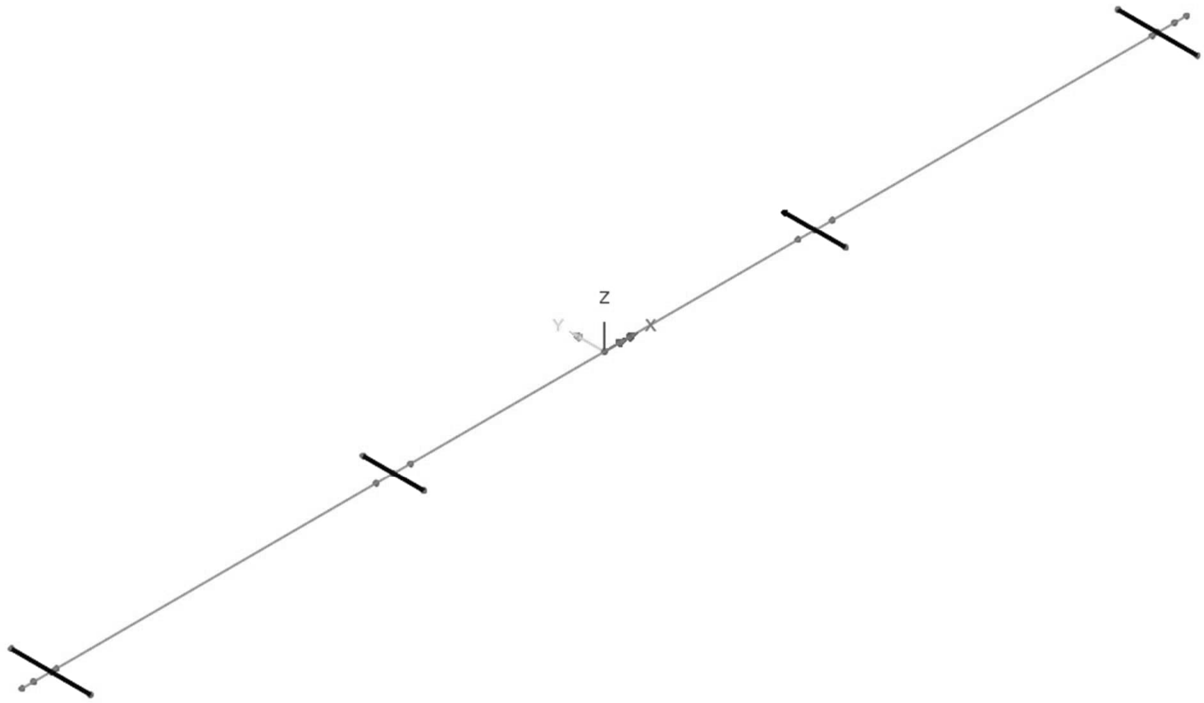
A fictive rigid beam is introduced at supports in order to model bearings.



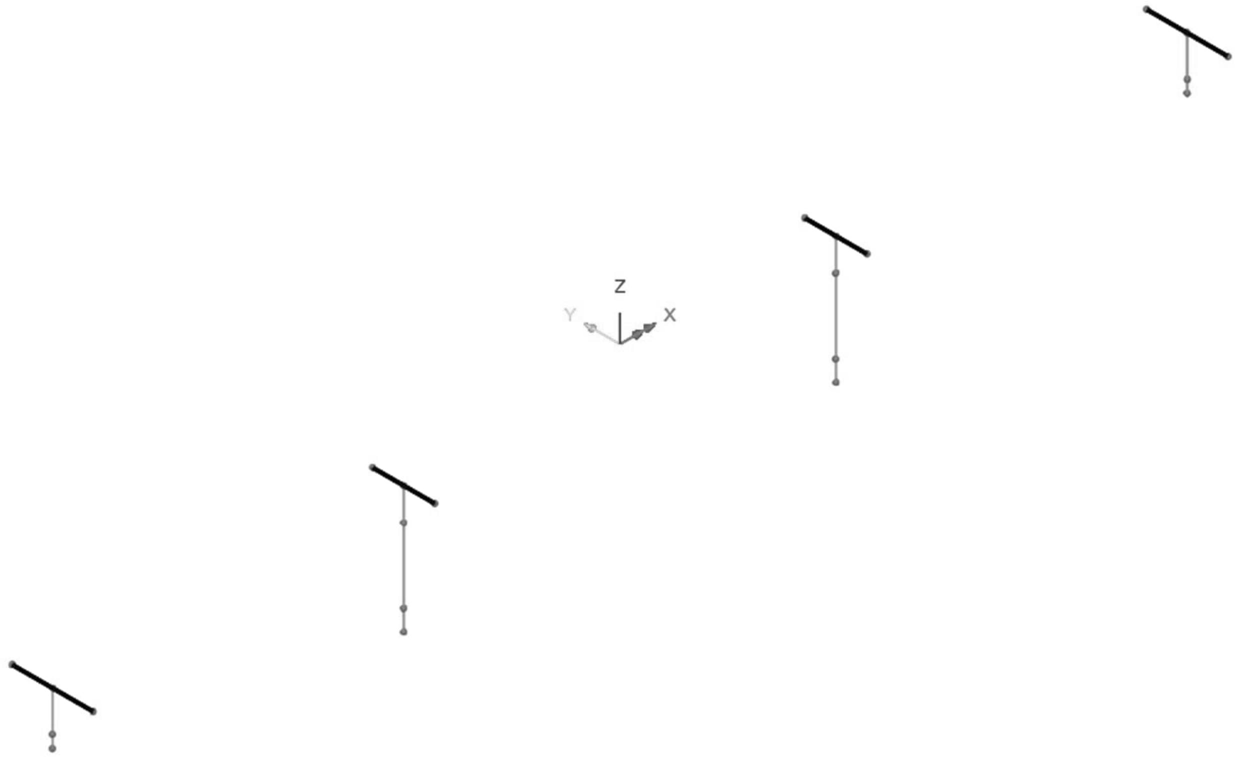
Remark

Due to high fictive cross sectional area a weightless material needs to be applied.

Graphic visualization superstructure (Rigid:T)



Graphic visualization substructure (Rigid:B)



2.4 MATERIAL

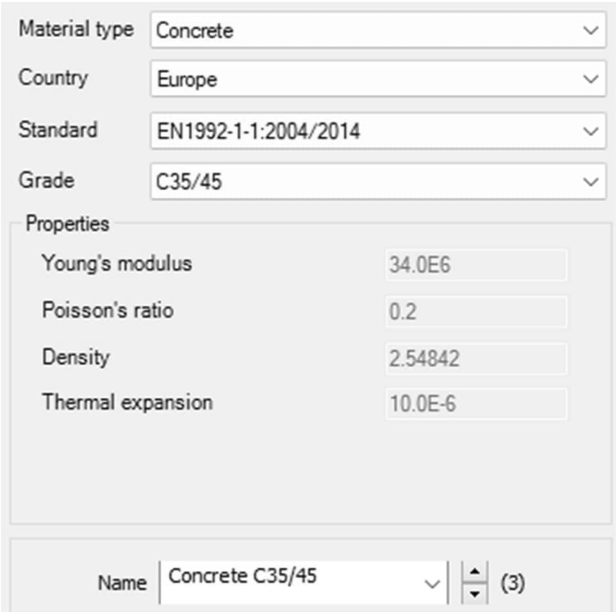
Material properties seen below are to be used.

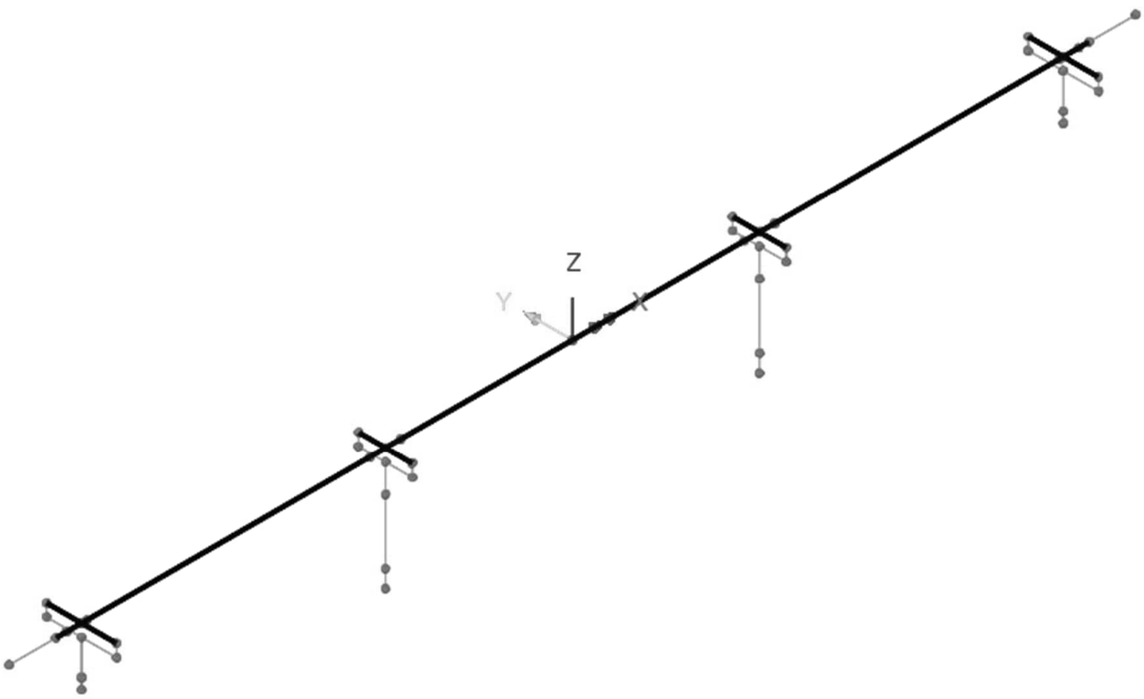
Substructure C30/37 : E_{cm} = 33 GPa

Superstructure C35/45 : E_{cm} = 34 GPa

2.4.2.1 Material : Isotropic concrete C35/45

Applied to superstructure.

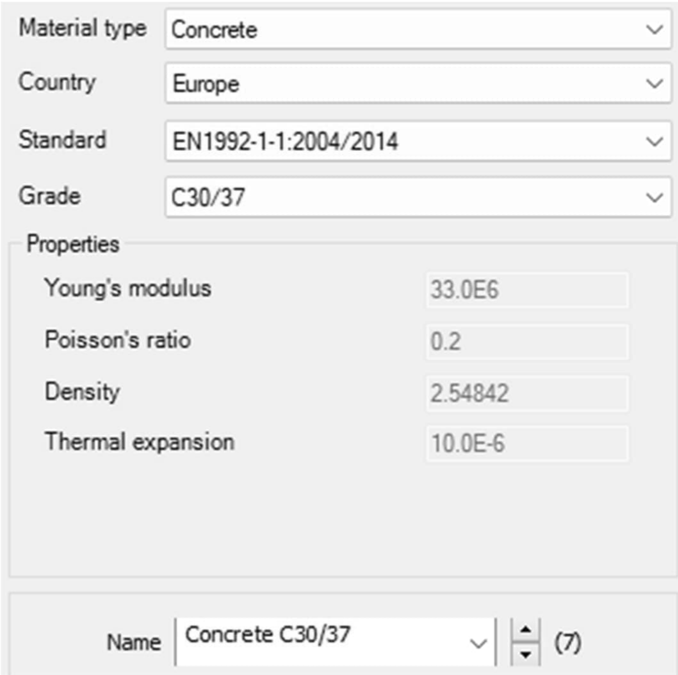


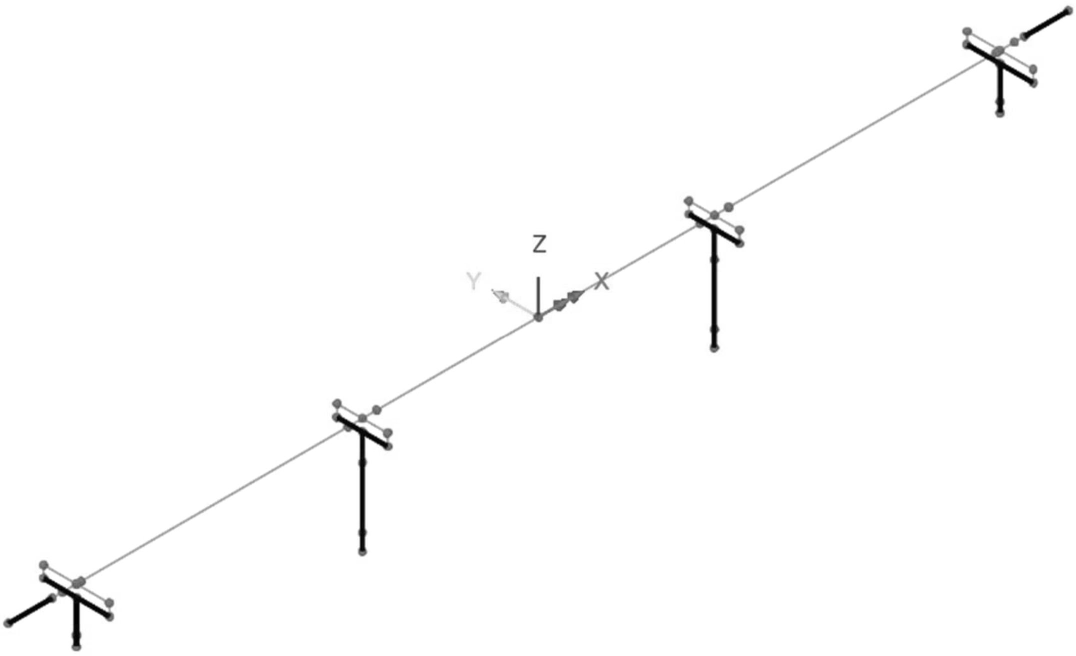


Overview

2.4.2.2 Material : Isotropic concrete C30/37

Applied to substructure and link slabs.

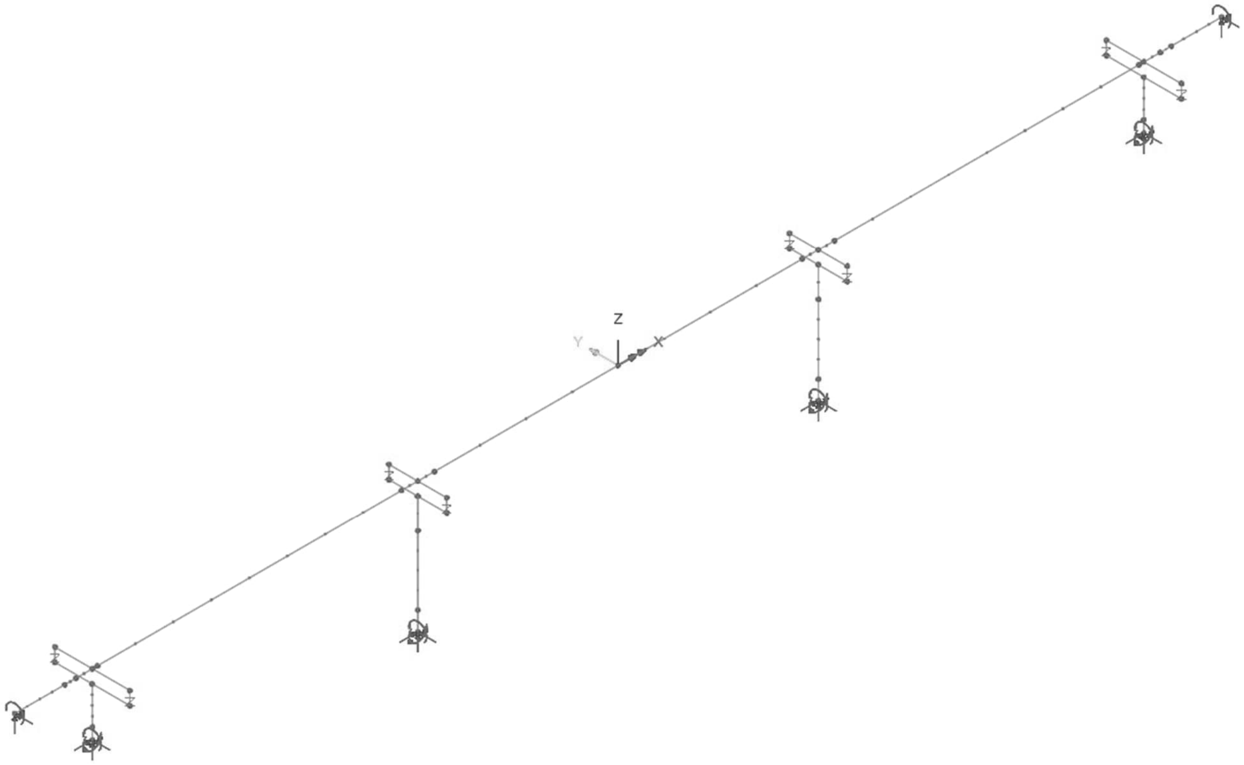




Overview

2.5 BOUNDARY CONDITIONS

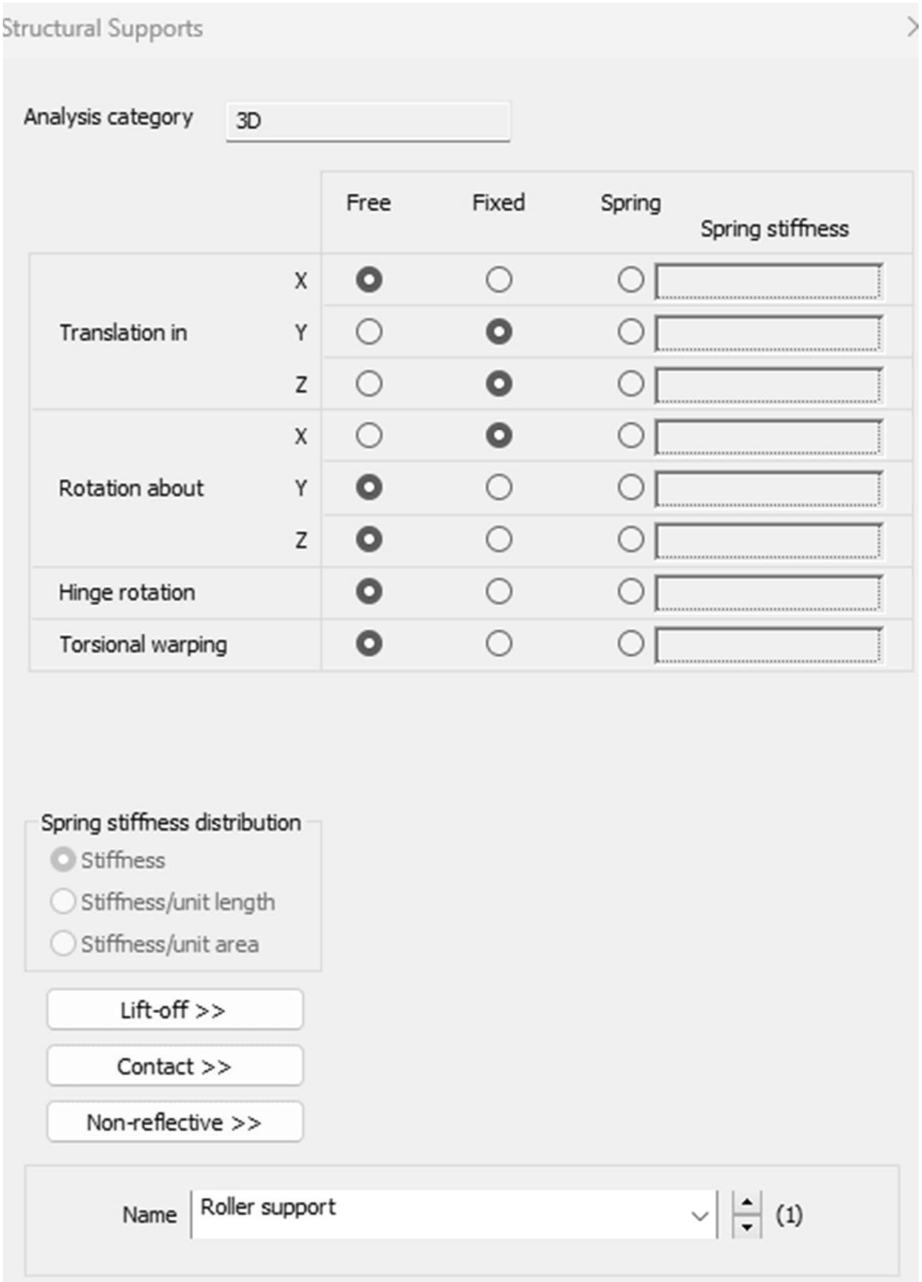
Supports are introduced at every support and free end of link slab.



Overview

2.5.1 Boundary conditions link slab

At a distance 1 m from freed edge of link slab a fictive point support (Roller support) as seen below.

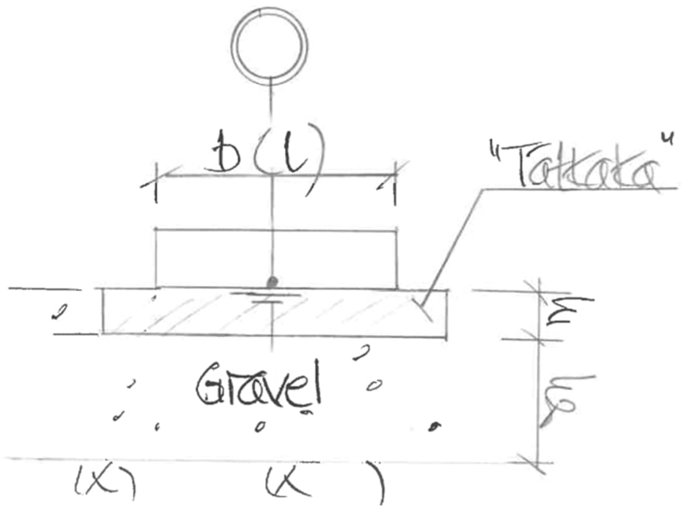


2.5.2 Boundary conditions abutments

Boundary conditions for each support is modelled using super nodes.

The super nodes are location at centre of rigid beam abutment, see sketches below.

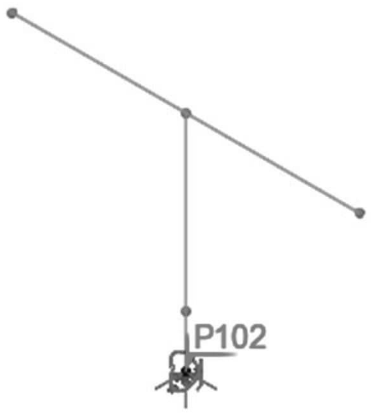
No deformation in “Tätkaka” (C25/35) is considered.



Geotechnical section at support

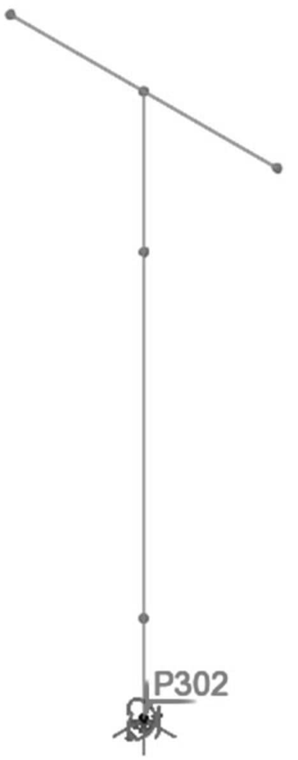
Support	b	l	h_1	h_2	Ek
1	4.00	9.00	1.00	6.00	50
2	6.00	10.00	1.20	2.00	50
3	6.00	10.00	1.20	4.00	50
4	4.00	8.00	1.00	9.00	50
-	m	m	m	m	MPa

Support 1:



Support 2:

Support 3:



Support 4 :

Rotational stiffness of foundation is determined using PROG G3.005 performed in Mathcad. All formulas and partial results are shown.

Since the distance to solid ground (H) is less than twice the width of the bottom plate (2B), the method according to TRVINFRA-00227 appendix B5.1 is not applicable. Instead, a derived method for cases where H < 2B is used.

Stiffness transversal direction (Rotation X-X) :

$K_{Rx} = 2025 \cdot 10^3 \frac{kNm}{rad}$: support 1, see page A2:53

$K_{Rx} = 12500 \cdot 10^3 \frac{kNm}{rad}$: support 2, see page A2:59

$K_{Rx} = 6250 \cdot 10^3 \frac{kNm}{rad}$: support 3, see page A2:59

$K_{Rx} = 1286 \cdot 10^3 \frac{kNm}{rad}$: support 4, see page A2:53

Stiffness longitudinal direction (Rotation Y-Y) :

$K_{Ry} = 400 \cdot 10^3 \frac{kNm}{rad}$: support 1, see page A2:53

$K_{Ry} = 4500 \cdot 10^3 \frac{kNm}{rad}$: support 2, see page A2:59

$K_{Ry} = 2250 \cdot 10^3 \frac{kNm}{rad}$: support 3, see page A2:59

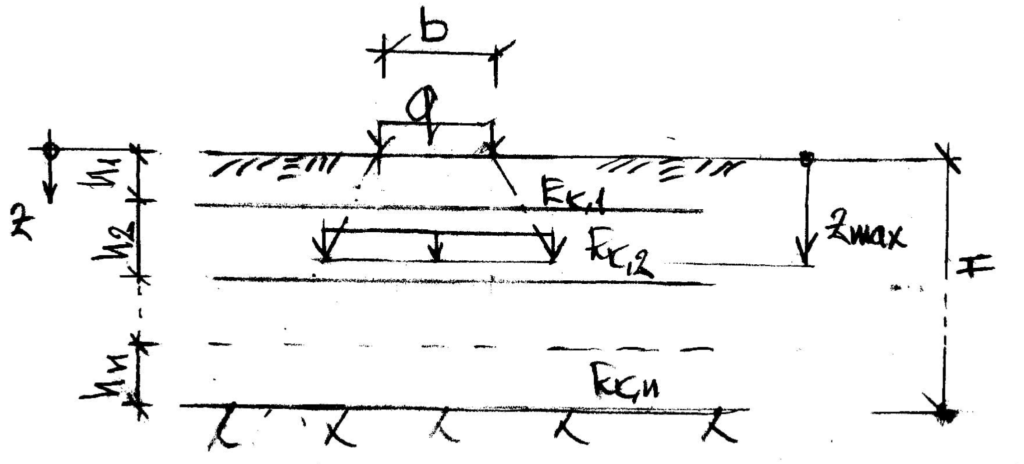
$K_{Ry} = 254 \cdot 10^3 \frac{kNm}{rad}$: support 4, see page A2:53

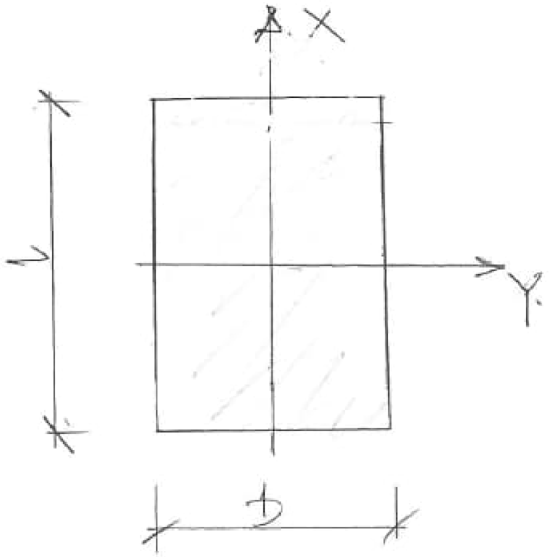
Objekt : Support 1 (4)

PRINCIPFIGUR

Geometri och undergrund

Beräkningen av ekivalent styvhet i grund är utförd enligt Råd Brobyggande bilaga 106. Den ekvivalenta E-modulen förutsätter lastspridning 2:1. Bestämningen har skett för en fiktiv lasten motsvarande q (= 100 kPa) .

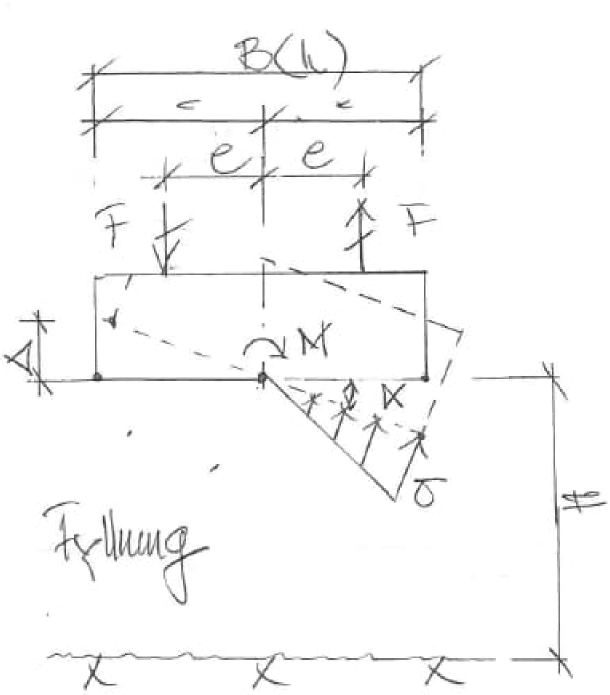




TEORI

När avståndet till fast botten är mindre än 2B så tilllämpas härled formel nedan som även förekommer i BH sida 594 (avsnitt 6.4:22 Beräkningsmodell).

När avstånd till fast botten är större än 2B tillämpas Råd Brobyggnade bilaga 107.



$$\Delta = \alpha \cdot \frac{B}{2} \;; \qquad \varepsilon = \frac{\Delta}{H} = \frac{\alpha \cdot \frac{B}{2}}{H}$$

$$\sigma = \varepsilon \cdot E'_k = \frac{E'_k \cdot \alpha \cdot B}{2 \cdot H}$$

$$F = \sigma \cdot \frac{B}{2} \cdot \frac{1}{2} \cdot L = \frac{E'_k \cdot \alpha \cdot B}{2 \cdot H} \cdot \frac{B \cdot L}{4} = \frac{E'_k \cdot \alpha \cdot B^2 \cdot L}{8 \cdot H}$$

$$M = F \cdot 2e \;; \qquad e = \frac{B}{3} \;;$$

$$M = F \cdot \frac{2 \cdot B}{3} = \alpha \cdot \frac{L \cdot B^3 \cdot E'_k}{12 \cdot H}$$

$$\Rightarrow \frac{\alpha}{M} = \frac{12 \cdot H}{L \cdot B^3 \cdot E'_k}$$

INDATA

Geometri

Bottenplatta : $b = 4.0m$ $l = 9.0m$

Underliggande jordmaterial

Antal skikt (minst 2 skickt erfordras): $n = 2st$

Skikt	E_k	h
1	50	3.00
2	50	3.00
-	MPa	m

BERÄKNINGAR

Total skikttjocklek

$$H = \sum_{i=1}^{n} h_i$$

$H = 6\,m$

Sättningsområde

$$z_{max} = \min(2 \cdot b, H)$$

$z_{max} = 6\,m$

Nivåer för respektive skikt

$$z_s = \begin{array}{|l} \text{for } i \in 1..n \\ \quad \begin{array}{|l} z_{2 \cdot i} \leftarrow z_{2 \cdot i - 1} + h_i - 1mm \\ z_{2 \cdot i + 1} \leftarrow z_{2 \cdot i} + 1mm \end{array} \\ z \end{array}$$

$$z_s^T = (0.000 \quad 3.000 \quad 3.001 \quad 6.000 \quad 6.001)\,m$$

Funktion för sättningsmodul

$$E_{sk} := \left| \begin{array}{l} \text{for } i \in 1..n-1 \\ \quad \left| \begin{array}{l} E_{2 \cdot i} \leftarrow E_{k_i} \\ E_{2 \cdot i+1} \leftarrow E_{k_{i+1}} \end{array} \right. \\ E \end{array} \right.$$

$$E_{sk}^{T} = (50 \quad 50 \quad 50 \quad 50 \quad 1000) \cdot MPa$$

$$E_k := \mathrm{linterp}\left(z_s, E_{sk}, z\right)$$

Påkänningar enligt 2:1

$$q = 100kPa$$

$$\Delta\sigma_v = q \cdot \frac{b \cdot l}{(b + z) \cdot (l + z)}$$

Karakteristisk sättning

$$s_k = \int_{0m}^{H} \frac{\Delta\sigma_v}{E_k} dz \qquad s_k = 5.8 \cdot mm$$

Ekvivalent sättningsmodul

$$E'_k = \frac{\int_{0m}^{z_{max}} \Delta\sigma_v \, dz}{s_k} \qquad E'_k = 50 \cdot MPa$$

Funktion för styvhet grunden när H < 2B
(Se härledning avsnitt TEORI)

$$k_{\theta k}(B, L) = \frac{L \cdot B^3 \cdot E'_k}{12H}$$

RESULTAT

Resultat då H < 2B :

Rotation kring plattans korta riktning (x-x riktning):

$$k_{\theta k}(b,l) = 400000 \cdot \frac{kNm}{rad}$$

$$C_{\phi} = \frac{1}{k_{\theta k}(b,l)} \qquad 10^{9} \cdot C_{\phi} = 2500 \cdot \frac{rad}{kNm}$$

Rotation kring plattans långa riktning (y-y riktning):

$$k_{\theta k}(l,b) = 2025000 \cdot \frac{kNm}{rad}$$

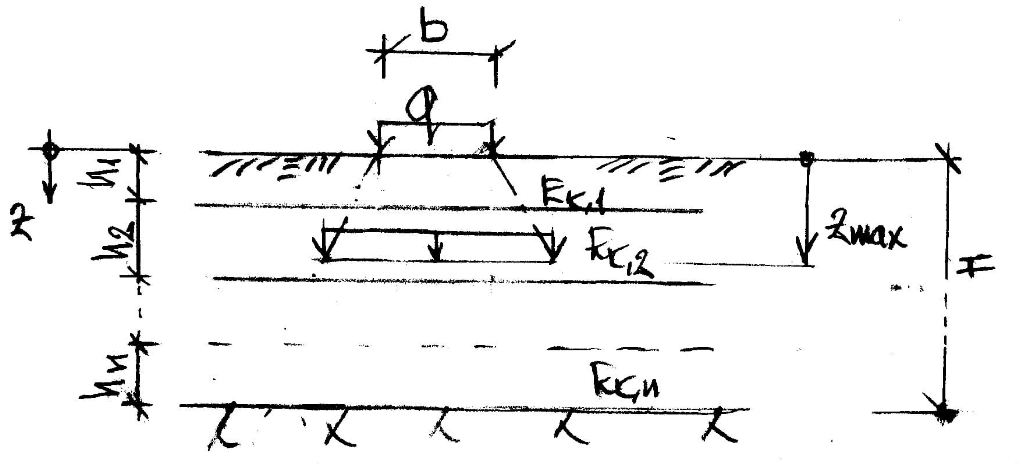
$$C_{\eta} = \frac{1}{k_{\theta k}(l,b)} \qquad 10^{9} \cdot C_{\eta} = 494 \cdot \frac{rad}{kNm}$$

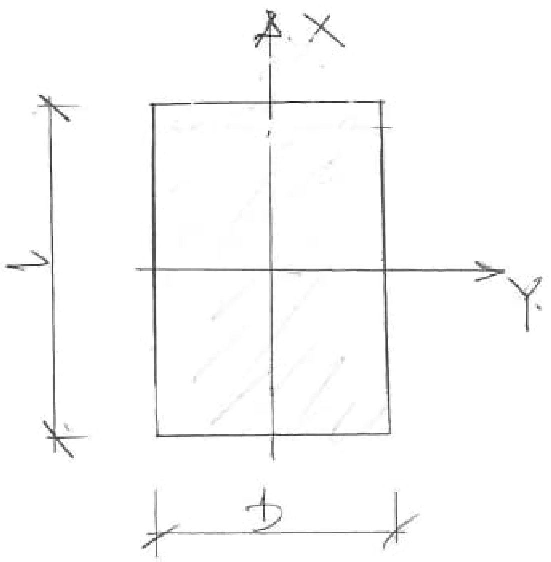
Objekt : Support 2 (3)

PRINCIPFIGUR

Geometri och undergrund

Beräkningen av ekivalent styvhet i grund är utförd enligt Råd Brobyggande bilaga 106. Den ekvivalenta E-modulen förutsätter lastspridning 2:1. Bestämningen har skett för en fiktiv lasten motsvarande q (= 100 kPa) .

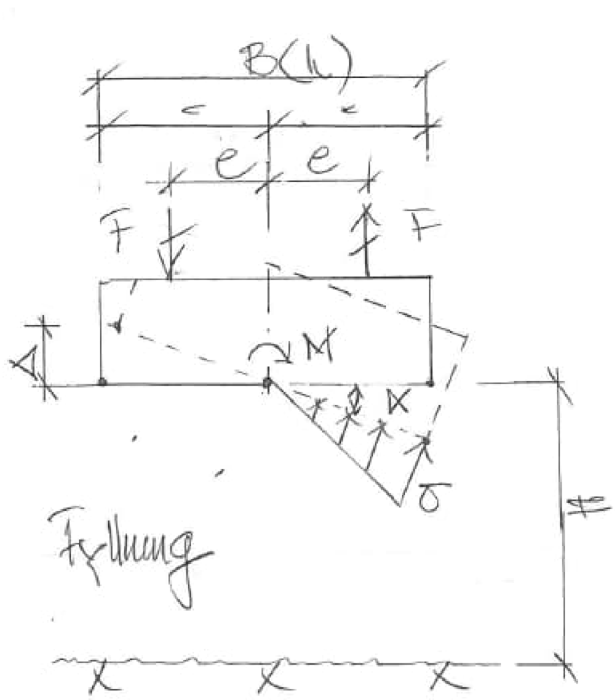




TEORI

När avståndet till fast botten är mindre än 2B så tilllämpas härled formel nedan som även förekommer i BH sida 594 (avsnitt 6.4:22 Beräkningsmodell).

När avstånd till fast botten är större än 2B tillämpas Råd Brobyggnade bilaga 107.



$$\Delta = \alpha \cdot \frac{B}{2} \;; \qquad \varepsilon = \frac{\Delta}{H} = \frac{\alpha \cdot \frac{B}{2}}{H}$$

$$\sigma = \varepsilon \cdot E'_k = \frac{E'_k \cdot \alpha \cdot B}{2 \cdot H}$$

$$F = \sigma \cdot \frac{B}{2} \cdot \frac{1}{2} \cdot L = \frac{E'_k \cdot \alpha \cdot B}{2 \cdot H} \cdot \frac{B \cdot L}{4} = \frac{E'_k \cdot \alpha \cdot B^2 \cdot L}{8 \cdot H}$$

$$M = F \cdot 2e \;; \qquad e = \frac{B}{3} \;;$$

$$M = F \cdot \frac{2 \cdot B}{3} = \alpha \cdot \frac{L \cdot B^3 \cdot E'_k}{12 \cdot H}$$

$$\Rightarrow \frac{\alpha}{M} = \frac{12 \cdot H}{L \cdot B^3 \cdot E'_k}$$

INDATA

Geometri

Bottenplatta : $b = 6.0m$ $l = 10.0m$

Underliggande jordmaterial

Antal skikt (minst 2 skickt erfordras): $n = 2st$

Skikt	E_k	h
1	50	1.00
2	50	1.00
-	MPa	m

BERÄKNINGAR

Total skikttjocklek

$$H = \sum_{i=1}^{n} h_i$$

$H = 2\,m$

Sättningsområde

$$z_{max} = \min(2 \cdot b, H)$$

$z_{max} = 2\,m$

Nivåer för respektive skikt

$$z_s = \left| \begin{array}{l} \text{for } i \in 1..n \\ \quad \left| \begin{array}{l} z_{2 \cdot i} \leftarrow z_{2 \cdot i-1} + h_i - 1mm \\ z_{2 \cdot i+1} \leftarrow z_{2 \cdot i} + 1mm \end{array} \right. \\ z \end{array} \right.$$

$z_s = (0.000 \quad 1.000 \quad 1.001 \quad 2.000 \quad 2.001)\,m$

Funktion för sättningsmodul

$$E_{sk} := \begin{array}{|l} \text{for } i \in 1..n-1 \\ \quad \begin{array}{|l} E_{2\cdot i} \leftarrow E_{k_i} \\ E_{2\cdot i+1} \leftarrow E_{k_{i+1}} \end{array} \\ E \end{array}$$

$$E_{sk}^{T} = (50 \quad 50 \quad 50 \quad 50 \quad 1000)\cdot MPa$$

$$E_k := \mathrm{linterp}\left(z_s, E_{sk}, z\right)$$

Påkänningar enligt 2:1

$$q = 100kPa$$

$$\Delta\sigma_v = q\cdot\frac{b\cdot l}{(b+z)\cdot(l+z)}$$

Karakteristisk sättning

$$s_k = \int_{0m}^{H} \frac{\Delta\sigma_v}{E_k}\,dz \qquad s_k = 3.2\cdot mm$$

Ekvivalent sättningsmodul

$$E'_k = \frac{\int_{0m}^{z_{max}} \Delta\sigma_v\,dz}{s_k} \qquad E'_k = 50\cdot MPa$$

Funktion för styvhet grunden när H < 2B
(Se härledning avsnitt TEORI)

$$k_{\theta k}(B,L) = \frac{L\cdot B^3\cdot E'_k}{12H}$$

RESULTAT

Resultat då H < 2B :

Rotation kring plattans korta riktning (x-x riktning):

$$k_{\theta k}(b,l) = 4500000 \cdot \frac{kNm}{rad}$$

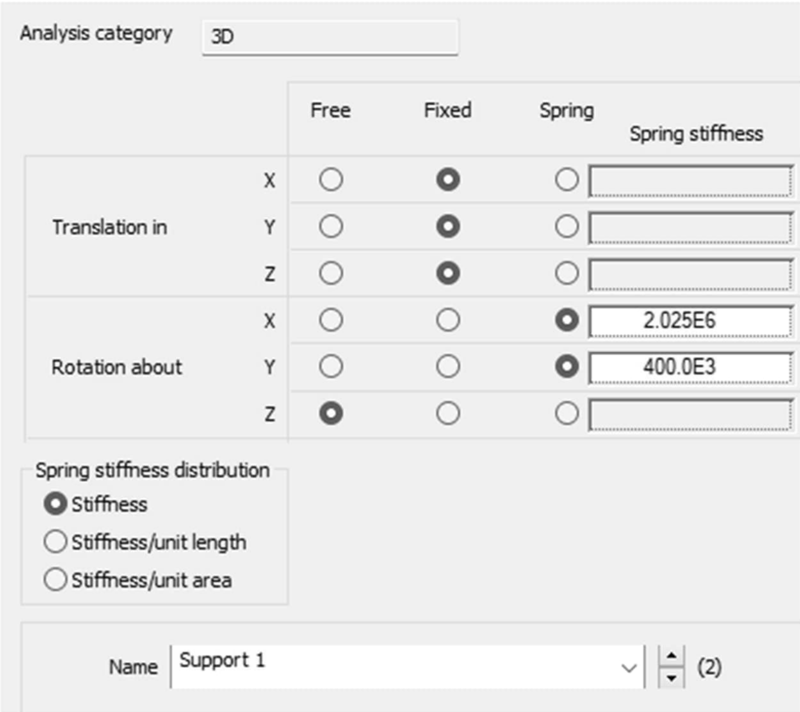
$$C_{\phi} = \frac{1}{k_{\theta k}(b,l)} \qquad 10^9 \cdot C_{\phi} = 222 \cdot \frac{rad}{kNm}$$

Rotation kring plattans långa riktning (y-y riktning):

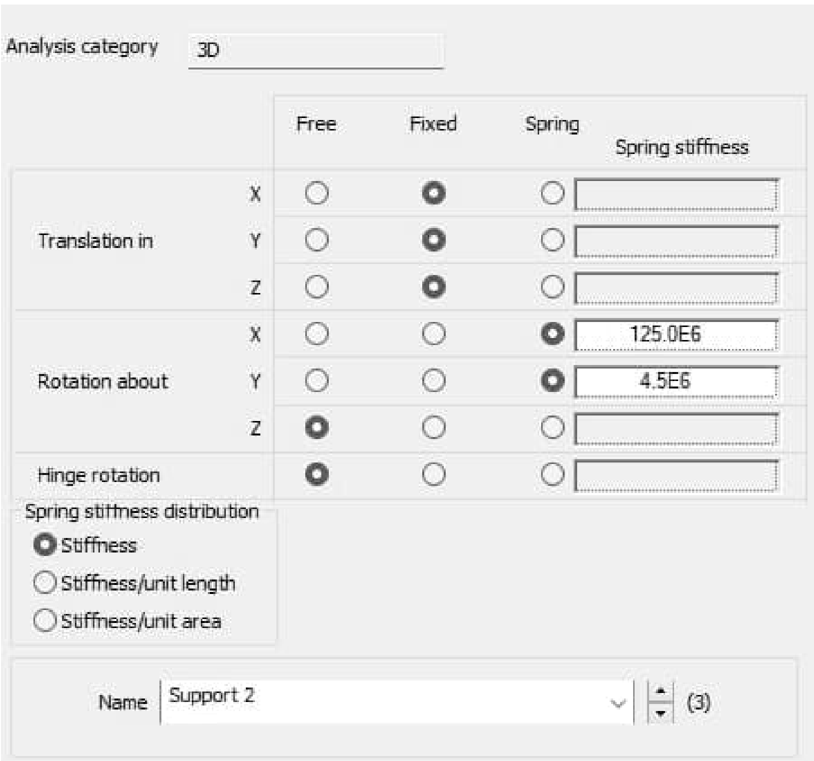
$$k_{\theta k}(l,b) = 12500000 \cdot \frac{kNm}{rad}$$

$$C_{\eta} = \frac{1}{k_{\theta k}(l,b)} \qquad 10^9 \cdot C_{\eta} = 80 \cdot \frac{rad}{kNm}$$

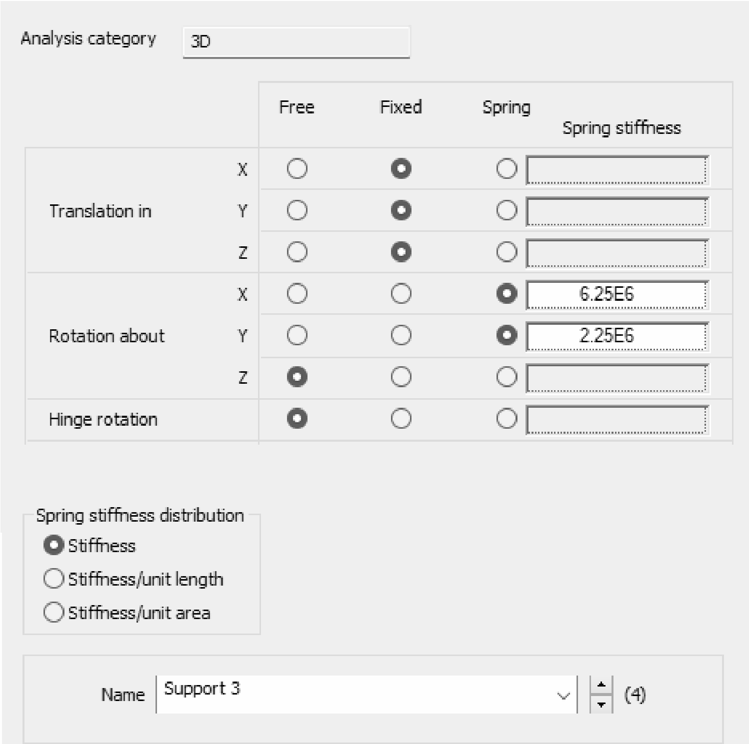
Boundary support 1:



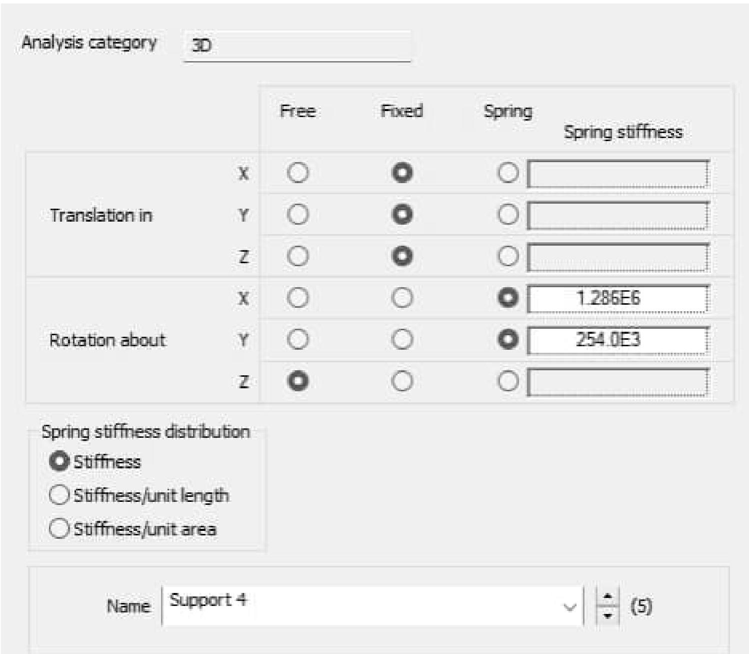
Boundary support 2:



Boundary support 3:



Boundary support 4:



2.6 MESH

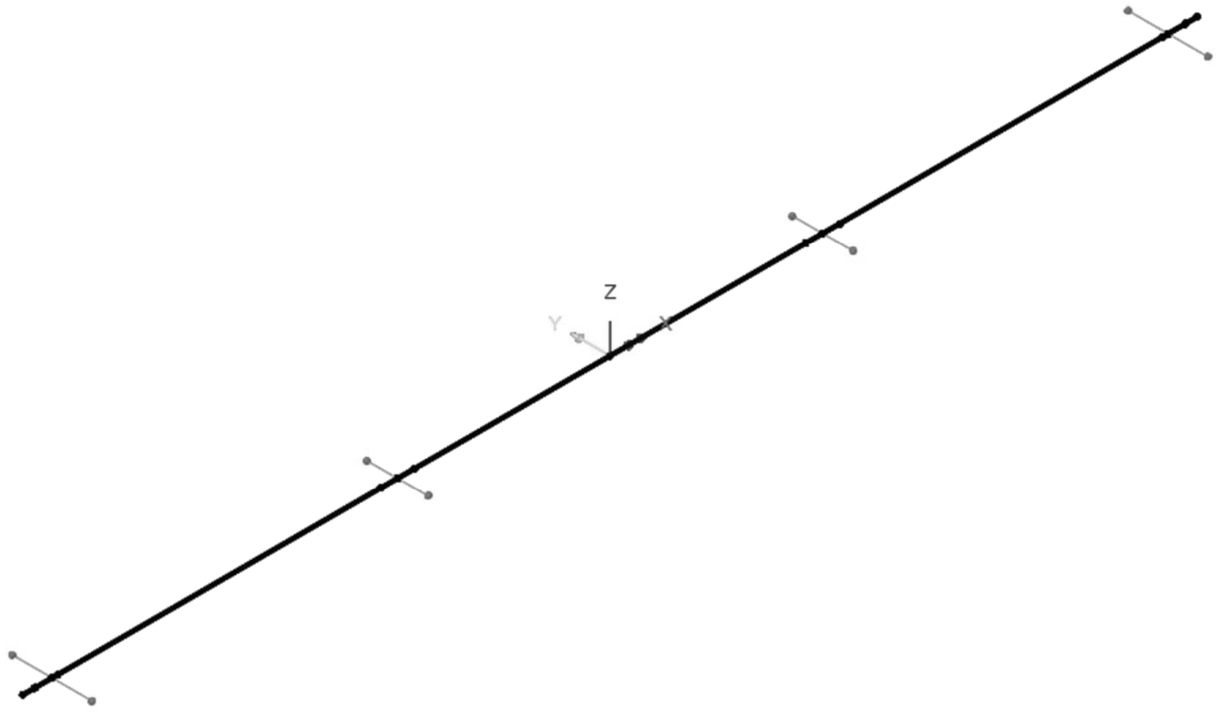
2.6.1 Beam element (BMI21) : linear

Longititudinal beams in superstructure are modelled using beam elements.

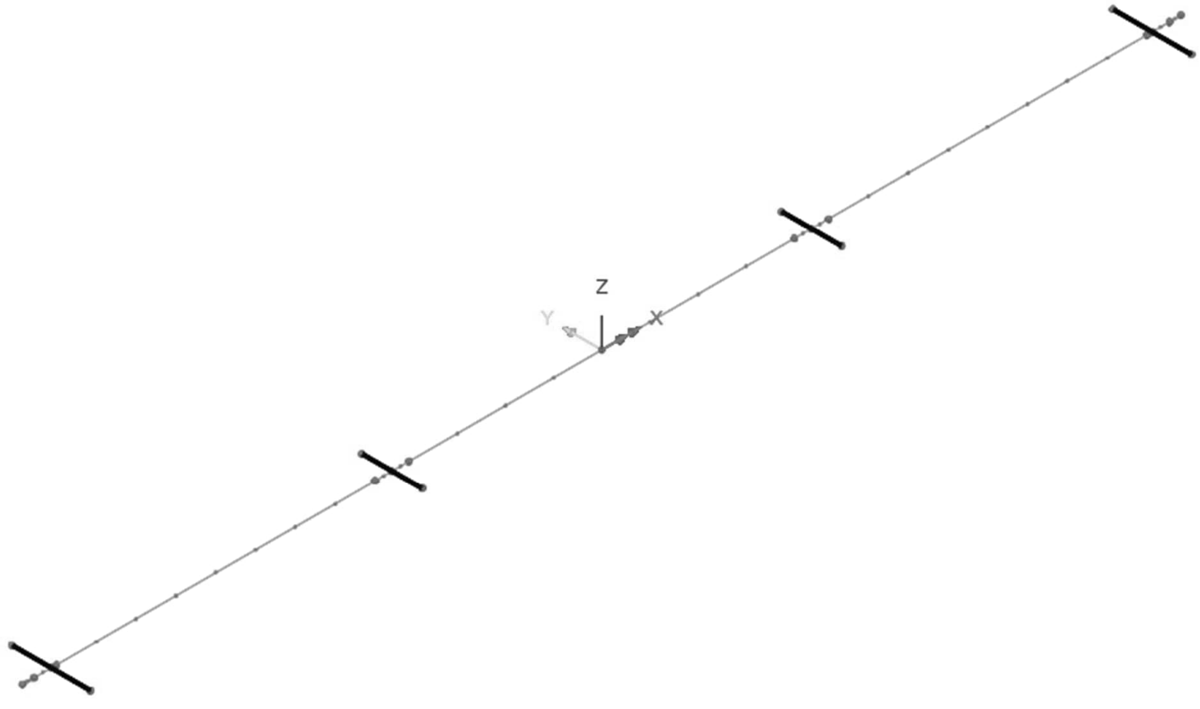
Beams elements are modelled with various subdivisions as seen below.

Typ	Divisions	End release: Start	End release: End
Element 1	1	None	None
Element 2	2	None	None
Element 4	4	None	None
Element 8	8	None	None
Element 4L:ML	4	None	Pinned
Element 4R:ML	4	Pinned	None

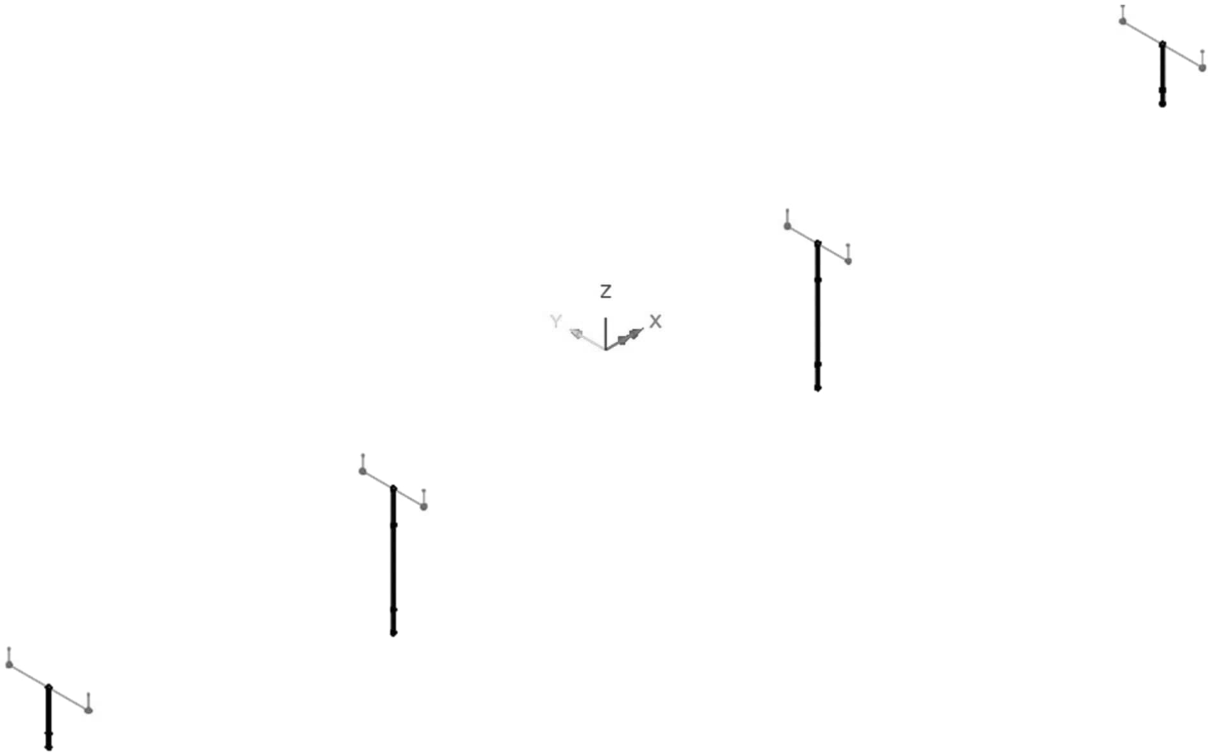
Longitudinal beam – superstructure (Element 1, 2 & 8):



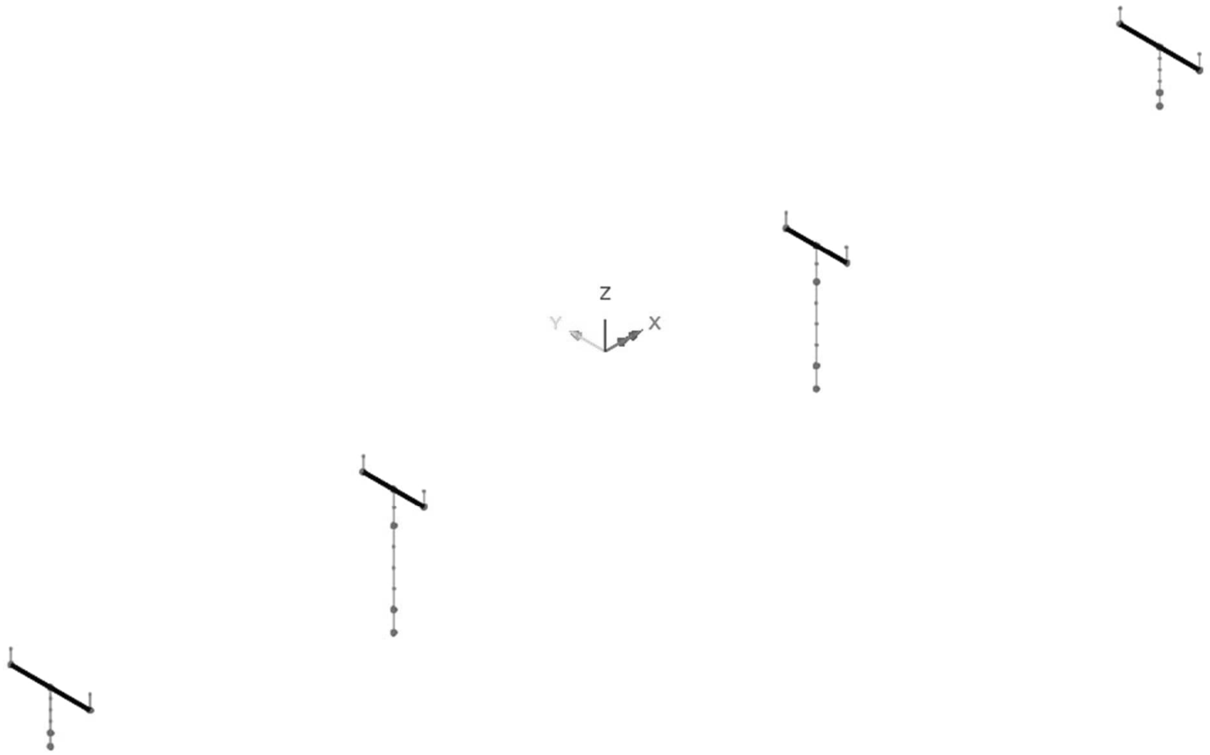
Rigid beam – superstructure (Element 1):



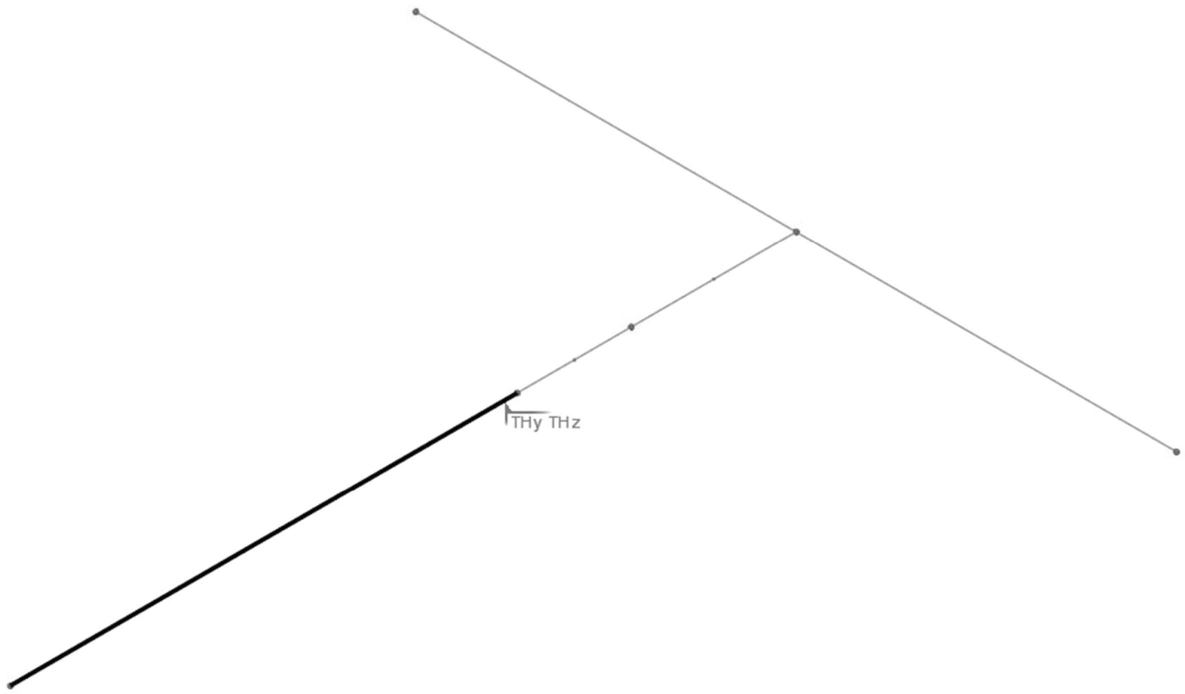
Abutments (Element 1, 2 & 4):



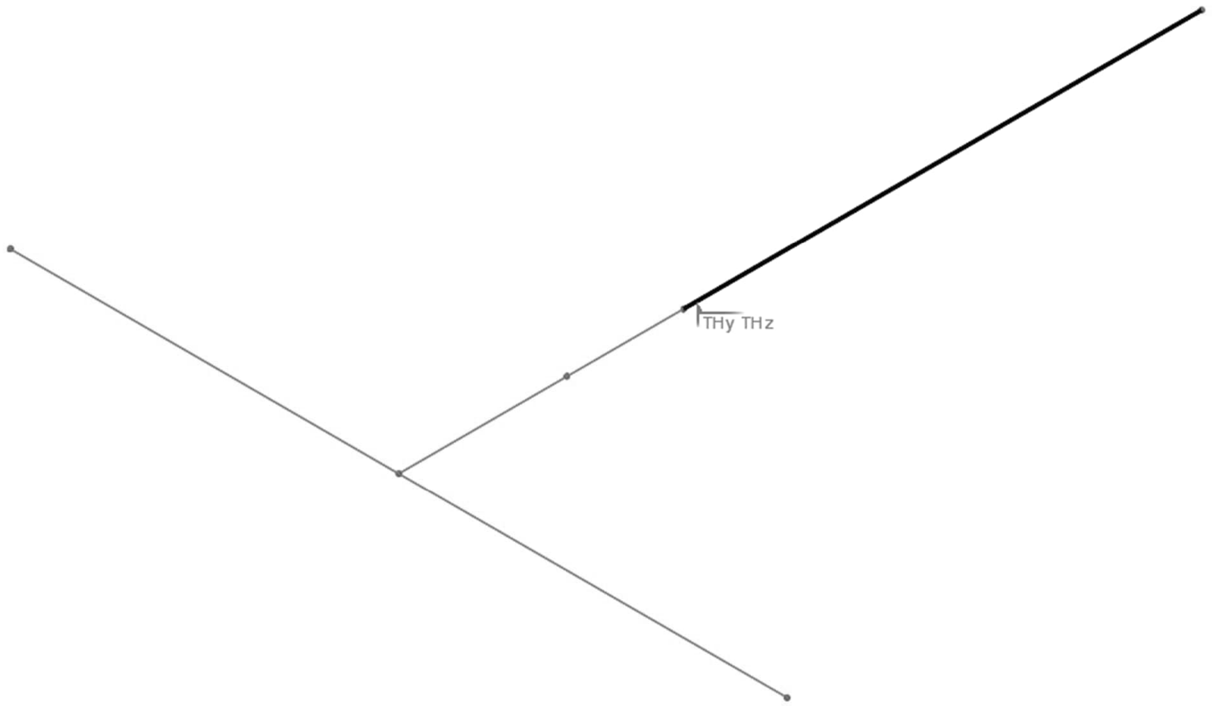
Rigid beam – abutments (Element 1):



Link slab – support 1 (Element 4L:ML):

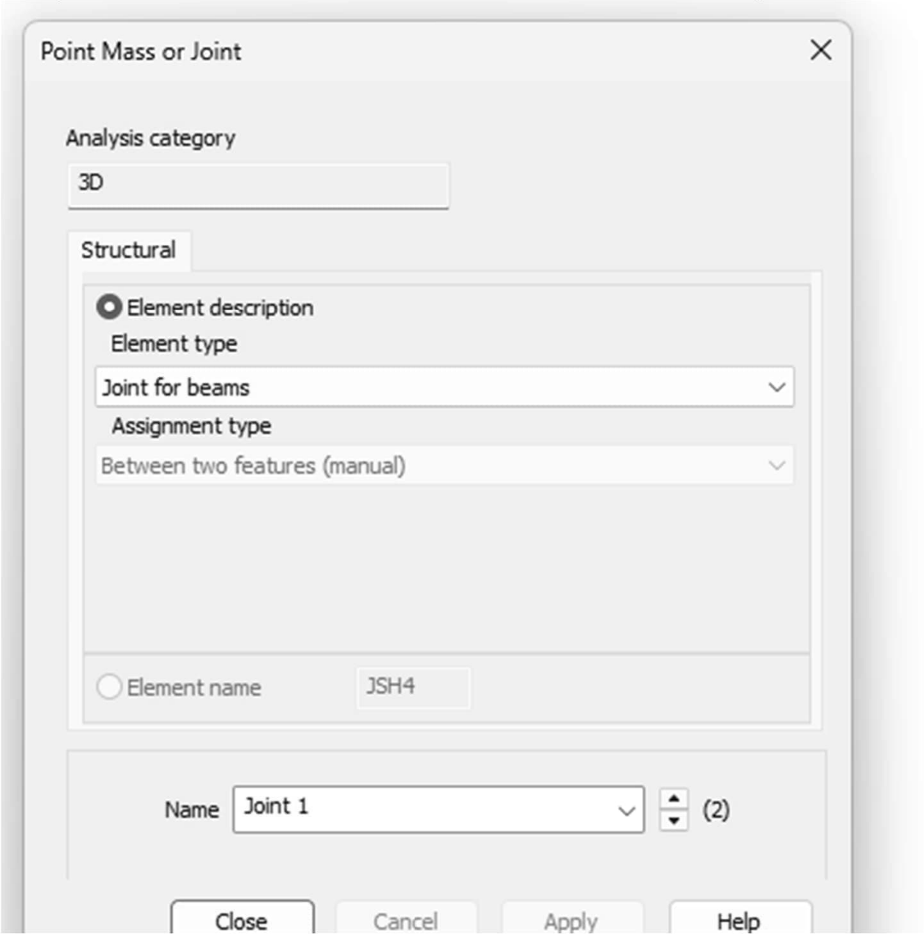


Link slab – support 4 (Element 4R:ML):

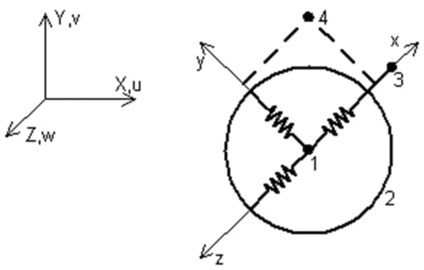


2.6.2 Joint element for beams (JSH4) : linear

Connection between link slab & superstructure is of type joint element, see presentation below. The joint uses no rotational stiffness in order achieve a hinge.



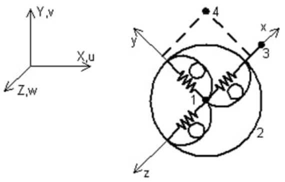
Element Name	JNT4



Element Group	Joints
Element Subgroup	3D Joints
Element Description	A 3D joint element which connects two nodes by three springs in the local x, y and z-directions.
Number Of Nodes	4. The 3rd and 4th nodes are used to define the local x-axis and local xy-plane.
Freedoms	U, V, W: at nodes 1 and 2 (active nodes).
Node Coordinates	X, Y, Z: at each node.

General

Element Name JSH4, JL46



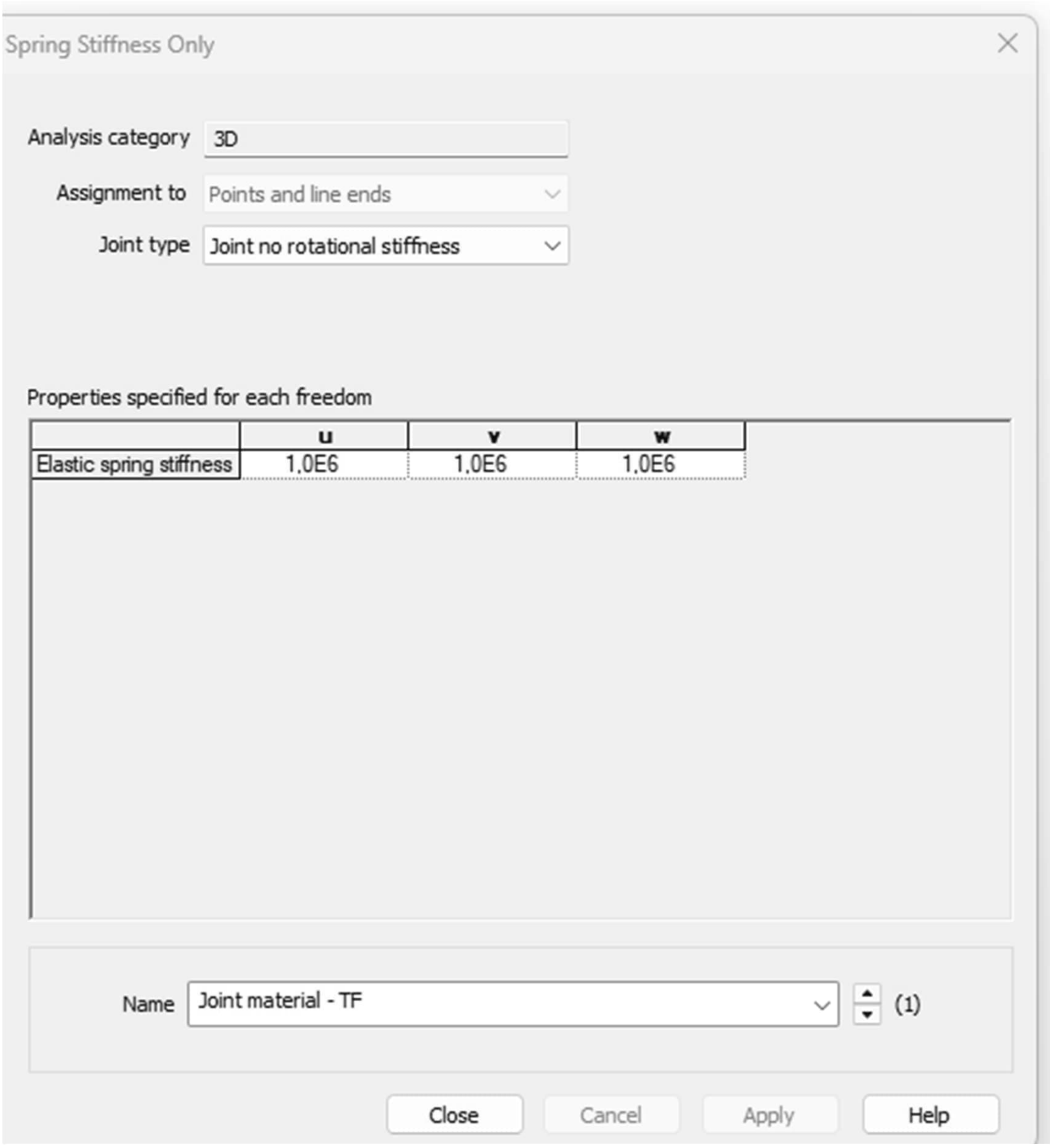
Element Group	Joints
Element Subgroup	3D Joints
Element Description	3D joint elements which connects two nodes by six springs in the local x, y and z-directions. Use JL46 for semiloof beam end nodes.
Number Of Nodes	4. The 3rd and 4th nodes are used to define the local x-axis and local xy-plane respectively.
Freedoms	U, V, W, θx, θy, θz: at nodes 1 and 2 (active nodes).
Node Coordinates	X, Y, Z: at each node.

Geometric Properties

ez	Eccentricity measured from the joint xy-plane to the nodal line.
dy	Parametric distance factor (between 0.0 and 1.0), which defines the position of the shear spring for the local y direction between nodes 1 and 2. It is measured from node 1 (dy=0) along the local x direction.
dz	Parametric distance factor (between 0.0 and 1.0), which defines the position of the shear spring for the local z direction between nodes 1 and 2. It is measured from node 1 (dz=0) along the local x direction

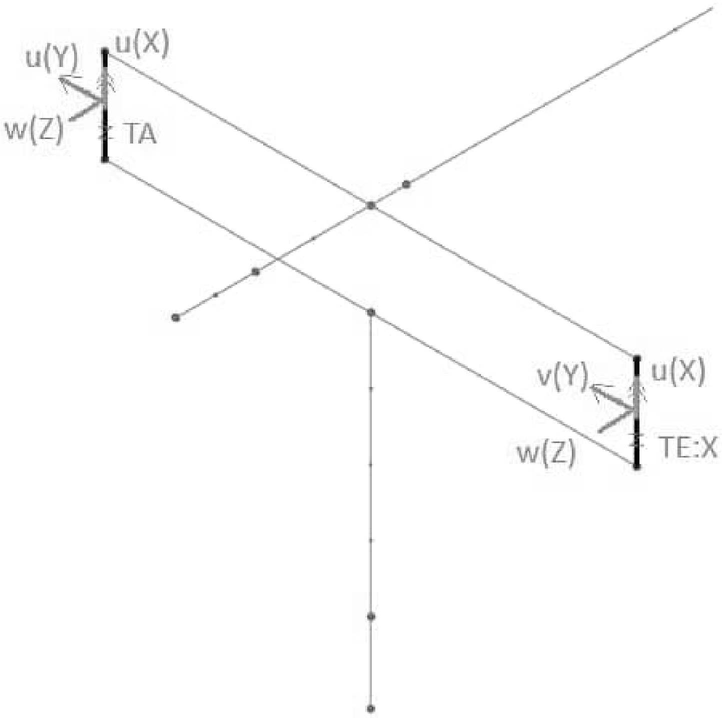
Joint types with no rotational stiffness:

Material	u (X)	v (Y)	w (Z)
Joint material - TF	1E+06	1E+06	1E+06
Joint material - TA	1E+06	0	0
Joint material - TE:X	1E+06	1.00E+06	0
Joint material - TE:Y	1E+06	0	1E+06
-	kN/m	kN/m	kN/m

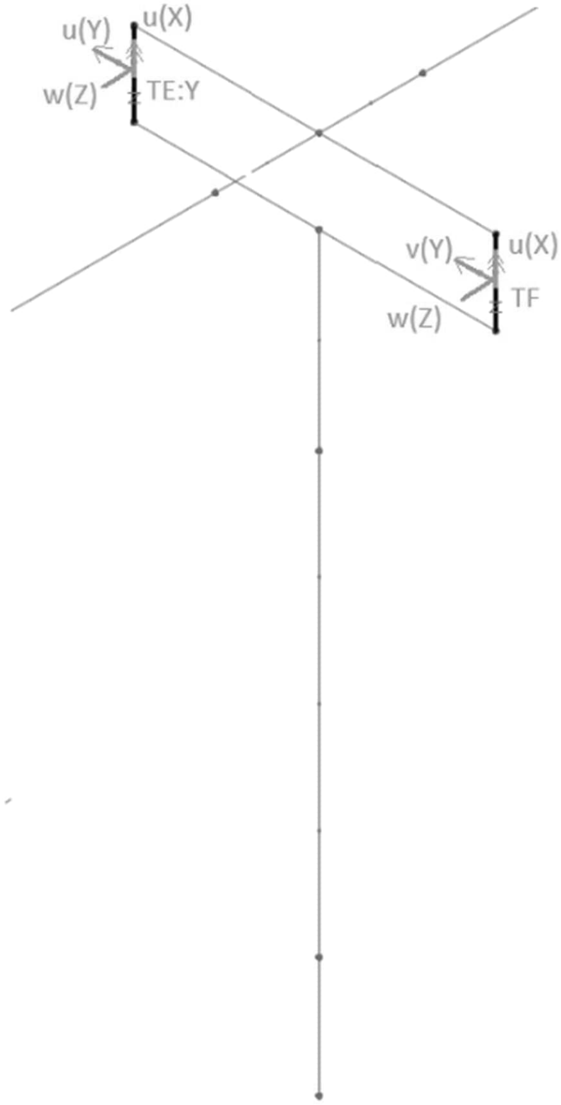


Spring Stiffness Only
Analysis category
3D
Assignment to
Points and line ends
Joint type
Joint no rotational stiffness
Properties specified for each freedom
u
v
w
Elastic spring stiffness
1,0E6
1,0E6
1,0E6
Name
Joint material - TF
(1)
Close
Cancel
Apply
Help

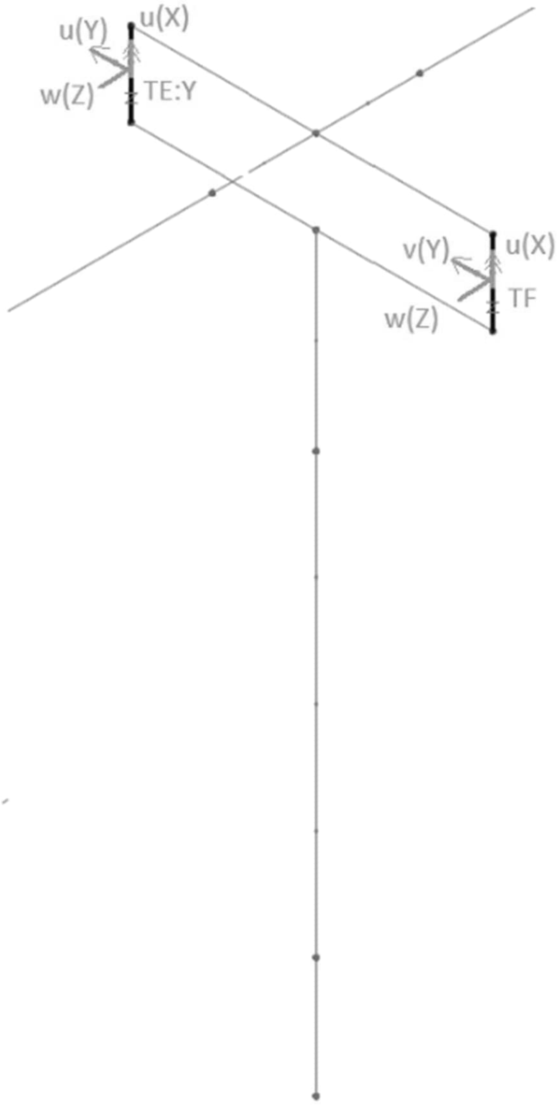
Joints support 1 :



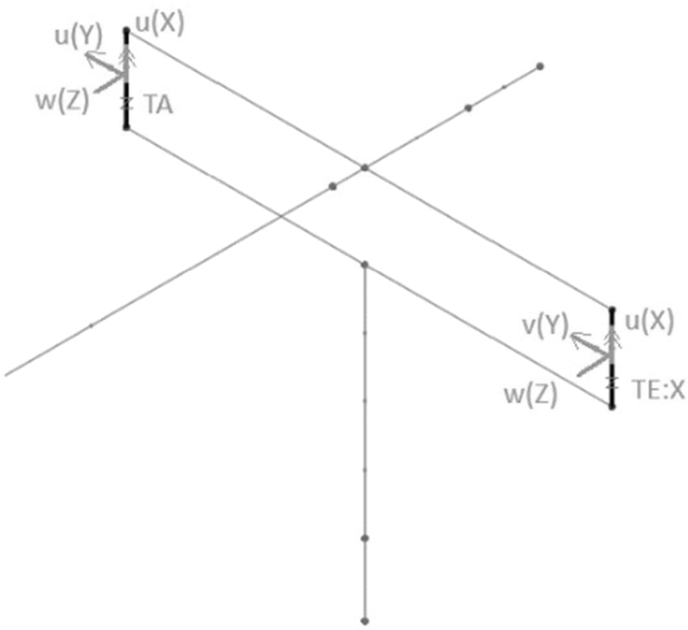
Joints support 2 :



Joints support 3 :



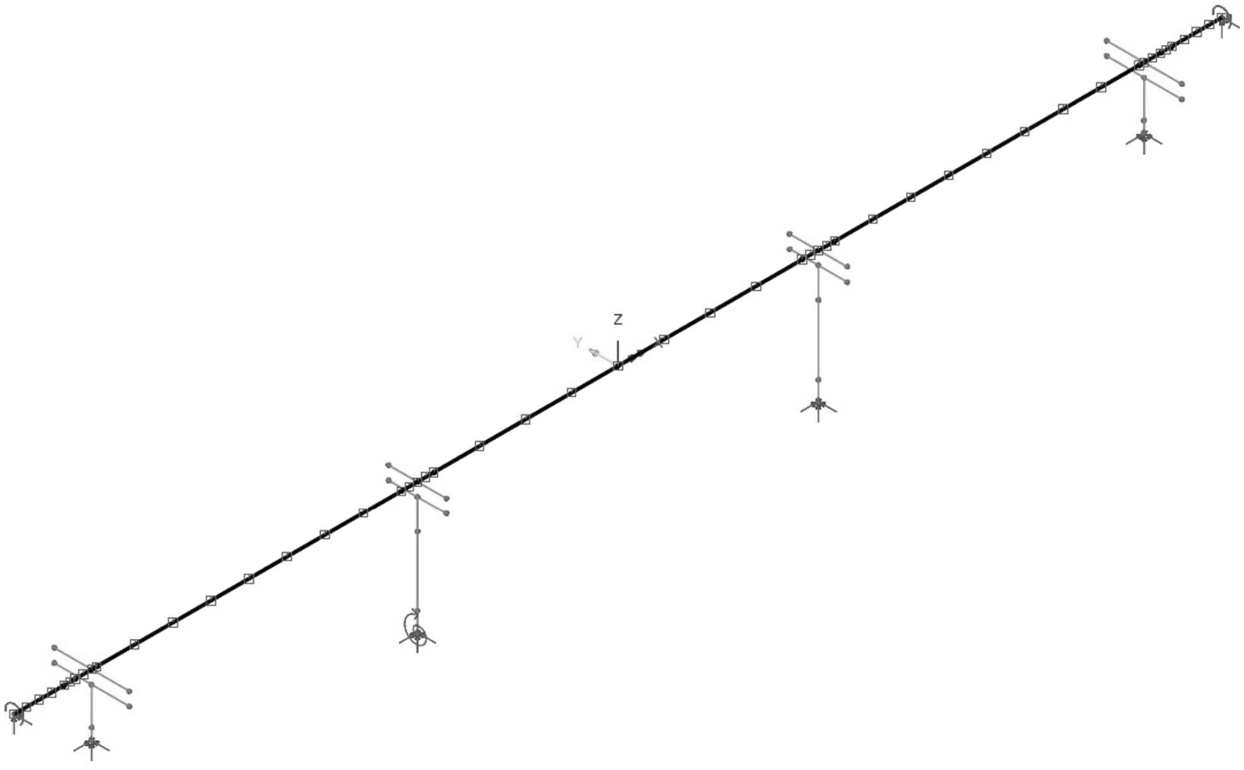
Joints support 4 :



2.7 SEARCH AREA

Discrete load can be applied to structure as geometrical load areas. In FEM program load areas are termed Search Area.

Search area : “Superstructure”



Remark
Contains longitudinal beam including link slab.

3. LOADS

3.1 DEAD WEIGHT

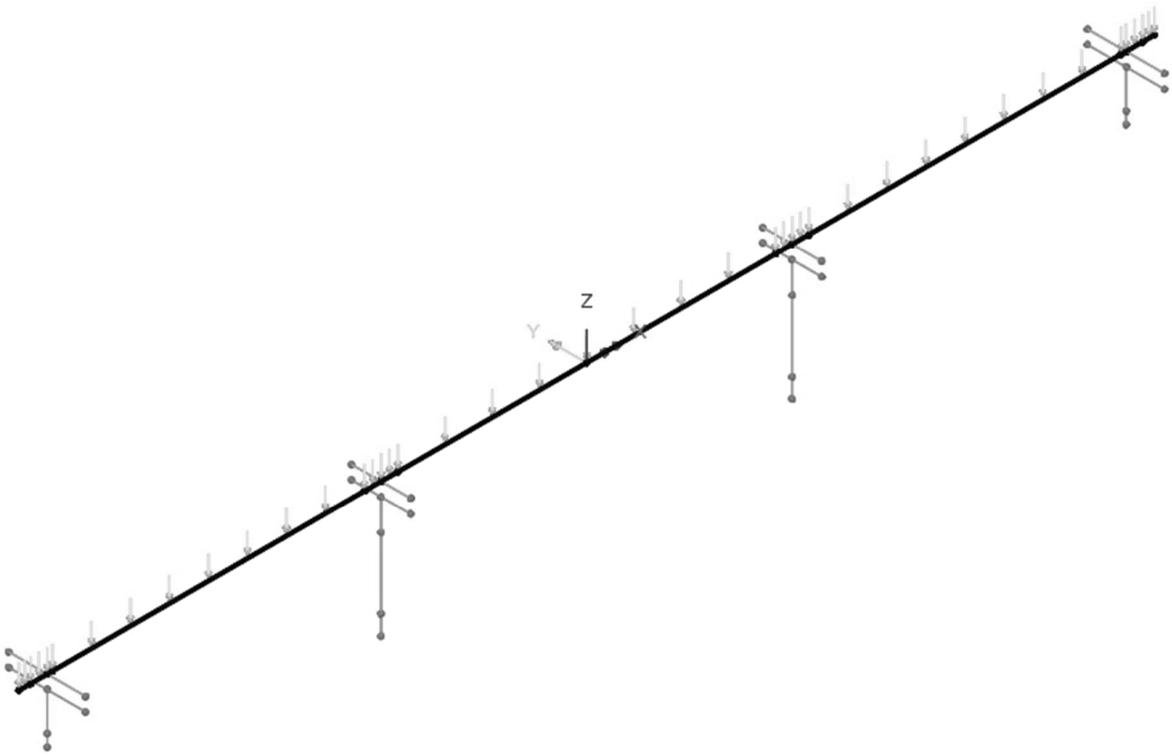
$\gamma_c = 25 \cdot \frac{kN}{m^3}$: concrete

3.1.1 Superstructure - superstructure

Load (loadcase) : EGEN 1

Structural loading : Body force

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



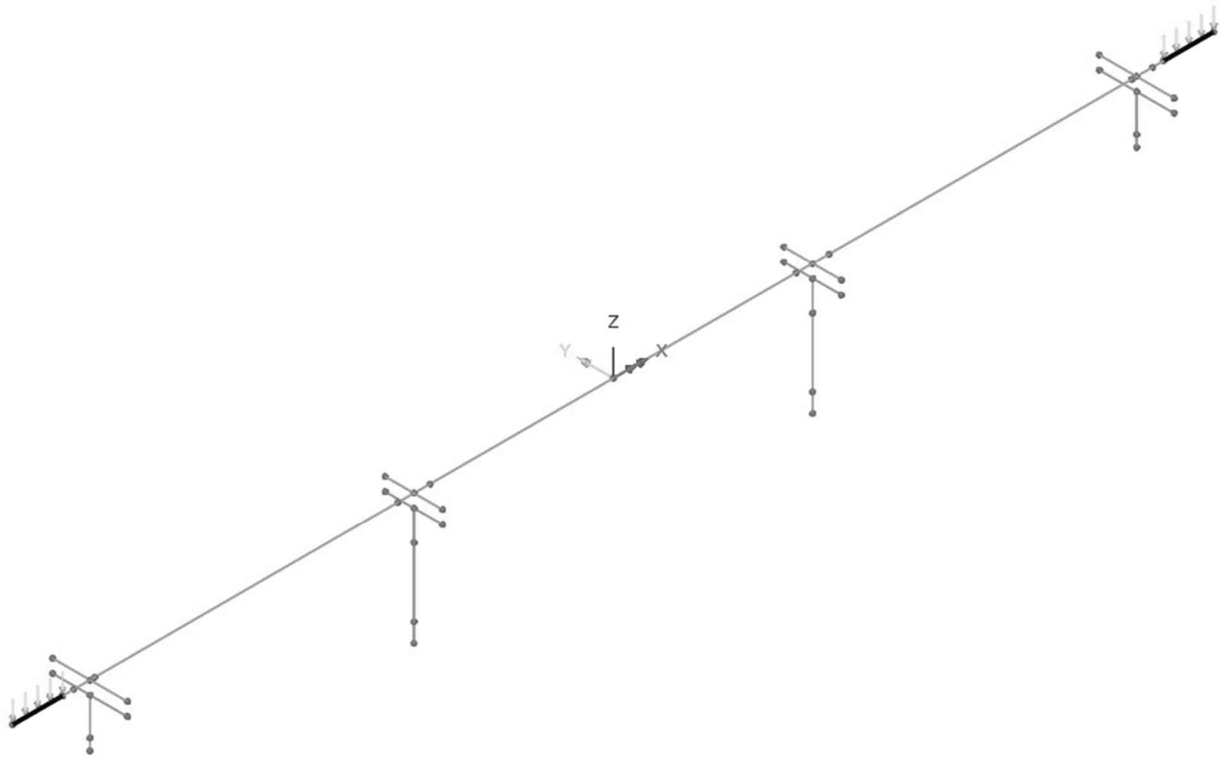
Overview 3D

3.1.2 Link slabs

Load (loadcase) : EGEN 2

Structural loading : Body force

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



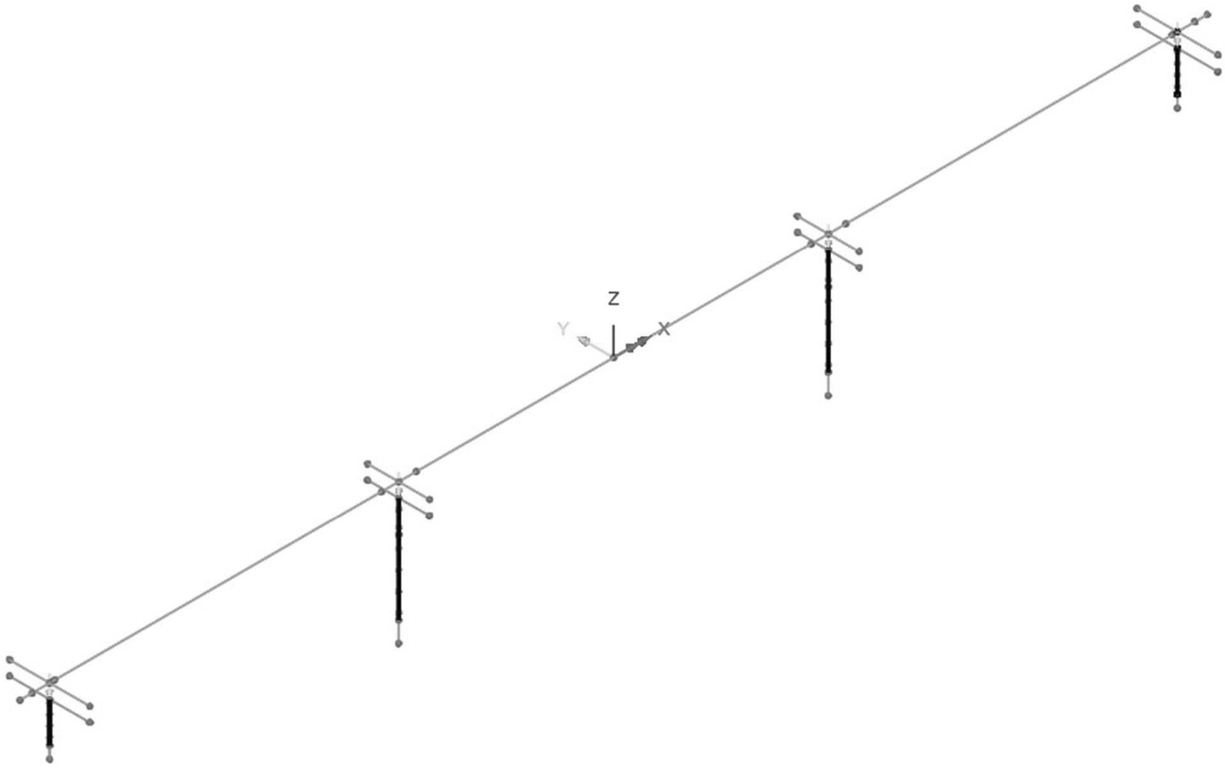
Overview 3D

3.1.3 Abutments

Load (loadcase) : EGEN 3

Structural loading : Body force

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



Overview 3D

3.1.4 Edge beams including railing

Along each edge bream a line load is introduced. The load includes weight of both edge beams and railings.

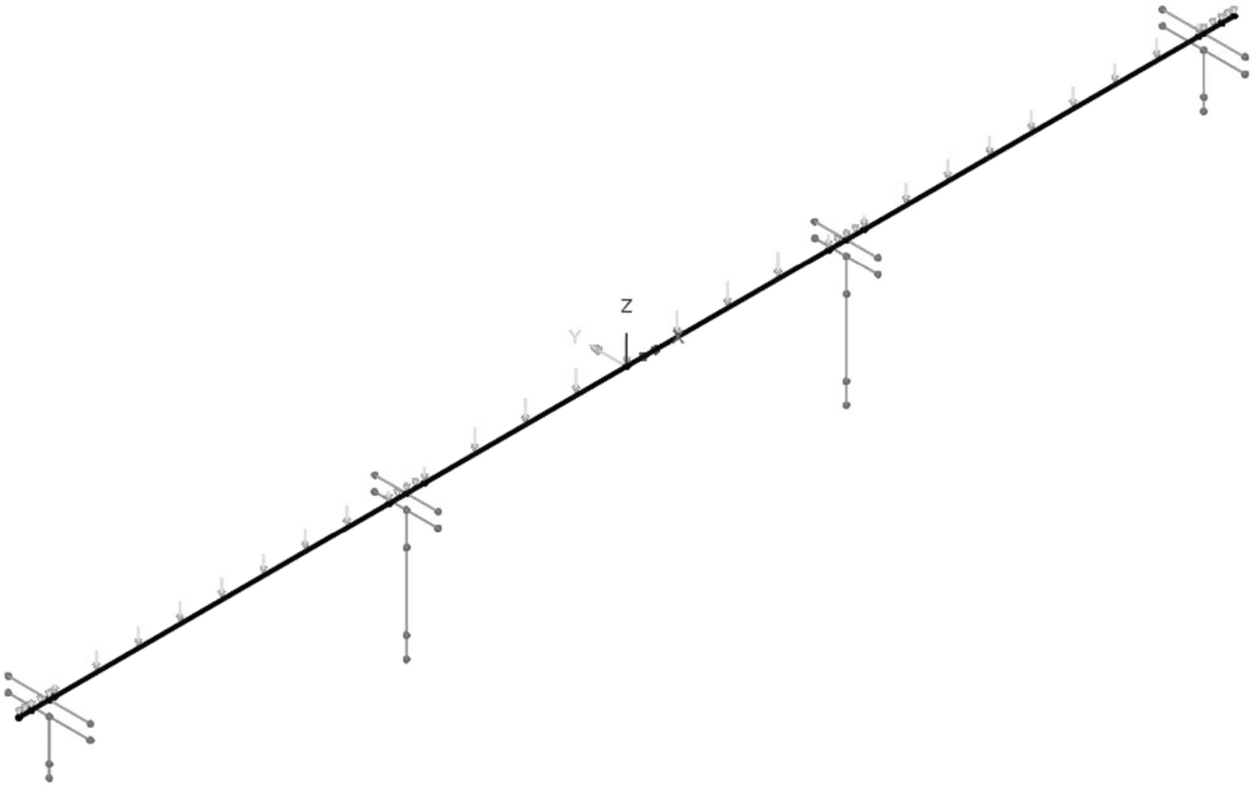
$p_{räcke} = 0.7 \frac{kN}{m}$: weight railing

$$\rightarrow p_z = 2p_{räcke} + 2p_{KB} = 2 \cdot 0.7 \frac{kN}{m} + 2 \cdot 0.45m \cdot 0.45m \cdot 25 \frac{kN}{m^3} = -12 \frac{kN}{m}$$

Load (loadcase) : EGEN 4

Structural loading : Global distributed

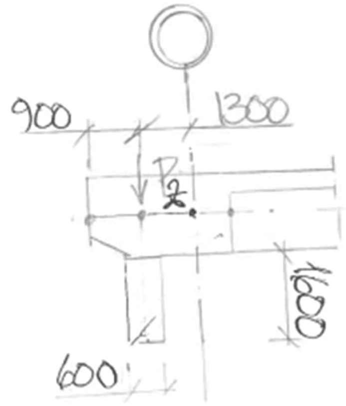
Line load per unit length in Z direction: -6 $\frac{kN}{m}$



Overview 3D

3.1.5 End-shield

The end-shields are alike as seen in sketch below.

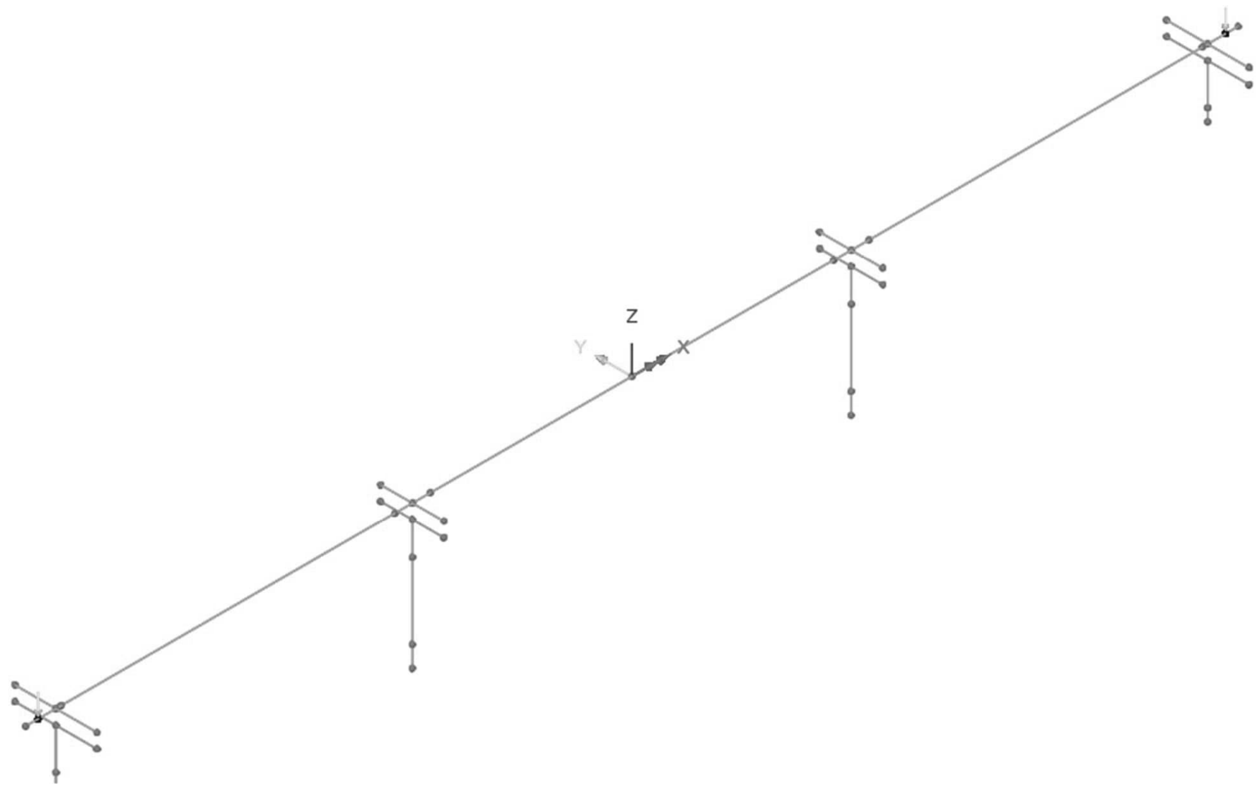


$$p_z = 0.60m \cdot 1.60m \cdot 25\frac{kN}{m^3} = -24\frac{kN}{m} \quad \rightarrow P_z = B \cdot p_z = -8.0m \cdot 24\frac{kN}{m} = -192kN$$

Load (loadcase) : EGEN 5

Structural loading : Concentrated

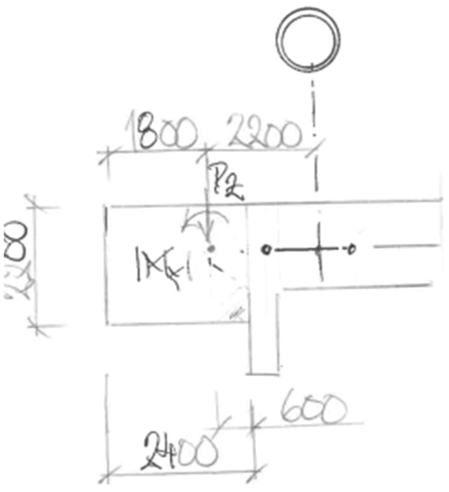
Concentrated load in Z (P_z) : -192 kN



Overview 3D

3.1.6 Wingwalls

All wingwalls are alike and seen in sketch below.



$$P_z = 2 \cdot 0.40m \cdot 2.20m \cdot 2.4m \cdot 25\frac{kN}{m^3} = -106kN$$

$$|M_y| = 106kN \cdot \left(\frac{2.4m}{2} - 0.6m\right) = 64kNm$$

Load : EGEN 6:V

Structural loading : Concentrated

Concentrated load in Z (P_z) : -106 kN

Moment about Y-axis (M_z) : -64 kNm

Load : EGEN 6:H

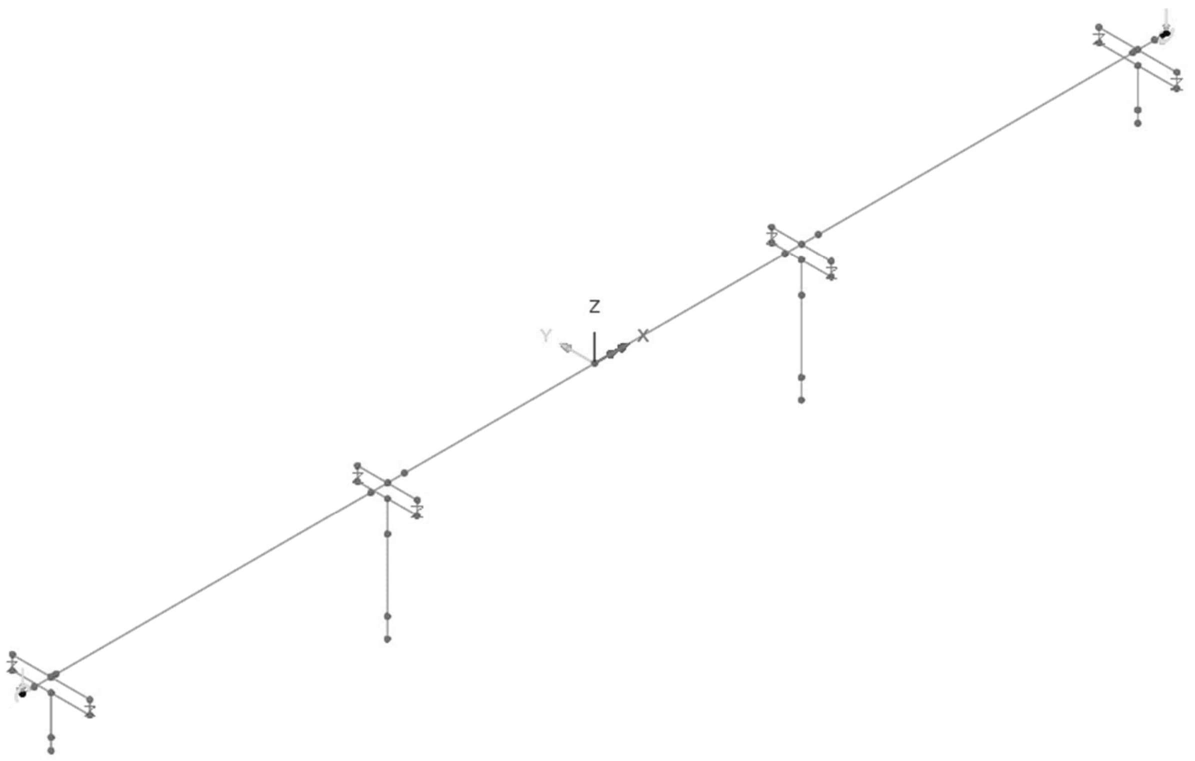
Structural loading : Concentrated

Concentrated load in Z (P_z) : -106 kN

Moment about Y-axis (M_z) : +64 kNm

Loadcase : EGEN 6

Load: EGEN 6:V
Load: EGEN 6:H



Overview 3D

3.1.7 Load combination deadweight : EGEN

Basic load combination EGEN :

Loadcase	Factor
EGEN 1	1.00
EGEN 2	1.00
EGEN 3	1.00
EGEN 4	1.00
EGEN 5	1.00
EGEN 6	1.00

3.2 SURFACING

3.2.1 Load on superstructure

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

$q_{matta} = 0.11kPa$: waterproofing

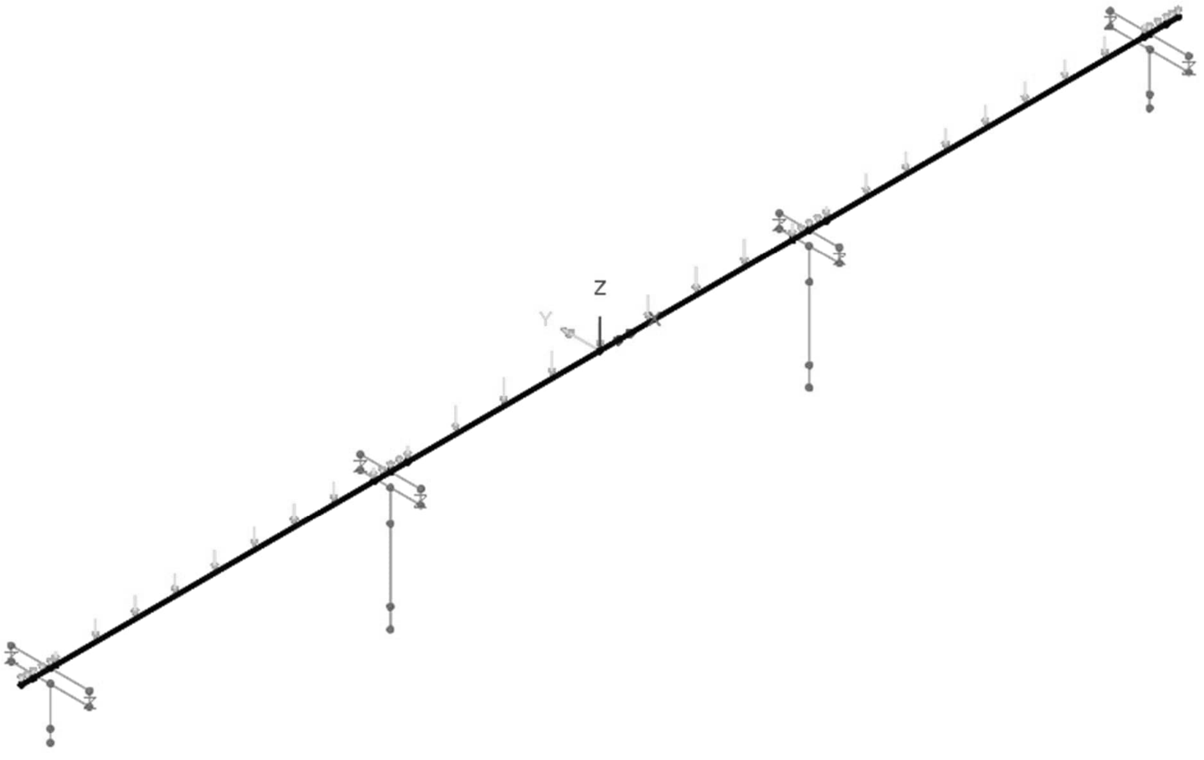
$q_{belägg} = \gamma_{beläggning} \cdot t + q_{matta} = 23\frac{kN}{m^3} \cdot 0.09m + 0.11kPa = 2.2kPa$

$\rightarrow p_z = B \cdot q_{belägg} = 8.0m \cdot 2.2kPa = -18\frac{kN}{m}$

Load (loadcase) : BELAGG 1

Structural loading : Global distributed

Surface load per unit length in Z direction: -18 $\frac{kN}{m}$



Overview

3.2.2 Load on link slab

On the upper side of the link plate, there is a 95 mm pavement and an overfill with varying thickness (100-400 mm).

The overfill is considered equivalent to the base layer. In the static model, a fictitious load corresponding to the weights for the pavement and overfill is introduced (an average thickness of 250 mm is applied.

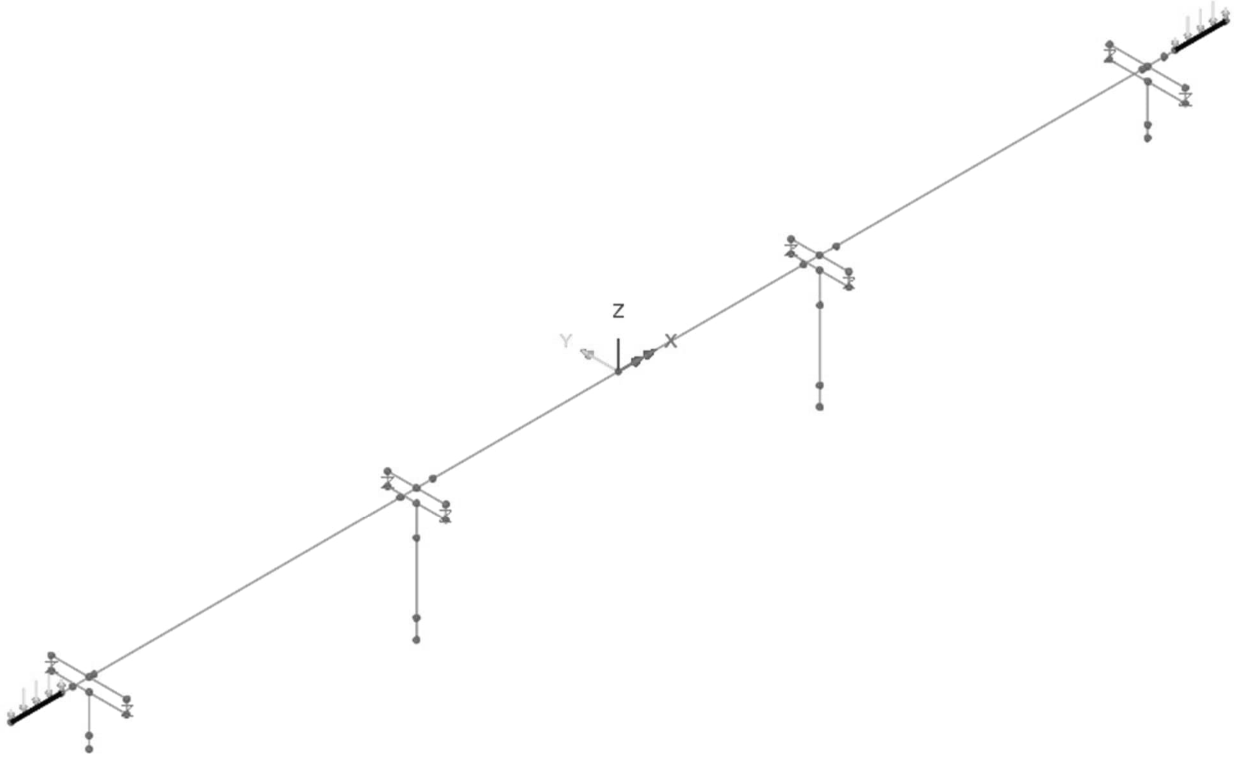
$$q_{belägg} = 2.2kPa + 22\frac{kN}{m^3} \cdot 0.25m = 8.0kPa$$

$$\rightarrow p_z = B \cdot q_{belägg} = 8.0m \cdot 8.0kPa = -64\frac{kN}{m}$$

Loadcase : BELAGG 2

Structural loading : Global distributed

Surface load per unit length in Z direction: -64 $\frac{kN}{m}$



Overview

3.2.3 Load combination surfacing: BELAGG

Basic loadcomination BELAGG :

Loadcase	Factor
BELAGG 1	1.00
BELAGG 2	1.00

3.3 EARTH PRESSURE

Earth pressure in filling corresponds to coarse crushed blasted rock (AMA CEB.524).

φ_k = 45°

$\gamma = 20 \frac{kN}{m^3}$

$\gamma' = 13 \frac{kN}{m^3}$

$$X_d = \frac{1}{\gamma_m} \cdot \eta \cdot \overline{X} \equiv \frac{1}{\gamma_m} \cdot X_k$$

Earth pressure coefficient for design method 2 (D2) :
Design coefficients associated to *A1 + M1 + R2* according to SS-EN 1997-1 section 2.4.7.3.4.3 is applied.

$\gamma_{m.D2}$ = 1.0 : see TSFS chapter 38 table 38.3 for M1

$\rightarrow \varphi_d = artctan \left(\frac{tan\varphi_k}{\gamma_{m.D2}}\right) = arctan\left(\frac{tan45°}{1.0}\right) = 45°$

$K_0 = 1 - \sin(\varphi_d) = 0.29$

$K_a = tan^2\left(45° - \frac{\varphi_d}{2}\right) = 0.17$

$K_p = tan^2\left(45° + \frac{\varphi_d}{2}\right) = 5.82$

Earth pressure for design method 3 (D3) :
Design coefficients associated to *A1(design loads) + A2(geotechnical loads) + M2 + R3* according to SS-EN 1997-1 section 2.4.7.3.4.4 is applied.

$\gamma_{m.D3}$ = 1.3 : see TSFS chapter 8 table 38.3 för M2

$\rightarrow \varphi_d = artctan \left(\frac{tan\varphi_k}{\gamma_m}\right) = arctan\left(\frac{tan45°}{1.3}\right) = 38°$

Remark
These are not used in FEM-analysis. This is done by adjusting load coefficients.

Earth pressure in FEM-analysis:

During design earth press coefficients associated to method D2 will used applied, however the load coefficients are adjusted according verification, see pages A3:170.

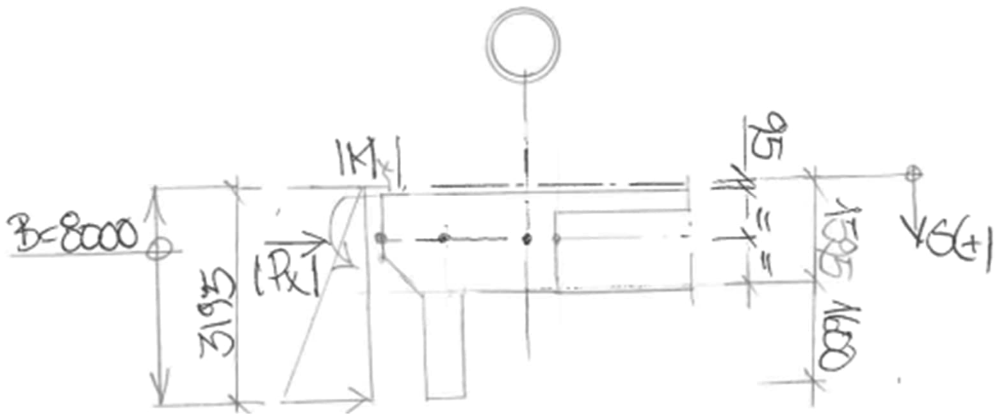
$K_0 = 0.29$

$K_a = 0.17$

$K_p = 5.82$

$$q_{vilo}(s) = K_0 \cdot \gamma \cdot s = 0.29 \cdot 20 \frac{kN}{m^3} \cdot s(+) = s(+) \cdot 5.8 kPa$$

3.3.1 Load against superstructure at support 1 & 4



$q_{vilo}\ (0m) = 0kPa$

$q_{vilo}\ (3.195m) = 3.195m \cdot 5.8\frac{kN}{m^3} = 19kPa$

$\rightarrow p_{vilo}\ (3.195m) = 19kPa \cdot 8.0m = 148\frac{kN}{m}$

$|P_x| = 148\frac{kN}{m} \cdot \frac{3.195m}{2} = 236kN$

$|M_y| = 236kN \cdot \left(\frac{2 \cdot 3.195m}{3} - 0.845m\right) = 303kNm$

Load : JORD 1:V

Structural loading : Concentrated

Concentrated load in X (P_x) : +236kN

Moment about Y axis (M_y) : -303 kNm

Load : JORD 1:H

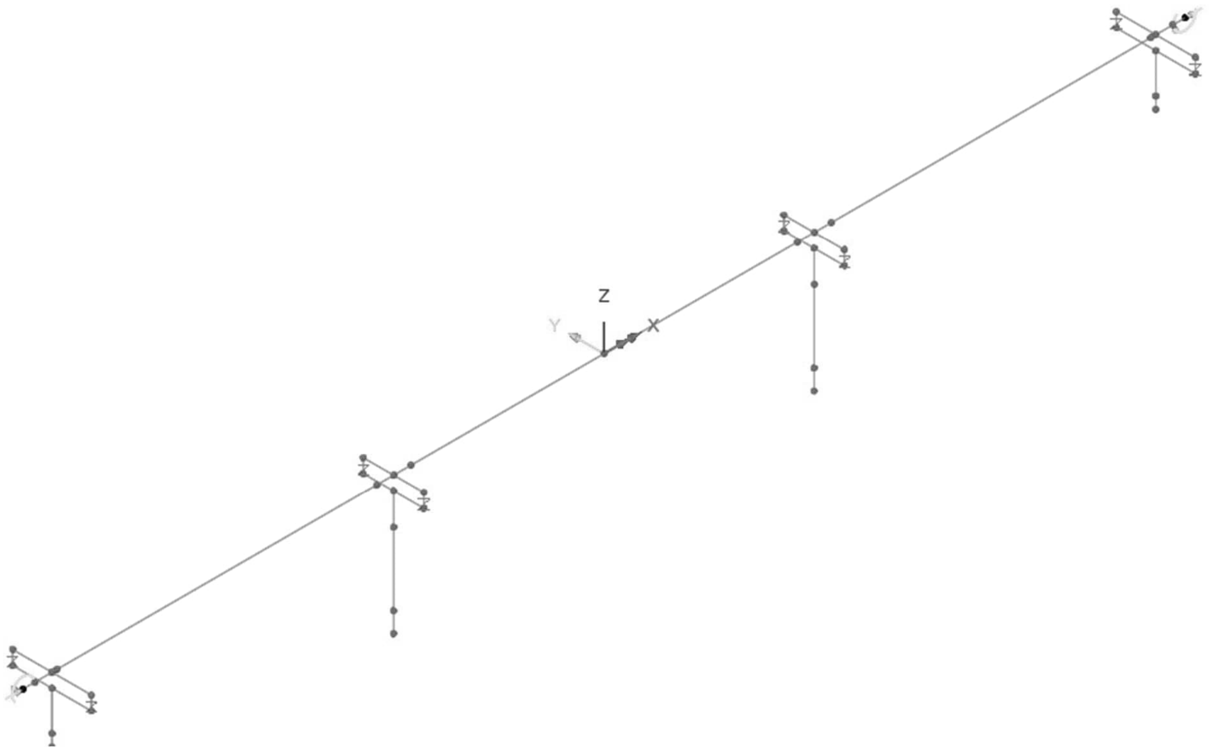
Structural loading : Concentrated

Concentrated load in X (P_x) : -236kN

Moment about Y axis (M_y) : +303 kNm

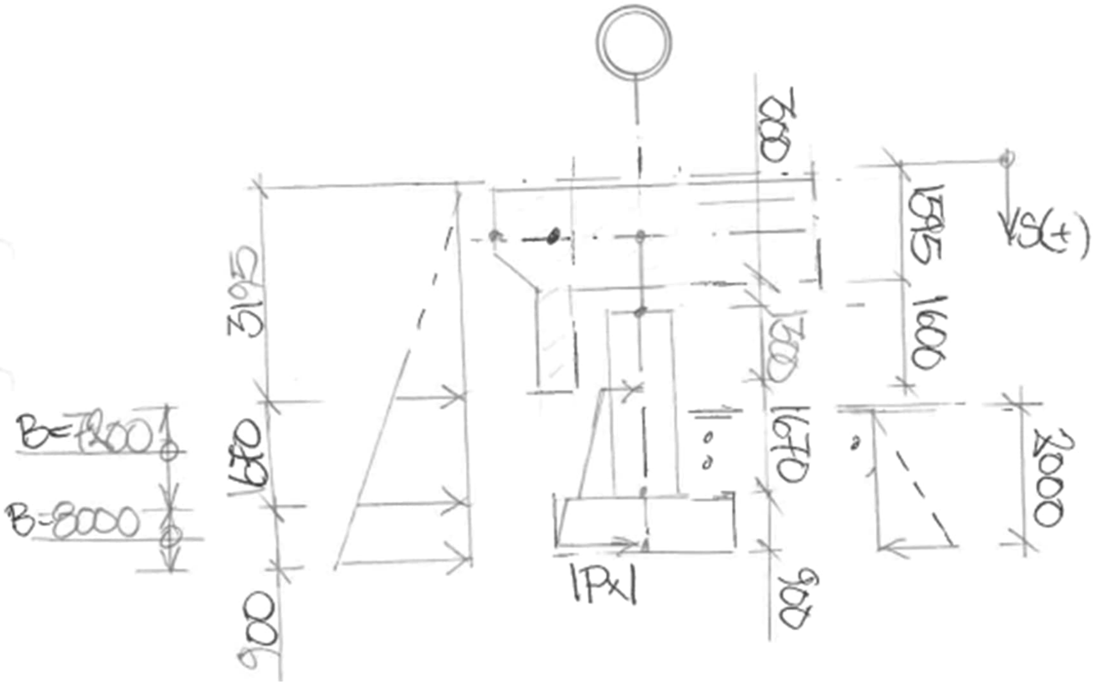
Loadcase : JORD 1

Load: JORD 1:V
Load: JORD 1:H



Overview

3.3.2 Load against abutments at support 1 & 4



$$q_{vilo}\ (3.195m) = 3.195m \cdot 5.8\frac{kN}{m^3} = 19kPa$$

$$\rightarrow\ |p_x(B = 7.2m)| = 19kPa \cdot 7.2m = 137\frac{kN}{m}$$

$$q_{vilo}\ (4.865m) = 4.865m \cdot 5.8\frac{kN}{m^3} = 28kPa$$

$$\rightarrow\ |p_x(B = 7.2m)| = 28kPa \cdot 7.2m = 202\frac{kN}{m}$$

$$|p_x(B = 8.0m)| = 28kPa \cdot 8.0m = 224\frac{kN}{m}$$

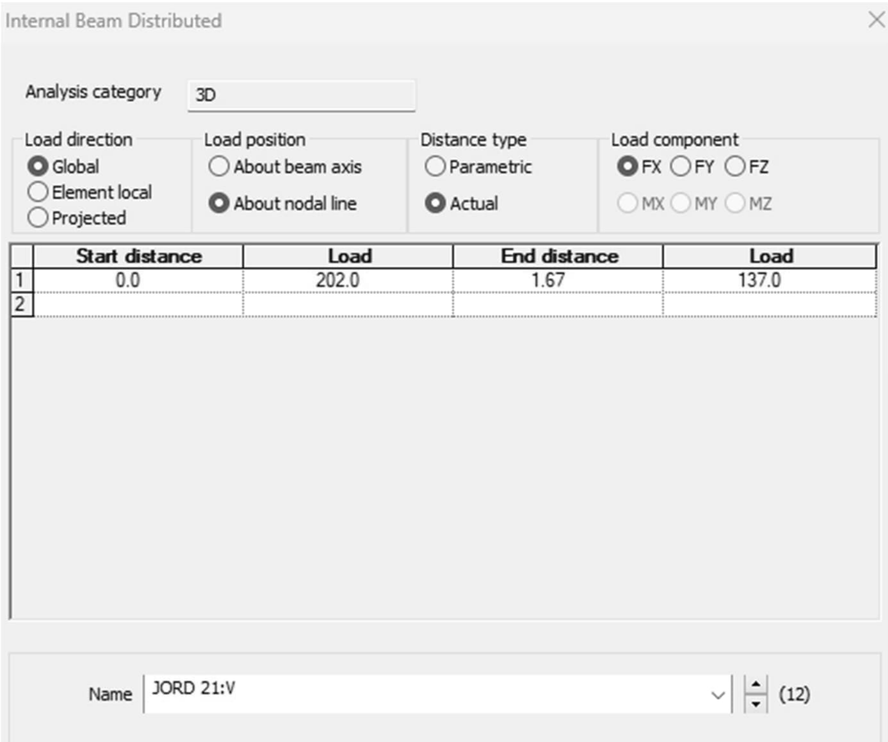
$$q_{vilo}\ (5.665m) = 5.665m \cdot 5.8\frac{kN}{m^3} = 33kPa$$

$$\rightarrow\ |p_x(B = 8.0m)| = 33kPa \cdot 7.2m = 264\frac{kN}{m}$$

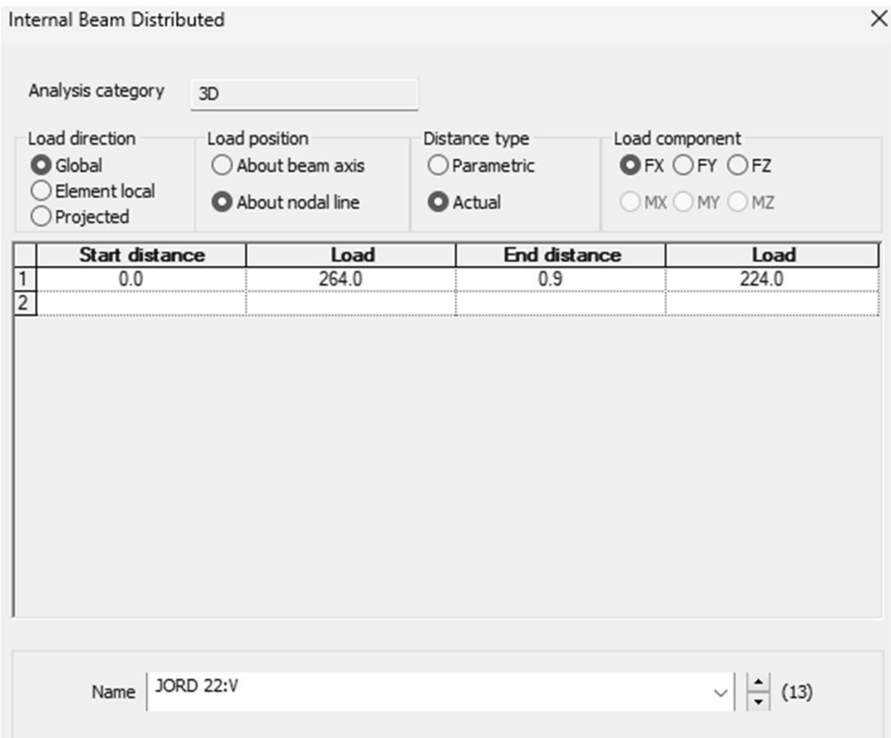
Remark

Load on side from filling is neglected on safe side.

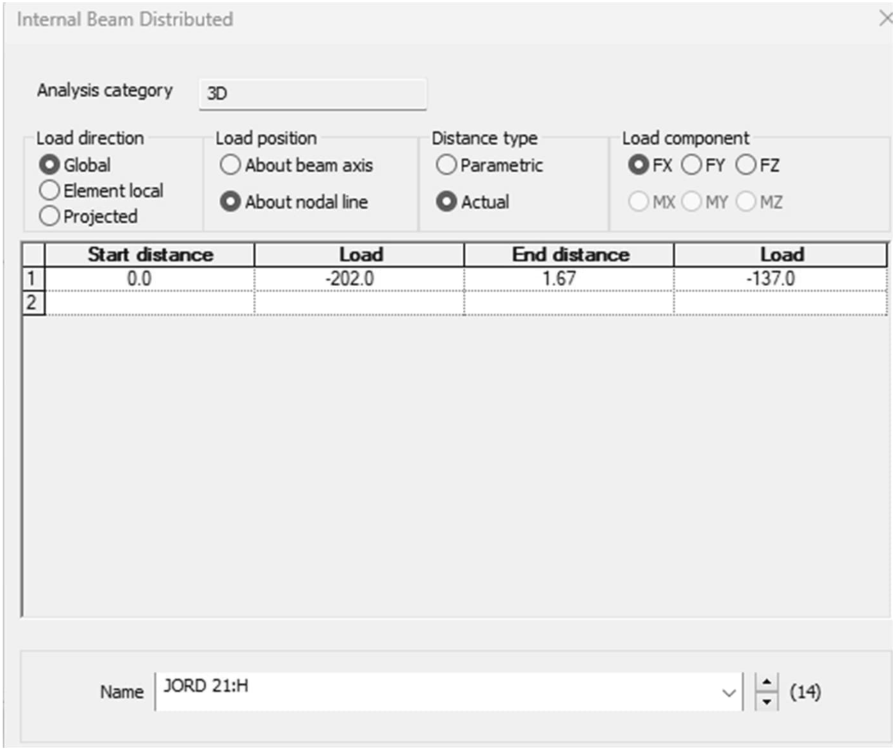
Load : JORD21:V



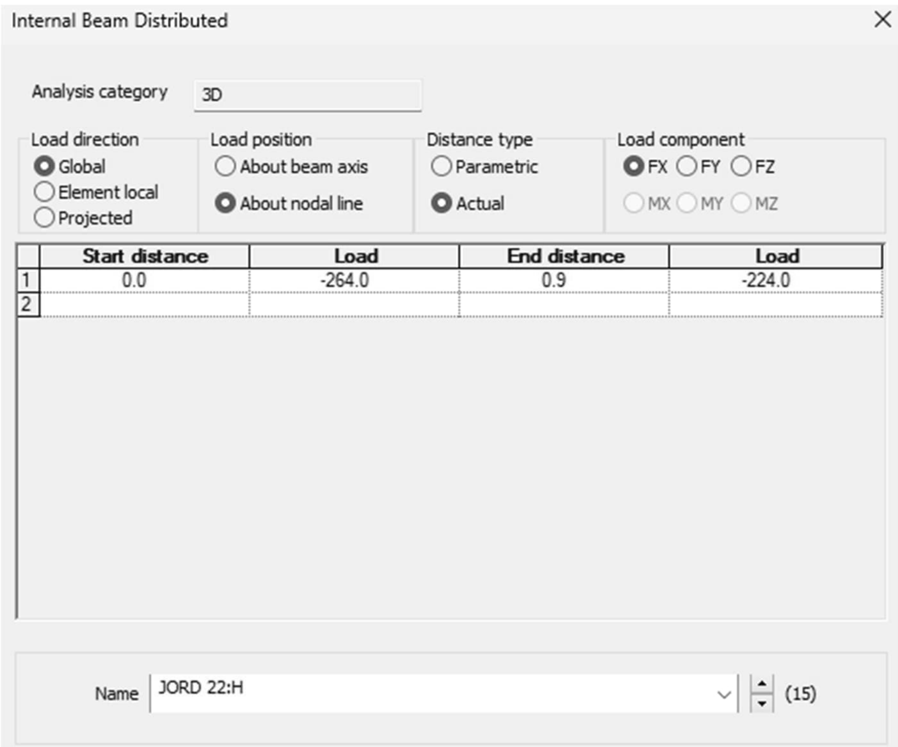
Load : JORD 22:V



Load : JORD21:H

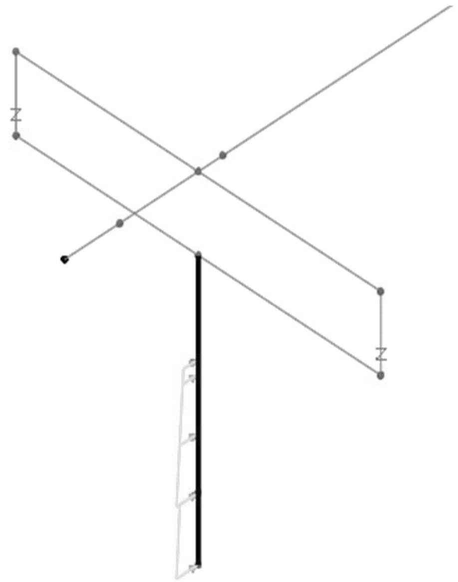


Load : JORD 22:H

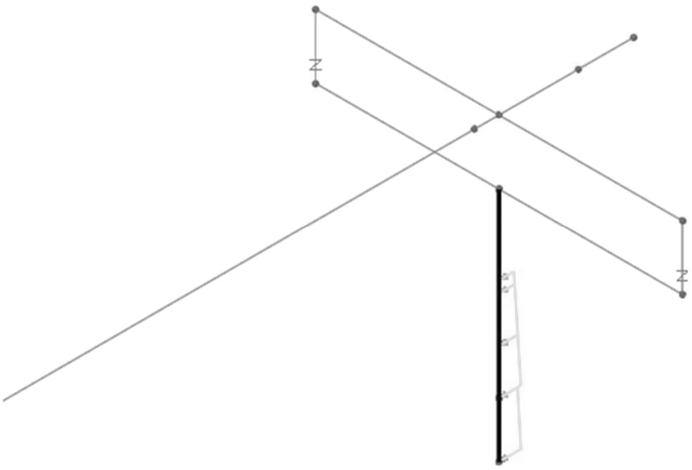


Loadcase : JORD 2

Load: JORD 21:V
Load: JORD 22:V
Load: JORD 21:H
Load: JORD 22:H



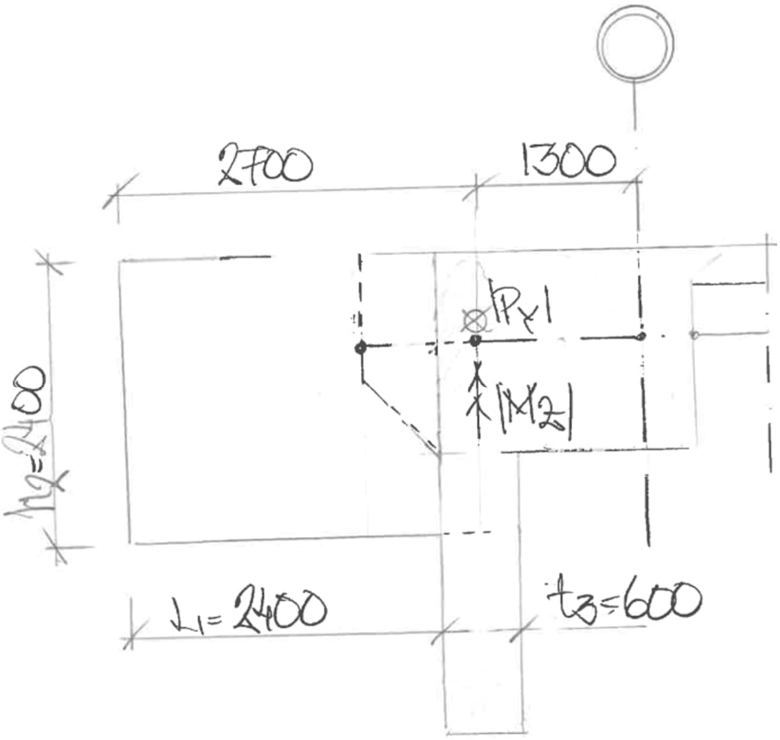
Overview 3D
Abutement 1



Overview 3D
Abutement 4

3.3.3 Load against wingwalls

Design software K2.002 is used to determine earth pressure against wingwalls according to Culmans´s theory. All wingwalls are assumed to have same length (L = 4 m).



$t_3 = 0.6m$

$h_2 = 2.4m$

$h_3 = 2.4m$

$h_4 = 0.1m$

Effective height along edge end-shield:

$H_{ef} = 2.3m$: see page A3:33

Load at abutment edge quasi-load status (SLS-Q):

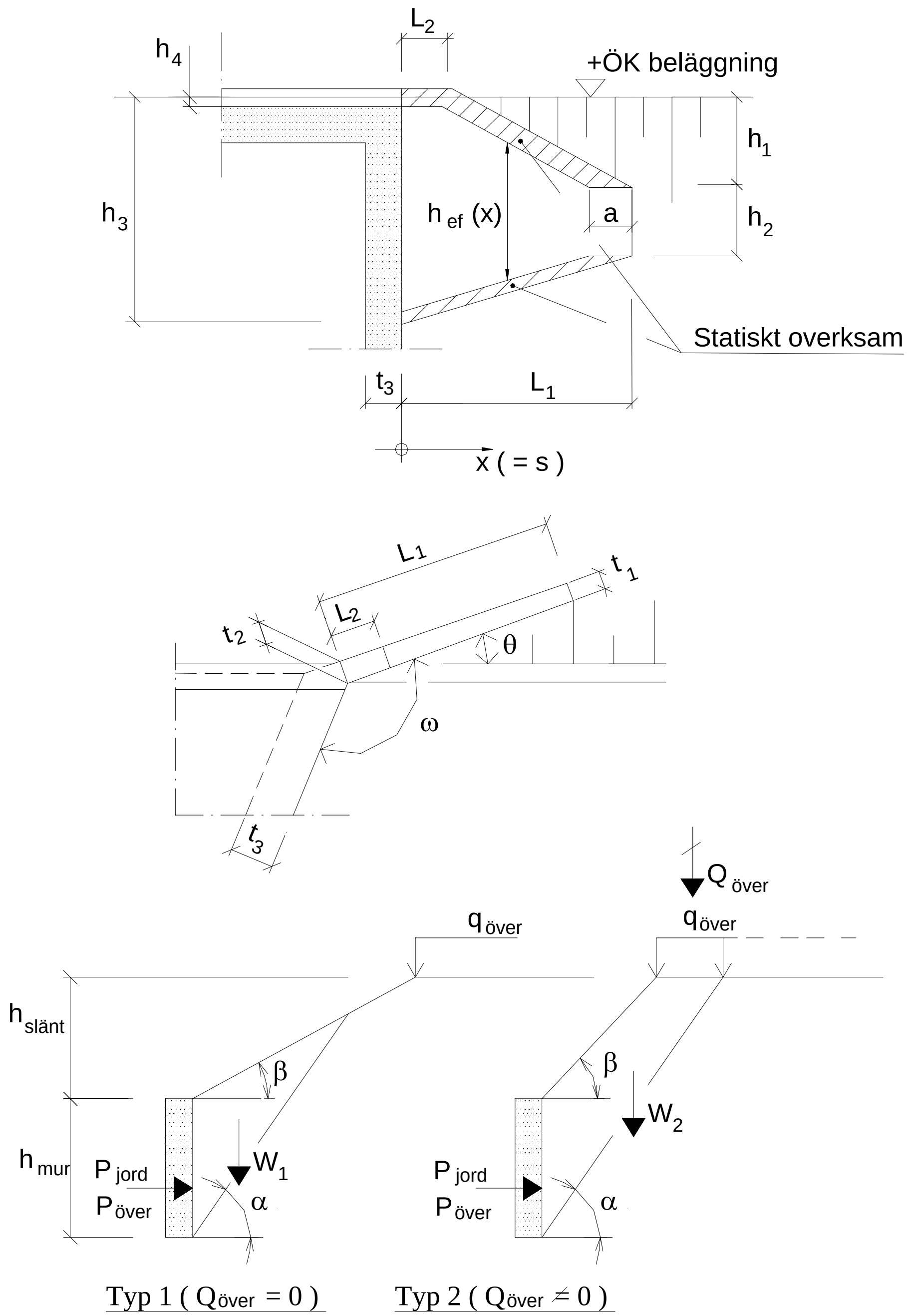
$N_{SLS-Q} = +23\frac{kNm}{m}$: see page A3:33

$M_{SLS-Q} = 35\frac{kNm}{m}$: see page A3:33

Remark.
Since all wingwall are equal the total load in transversal direction and balanced, thus this load is not applied to 3D beam model.

Objekt : Vingmur L = 2.4 m

PRINCIPFIGUR



Jordtryck enligt Culmans metod

INDATA

Geometri :

$L_1 = 2.4m$ $L_2 = 1mm$

$h_1 = 1mm$ $h_2 = 2.40m$ $h_3 = 2.401m$ $h_4 = 0.10m$

$t_1 = 0.40m$ $t_2 = 0.40m$ $t_3 = 0.60m$

Vinkel vinge-ramben på baksidan : $\omega = 91°$

Vinkel vinge-vägbankskrön på baksidan : $\theta = 1°$

Avstånd till brytpunkt för effektiv höjd : $a = 1mm$

Material :

Jordmaterial : $\gamma_{jord} = 20 \frac{kN}{m^3}$ $K_o = 0.29$ $K_a = 0.17$

Betong : $\gamma_{btg} = 25 \frac{kN}{m^3}$

Laster :

Överlast : $q_{över} = 20kPa$

Lastkoefficienter :

Jordtryck

$\psi\gamma_{ULS.1} = 1.49$ $\psi\gamma_{SLS.1} = 1.34$

Överlast

$\psi\gamma_{ULS.2} = 1.71$ $\psi\gamma_{SLS.2} = 0$

BERÄKNING

Jordtryck enligt Culmans metod :

Nivå överkant vingmur : $mur_{ök} = \text{linterp}\left[\left(0m \;\; L_2 \;\; L_1\right), \left(h_3 \;\; h_3 \;\; h_3 - h_1\right), s\right]$

Nivå underkant vingmur : $mur_{uk} = \text{linterp}\left[\left(0m \;\; L_1\right), \left(0m \;\; h_3 - h_1 - h_2\right), s\right]$

Vingmurens höjd : $h_{mur} = mur_{ök} - mur_{uk}$

Släntens höjd : $h_{slänt} = \text{linterp}\left[\left(0m \;\; L_2 \;\; L_1\right), \left(0m \;\; 0m \;\; h_1\right), s\right]$

Friktionsvinkel: $\varphi = \text{asin}\left(1 - K_o\right)$

Lutning hos slänten ned till överkant vingmur mätt vinkelrätt mot vingen :

$$\beta = \text{atan}\left[\frac{h_1}{\left(L_1 - L_2\right)\tan(\theta)}\right]$$

Vertikallast för brottfigur typ 1 (= brottlinje i slänt, sålunda inget tillskott av överlast) :

$$W_1 = h_{mur}\cdot\sin\left(\frac{\pi}{2} - \alpha\right)\cdot\left(h_{mur}\cdot\cos\left(\frac{\pi}{2} - \alpha\right) + \frac{h_{mur}\cdot\sin\left(\frac{\pi}{2} - \alpha\right)}{\tan(\alpha - \beta)}\right)\cdot\frac{\gamma_{jord}}{2}$$

Vertikallaster för brottfigur typ 2 (= brottlinje hamnar ovanför slänt vilket ger ett bidrag från överlast) :

$$W_2 = \left[\left(h_{mur} + h_{slänt}\right)^2\cdot\tan\left(\frac{\pi}{2} - \alpha\right) - \frac{h_{slänt}^{\;2}}{\tan(\beta)}\right]\cdot\frac{\gamma_{jord}}{2}$$

$$Q_{över}(q) = q\cdot\left[\left(h_{mur} + h_{slänt}\right)\cdot\tan\left(\frac{\pi}{2} - \alpha\right) - \frac{h_{slänt}(s)}{\tan(\beta)}\right]$$

Vilojordtrycksresultant enligt Culmann under inverkan av jordlast + överlast :

$$p_o(q) = \left| \begin{array}{l} W_{jord} \leftarrow W_1 \ \text{ if } \left(h_{mur} + h_{slänt}\right)\cdot\tan(90° - \alpha) < \dfrac{h_{slänt}}{\tan(\beta)} \\ W_{jord} \leftarrow W_2 + Q_{över}(q) \ \text{ otherwise} \\ p_{aktiv} \leftarrow W_{jord}\cdot\tan(\alpha - \varphi) \\ p_{aktiv}\cdot\dfrac{K_o}{K_a} \end{array} \right.$$

Utvärdera största last av jordtryck och överlast genom att kontrollera N_a antal vinklar mellan φ och 90°. Överlastens lasteffekt fås som skillnaden mellan jordtrycksresultant med och utan överlast.

$$p_{jord}(s) = \left| \begin{array}{l} N_\alpha \leftarrow 20st \\ \Delta\alpha \leftarrow \dfrac{90° - \varphi}{N_\alpha - 1} \\ \alpha \leftarrow \varphi \\ p_{max} \leftarrow p_o(0kPa) \\ \text{for } i \in 2..N_\alpha \\ \quad \left| \begin{array}{l} \alpha \leftarrow \alpha + \Delta\alpha \\ p_{vilo} \leftarrow p_o(0kPa) \\ \text{if } p_{vilo} > p_{max} \\ \quad \left| \begin{array}{l} p_{max} \leftarrow p_{vilo} \\ \alpha_{max} \leftarrow \alpha \end{array} \right. \end{array} \right. \end{array} \right.$$

$$p_{över}(s) = \left| \begin{array}{l} N_\alpha \leftarrow 20st \\ \Delta\alpha \leftarrow \dfrac{90° - \varphi}{N_\alpha - 1} \\ \alpha \leftarrow \varphi \\ p_{max} \leftarrow p_o\left(q_{över}\right) - p_o(0kPa) \\ \text{for } i \in 2..N_\alpha \\ \quad \left| \begin{array}{l} \alpha \leftarrow \alpha + \Delta\alpha \\ p_{över} \leftarrow p_o\left(q_{över}\right) - p_o(0kPa) \\ \text{if } p_{över} > p_{max} \\ \quad \left| \begin{array}{l} p_{max} \leftarrow p_{över} \\ \alpha_{max} \leftarrow \alpha \end{array} \right. \end{array} \right. \end{array} \right.$$

Snittkrafter jordtryck + överlast :

$$H'_{jord}\left(x_s\right) = \int_{x_s}^{L_1} p_{jord}(s)\, ds \qquad M'_{jord}\left(x_s\right) = \int_{x_s}^{L_1} \left(s - x_s\right)\cdot p_{jord}(s)\, ds$$

$$H'_{över}\left(x_s\right) = \int_{x_s}^{L_1} p_{över}(s)\, ds \qquad M'_{över}\left(x_s\right) = \int_{x_s}^{L_1} \left(s - x_s\right)\cdot p_{över}(s)\, ds$$

Lastkombinering - Lk ULS och Lk SLS :

Snittkraft i frontmur för inspänningssnitt :

$$N'_{ULS.front} = \left(\psi\gamma_{ULS.1} \cdot H'_{jord}(0 \cdot m) + \psi\gamma_{ULS.2} \cdot H'_{över}(0 \cdot m)\right) \cdot \sin(\omega)$$

$$M'_{ULS.front} = \psi\gamma_{ULS.1} \cdot M'_{jord}(0 \cdot m) + \psi\gamma_{ULS.2} \cdot M'_{över}(0 \cdot m) + N'_{ULS.front} \cdot \frac{t_3}{2}$$

$$N'_{SLS.front} = \left(\psi\gamma_{SLS.1} \cdot H'_{jord}(0 \cdot m) + \psi\gamma_{SLS.2} \cdot H'_{över}(0 \cdot m)\right) \cdot \sin(\omega)$$

$$M'_{SLS.front} = \psi\gamma_{SLS.1} \cdot M'_{jord}(0 \cdot m) + \psi\gamma_{SLS.2} \cdot M'_{över}(0 \cdot m) + N'_{SLS.front} \cdot \frac{t_3}{2}$$

Snittkrafter i vingmur :

$$Q'_{ULS}(s) = \psi\gamma_{ULS.1} \cdot H'_{jord}(s) + \psi\gamma_{ULS.2} \cdot H'_{över}(s)$$

$$M'_{ULS}(s) = \psi\gamma_{ULS.1} \cdot M'_{jord}(s) + \psi\gamma_{ULS.2} \cdot M'_{över}(s)$$

$$M'_{SLS}(s) = \psi\gamma_{SLS.1} \cdot M'_{jord}(s) + \psi\gamma_{SLS.2} \cdot M'_{över}(s)$$

Beräkning av effektiv höjd :

$$\Delta h = h_3 - h_2 - h_1 \qquad \Delta h = 0.000 \cdot m$$

Nivå överkant effektiv vingmur :

$$Nivå_{ök} = \mathrm{linterp}\left[\left(0m \;\; L_2 \;\; L_1 - a \;\; L_1\right), \left(h_3 - h_4 \;\; h_3 - h_4 \;\; h_3 - h_1 \;\; h_3 - h_1\right), s\right]$$

Nivå underkant effektiv vingmur :

$$Nivå_{uk} = \mathrm{linterp}\left[\left(0m \;\; L_1 - L_2 \;\; L_1\right), \left(\frac{a}{L} \cdot \Delta h \;\; \Delta h \;\; \Delta h\right), s\right]$$

Effektiv höjd vingmur :

$$h_{ef}(s) = Nivå_{ök} - Nivå_{uk}$$

Dimensionerande snittkrafter (Lk ULS och Lk SLS) fördelade på effektiv höjd :

Snittkraft i frontmur för inspänningssnitt :

$$H_{ef} = h_{ef}(0m)$$

$$N_{ULS.front} = \frac{N'_{ULS.front}}{H_{ef}}$$

$$M_{ULS.front} = \frac{M'_{ULS.front}}{H_{ef}}$$

$$N_{SLS.front} = \frac{N'_{SLS.front}}{H_{ef}}$$

$$M_{SLS.front} = \frac{M'_{SLS.front}}{H_{ef}}$$

Snittkrafter i vingmur :

$$Q_{ULS.ving} = \frac{Q'_{ULS}(s)}{h_{ef}(s)}$$

$$M_{ULS.ving} = \frac{M'_{ULS}(s)}{h_{ef}(s)}$$

$$M_{SLS.ving} = \frac{M'_{SLS}(s)}{h_{ef}(s)}$$

Egenvikt vingmur :

$$t = t_2 - \frac{t_2 - t_1}{L_1} \cdot s$$

$$A(s) = h_{mur} \cdot t$$

$$V_{egen} = \gamma_{btg} \cdot \int_0^{L_1} A(s)\, ds$$

$$M_{egen} = \gamma_{btg} \cdot \int_0^{L_1} A(s) \cdot s\, ds$$

RESULTAT

Mellanresultat

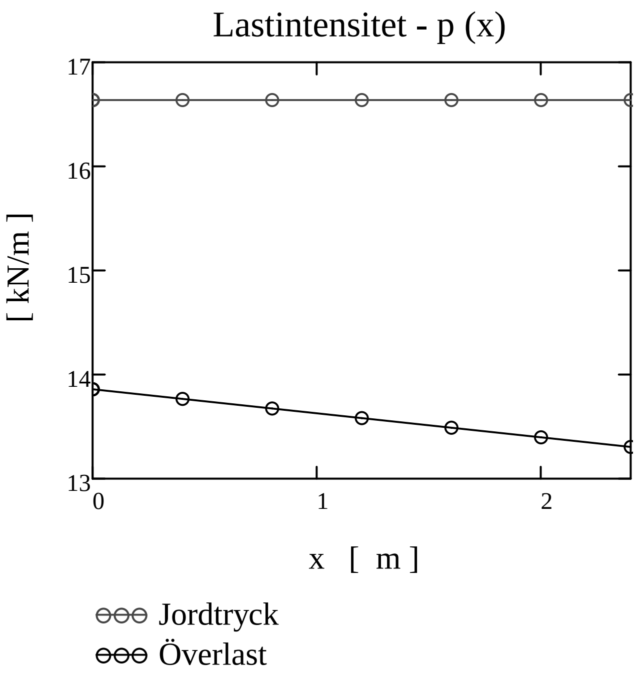
$\varphi = 45 \cdot °$: Dimensionerande friktionsvinkel tillhörande K_o

$\beta = 1 \cdot °$: Lutning hos slänten ned till överkant vingmur mätt vinkelrätt mot vingen

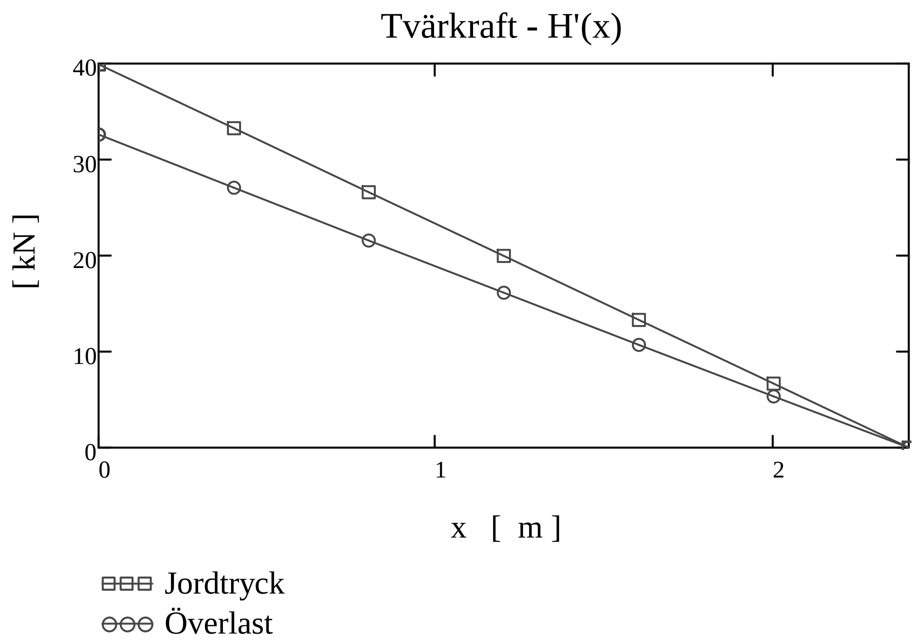
Utvärdering av jordtryck + överlast samt tilhörande farligaste brottvinkel redovisad i tabellform :

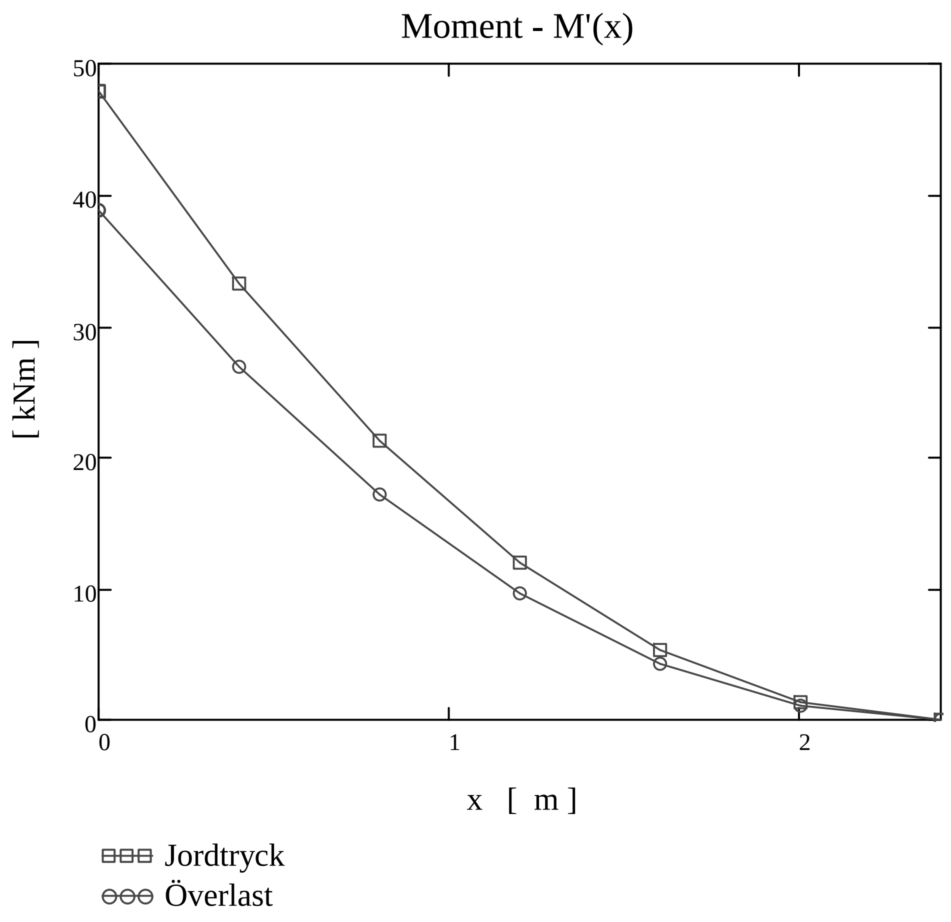
x	p_{jord}	α_{tillh}	$p_{över}$	α_{tillh}
0	16.6	66	13.9	66
0.000	16.6	66	13.9	66
0.001	16.6	66	13.9	66
0.001	16.6	66	13.9	66
0.40	16.6	66	13.8	66
0.80	16.6	66	13.7	66
1.20	16.6	66	13.6	66
1.60	16.6	66	13.5	66
2.00	16.6	66	13.4	66
2.40	16.6	66	13.3	66
m	kN/m	grader	kN/m	grader

Utvärdering av jordtryck + överlast i diagramform :

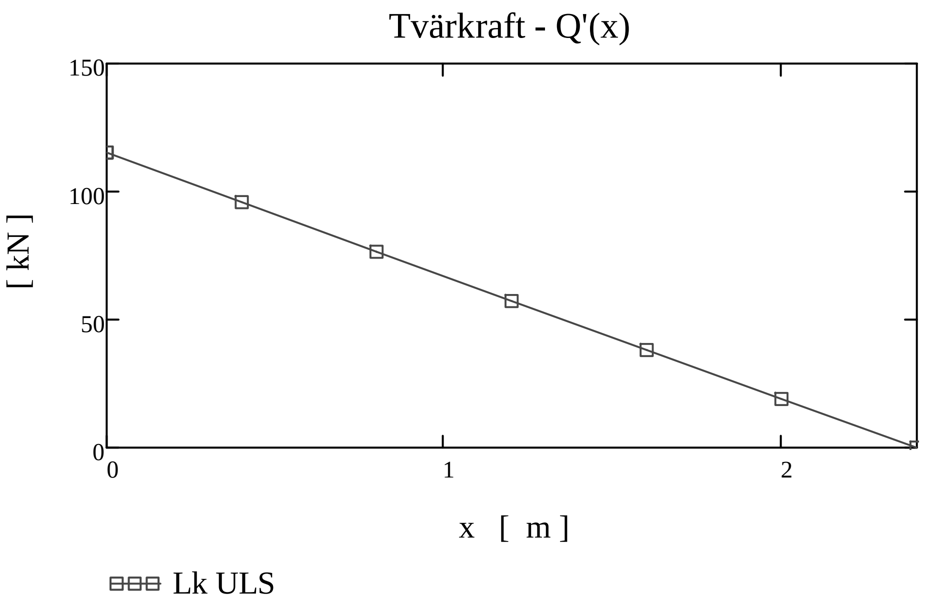


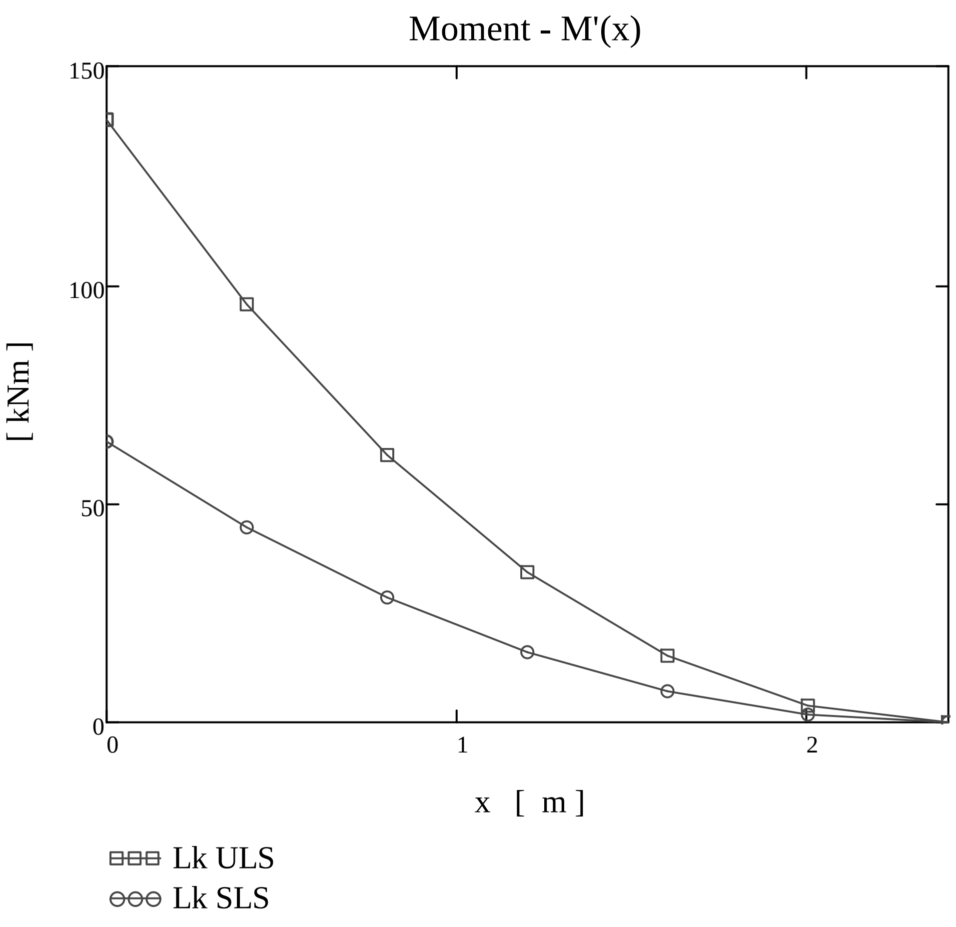
Uvärdering av snittkrafter tillhörande jordtryck + överlast i diagramform :



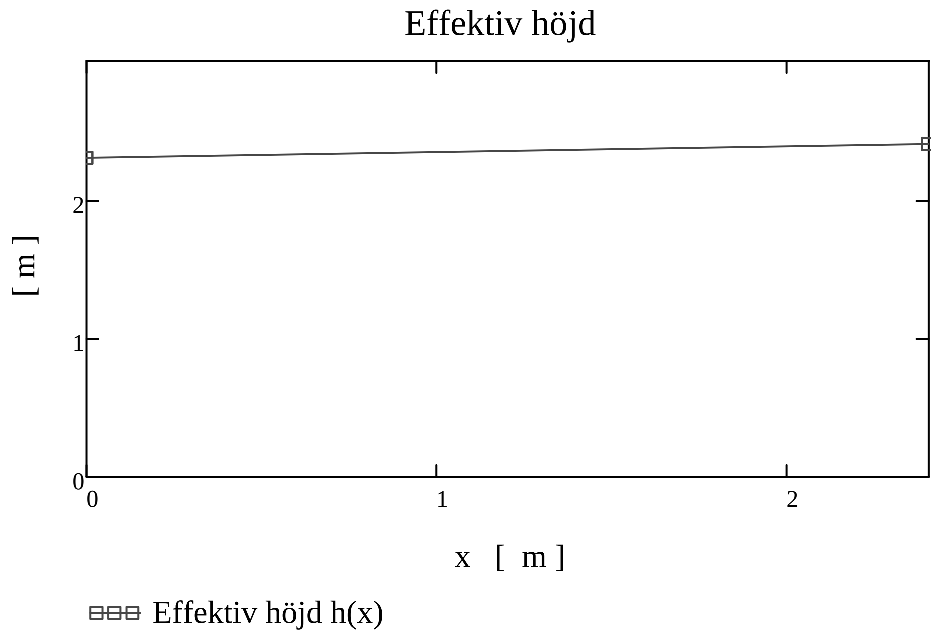


Uvärdering av dimensionerande snittkrafter för Lk ULS och Lk SLS i diagramform :





Uvärdering av effektivhöjd i diagramform :



Resultat

Dimensionerande snittkrafter i frontmur för inspänningssnitt

Effektiv höjd i inspänningssnitt : $H_{ef} = h_{ef}(0m)$ $H_{ef} = 2.3 \cdot m$

$N_{ULS.front}$	$M_{ULS.front}$	$N_{SLS.front}$	$M_{SLS.front}$
50	75	23	35
kN/m	kNm/m	kN/m	kNm/m

Dimensionerande snittkrafter i vingmur

x	$Q_{ULS.ving}$	$M_{ULS.ving}$	$M_{SLS.ving}$	t (x)
0	50	60	28	0.400
0.000	50	60	28	0.400
0.001	50	60	28	0.400
0.001	50	60	28	0.400
0.40	41	41	19	0.400
0.80	33	26	12	0.400
1.20	24	15	7	0.400
1.60	16	6	3	0.400
2.00	8	2	1	0.400
2.40	0	0	0	0.400
m	kN/m	kNm/m	kNm/m	m

Egenvikt vingmur

Egenvikt ger upphov till en triangulär linjelast med största intensiteten enligt nedan :

$V_{egen} = 58 \cdot kN$ $M_{egen} = 69 \cdot kNm$

$$x_{tp} = \frac{M_{egen}}{V_{egen}}$$ $x_{tp} = 1.2\,m$

Last vinkelrätt mot frontmur / ramben av egentyngd + jordtryck + överlast

Egenvikt ger upphov till en triangulär linjelast med största intensiteten enligt nedan :

$$p_{egen} = M_{egen} \cdot \frac{6}{H_{ef}^{2}} \cdot \sin(\omega) \qquad p_{egen} = 78 \cdot \frac{kN}{m}$$

Jordtryck + överlast ger upphov till en reaktangulär linjelast med intensiteten enligt nedan :

$$p_{jord} = -\frac{H'_{jord}(0m)}{H_{ef}} \cdot \cos(\omega) \qquad p_{jord} = 0 \cdot \frac{kN}{m}$$

$$p_{över} = -\frac{H'_{över}(0m)}{H_{ef}} \cdot \cos(\omega) \qquad p_{över} = 0 \cdot \frac{kN}{m}$$

3.3.4 Summary earth pressure: JORD

Combination of occurring load cases.

Basic loadcombination JORD :

Loadcase	Factor
JORD 1	1
JORD 2	1

3.4 SUPPORT SETTLEMENT

Load effect of support settlement shall be considered in TRVINFRA-00227 section 7.2.1.1.1.1.

Only horizontal support displacement in the longitudinal direction of the bridge needs to be considered. Additionally, it is stated that horizontal and vertical support displacements do not need to be combined.

A horizontal support displacement in the longitudinal direction of the bridge (x-direction) of ± 10 mm for each support is applied.

Vertical settlement difference (Z-direction) corresponding to support settlement of 15 mm is assumed to occur for all supports.

A verification will be performed to demonstrate that this is on the safe side.

When determining associated load effects, reduction is carried out with consideration to creep and cracking.

Note:
The impact of support settlement in serviceability limit state (SLS) according to SS-EN 1992-1-1 §2.3.1.3. If this occurs, a gradual crack development should be applied according to SS-EN 1992-1-1 §5.4(3). Reduction is carried out with consideration to creep and cracking.

The impact of support settlement is not considered in the ultimate limit state (ULS) according to SS-EN 1992-1-1 §2.3.1.3 for this type of bridge.

3.4.1 Vertical settlement

3.4.1.1 Support 1

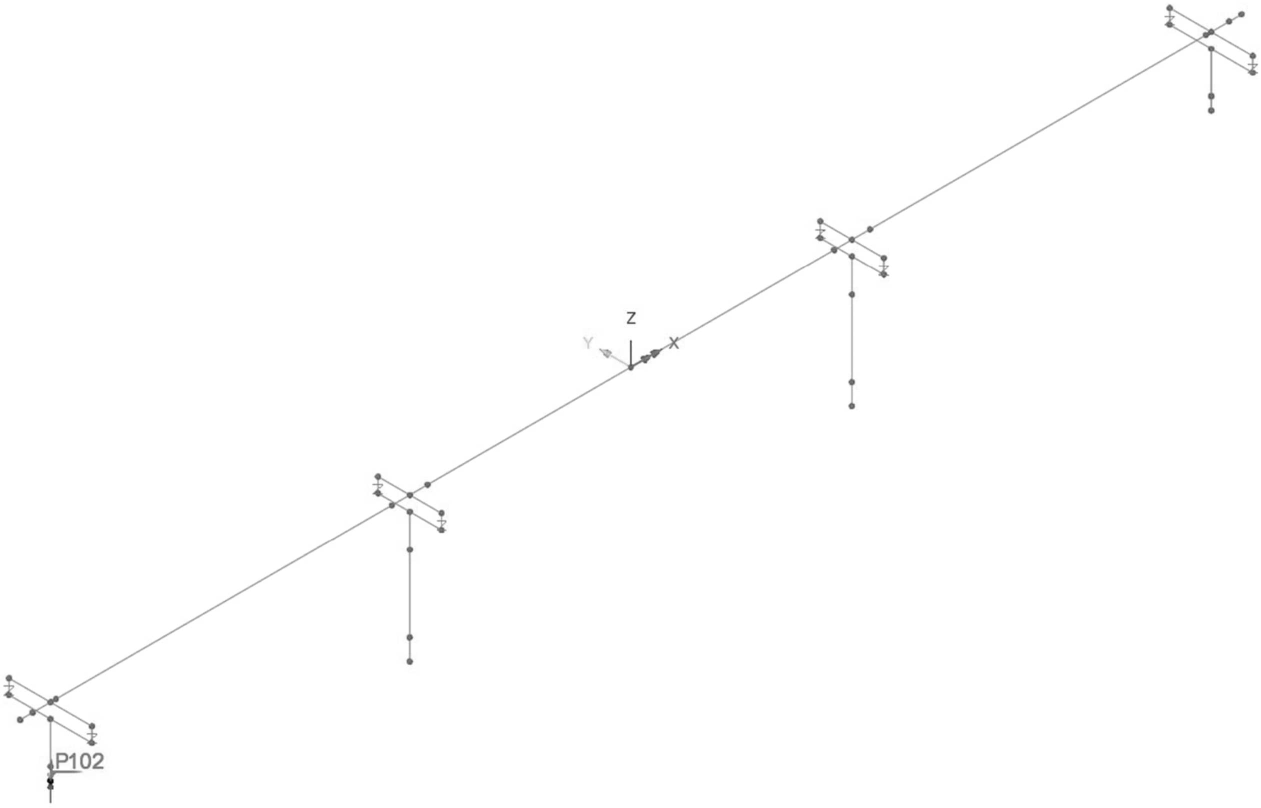
Load (loadcase) : STOD_1Z

Structural loading : Perscribed Displacement

Translation at point in Z direction : -0.015 m

Loadcase : STOD_1Z

Point : P102



Overview 3D

3.4.1.2 Support 2

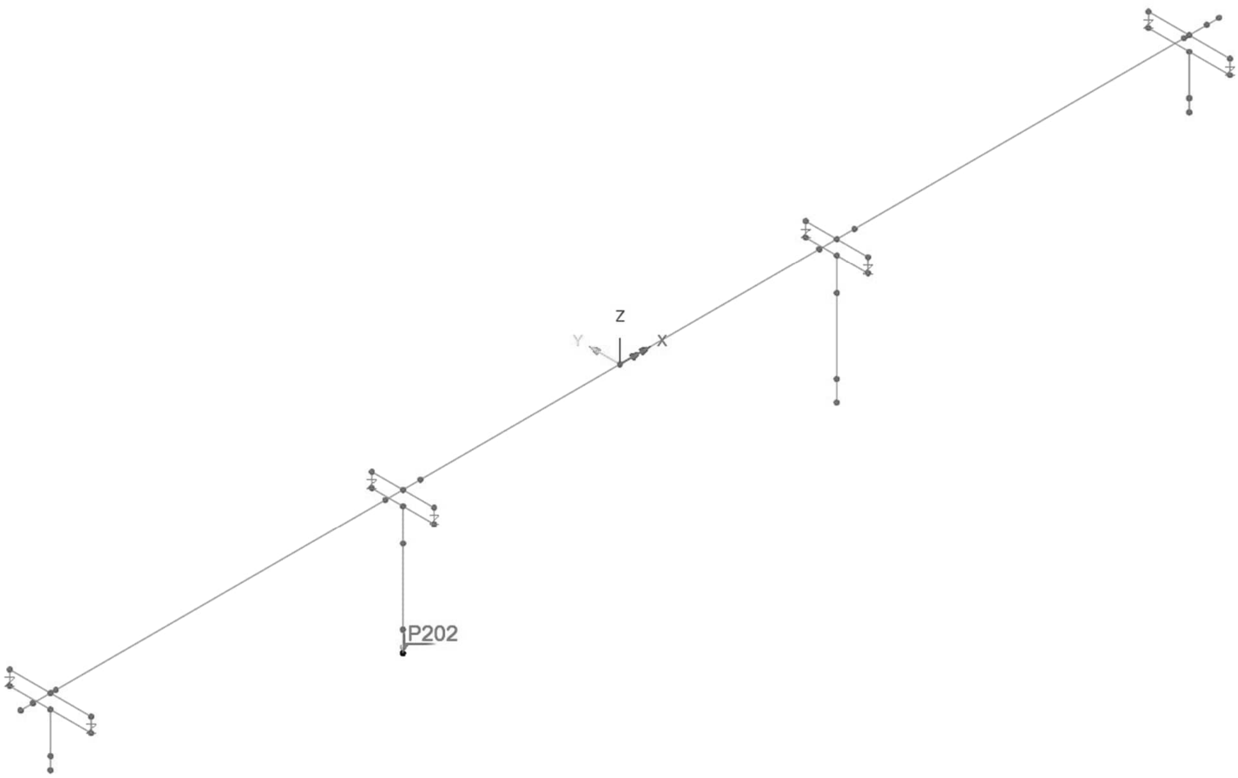
Load: STOD_2Z

Structural loading : Perscribed Displacement

Translation at point in Z direction : -0.015 m

Loadcase : STOD_2Z

Point : P202



Overview 3D

3.4.1.3 Support 3

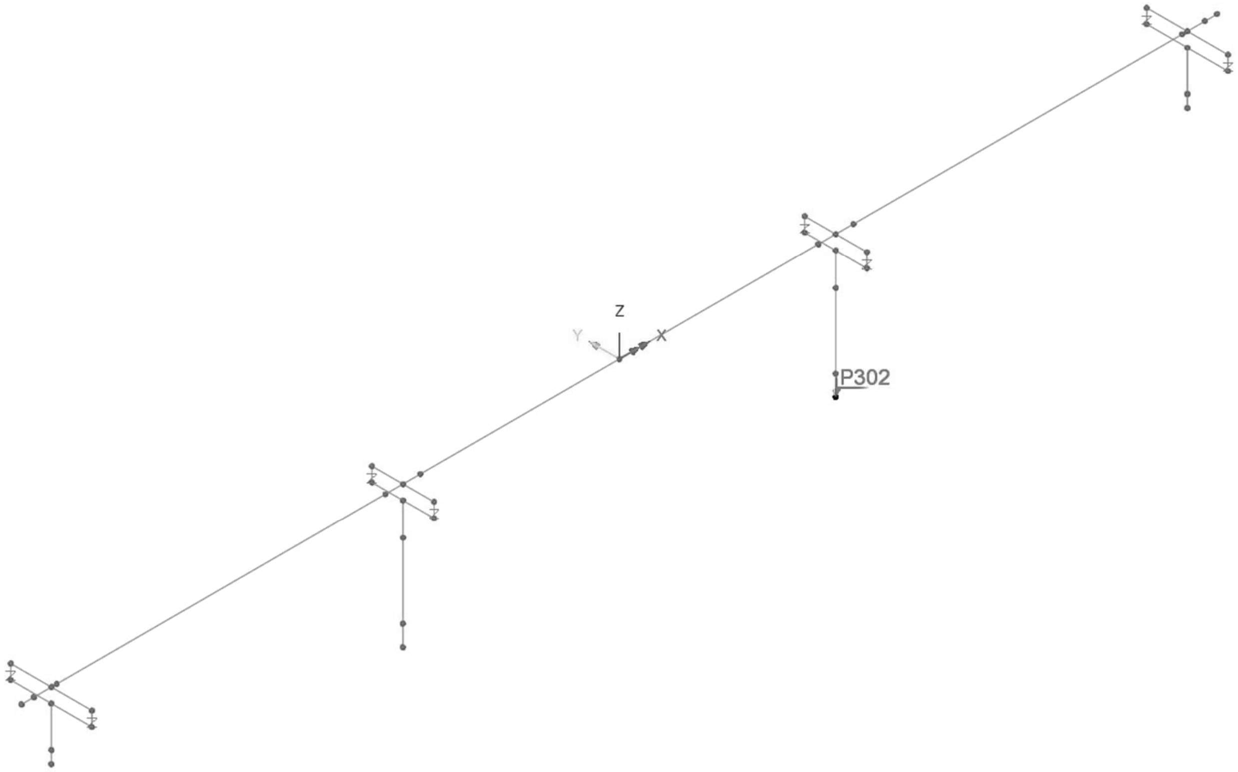
Load: STOD_3Z

Structural loading : Perscribed Displacement

Translation at point in Z direction : -0.015 m

Loadcase : STOD_2Z

Point : P302



Overview 3D

3.4.1.4 Support 4

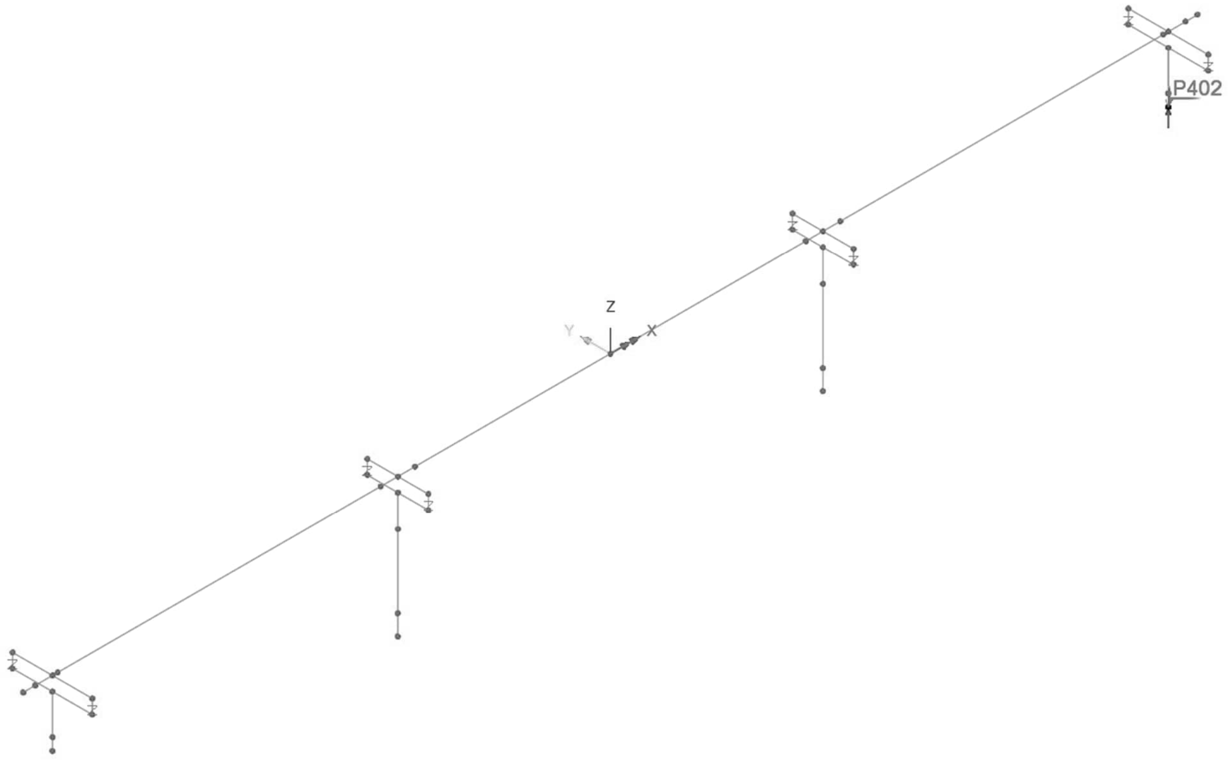
Load: STOD_4Z

Structural loading : Perscribed Displacement

Translation at point in Z direction : -0.015 m

Loadcase : STOD_2Z

Point : P402



Overview 3D

3.4.2 Horizontal settlement

3.4.2.1 Support 2

Load : STOD_2X

Structural loading : Prescribed Displacement

Translation at point in X direction : 0.010 m

Loadcase : STOD_1X+

Point : P202

3.4.2.2 Support 3

Load : STOD_3X

Structural loading : Prescribed Displacement

Translation at point in X direction : 0.010 m

Loadcase : STOD_2X+

Point : P302

3.4.3 Load combination settlement: STOD

Basic load cases :

Load case	Load	Factor
STOD_2X-	STOD_2X+	-1
STOD_3X-	STOD_3X+	-1

Envelope STOD-X :

Load case
STOD_2X+
STOD_2X+
STOD_3X-
STOD_3X-

Load combination smart *STOD-Z :*

Load case	Permanent factor	Variable factor
STOD_1Z	0	1
STOD_2Z	0	1
STOD_3Z	0	1
STOD_4Z	0	1

Envelope STOD :

Load case
STOD-X
STOD-Z

3.5 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.

$t_0 = 5\ days$

$t_1 = 120\ years$

Bridge consists of parts with different thicknesses as seen below.

Creep is determine using Mathcad program PROG A001.

Superstructure (b = 3.50 m; C35/45):
For t = 1.50 m → $\phi(t_1, t_0) = 1.90$: see page A3:46

Creep $\phi(t_1, t_0) = 1.9$ is used for the entire bridge on safe side since reduces stiffness and associated constraint forces (∴ support settlement, shrinkage and temperature).

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

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	1.9
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.

$$f_{KRYMP} = \frac{1}{1+\varphi_{ef}} = \frac{1}{1+1.90} = 0.34$$

$$f_{STÖD} = \frac{1}{1+\varphi_{ef}} = \frac{1}{1+1.90} = 0.34$$

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

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).

Objekt: Superstructure

Betong (C30/37, C35/45, C40/50 och C45/55): BTG = "C35/45"

Relativ fuktighet : $RH = 80\%$

Tvärsnittetsbredd : $b = \frac{3.0m + 4.0m}{2} = 3.5\,m$

Tvärsnittetshöjd : $h = 1.5m$

Tvärsnittsarea : $A_c = b \cdot h = 5.25 \cdot m^2$

Omkrets i kontakt med "luft" : $u = 2 \cdot b = 7\,m$

Bärverkets ekvivalenta tjocklek : $h_0 = \frac{2 \cdot A_c}{u} = 1.5\,m$

Studerad tidpunkt för bestämning av krypning : $t_1 = 120år$ $t_1 = 43800 \cdot dag$

Tidpunkt för pålastning (= formrivning): $t_0 = 5dag$

Indatakvitto

$f_{cm} = 43 \cdot MPa$

BERÄKNING

Uttryck för bestämning av kryptalet är hämtat från SS-EN 1992-1-1 Bilaga B.1.

$$\alpha_1 = \left(\frac{35MPa}{f_{cm}}\right)^{0.7} = 0.87$$

$$\alpha_2 = \left(\frac{35MPa}{f_{cm}}\right)^{0.2} = 0.96$$

$$\alpha_3 = \left(\frac{35MPa}{f_{cm}}\right)^{0.5} = 0.9$$

$$\varphi_{RH} = \begin{vmatrix} 1 + \dfrac{1 - RH}{0.1 \sqrt[3]{\dfrac{h_0}{mm}}} \quad \text{if } f_{cm} \le 35MPa \\ \left(1 + \dfrac{1 - RH}{0.1 \sqrt[3]{\dfrac{h_0}{mm}}} \cdot \alpha_1\right) \cdot \alpha_2 \quad \text{otherwise} \end{vmatrix} = 1.1$$

$$\beta_0 = \frac{1}{0.1 + t_0^{0.20}} = 0.68$$

$$\beta_{fcm} = \frac{16.8}{\sqrt{\dfrac{f_{cm}}{MPa}}} = 2.56$$

$$\beta_H = \begin{array}{|l} \text{if } f_{cm} \le 35\text{MPa} \\ \quad \begin{array}{|l} \beta_{H.max} \leftarrow 1500 \\ \beta_H \leftarrow \beta_{H.max} \;\; \text{if } 1.5\cdot\left[1 + (0.012\cdot 100RH)^{18}\right]\cdot\dfrac{h_0}{mm} + 250 > \beta_{H.max} \\ \beta_H \leftarrow 1.5\cdot\left[1 + (0.012\cdot 100RH)^{18}\right]\cdot\dfrac{h_0}{mm} + 250 \;\; \text{otherwise} \end{array} \\ \text{if } f_{cm} > 35\text{MPa} \\ \quad \begin{array}{|l} \beta_{H.max} \leftarrow 1500\cdot\alpha_3 \\ \beta_H \leftarrow \beta_{H.max} \;\; \text{if } 1.5\cdot\left[1 + (0.012\cdot 100RH)^{18}\right]\cdot\dfrac{h_0}{mm} + 250 > \beta_{H.max} \\ \beta_H \leftarrow 1.5\cdot\left[1 + (0.012\cdot 100RH)^{18}\right]\cdot\dfrac{h_0}{mm} + 250\cdot\alpha_3 \;\; \text{otherwise} \end{array} \\ \beta_H \end{array}$$

$$\beta_H = 1353$$

$$\beta_c = \left(\frac{t_1 - t_0}{\beta_H + t_1 - t_0}\right)^{0.3} = 0.99$$

$$\varphi_{t0} = \varphi_{RH}\cdot\beta_{fcm}\cdot\beta_0 = 1.91$$

$$\varphi_{t1} = \varphi_{t0}\cdot\beta_c = 1.90$$

3.6 SHRINKAGE

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.

$t_s = 0\ days$

$t_1 = 120\ years$

Shrinkage is determined using Mathcad program PROG A002 after time t_1.

Superstructure (b = 3.50 m; C35/45):
For t = 1.50 m → $\varepsilon_{cs}\ (t_1) = 0.023\%$: see page A3:49

Shrinkage $\varepsilon_{cs} = 0.025\%$ is applied to all construction parts for safety. The movement corresponds to that which occurs due to an imaginary temperature load ∴ T = -25°C.

Remark
Shrinkage must be considered for service state (SLS) see SS-EN 1992-1-1 §2.3.2.2(1).

Shrinkage does not have to be used for ultimate state (ULS) see SS-EN 1992-1-1 §2.3.2.2(2).

Objekt: Superstructure

Betong (C30/37, C35/45, C40/50 och C45/55): BTG = "C35/45"

Relativ fuktighet (se KBB avsnitt B.3.3.6): $RH = 80\%$

Tvärsnittetsbredd : $b = \frac{3.0m + 4.0m}{2} = 3.5\,m$

Tvärsnittetshöjd : $h = 1.5m$

Tvärsnittsarea : $A_c = b \cdot h = 5.25 \cdot m^2$

Omkrets i kontakt med "luft" : $u = 2 \cdot b = 7\,m$

Bärverkets ekvivalenta tjocklek : $h_0 = \frac{2 \cdot A_c}{u} = 1.5\,m$

Studerad tidpunkt för bestämning av krympning : $t_1 = 120år$ $t_1 = 43800 \cdot dag$

Tidpunkt för pålastning (= formrivning): $t_0 = 5dag$

Cementklass (S, N, R) : Klass = "N"

Betongens ålder då uttorkningskrympning påbörjas : $t_s = 0dag$

Indatakvitto

$f_{cm} = 43 \cdot MPa$ $f_{ck} = 35 \cdot MPa$ $f_{ck.kub} = 45 \cdot MPa$

BERÄKNING

Grundvärdet för krympning från uttorkning (SS-EN 1992-1-1 Bilaga B.2)

$$\alpha_{ds1} = \begin{cases} 3.0 & \text{if Klass = "S"} \\ 4.0 & \text{if Klass = "N"} \\ 6.0 & \text{if Klass = "R"} \end{cases} = 4.00$$

$$\alpha_{ds2} = \begin{cases} 0.13 & \text{if Klass = "S"} \\ 0.12 & \text{if Klass = "N"} \\ 0.11 & \text{if Klass = "R"} \end{cases} = 0.12$$

Thout

$$RH_o = 100 \cdot \%$$

$$\beta_{RH} = 1.55 \cdot \left[1 - \left(\frac{RH}{RH_o}\right)^3\right] = 0.76$$

$$\varepsilon_{cd.0} = 0.85 \left[(220 + 110 \cdot \alpha_{ds1}) \cdot e^{-\alpha_{ds2} \cdot \frac{f_{cm}}{f_{cmo}}}\right] \cdot 10^{-6} \cdot \beta_{RH} = 0.025 \cdot \%$$

Grundvärdet för krympning från uttorkning (SS-EN 1992-1-1 avsnitt 3.1.4 ekv. 3.9 och 3.10)

$$k_h = \text{linterp}\left[\left(0 \quad 100 \quad 200 \quad 300 \quad 500 \quad 10^4\right) mm^T, (1.00 \quad 1.00 \quad 0.85 \quad 0.75 \quad 0.70 \quad 0.70)^T, h_0\right] = 0.70$$

$$\beta_{ds} = \frac{t_1 - t_s}{t_1 - t_s + 0.04\sqrt{\left(\frac{h_0}{mm}\right)^3}} = 0.95$$

$$\varepsilon_{cd} = \beta_{ds} \cdot k_h \cdot \varepsilon_{cd.0} = 0.017 \cdot \%$$

Autogen krympning (SS-EN 1992-1-1 avsnitt 3.1.4 ekv. 3.11, 3.12 och 3.13)

$$k_h = \mathrm{linterp}\left[\left(0 \quad 100 \quad 200 \quad 300 \quad 500 \quad 10^4\right)\mathrm{mm}^T, \left(1.00 \quad 1.00 \quad 0.85 \quad 0.75 \quad 0.70 \quad 0.70\right)^T, h_0\right] = 0.70$$

$$\beta_{as} = 1 - e^{-0.2\cdot\sqrt{t_1}} = 1.00$$

$$\varepsilon_{ca.\propto} = 2.5\cdot\left(\frac{f_{ck}}{MPa} - 10\right)\cdot 10^{-6} = 0.006\cdot\%$$

$$\varepsilon_{ca} = \beta_{as}\cdot\varepsilon_{ca.\propto} = 0.006\cdot\%$$

Total krympning (SS-EN 1992-1-1 avsnitt 3.1.4 ekv. 3.8)

$$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 0.023\cdot\%$$

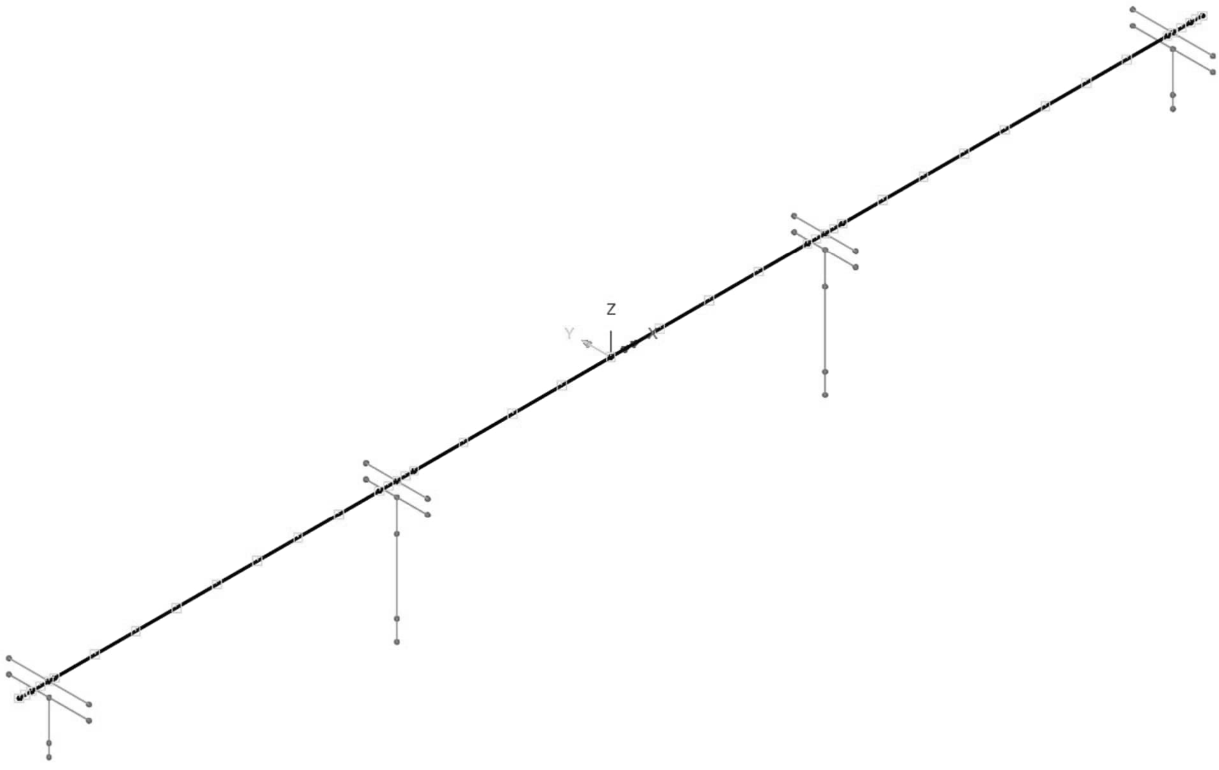
Loadcase : KRYMP

Structural loading : Temperature

Definition : Element

Initial temperature : 0 °C

Final temperature : -25 °C



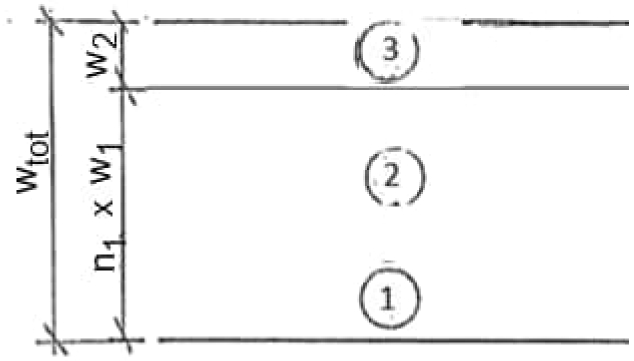
Overview 3D

3.7 TRAFFIC

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

Evaluation will also be performed EG A/B = 180kN/300 kN according to TRVFS 2011:12 chapter 6 point 3§.

3.7.1 Traffic lane division



Total traffic width : $w_{tot} = 8.0\,m$

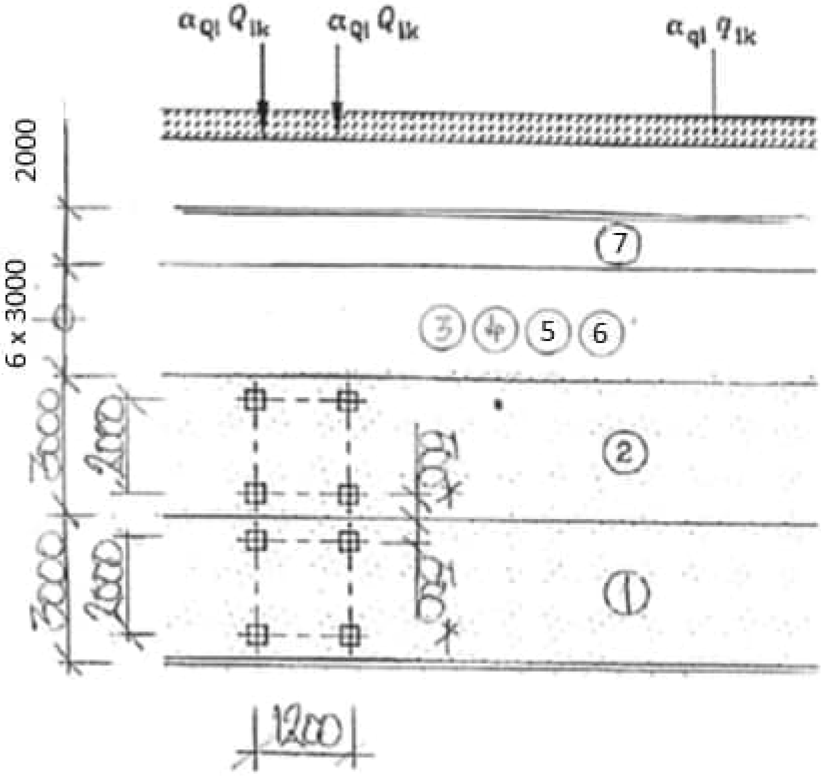
Number of traffic lanes : $n_1 = Integer\left[\frac{w_{tot}}{3.0m}\right] = 2\ lanes$

Full traffic width : $w_1 = 3.0m$

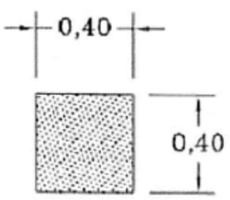
Remaining width : $w_2 = 2.0m$

3.7.2 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.



Axellaster :

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
3-6	100	0	0	No load
-	kN	-	kN	-

Utbredda laster :

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

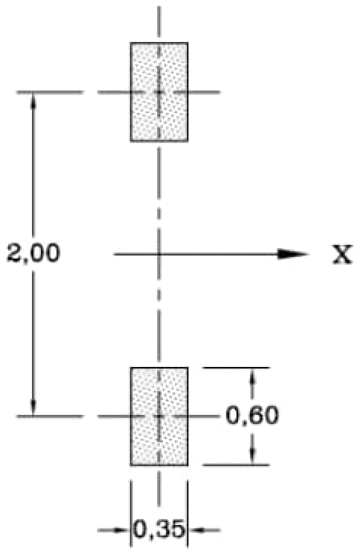
Traffic lande	q_k	α_q	q'_k
1	9.0	0.8	7.2
2-7	2.5	1.0	2.5
-	kPa	-	kPa

Remark

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

3.7.3 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

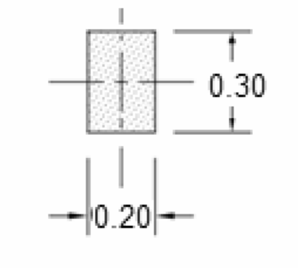
TSFS Chapter 11 Section 4 states that the same contact surface as LM 1 may be used.

3.7.4 Load model EG A/B

Calculation is performed using traffic load EG A/B = 180 kN/300 kN excluding dynamic factor.

Traffic load EG A/B are applied to two traffic lanes. Traffic on first lane is multiplied by 1.00 while second lane is multiplied 0.80.

The center distance between the wheel pressures is 2.0 meters according to TSFS chapter 11 §2.



Wheel pressure

$\varepsilon_{dyn} = 25$ % : dynamic factor [1.)]

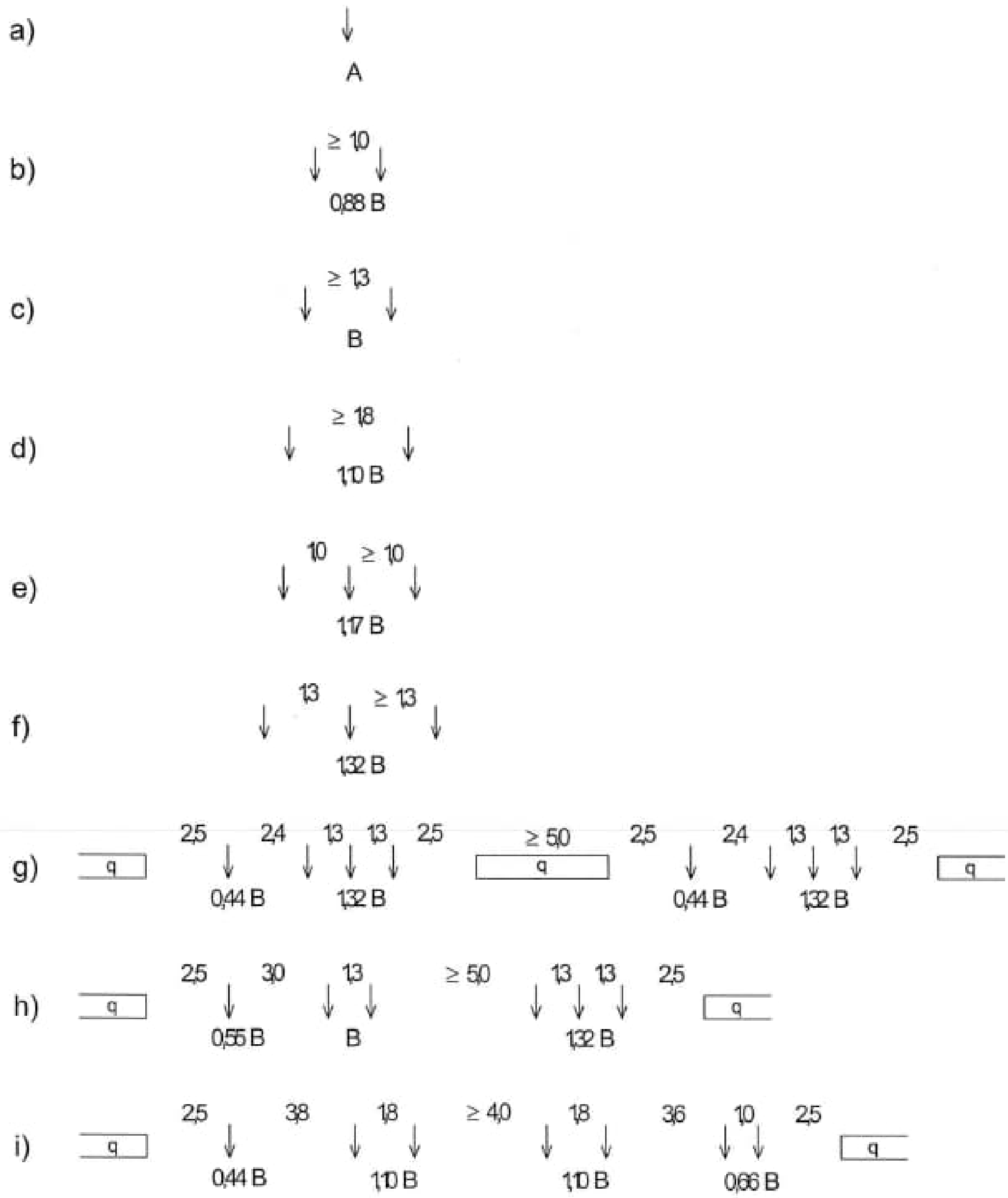
$A' = A \cdot (1 + \varepsilon_{dyn}) = 180$ kN$\cdot(1+0.25) = 225$ kN : single load including dynamic factor

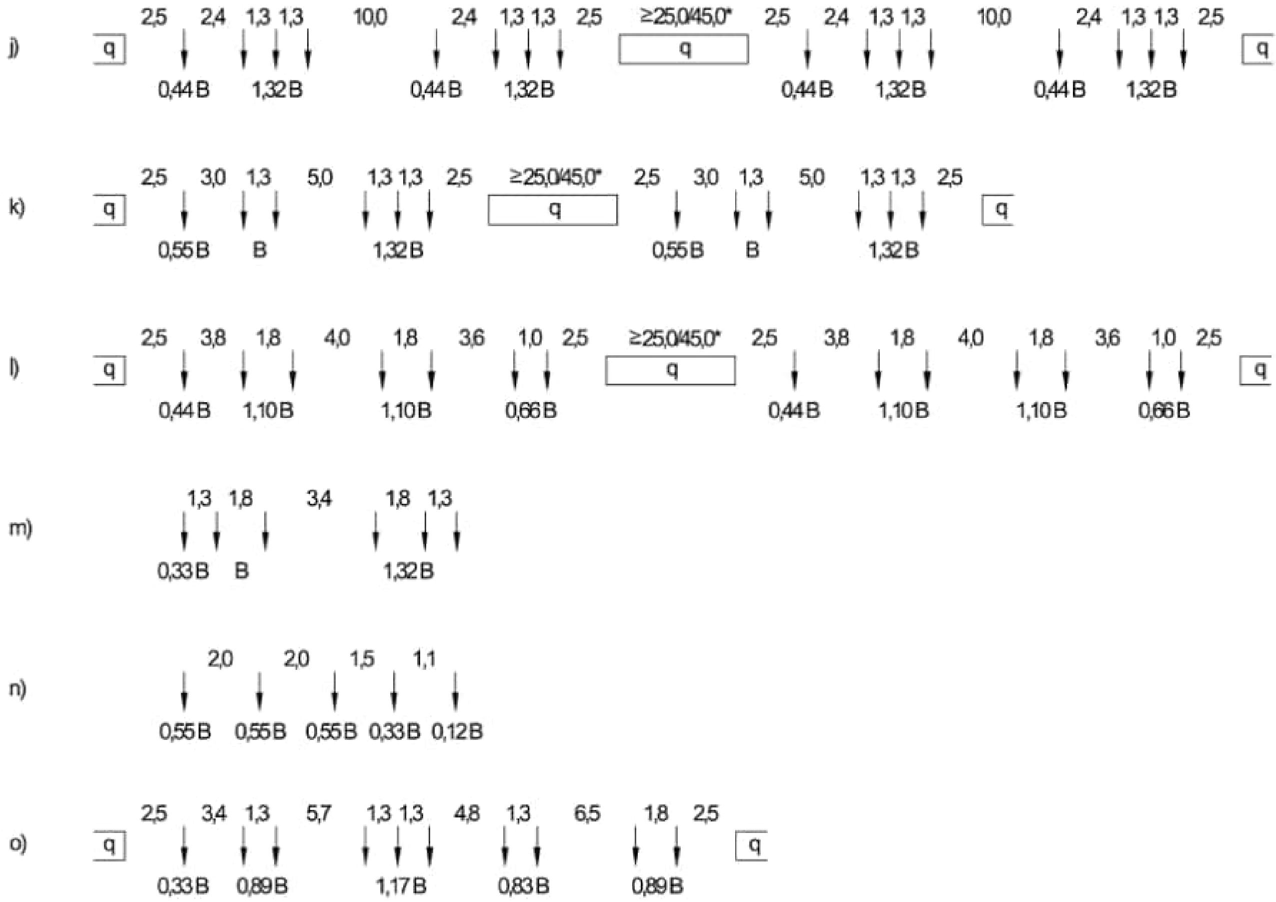
$B' = B \cdot (1 + \varepsilon_{dyn}) = 300$ kN$\cdot(1+0.25) = 375$ kN : tandem load including dynamic factor

$p = 5\frac{kN}{m}$: surface load

Footnote:
1.) TRVINFRA-00227 table 7.1-5 section 4.2.1(1) states apply 25 % ..

Graphic presentation of common vehicle types:
(Vehicle types according to TRVINFRA-00331 Appendix 1)





Note:

Evaluation is carried out with the script Vehicle Load Optimization (VLO), see sections 3.5.3 and 3.5.4.

Since there is no motorway, * = 45 m is applied according to TRVINFRA-00331 section 8.3.2.2.1 for vehicle types j, k, and l.

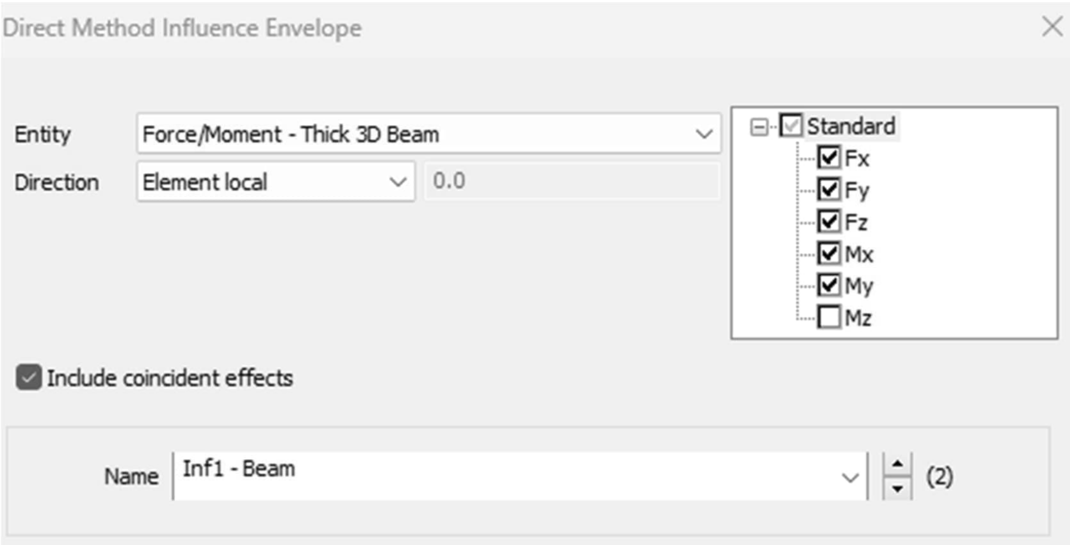
3.7.5 Vehicle Load Optimization (VLO)

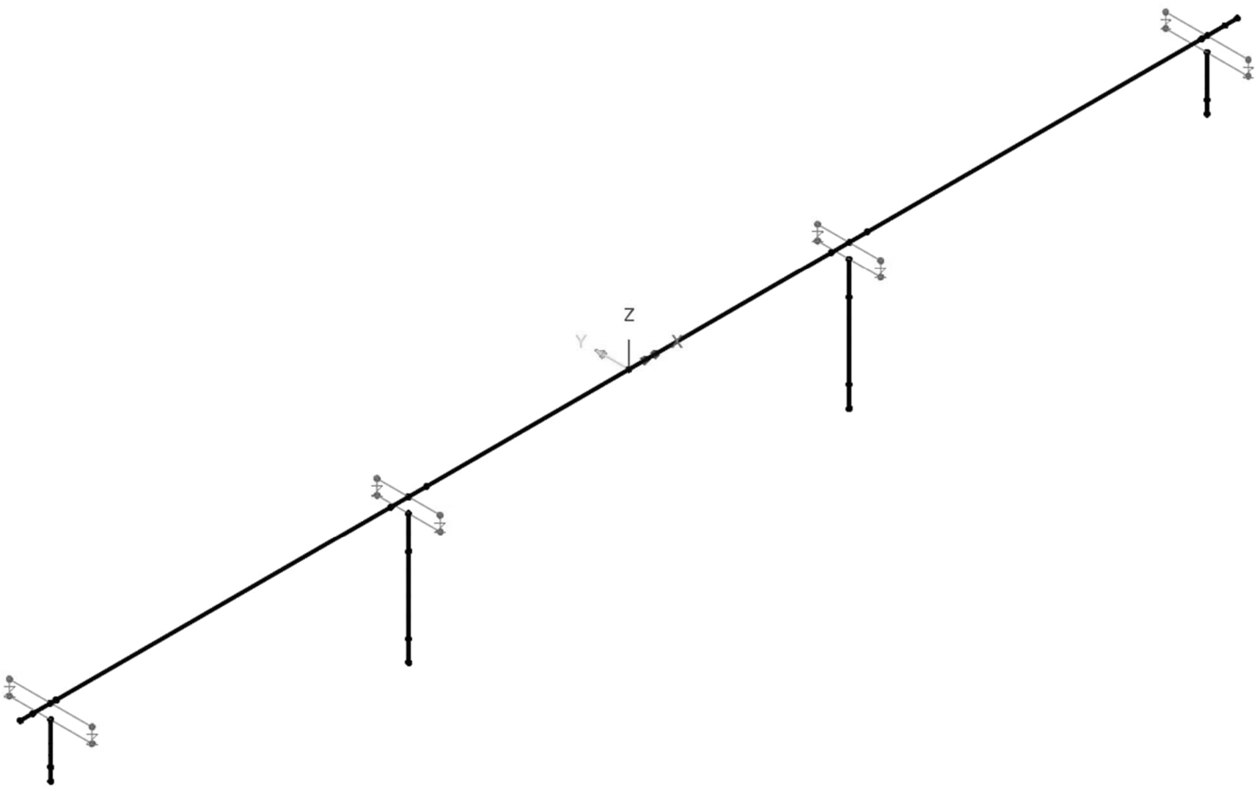
3.7.5.1 Influence components

Influence surfaces are created using *Method Influence Envelope* or *Method direct Influence* for indicated components.

Influence	Components	Entity	Method
Inf1 - Beam	Fx, Fy, Fz, Mx, My	Forces 3D-beam	*Influence Envelope*
Inf2 - Reaction	FX, FY, FZ, MX, MY	Reaction	*Influence Envelope*
Inf3 - Bearing	Fx	3D Joint	*Direct Influence*
Inf4 - Bearing	Fy	3D Joint	*Direct Influence*
Inf5 - Bearing	Fz	3D Joint	*Direct Influence*

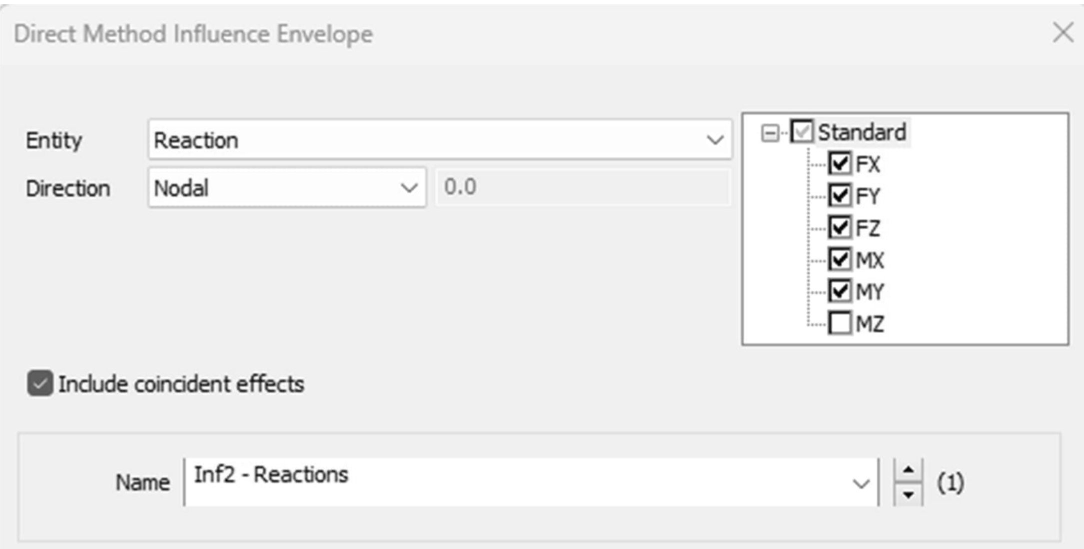
Inf1 – Beam :

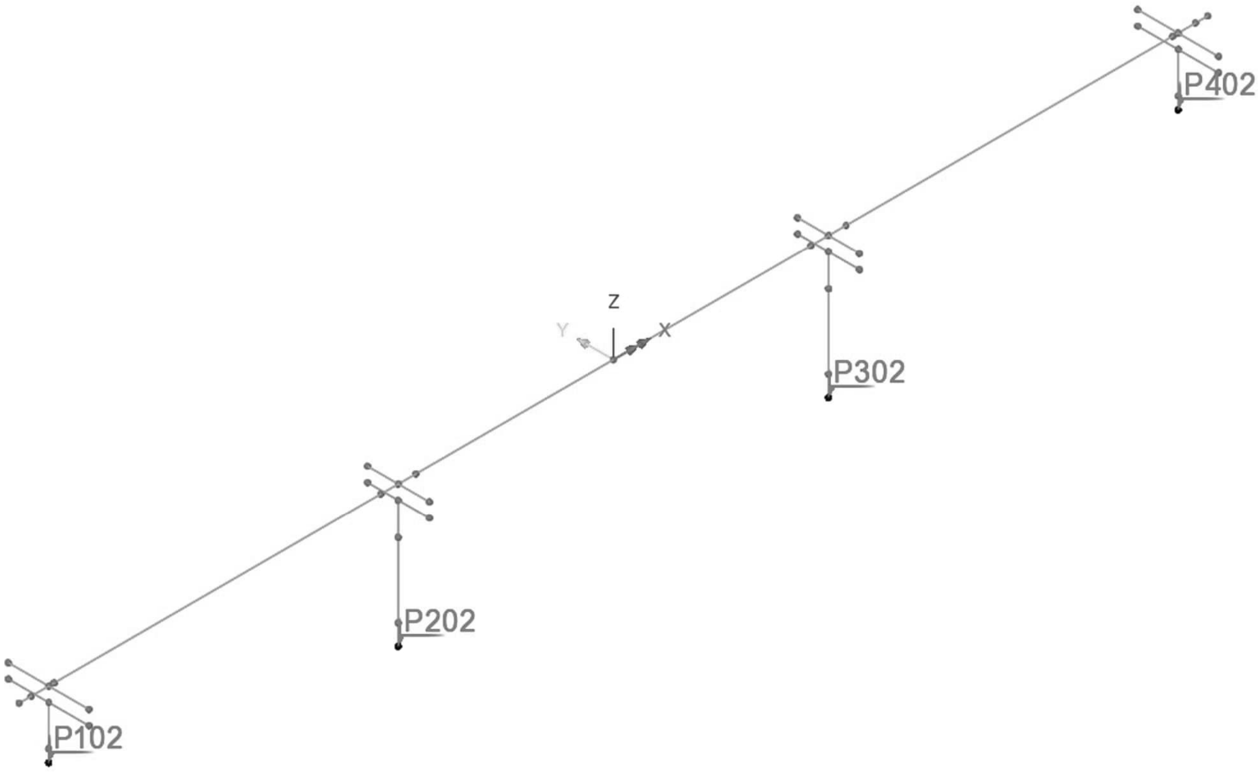




Overview 3D

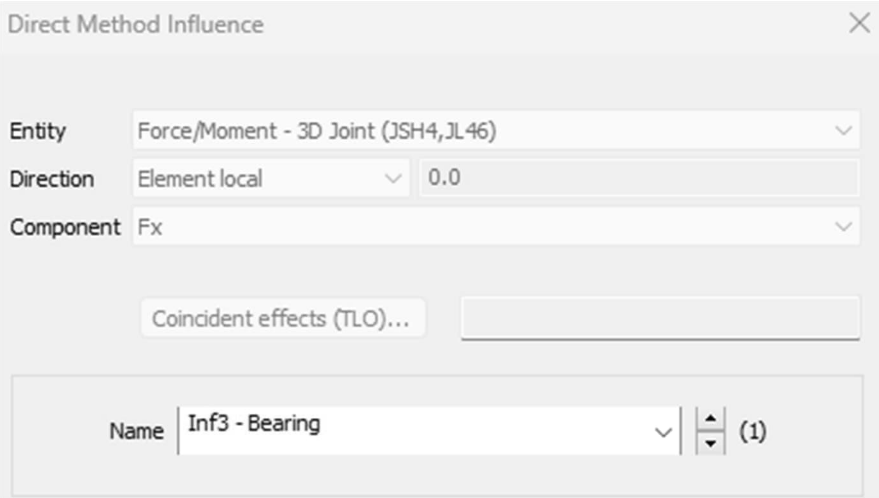
Inf2 – Reactions :

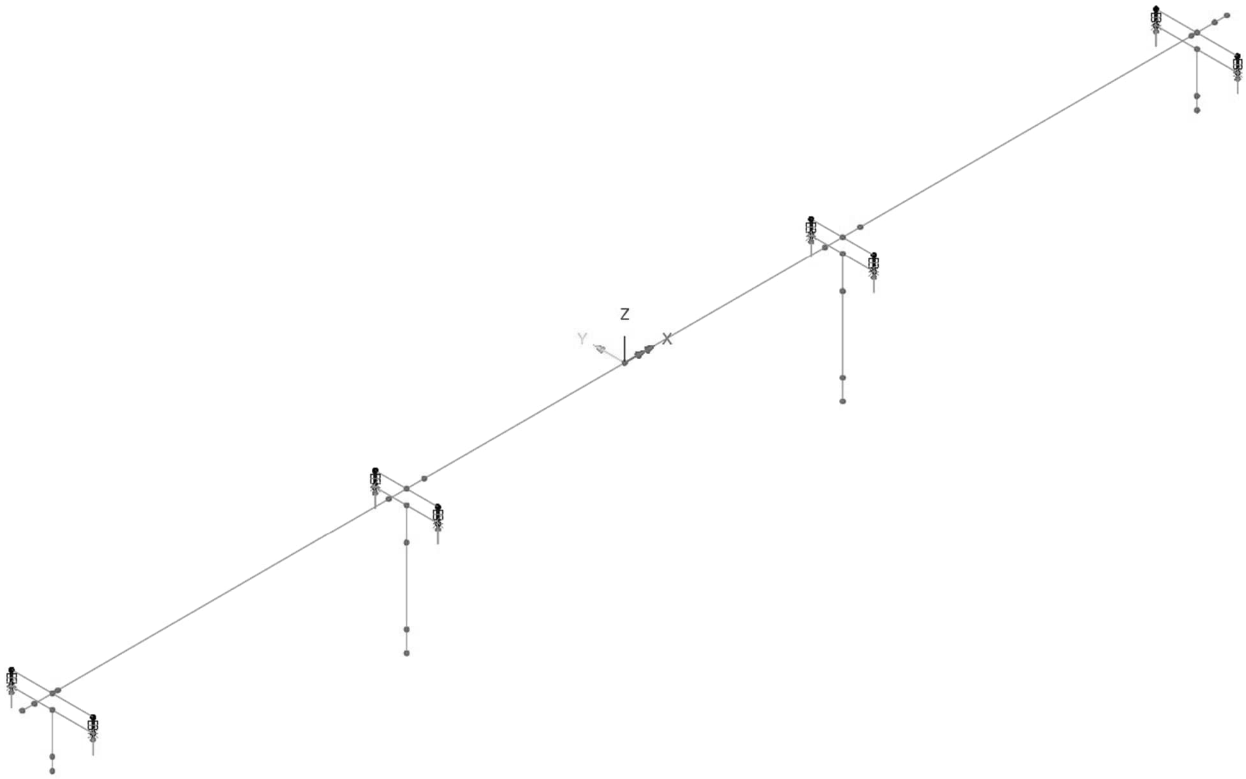




Overview 3D

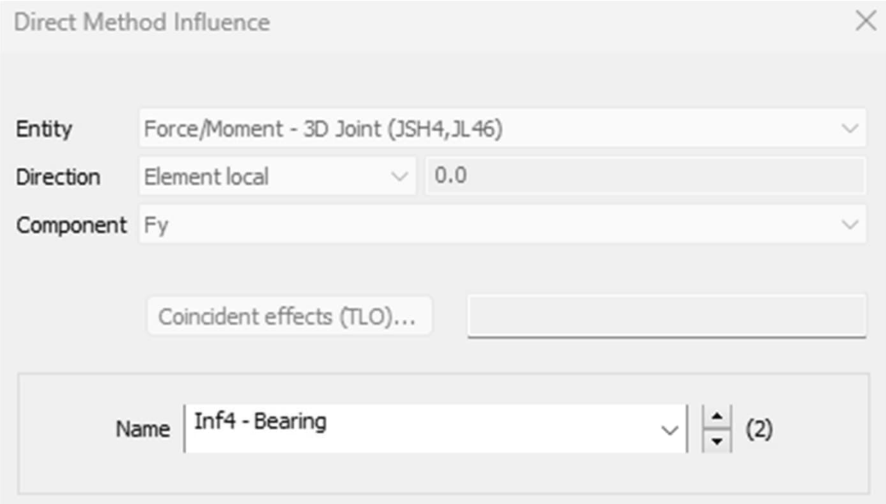
Inf3 – Bearing (Fx):

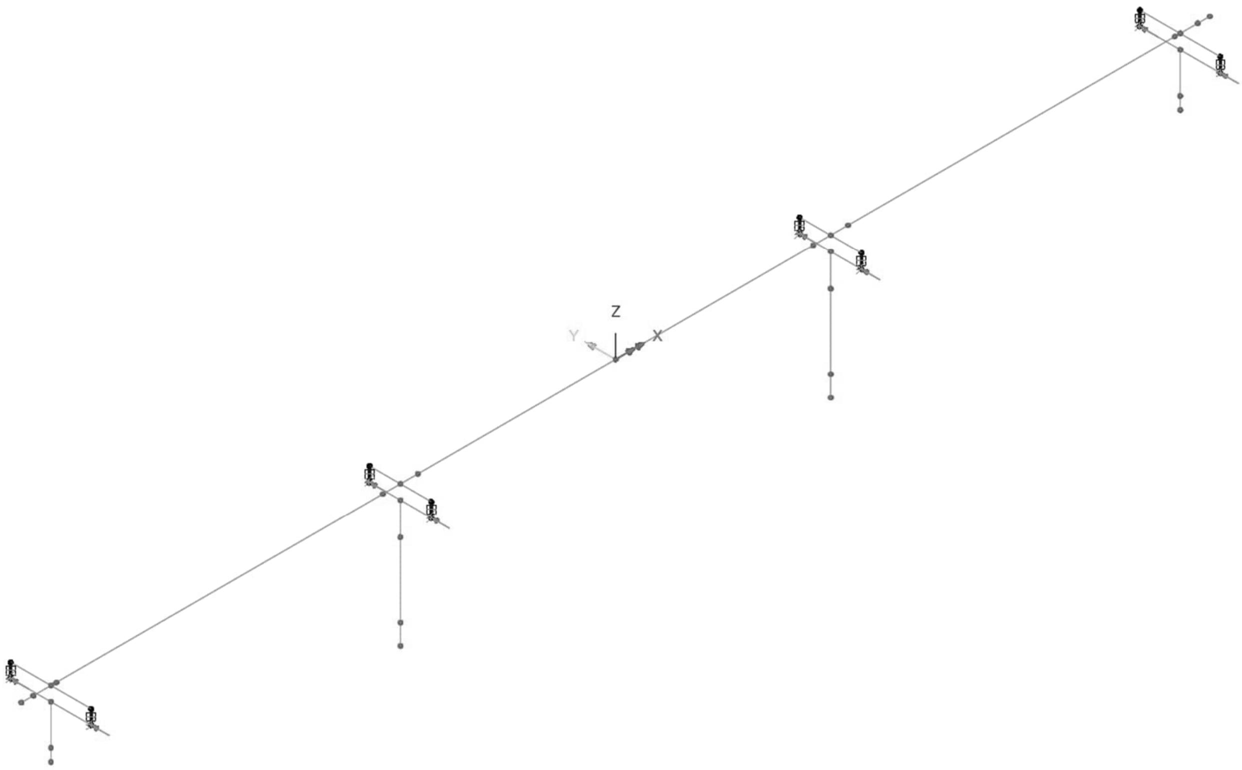




Overview 3D

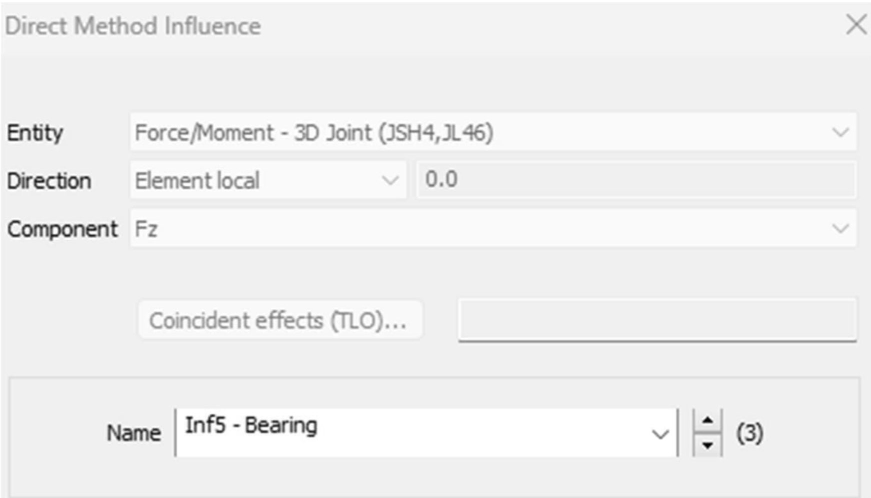
Inf4 – Bearing (Fy) :

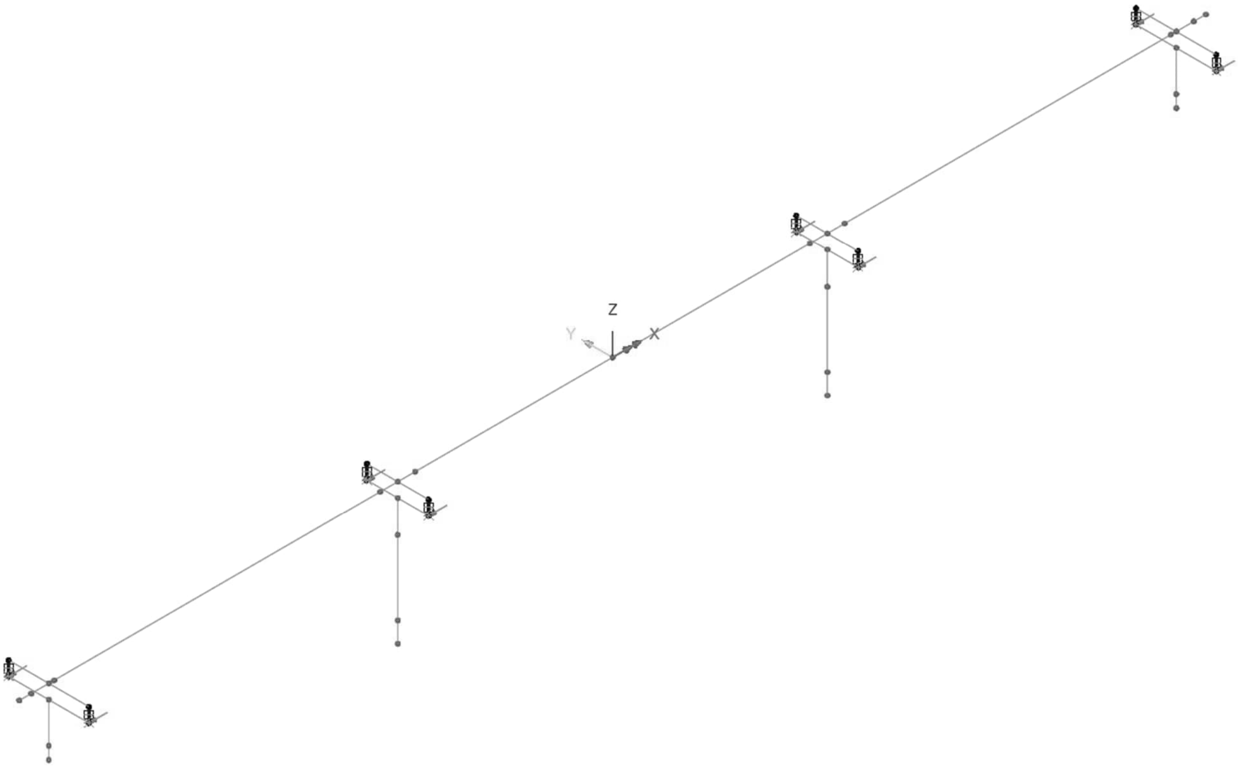




Overview 3D

Inf5 – Bearing (Fz) :





Overview 3D

3.7.5.2 Influence surface analysis

Influence surfaces :

Search area: Superstructure

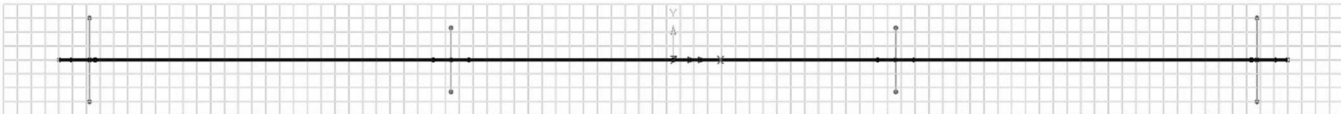
Definition type: Grid

Path: Centerline X

Transverse width: 8.0 m

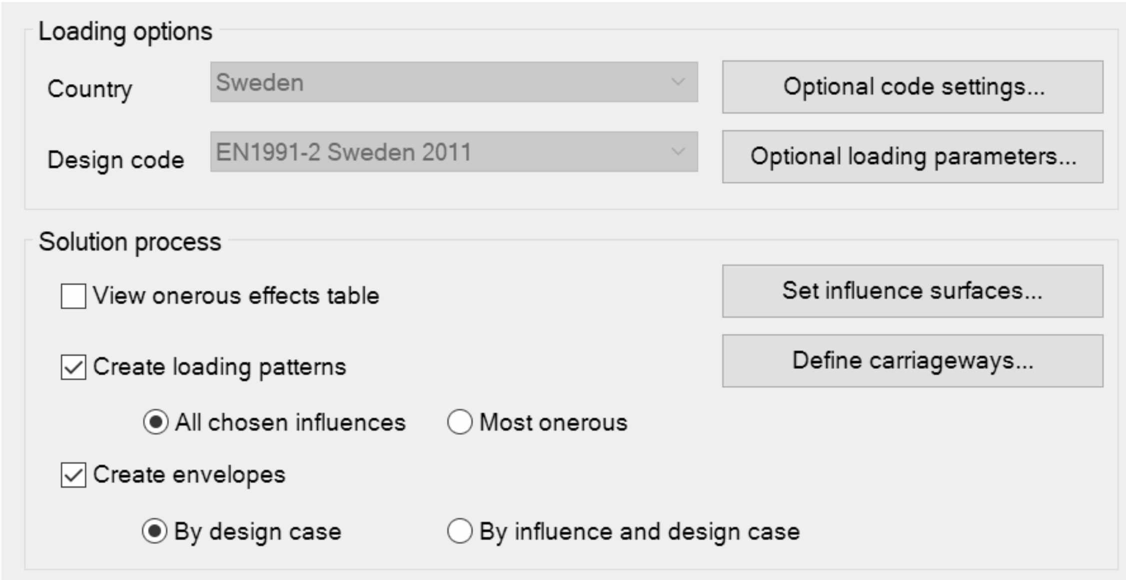
Longitudinal spacing: 1.0 m

Transversal spacing: 1.0 m



PLAN

3.7.5.3 Traffic load analysis (VLO)



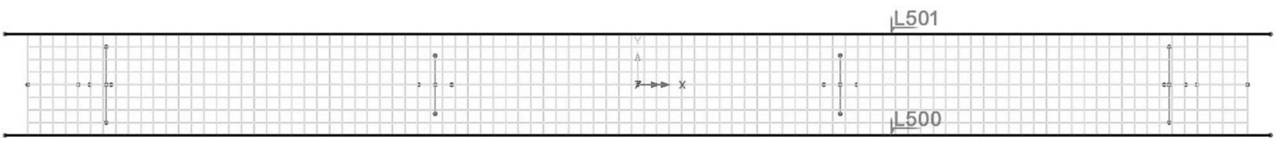
Vehicle longitudinal incremental movement: 0.25 m

Vehicle transverse incremental movement: 0.25 m

Vehicle direction: both

Definition of carriageway (kerbs): L500 & L501

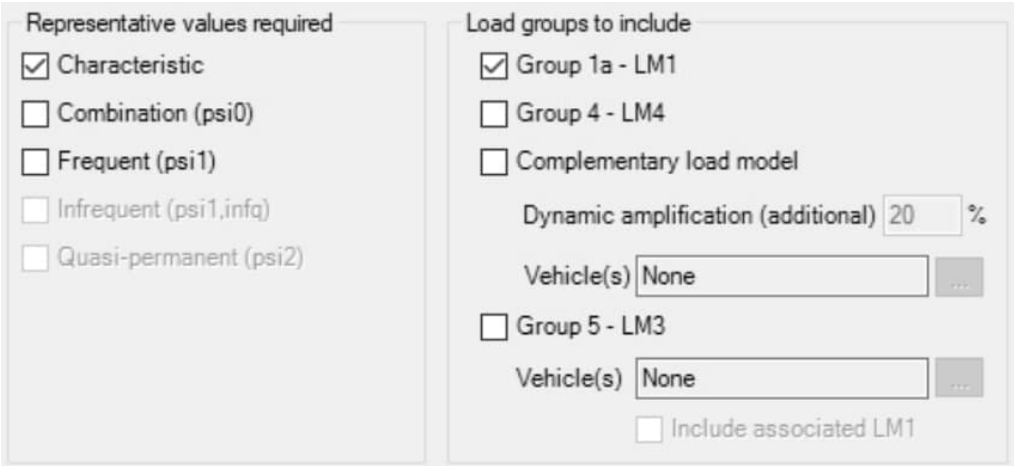
Influence surfaces: Include all (positive & negative)



PLAN

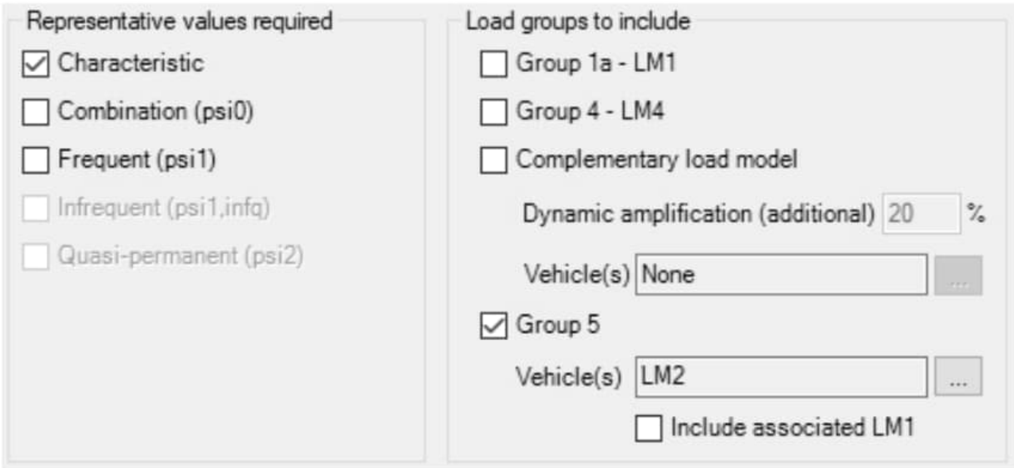
3.7.5.4 Envelope : LM 1

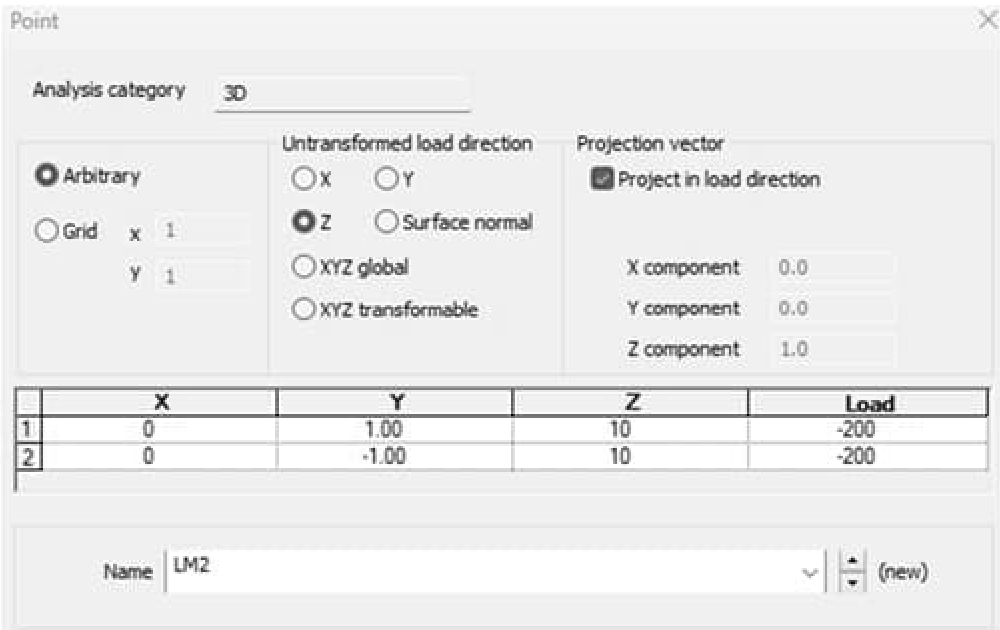
Load model 1 (LM1) defined in SS-EN 1991-2 section 4.3.2.



3.7.5.5 Envelope : LM 2

Load model 2 (LM2) defined in SS-EN 1991-2 section 4.3.3. The load is defined in Group 5 vehicle) since Group 1b is not defined in present version of software.

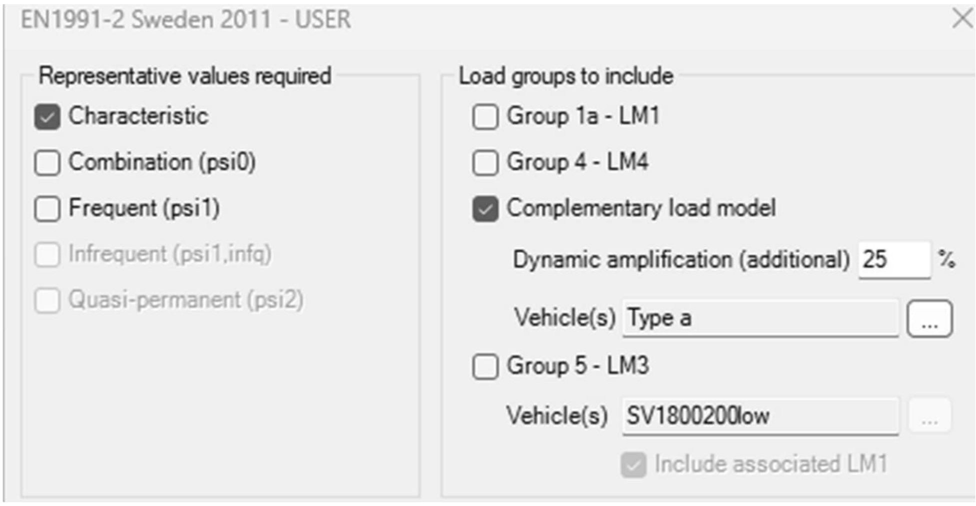




Remark
Load above (LM2) is defined as special vehicle in file C:\Users\senair\AppData\Local\LUSAS220\VLO\config\Eurocode\recValues\LM3.xml" as load SVLM2.

3.7.5.6 Envelope : EG A

EG A is defined as complementary load model with options seen below.

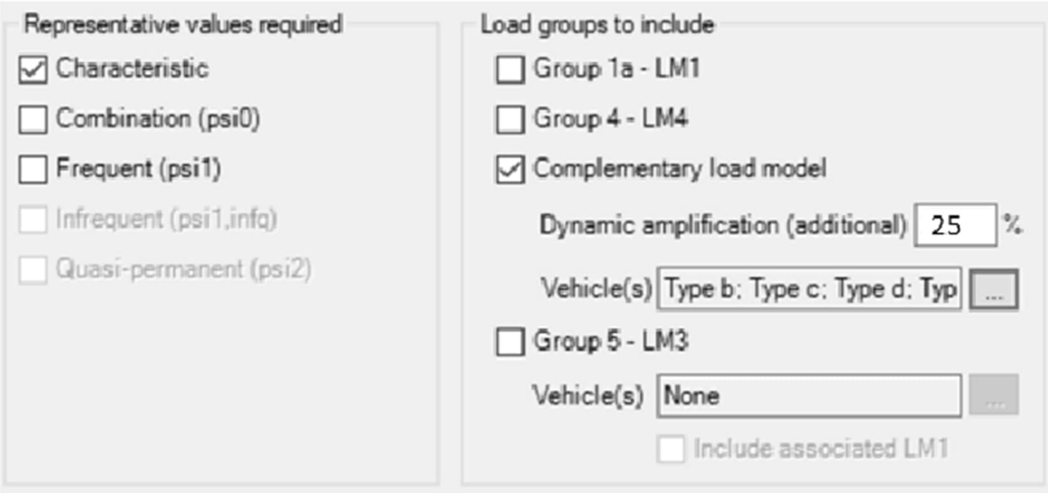


Dynamic amplification (additional): 25 %

Vehicle selection: Type a

3.7.5.7 Envelope : EG B

EG B is defined as complementary load model with options seen below.



Dynamic amplification (additional): 25 %

Vehicle selection: Type b → o

3.7.5.8 Combined traffic load (TRAFIK)

There are a total 4 different traffic loads termed LM 1, LM2, EG A and EG B.

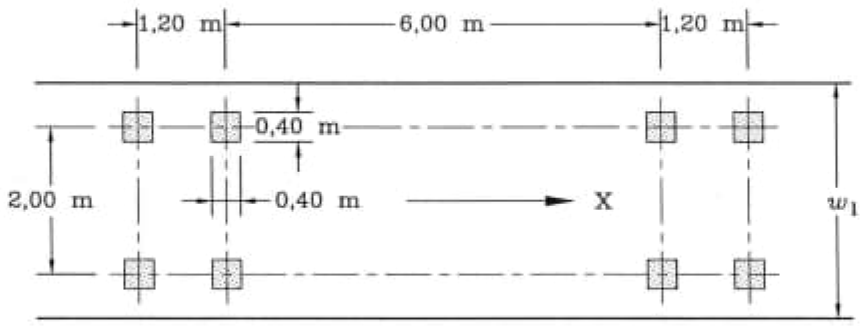
The envelope is used to identify the most onerous load effect.

Envelope TRAFIK :

Envelope
LM 1
LM 2
EG A
EG B

3.7.5.9 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.

Traffic data according to document 1C070001 section B1:

· Reference speed: 80 km/h

· Annual average heavy traffic (120 years): 283 vehicles/day → N_{obs} = 103 300 vehicles/year.

Traffic category:
TRVINFRA-0027 table 7.1-5(h) gives traffic category 3

Reference values for the number of heavy vehicles:
According to SS-EN 1991-2 section 4.6.1 table 4.5(n), Category 3 is obtained

→ N_o
Trafikuppgifter enligt teknisk beskrivning Oxberg (15822-00-1010):
Medel ÅDT tung (120 år) = 283 fordon/dygn → N_{obs} = 103 300 fordon/år.

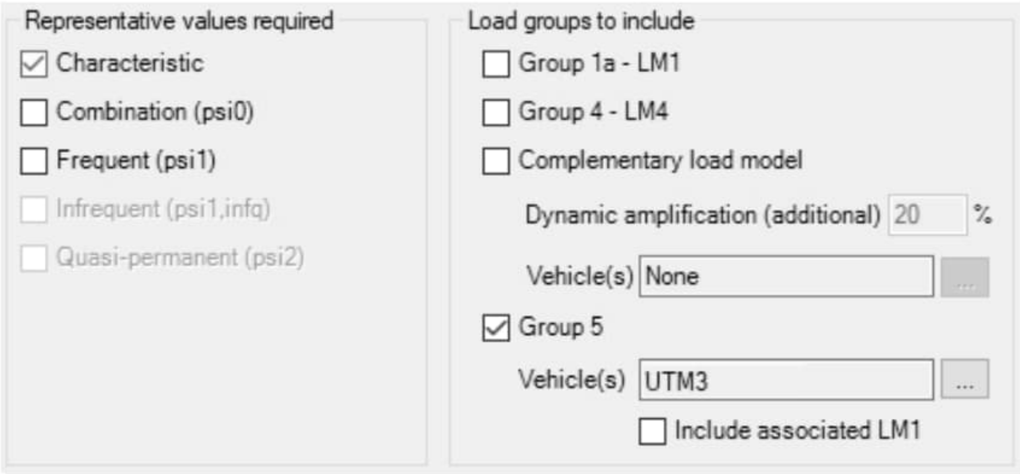
TRVINFRA-0027 tabell 7.1-5 (h) ger trafikkategori 4.

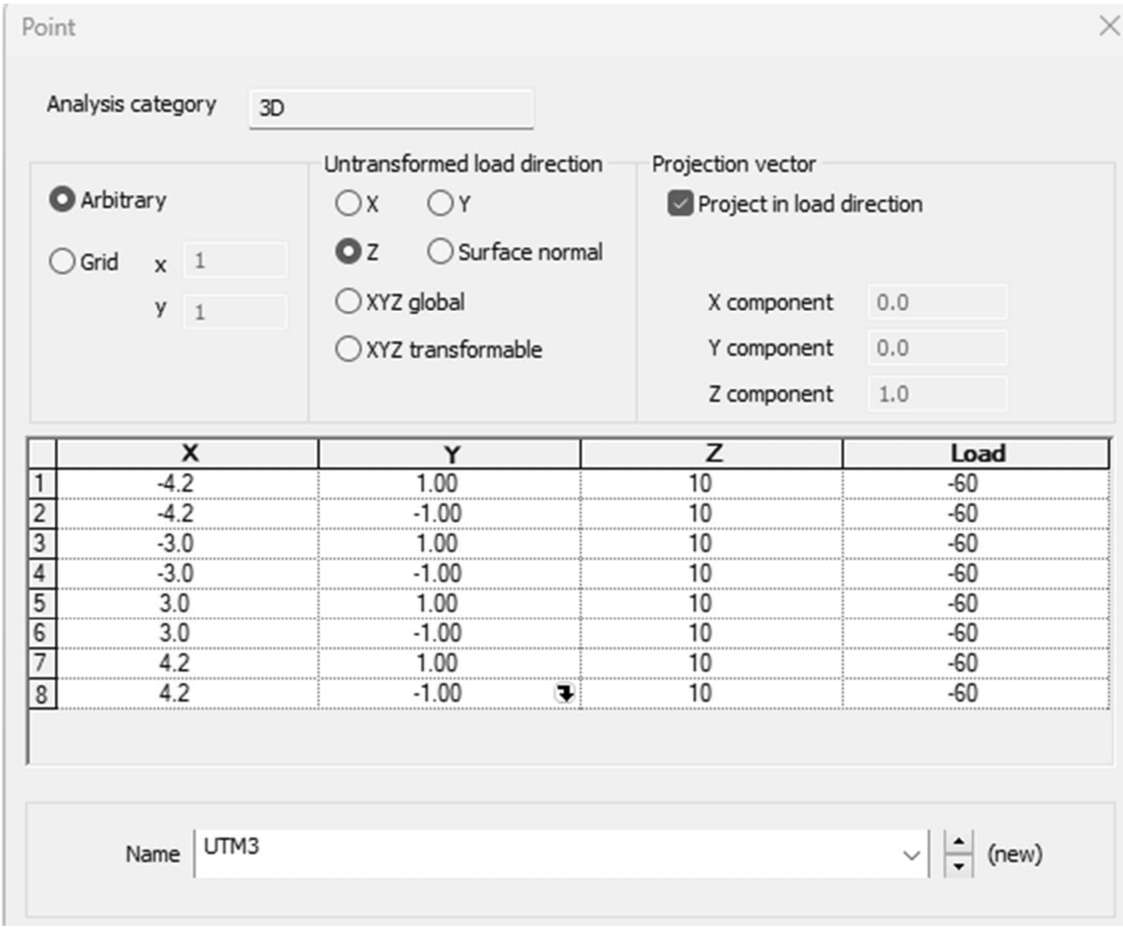
Riktvärden för antalet tunga fordon:
Enligt SS-EN 1991-2 avsnitt 4.6.1 tabell 4.5(n) erhålles för N_{obs} = 125 000 fordon/år för trafikkategori 3.

Anm.
På säker sida tillämpas N_{obs} = 125 000 fordon/år vid dimensionering.

$_{bs}$ = 125,000 vehicles/year

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





	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

Remark
Load above (UTM3) s defined as special vehicle in file C:\Users\senair\AppData\Local\LUSAS220\VLO\config\Eurocode\recValues\LM3.xml" as load SVUTM3.

3.8 BRAKING LOAD

Braking load is defined by SS-EN 1991-2 §4.4.1.

Load acts at level of surfacing.

L = 2.2 m + 26.0 m + 32.0 m + 26.0 m + 2.2 m = 88.4 m

Loade model LM 1 :

$$Q_{lk} = 0.6\alpha_{Q1} \cdot (2Q_{ik}) + 0.1\alpha_{q1} \cdot q_{1k} \cdot w_1 \cdot L$$

$$180kN \cdot \alpha_{Q1} \leq Q_{lk} \leq 900kN$$

$$Q_{broms} = 0.6 \cdot (2 \cdot 270kN) + 0.1 \cdot 7.2kPa \cdot 3.0m \cdot 88.4m = 324kN + 191kN = 515kN$$

Lastmodell EG B = 300 kN (see TSFS chapter 11 §2) :

Typ o is dimensioning → L_{broms} = 32.4 m (for axle loads)

$$Q_{lk} = 0.35 \cdot \sum Q_{EG\ B} + 0.1 \cdot p \cdot L_q$$

$$Q_{lk} \leq 500kN$$

$$Q_{broms} = 0.35 \cdot (0.33 + 0.89 + 1.17 + 0.83 + 0.89) \cdot B + 0.1 \cdot 5\frac{kN}{m} \cdot (88.4m - 32.4m) =$$
$$= 0.35 \cdot 4.11 \cdot 300kN + 28kN = 459kN$$

Remark

The braking force associated with LM 1 is applied on the safe side in the system calculation.

The impact of the earth pressure resisting against end-shield is neglected on the safe side.

No load on end-shield is assumed, instead load is distributed at support 2 & 3. The assumption is on safe side.

3.8.1 Load definition

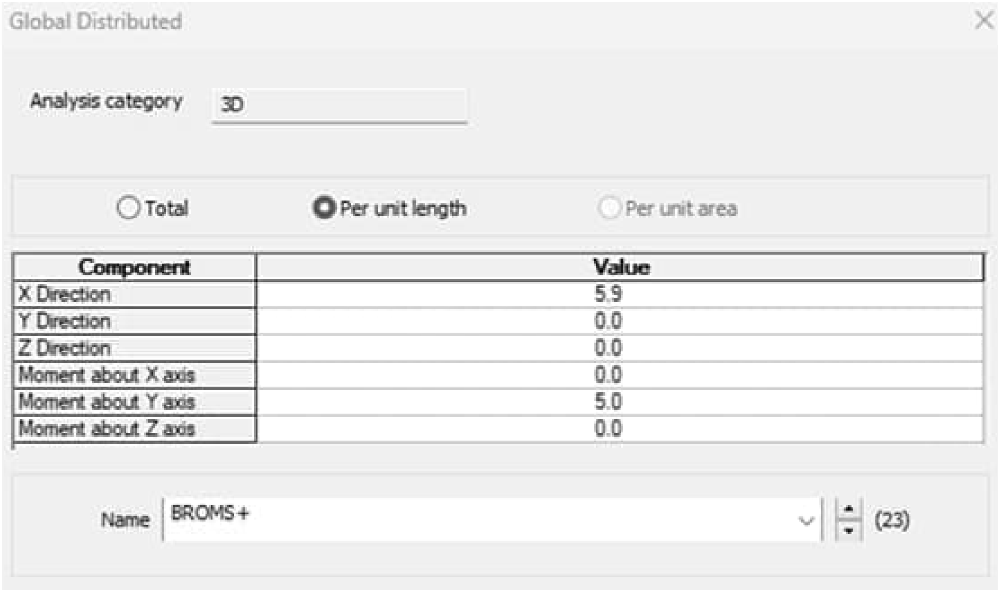
The load acts on pavement, however nodal line is located 0.85 meters below.

The braking force is considered evenly distributed over the entire bridge deck.

$$p_x = \frac{Q_{broms}}{L} = \frac{515kN}{88.4m} = 5.9\frac{kN}{m}$$

$$m_y = p_x \cdot (0.15m + t_{bel}) = 5.9\frac{kN}{m} \cdot (0.75m + 0.10m) = 5.0\frac{kNm}{m}$$

Load case : BROMS +



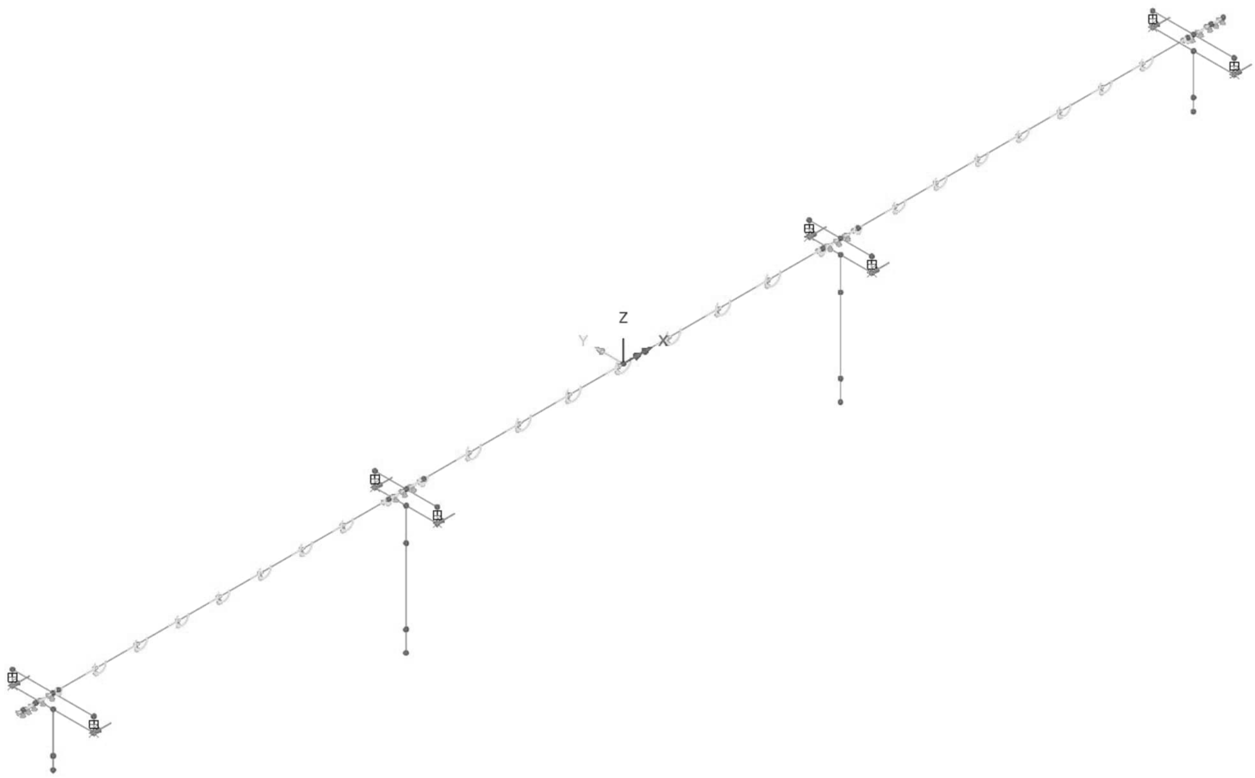
Global Distributed

Analysis category: 3D

( ) Total (•) Per unit length ( ) Per unit area

Component	Value
X Direction	5.9
Y Direction	0.0
Z Direction	0.0
Moment about X axis	0.0
Moment about Y axis	5.0
Moment about Z axis	0.0

Name: BROMS+ (23)



Overview 3D

Loadcase : BROMS-

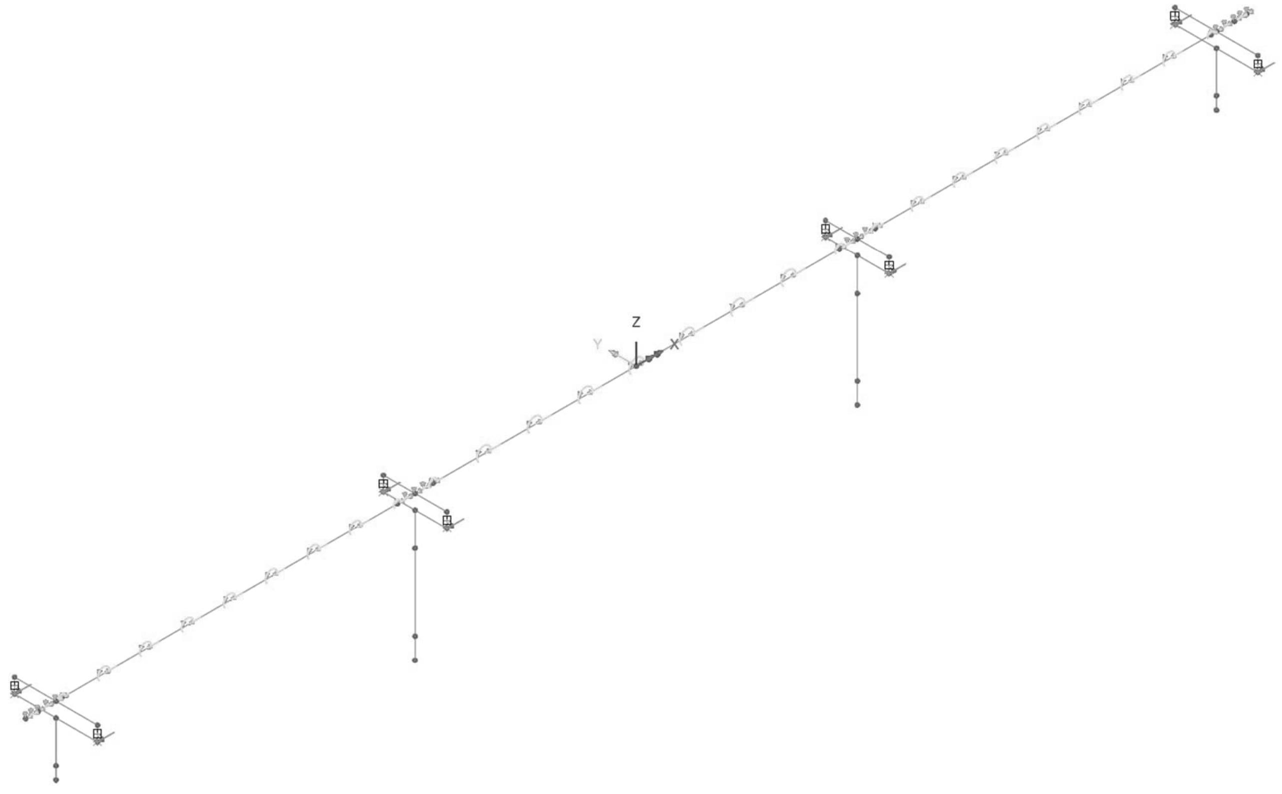
Global Distributed

Analysis category: 3D

( ) Total (•) Per unit length ( ) Per unit area

Component	Value
X Direction	-5.9
Y Direction	0.0
Z Direction	0.0
Moment about X axis	0.0
Moment about Y axis	-5.0
Moment about Z axis	0.0

Name: BROMS- (24)



Overview 3D

3.8.2 Load combination (BROMS)

Envelope BROMS :

Load case
BROMS +
BROMS -

3.9 LATERAL FORCE

Lateral force is defined by SS-EN 1991-2 §4.4.2.

The load is orthogonal to braking force and acts due to skewed braking.

The acting load acts at the level of the pavement and evenly distributed over the load length.

Load model LM 1 :

$Q_{tk} = 0.25Q_{lk} = 0.25 \cdot 515kN = 130kN$: skewed braking

Load model EG B = 300 kN (see TSFS chapter 11 §2) :

$Q_{tk} = 0.25Q_{lk} = 0.25 \cdot 459kN = 115kN$: skewed braking

Last definition:
The load is applied as a line load along nodal line of superstructure, which is located 0.85 m below.

$P_y = 130kN$

$M_x = P_y \cdot (0.75m + t_{bel}) = 130kN \cdot (0.75m + 0.10m) = 111\ kNm$

Note:
The braking force associated with LM 1 is applied on the safe side in the system calculation.

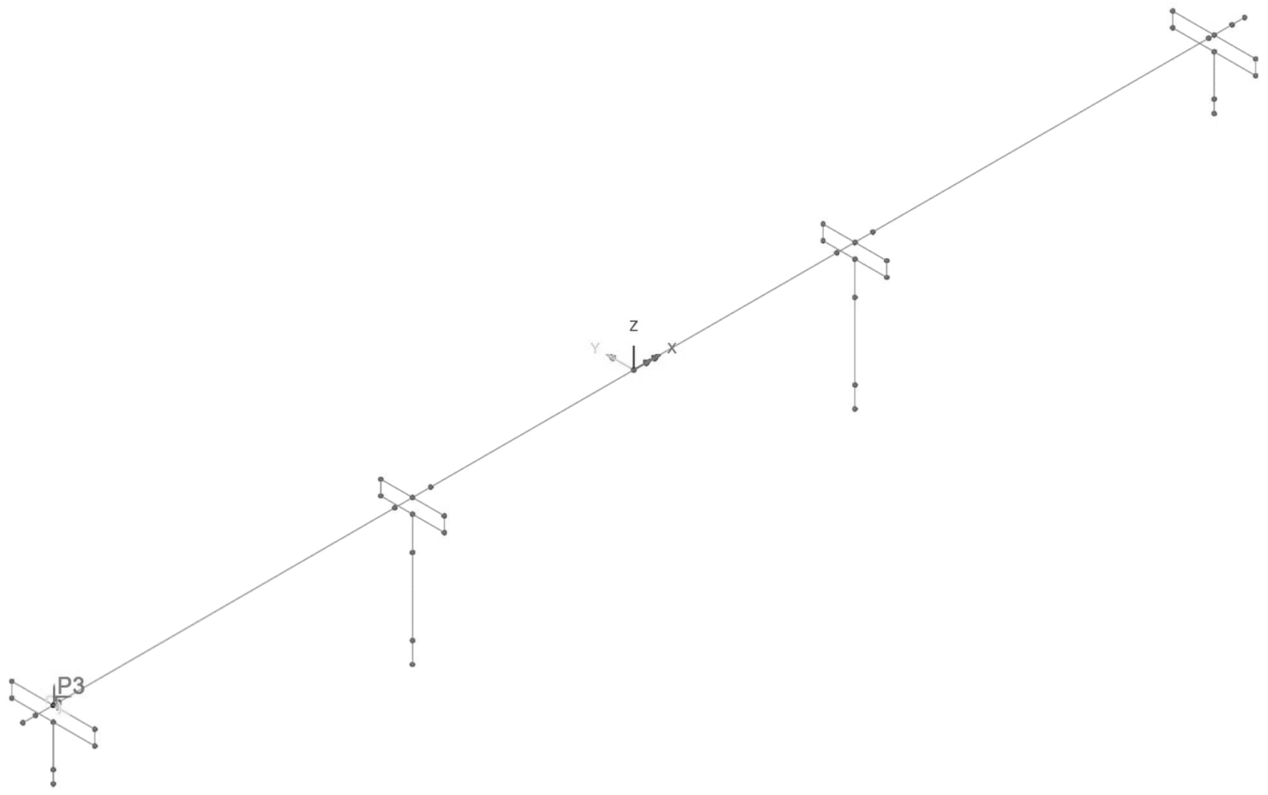
Load case : SIDO_1+

Concentrated

Analysis category: 3D

Component	Value
Concentrated load in X Dir	0.0
Concentrated load in Y Dir	130.0
Concentrated load in Z Dir	0.0
Moment about X axis	111.0
Moment about Y axis	0.0
Moment about Z axis	0.0

Name: SIDO 1+ (25)



Overview_3D

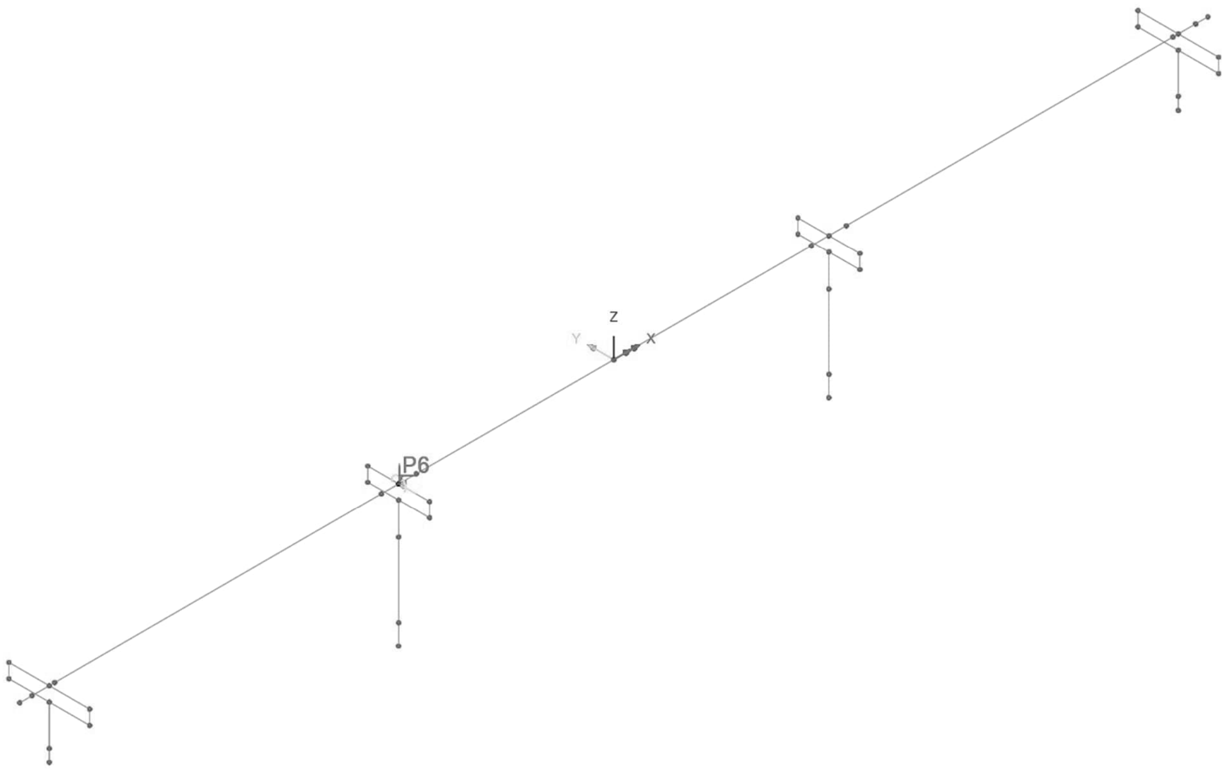
Load case : SIDO_2+

Concentrated

Analysis category: 3D

Component	Value
Concentrated load in X Dir	0.0
Concentrated load in Y Dir	130.0
Concentrated load in Z Dir	0.0
Moment about X axis	111.0
Moment about Y axis	0.0
Moment about Z axis	0.0

Name: SIDO 2+ (26)



Overview_3D

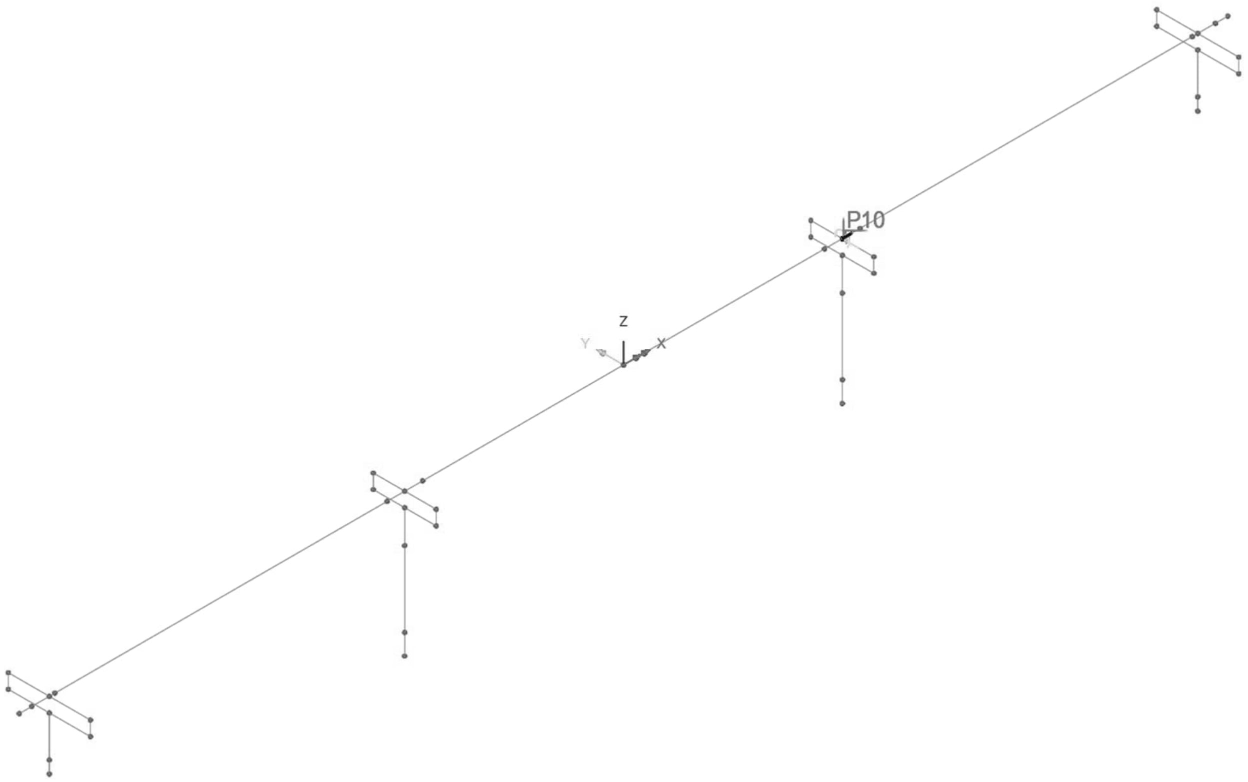
Load case : SIDO_3+

Concentrated

Analysis category: 3D

Component	Value
Concentrated load in X Dir	0.0
Concentrated load in Y Dir	130.0
Concentrated load in Z Dir	0.0
Moment about X axis	111.0
Moment about Y axis	0.0
Moment about Z axis	0.0

Name: SIDO 3+ (27)



Overview_3D

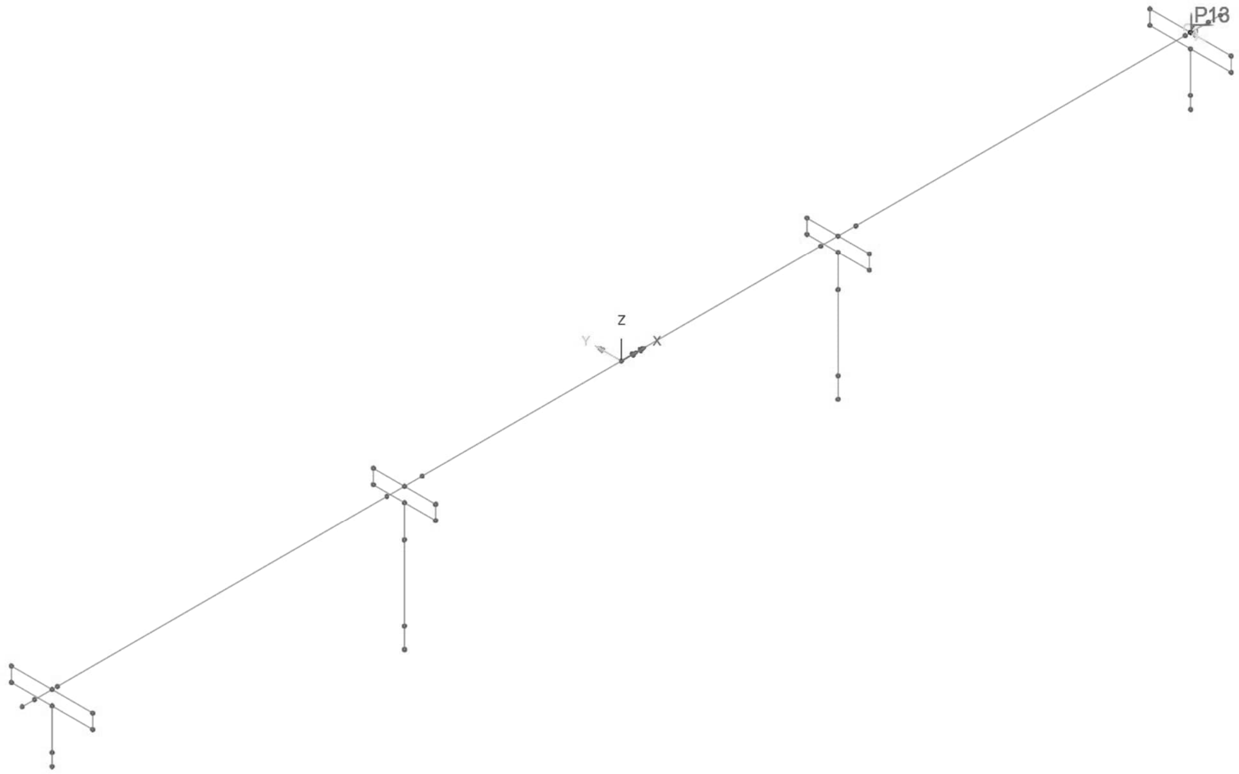
Load case : SIDO 4+

Concentrated

Analysis category: 3D

Component	Value
Concentrated load in X Dir	0.0
Concentrated load in Y Dir	130.0
Concentrated load in Z Dir	0.0
Moment about X axis	111.0
Moment about Y axis	0.0
Moment about Z axis	0.0

Name: SIDO 4+ (28)



Overview 3D

3.9.2.2 Load combination

Basic load cases :

Load case	Load	Factor
SIDO 1-	SIDO 1+	-1
SIDO 2-	SIDO 2+	-1
SIDO 3-	SIDO 3+	-1
SIDO 4-	SIDO 4+	-1

Envelope SIDO :

Load case
SIDO_1+
SIDO_2+
SIDO_3+
SIDO_4+
SIDO_1-
SIDO_2-
SIDO_3-
SIDO_4-

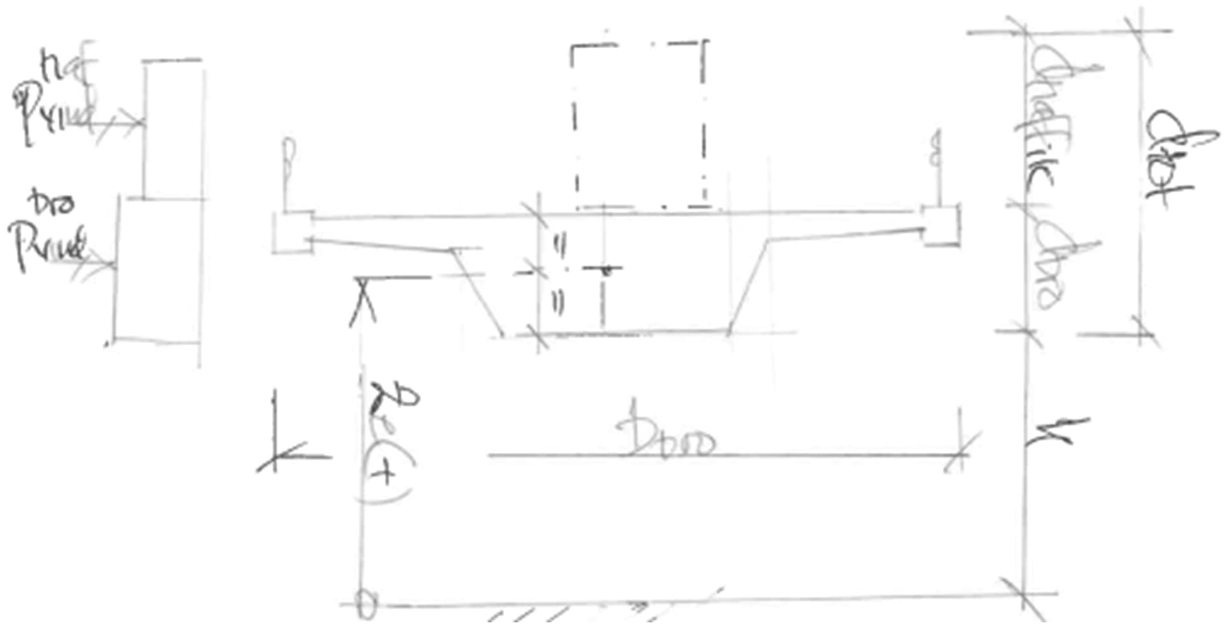
3.10 WIND LOAD

Windload on bridges is defined by EN 1991-1-4 chapter 8.

Duration coefficients (see SS-EN 1990 attachment A2 table A2.1) :

$\psi_k = 1.00$
$\psi_0 = 0.30$
$\psi_1 = 0.20$
$\psi_2 = 0$

Load intensity:



Terrain type II is applied on safe side according to SS-EN 1991-1-4 table 4.1.

Reference height z_e = 6 m : SS-EN 1991-1-4 section 8.3.1 (6)

$v_b(Oxberg; z_e = 10m; z_0 = 0.05m) = 22\frac{m}{s}$: TRVFS 2018:57 chapter 7 figure 7.1

$q_p\left(z_e = 6m, Terrängtyp\ II, v_b = 22\frac{m}{s}\right) = 0.56kPa$: TRVFS 2011:12 attachment 4 table 4.2

$q_b = \frac{1}{2}\cdot\rho\cdot v_b^2 = \frac{1}{2}\cdot 1.25\frac{kg}{m^3}\cdot\left(22\frac{m}{s}\right)^2 = 0.30\frac{kN}{m^2}$: SS-EN 1991-1-4 chapter 4.5

$c_e = \frac{q_p}{q_b} = \frac{0.56kPa}{0.30kPa} = 1.87$: SS-EN 1991-1-4 chapter 4.5

$d_{bro} = 1.5 + 0.1m = 1.6m$: construction height incl. pavement

$d_{traf} = 2.0m$: traffic height

$d_{tot} = 1.6m + 2.0m = 3.6m$

$\rightarrow \frac{b_{bro}}{d_{tot}} = \frac{8.9m}{3.6m} = 2.5$

$c_{f.x0}\left(\frac{b_{bro}}{d_{tot}} = 2.5\right) = 1.8$: SS-EN 1991-1-4 sketch 8.3

$c_{f.x} = c_{f.x0} = 1.8$: SS-EN 1991-1-4 section 8.3.1 (1)

$C = c_e \cdot c_{f.x} = 1.87 \cdot 1.8 = 3.37$

Wind load on structure (below pavement) :

$$\frac{A_{ref.x}^{bro}}{L} \equiv d_{bro}$$

$$p_{vind}^{bro} = \frac{F_w}{L} = \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot C \cdot \frac{A_{ref.x}^{bro}}{L} = \frac{1}{2} \cdot 1.25 \frac{kg}{m^3} \cdot \left(22 \frac{m}{s}\right)^2 \cdot 3.37 \cdot 1.6m = 1.6 \frac{kN}{m}$$

Wind load on traffic (above pavement) :

$$\frac{A_{ref.x}^{traf}}{L} \equiv d_{traf}$$

$$p_{vind}^{traf} = \frac{F_w}{L} = \frac{1}{2} \cdot \rho \cdot v_b^2 \cdot C \cdot \frac{A_{ref.x}^{bro}}{L} = \frac{1}{2} \cdot 1.25 \frac{kg}{m^3} \cdot \left(22 \frac{m}{s}\right)^2 \cdot 3.37 \cdot 2.0m = 2.0 \frac{kN}{m}$$

Reduction of wind load on traffic:
When traffic load acts om bridge together load associated to traffic can be reduced according to SS-EN 1991-1-4 section 8.1 (4)

$$p_{vind}^{traf.red} = \psi_0 \cdot \frac{F_w}{L} = \psi_0 \cdot \frac{1}{2} \cdot \rho \cdot v_{b.0}^2 \cdot C \cdot \frac{A_{ref.x}^{bro}}{L} = 0.3 \cdot \frac{1}{2} \cdot 1.25 \frac{kg}{m^3} \cdot \left(23 \frac{m}{s}\right)^2 \cdot 3.37 \cdot 2.00m = 0.7 \frac{kN}{m}$$

Remark
This reduction is not considered on safe side thus is not applied.

3.10.1 Definition of load

Load is applied as a line load acting along each edge beam.

$$p_{vind} = p_{vind}^{bro} + p_{vind}^{traf} = 1.6\frac{kN}{m} + 2.0\frac{kN}{m} = 3.6\frac{kN}{m}$$

$$|p_y| = 3.6\frac{kN}{m}$$

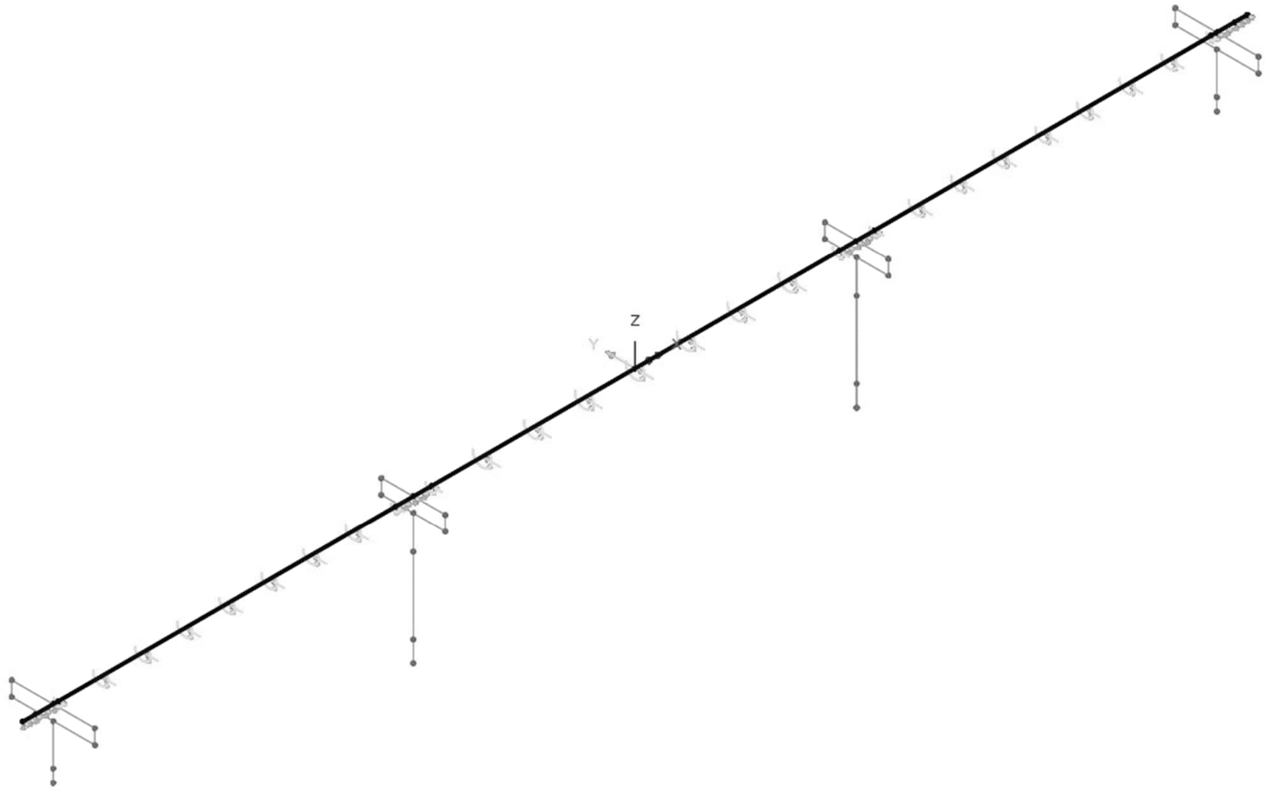
$$|m_x| = p_y \cdot \left[\frac{d_{tot} - d_{bro}}{2}\right] = 3.6\frac{kN}{m} \cdot \left[\frac{3.6m - 1.6m}{2}\right] = 3.6\frac{kNm}{m}$$

Load : VIND+

Structural loading : Global distributed

Line load in Y direction (p_y) : +3.6 $\frac{kN}{m}$

Line moment about X axis (m_x) : -3.6 $\frac{kNm}{m}$

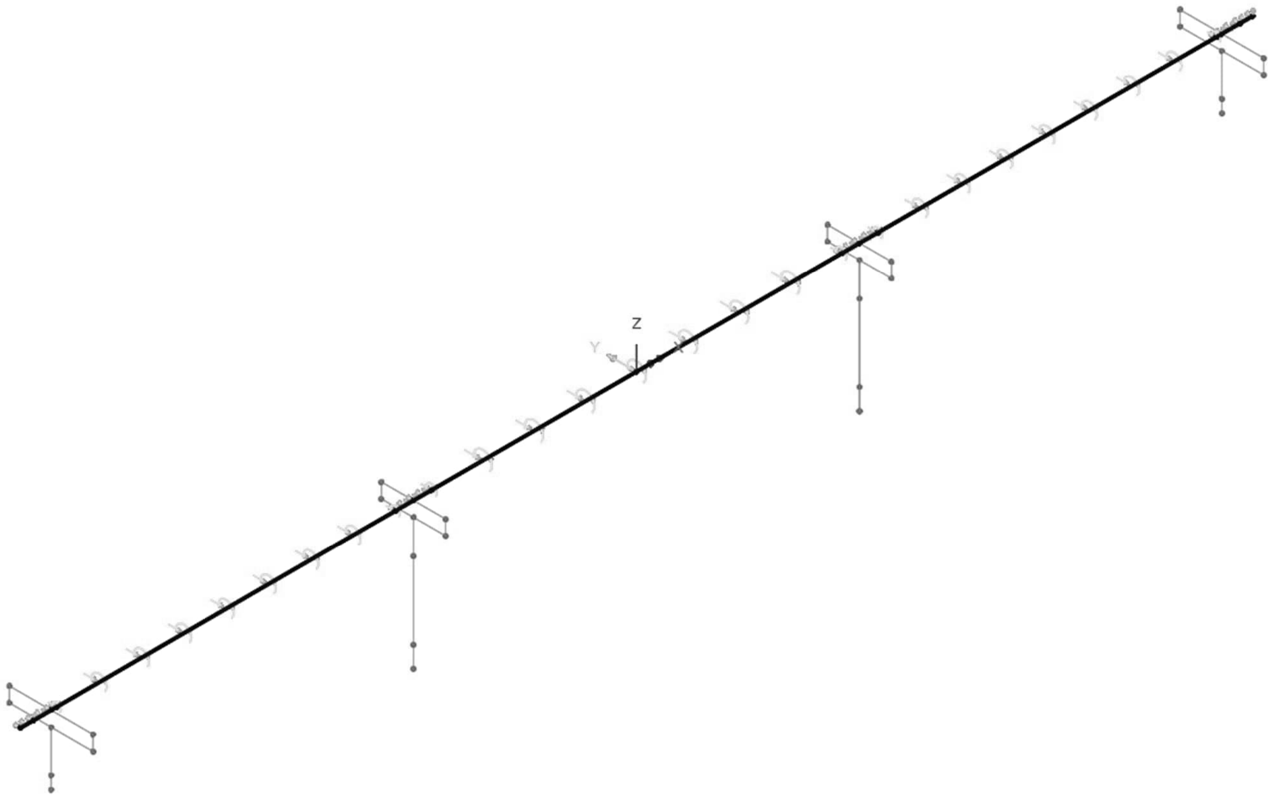


Load : VIND-

Structural loading : Global distributed

Line load in Y direction (p_y) : -3.6 $\frac{kN}{m}$

Line moment about X axis (m_x) : 3.6 $\frac{kNm}{m}$



3.10.2 Load combination

Envelope VIND :

Load case
VIND+
VIND-

3.11 SURCHARGE

TSFS chapter 11 section §8 describes load seen below.

$q_{ytlast.1} = 20kPa$: road width 6.0 m

$q_{ytlast.2} = 10kPa$: remaining width

$q_{över}(s) = K_0 \cdot q_{ytlast}$

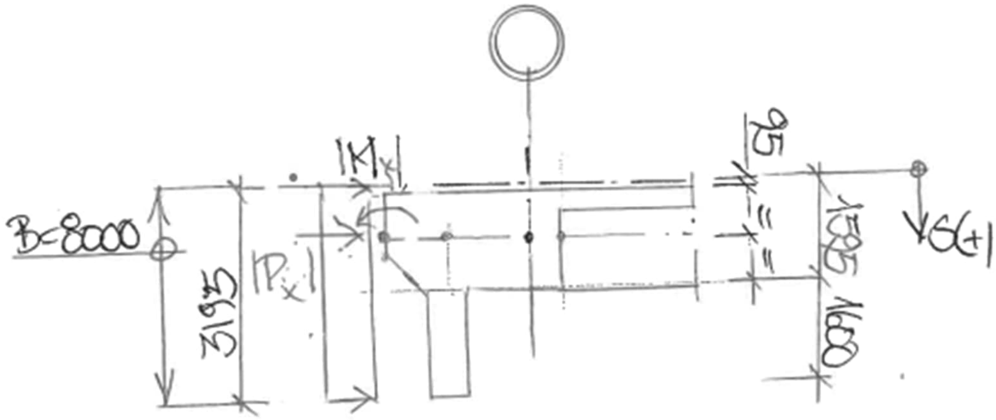
$q_{ytlast}^{b=6.0m} = 0.29 \cdot 20kPa = 6kPa$

$q_{ytlast}^{övrigt} = 0.29 \cdot 10kPa = 3kPa$

Remark
On safe side 20 kPa is assumed along entire width.

No load on end-shield is assumed, instead load is distributed at support 2 & 3. The assumption is on safe side.

3.11.1 Load abutment 1& 4



$$q_{ytlast} = 6kPa$$

$$p_x = 6kPa \cdot 8.0 = 48\frac{kN}{m}$$

$$|P_x| = 48\frac{kN}{m} \cdot 3.195 = 153kN$$

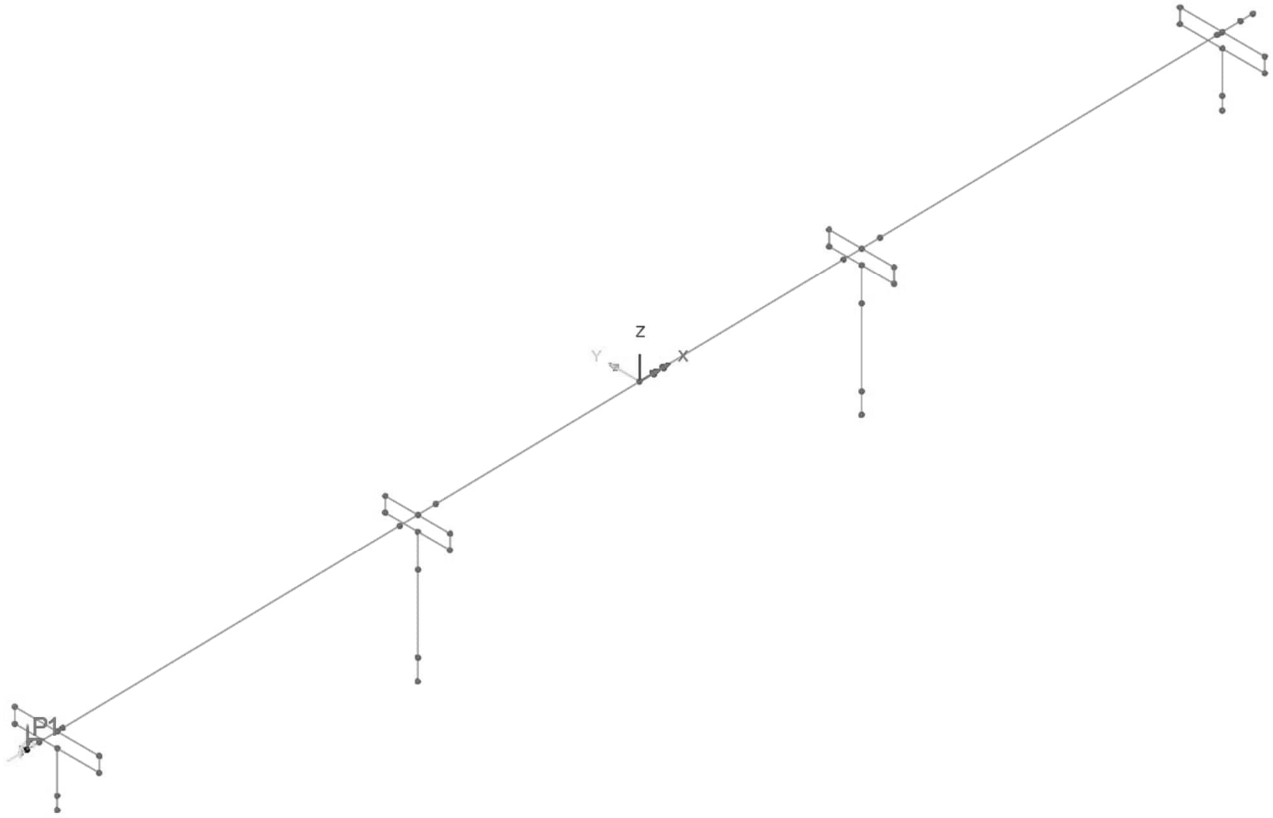
$$\left|M_y\right| = 153kN \cdot \left(\frac{3.195m}{2} - 0.845m\right) = 115kNm$$

Load : OVER 1:V

Structural loading : Concentrated

Concentrated load in X (P_x) : +153 kN

Moment about Y axis (M_y) : -115 kNm



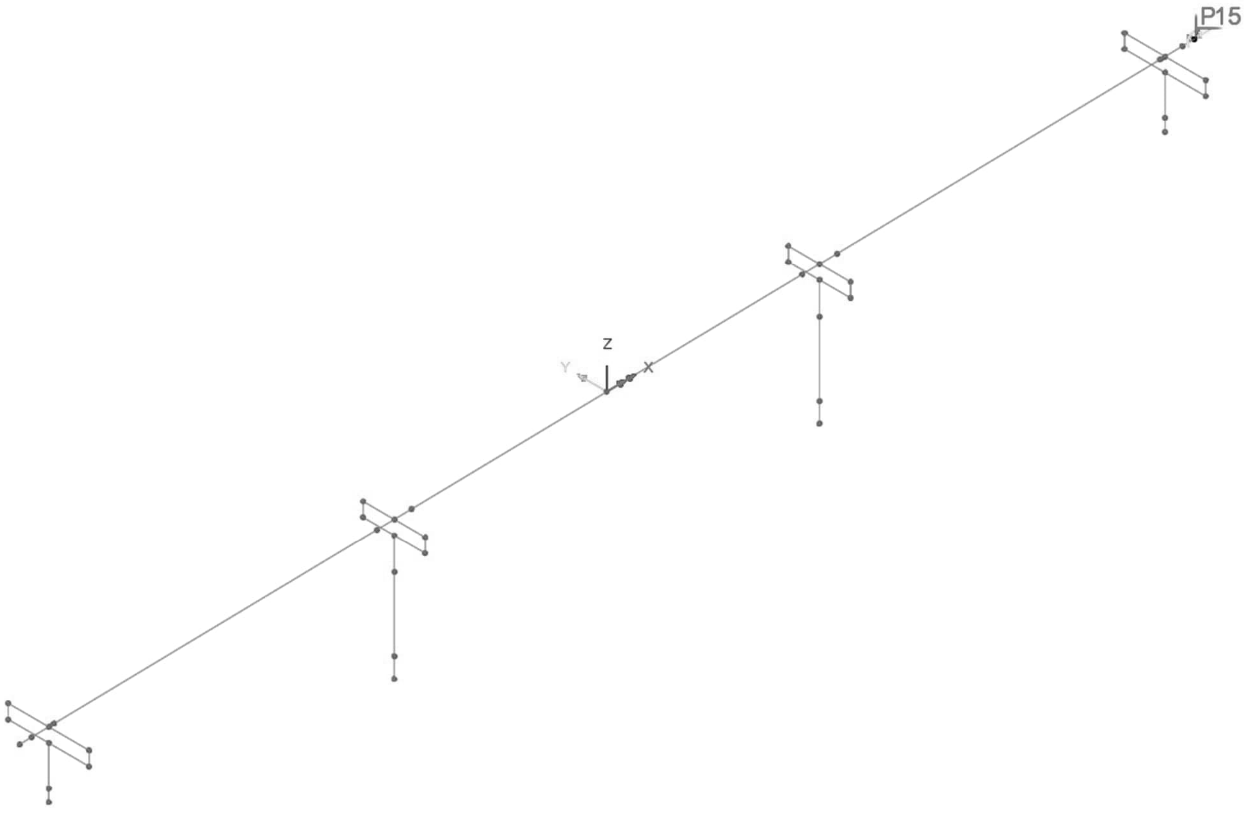
Overview

Load : OVER 1:H

Structural loading : Concentrated

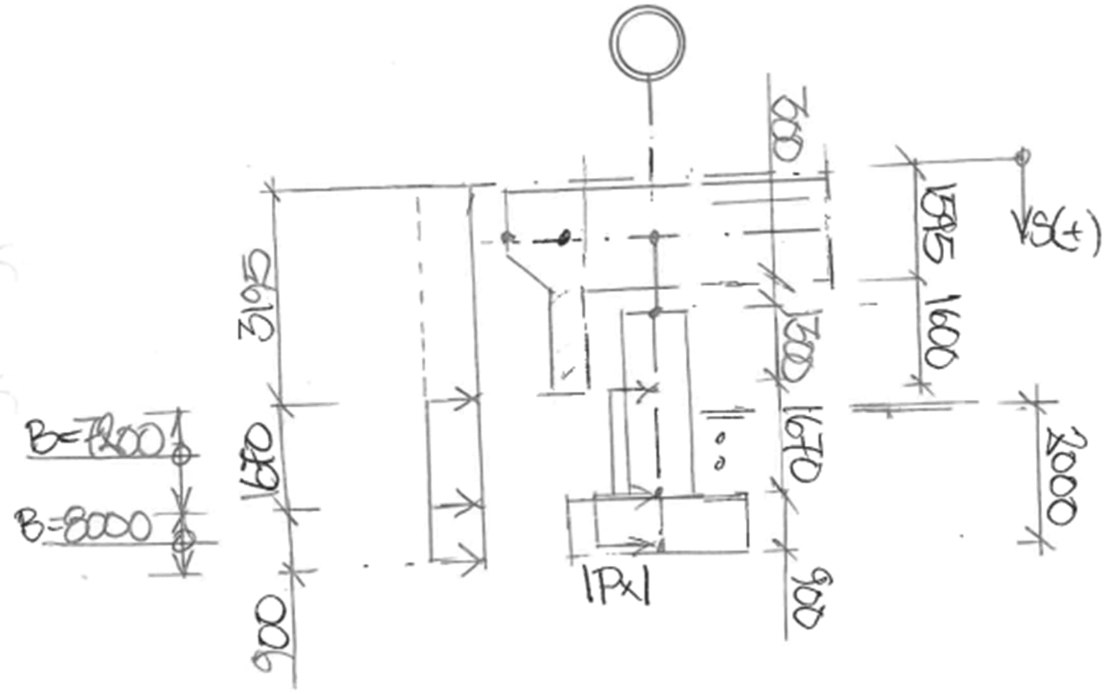
Concentrated load in X (P_x) : -153 kN

Moment about Y axis (M_y) : -115 kNm



Overview

3.11.2 Load against abutments at support 1 & 4



$q_{ytlast}(3.195m) = 6kPa$

$\rightarrow |p_x(B = 7.2m)| = 6kPa \cdot 7.2m = 42\frac{kN}{m}$

$q_{ytlast}(4.865m) = 6kPa$

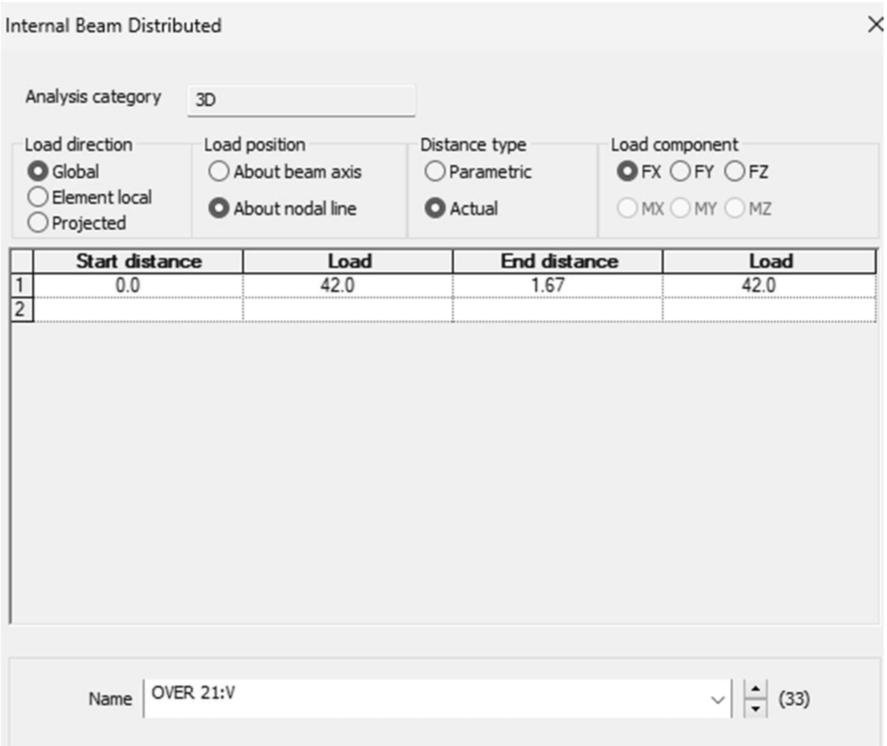
$\rightarrow |p_x(B = 7.2m)| = 6kPa \cdot 7.2m = 42\frac{kN}{m}$

$|p_x(B = 8.0m)| = 6kPa \cdot 8.0m = 48\frac{kN}{m}$

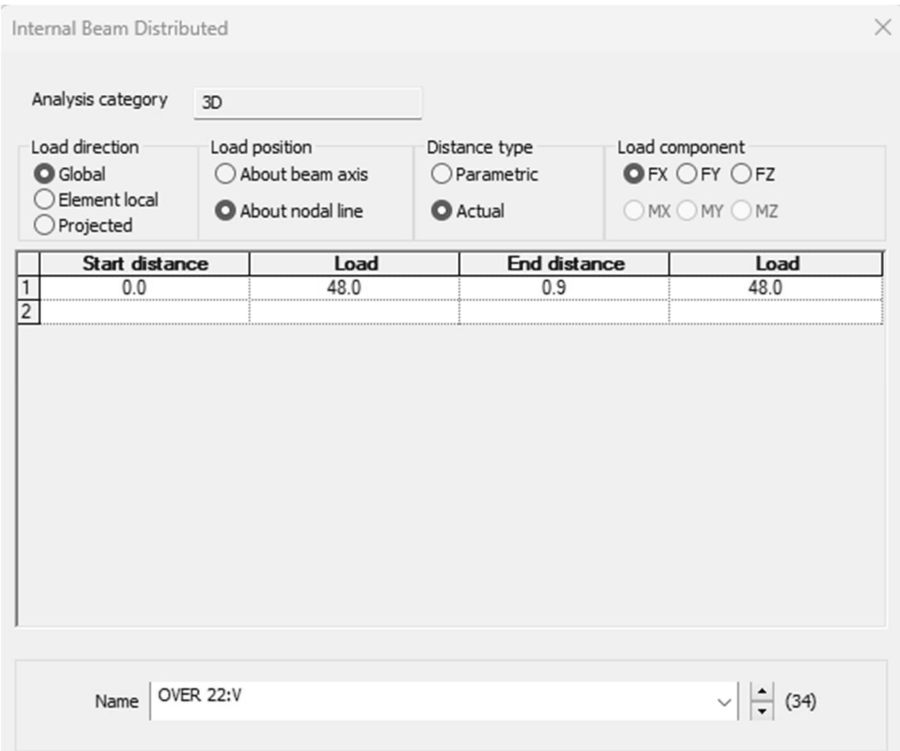
$q_{ytlast}(5.665m) = 6kPa$

$\rightarrow |p_x(B = 8.0m)| = 6kPa \cdot 8.0m = 48\frac{kN}{m}$

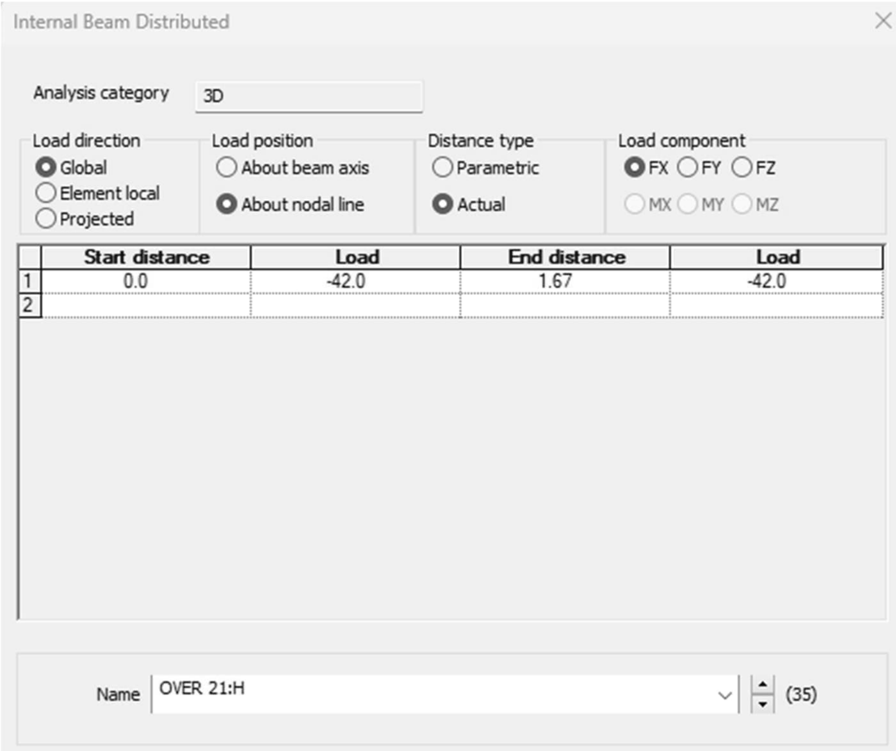
Load : OVER21:V



Load : OVER22:V



Load : OVER21:H



Internal Beam Distributed

Analysis category: 3D

Load direction: Global (selected) / Element local / Projected

Load position: About beam axis / About nodal line (selected)

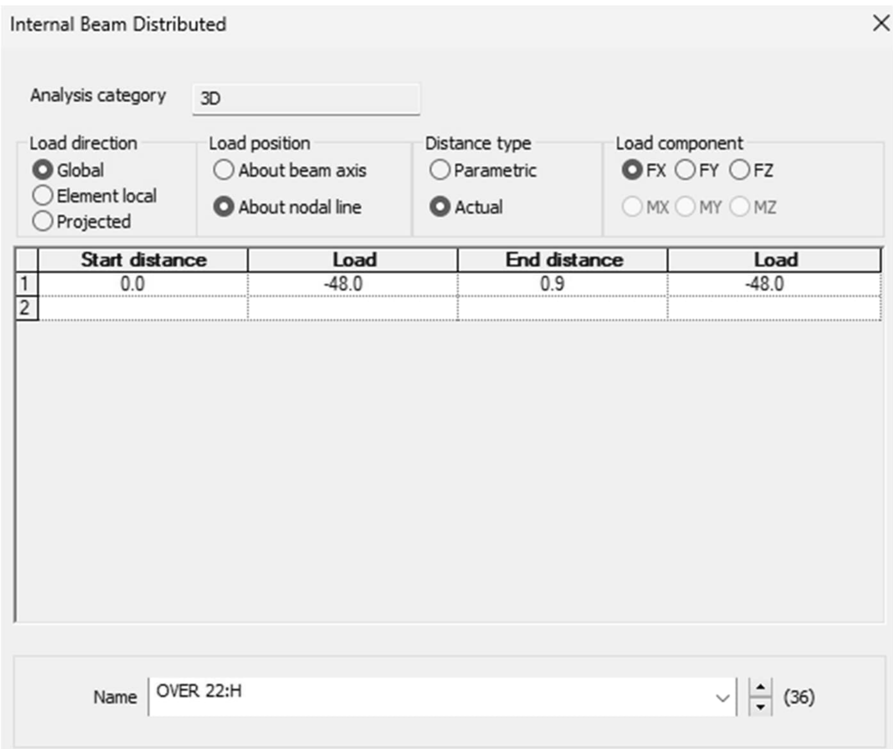
Distance type: Parametric / Actual (selected)

Load component: FX (selected) FY FZ / MX MY MZ

	Start distance	Load	End distance	Load
1	0.0	-42.0	1.67	-42.0
2				

Name: OVER 21:H (35)

Load : OVER22:H



Internal Beam Distributed

Analysis category: 3D

Load direction: Global (selected) / Element local / Projected

Load position: About beam axis / About nodal line (selected)

Distance type: Parametric / Actual (selected)

Load component: FX (selected) FY FZ / MX MY MZ

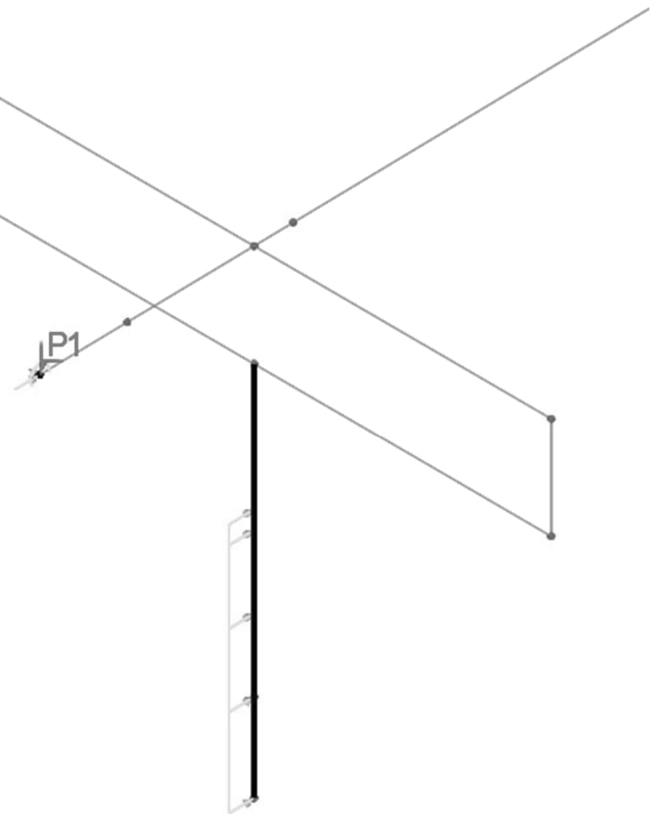
	Start distance	Load	End distance	Load
1	0.0	-48.0	0.9	-48.0
2				

Name: OVER 22:H (36)

3.11.4 Load combination

Basic loadcombination OVER:V :

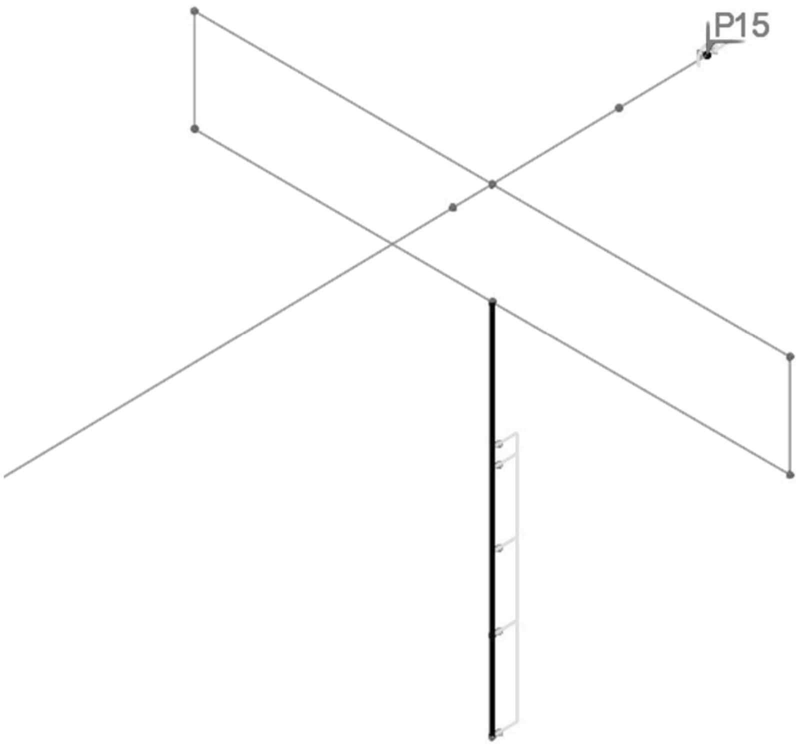
Loadcase	Factor
OVER 1:V	1
OVER 21:V	1
OVER 22:V	1



Overview 3D
Abutement 1

Basic loadcombination OVER:H :

Loadcase	Factor
OVER 1:H	1
OVER 21:V	1
OVER 22:H	1



Overview 3D
Abutement 4

Load combination smart OVER :

Loadcase	Permanent factor	Variable factor
OVER:V	0	1
OVER:H	0	1

3.12 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 beam ⇒ type 3

Location : Oxberg

$T_{max} = +34°C$: TSFS 2018:57 chapter 8 sketch 8.1
$T_{min} = -44°C$: TSFS 2018:57 chapter 8 sketch 8.2

Duration coefficients :

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

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

3.12.1 Even temperature over entire bridge (JTEMP)

Even temperature over entire bridge according to EN 1991-1-5 section 6.1.3.3. This temperature change is seasonal.

Uniform temperature change across the entire bridge is given by EN 1991-1-5, section 6.1.3.3. This temperature change is seasonal and primarily causes translation from the bridge's movement center towards the respective supports. This movement is considered to give rise to increased earth pressure due to the movement.

Function according to SS EN 1991-1-5 sketch 6.1 (bridge type 3) :

$$T_e(T) = \text{linterp}\left[(-50 \;\; 0 \;\; 30 \;\; 50)^T \cdot °C, (-42 \;\; 7 \;\; 32 \;\; 52)^T \cdot °C, T\right]$$

$$T_{e.max} = T_e\left(T_{max}\right) = 36\,°C$$

$$T_{e.min} = T_e\left(T_{min}\right) = -36\,°C$$

$$T^+ = T_{e.max} - T_0 = +36°C - 10°C = +26°C$$

$$T^- = T_{e.min} - T_0 = -36°C - 10°C = -46°C$$

Load : JTEMP+

Structural loading : Temperature

Final temperature : +26C

Initial temperature : ±0 C

Loadcase : JTEMP+

Load : JTEMP-

Structural loading : Temperature

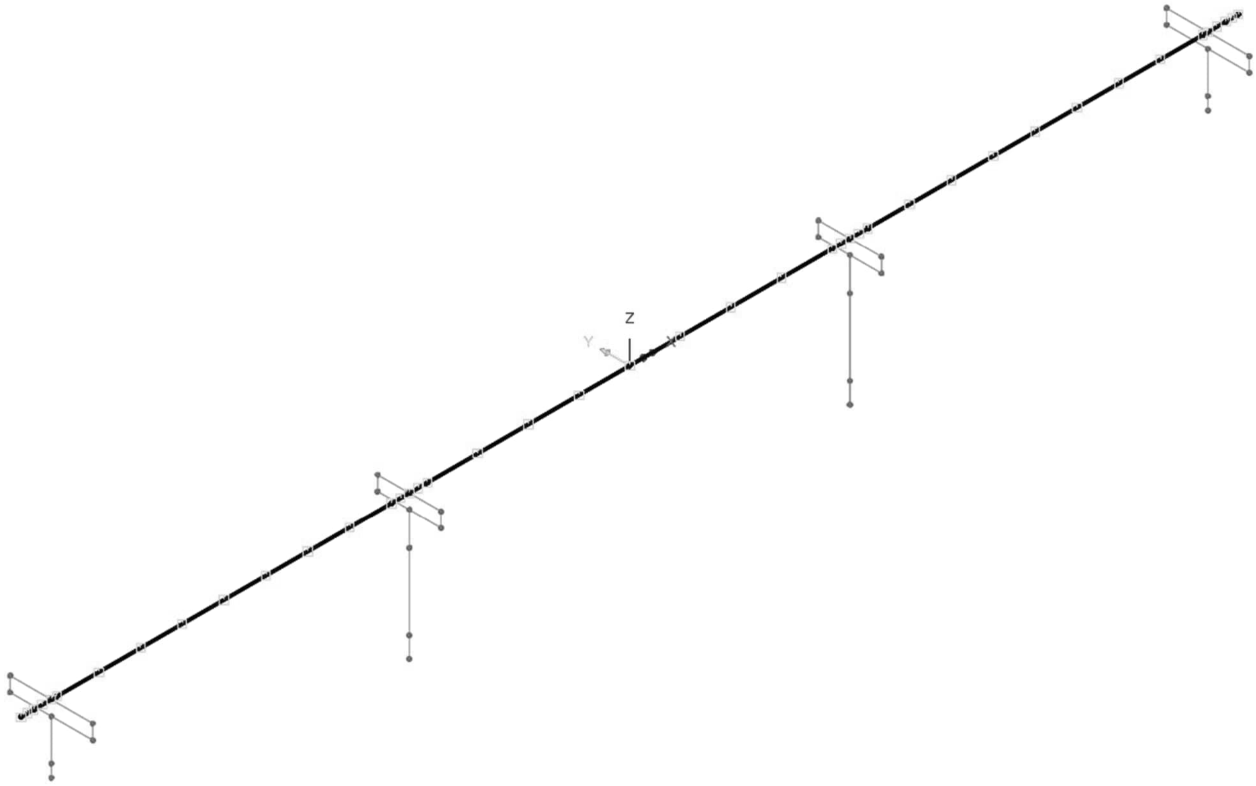
Final temperature : -46C

Initial temperature : ±0 C

Loadcase : JTEMP-

Envelope JTEMP :

Loadcase
JTEMP+
JTEMP-



Overview 3D

3.12.2 Increased earth pressure due to movement (DELTA-P)

This section is used to ensure that movements for Δq(s) do not exceed the limit for passive earth pressure

The increased earth pressure caused by the movement of end-shield.

$$v_t = (T^+ - T^-) \cdot \alpha \cdot \frac{L_{bro}}{2} = (26℃ + 46℃) \cdot 1.2 \cdot 10^{-5} \cdot \frac{88400mm}{2} = 38mm$$

Recommendation TRV

Passive earth pressure is “recommended” by TRVINFRA-00227, section 7.2.1.1.2.1.3 :

$$\sigma_p \rightarrow \frac{v_p}{h} = 0.5\%$$

Passive earth pressure arises since $v_p = h \cdot 0.5\% = 3200\text{mm} \cdot 0.5\% = 16\text{ mm} \ll v_t = 38\text{mm}$.

Remark

This recommendation is a lot less sophisticated than recommendation according to EC is considered, even so it is applied.

SS-EN 1990 section 6.1 (2) and TRVINFRA 00227 section 7.2.8.1.2 states temperature movement and ice load cannot physically act at same time. In design this assumption is made.

Recommendation EC

Passive earth pressure is increased according to SS-EN 1997-1, section C.3. During this check, "fast jord" and "väggens rörelsesätt typ b" is applied for table C.2:

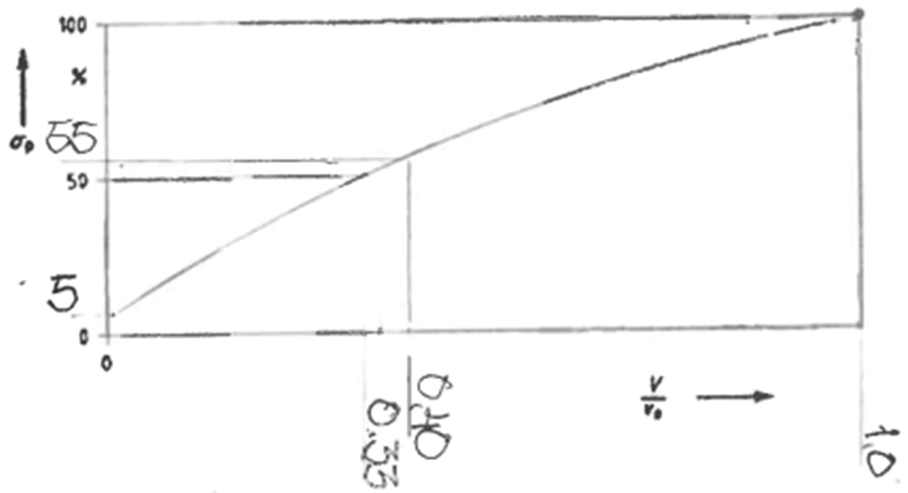
$$0.5\sigma_p \rightarrow \frac{v}{h} = 1\%$$

$$\sigma_p \rightarrow \frac{v_p}{h} = 3\% \rightarrow 6\%$$ but 3 % is chosen on safe side !

Passive earth pressure does not arise since $v_p = h \cdot 3\% = 3200mm \cdot 3\% = 96$ mm > $v_t = 38mm$.

$$\frac{K_0}{K_p} = \frac{0.29}{5.82} = 5\%$$

$$\frac{v(0.5\sigma_p)}{v(\sigma_p)} = \frac{1\% \cdot h}{3\% \cdot h} = 0.33$$

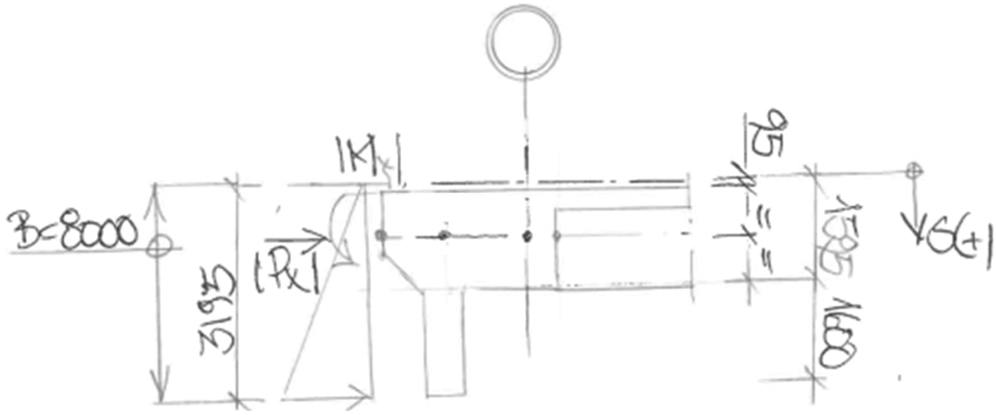


$$\frac{v_t}{v_p} = \frac{38mm}{96mm} = 0.40 \rightarrow \Delta p = 0.55 \cdot (p_p - p_0)$$

Remark

EC recommendation only results in 55 % of passive earth pressure, thus a lot less than TRV recommendation. Despite this it is not applied in design.

Passive earth pressure



$$\frac{v_t}{v_p} = \frac{38mm}{16mm} = 2.4 > 1.0 \rightarrow \Delta p = 1.0 \cdot (p_p - p_0)$$

$P_x^{vilo} = 236kN$: see page A3:15

$M_y^{vilo} = 303kNm$: see page A3:15

$$\rightarrow P_x^{passiv} = \frac{K_p}{K_0} \cdot P_x^{vilo} = \frac{5.82}{0.29} \cdot 236kN = 4736kN$$

$$P_x^{temp} = 1.0 \cdot (P_x^{passiv} - P_x^{vilo}) = 1.0 \cdot (4736kN - 236kN) = 4500kN$$

$$M_y^{temp} = P_x^{temp} \cdot \left(\frac{2 \cdot 3.195m}{3} - 0.845m\right) = 5783kNm$$

Note:
No reduction is made considering creep or cracking, as this is not an internal constraint load. This applies to both ultimate limit state (ULS) and serviceability limit state (SLS).

Load : DELTA-P:V

Structural loading : Concentrated

Concentrated load in X (P_x) : +4500kN

Moment about Y axis (M_y) : -5783 kNm

Load : DELTA-P:H

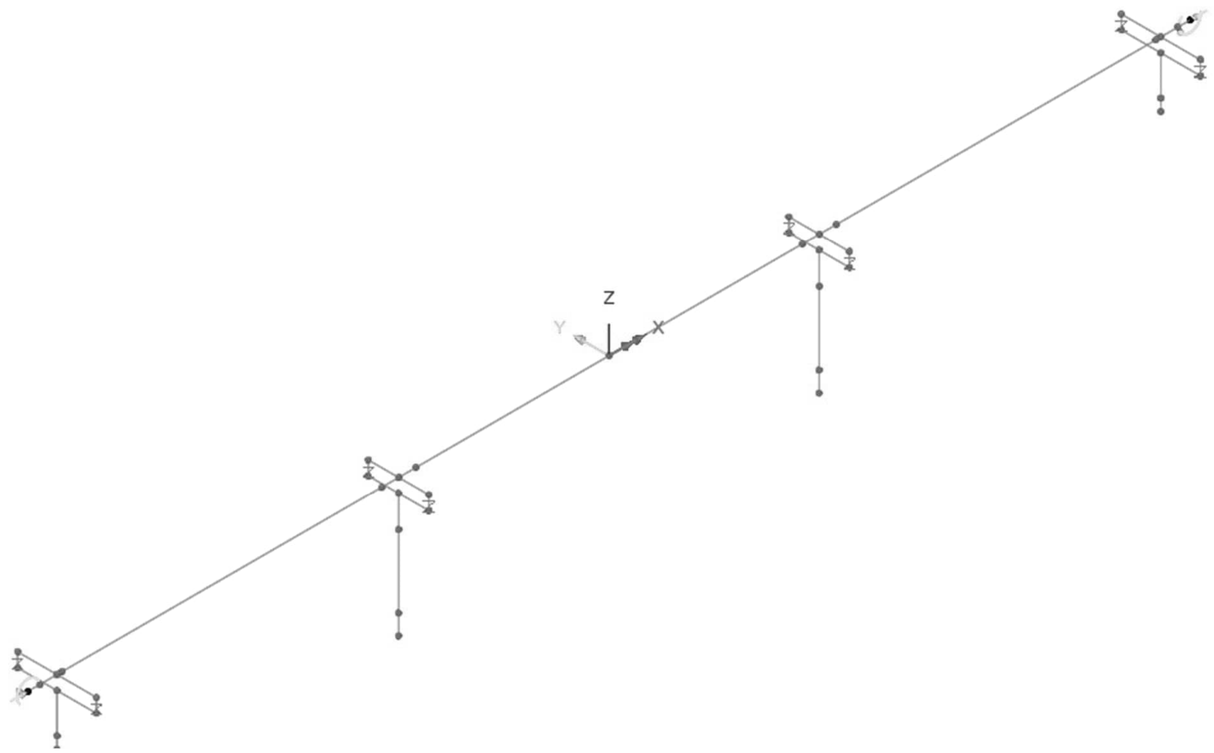
Structural loading : Concentrated

Concentrated load in X (P_x) : -4500kN

Moment about Y axis (M_y) : +5783 kNm

Loadcase : DELTA-P

Load: DELTA-P:V
Load: DELTA-P:H



Overview

3.12.3 Uneven temperature of entire cross section (OJTEMP1)

Determined according to EN 1991-1-5 § 6.1.4.1. When assessing the impact, a coating with a thickness of 110 mm is applied on the safe side.

$k_{1.sur}(t = 100mm) = 0.7$

$k_{2.sur}(t = 100mm) = 1.0$

$\Delta T_{max} = +15℃ \cdot k_{1.sur} = +11℃$: : upper surface warmer

$\Delta T_{min} = -8℃ \cdot k_{2.sur} = -8℃$: : lower surface warmer

The occurring temperature change ΔT refers to the linear difference between the temperature at the top and bottom of the bridge deck slab.

Uneven temperature is indicated as a temperature gradient $\frac{\delta T}{\delta Z}$ when defined in LUSAS.

$\frac{\delta T^{max}}{\delta Z} = \frac{+11℃}{1.50m} = +7\frac{℃}{m}$: maximal temperature gradient

$\frac{\delta T^{min}}{\delta Z} = \frac{-8℃}{1.50m} = -5\frac{℃}{m}$: minimal temperature gradient

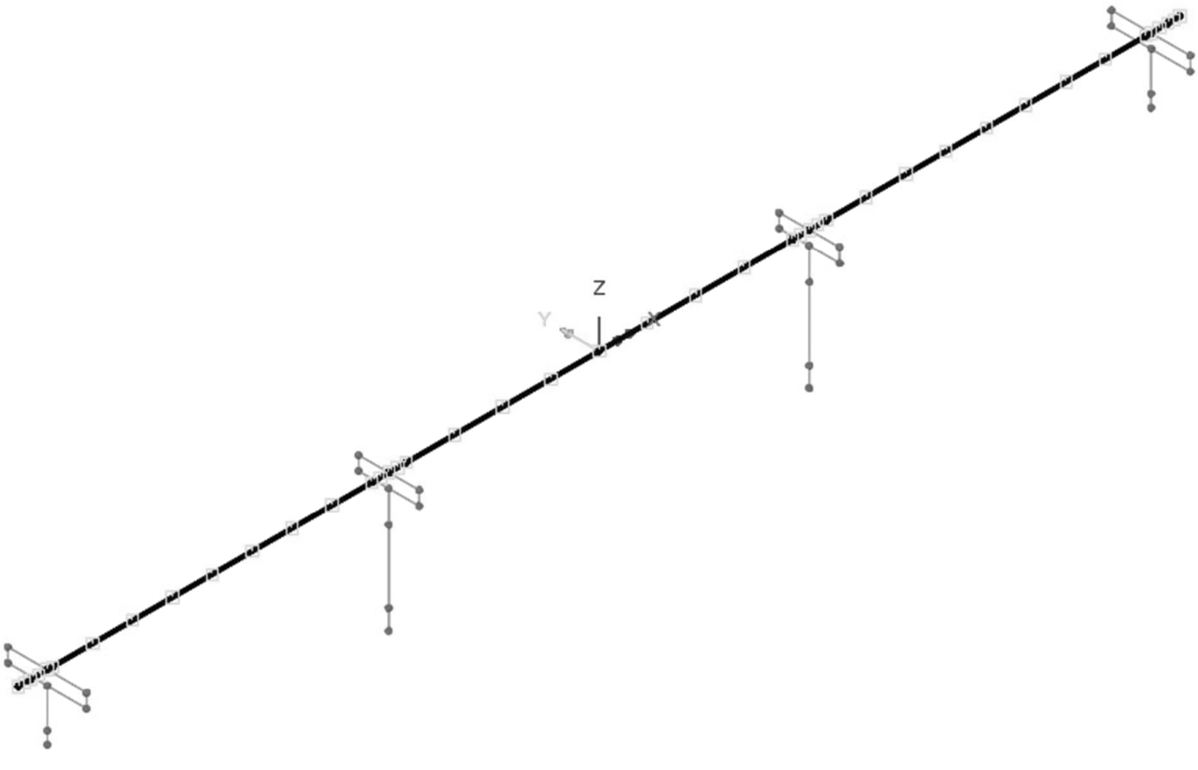
Loadcase : OJTEMP 1+

Structural loading : Temperature

Definition : Element

Final Z temperature gradient : +7 °C/m

Initial Z temperature gradient : 0°C/m



Overview 3D

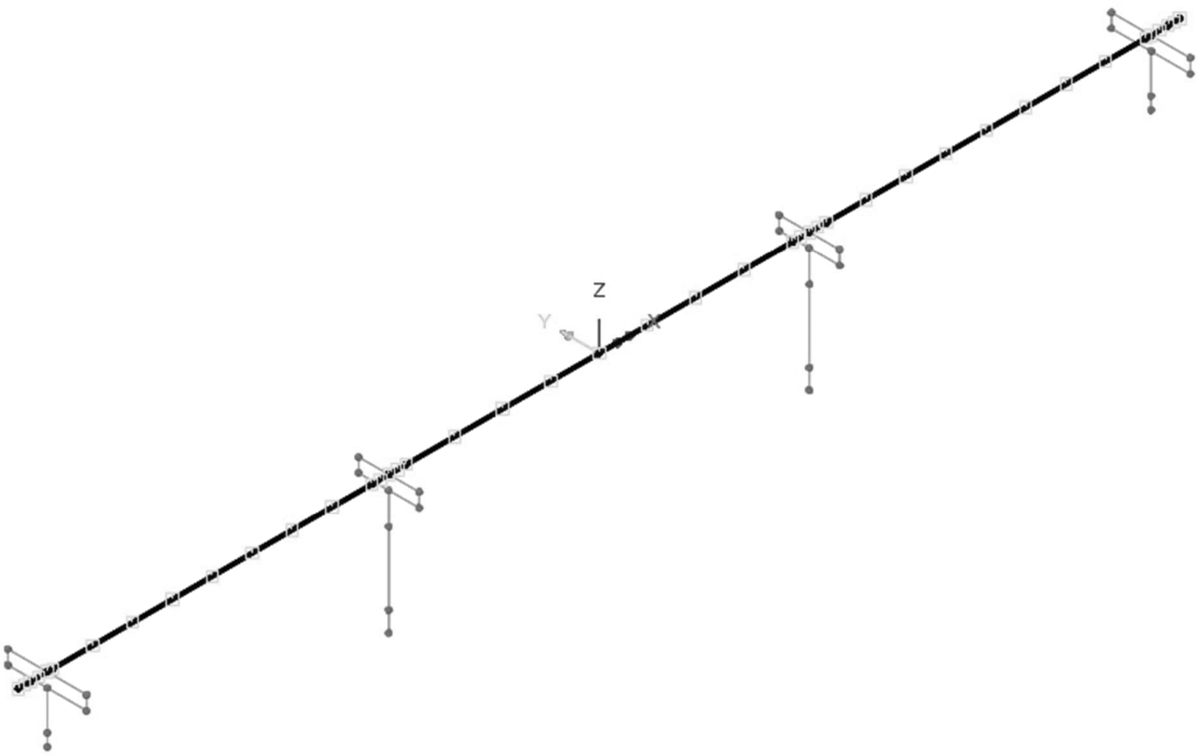
Loadcase : OJTEMP 1-

Structural loading : Temperature

Definition : Element

Final Z temperature gradient : -5°C/m

Initial Z temperature gradient : 0°C/m



Overview 3D

Envelope OJTEMP 1 :

Load case
OJTEMP 1+
OJTEMP 1-

3.12.4 Uneven temperature differences between different construction parts

This section states that these effects should be combined with those caused by uniform temperature across the entire bridge (TEMP 1). It handles differences of uneven temperature
See SS-EN 1991-1-5 section 6.1.6 and TRVINFRA-00227 section 7.2.1.1.2.4.

However no differences is consider in superstructure. Only differences with substructure occurs but this does not result in load effects for this bridge type, thus load is disregarded.

Remark
Since temperature load is not considered in the ultimate limit state (ULS).

3.12.5 Combining load case JTEMP and OJTEMP 1

Load combination is conducted according to SS-EN 1991-1-5, section 6.1.5. For such a combination, ω_M = 0.75 och ω_N = 0.35 shall be applied as shown below.

Alternative 1 ($\omega_M = 0.75$) : $T + \omega_M \cdot \Delta T$

Alternative 2 ($\omega_N = 0.35$) : $\omega_N \cdot T + \Delta T$

Load combination smart TEMP-1 :

Loadcase	Permanent factor	Variable factor
JTEMP	0	0.77 (= 0.77[1.)] x 1.00)
OJTEMP 1	0	0.75 (= 1.00[1.)] x 0.75)
DELTA-P	0	1.0

Load combination smart TEMP-2 :

Loadcase	Permanent factor	Variable factor
JTEMP	0	0.27 (= 0.77[1.)] x 0.35)
OJTEMP 1	0	1.00 (= 1.00[1.)] x 1.00)
DELTA-P	0	1.0

Note:

[1.)] Impact of creep results in reduced rigidity, see page A3:46.

Envelope TEMP :

Load case
TEMP-1
TEMP-2

3.13 ICE LOAD

Ice load is defined in document TB (18222-00-010) section GC.3. and TRVINFRA-00227, section 7.2.1.1.2.6.2.

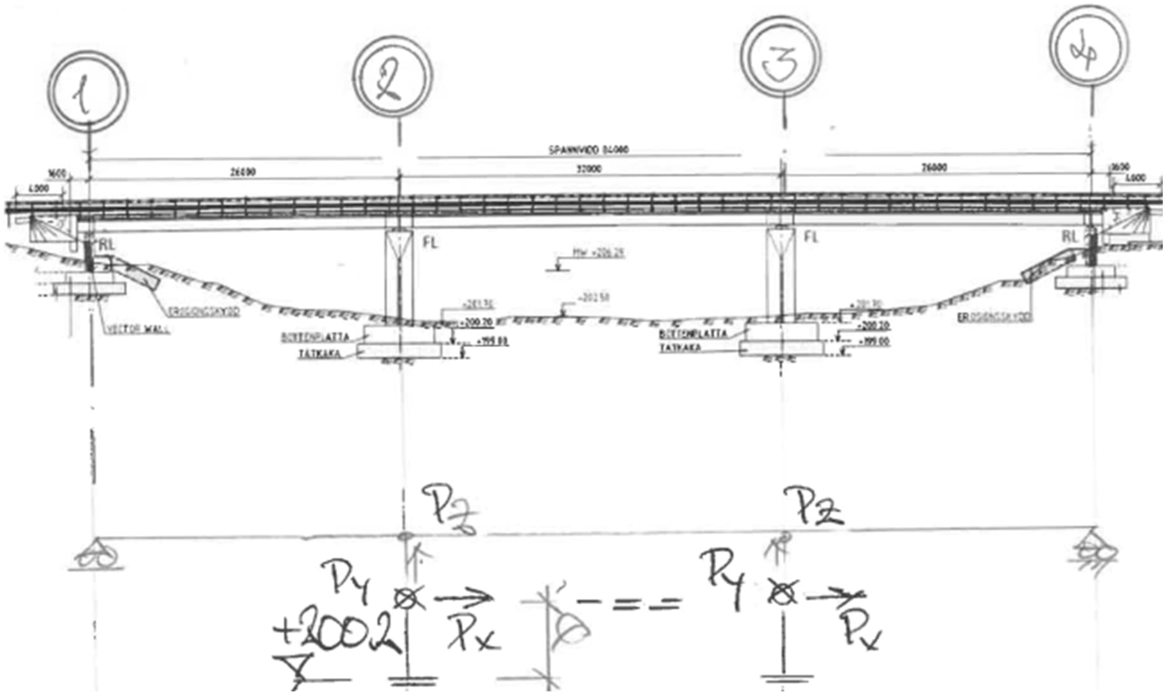
Ice loads do not act in X, Y and Z direction simultaneously.

TRVINFRA-00227 table 7.1-4 → $\psi_0 = \psi_1 = 0.40$; $\psi_2 = 0$

MHQ = +207.20 → a_H = 207.20 m - 200.20 m = 7.00 m : high ice level

MLQ = +205.74 → a_L = 205.74 m - 200.20 m = 5.54 m : low ice level

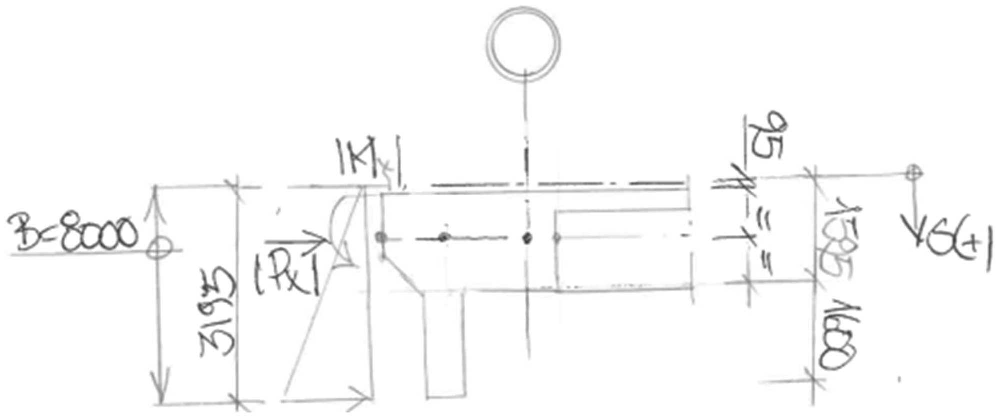
Level bottom slab: +200.20



Remark
Ice load is not considered to act in combination with seasonal even temperature over entire bridge (JTEMP), see page A3:104.

3.13.1 Defintion of load at support 1 & 2

At end-shield increased earth pressure arises.



$$|P_x| = f \cdot \left(P_x^{passiv} - P_x^{vilo}\right) = f \cdot 4500kN$$

$$\left|M_y\right| = f \cdot 4500kN \cdot \left(\frac{2 \cdot 3.195m}{3} - 0.845m\right) = f \cdot 5783kNm$$

$$\Delta_{is}(f = 1) = 63.9mm$$

Load : PASSIV 1X+

Structural loading : Concentrated

Concentrated load in X (P_x) : +4500 kN

Moment about Y axis (M_y) : -3213 kNm

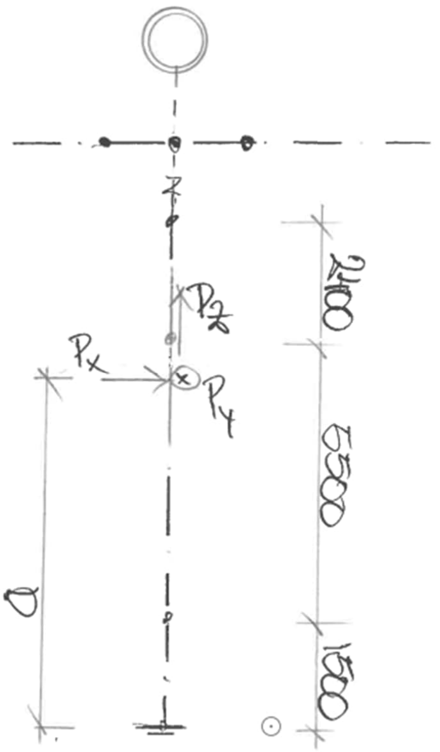
Load : PASSIV 4X-

Structural loading : Concentrated

Concentrated load in X (P_x) : -4500 kN

Moment about Y axis (M_y) : +3213 kNm

3.13.1 Defintion of load at support 2 & 3

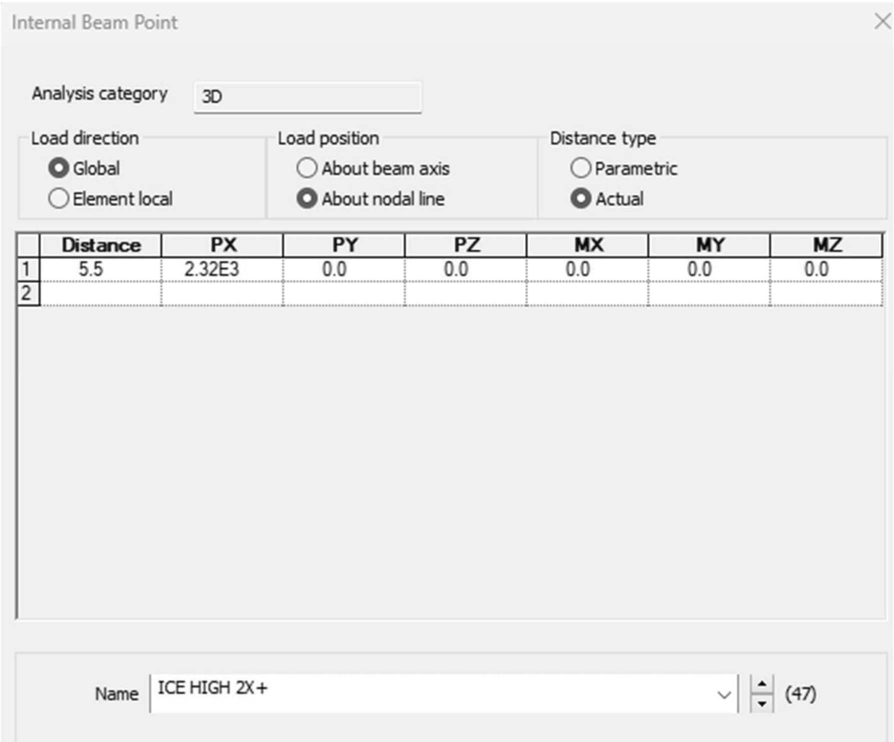


$P_x = \mp 2320kN$

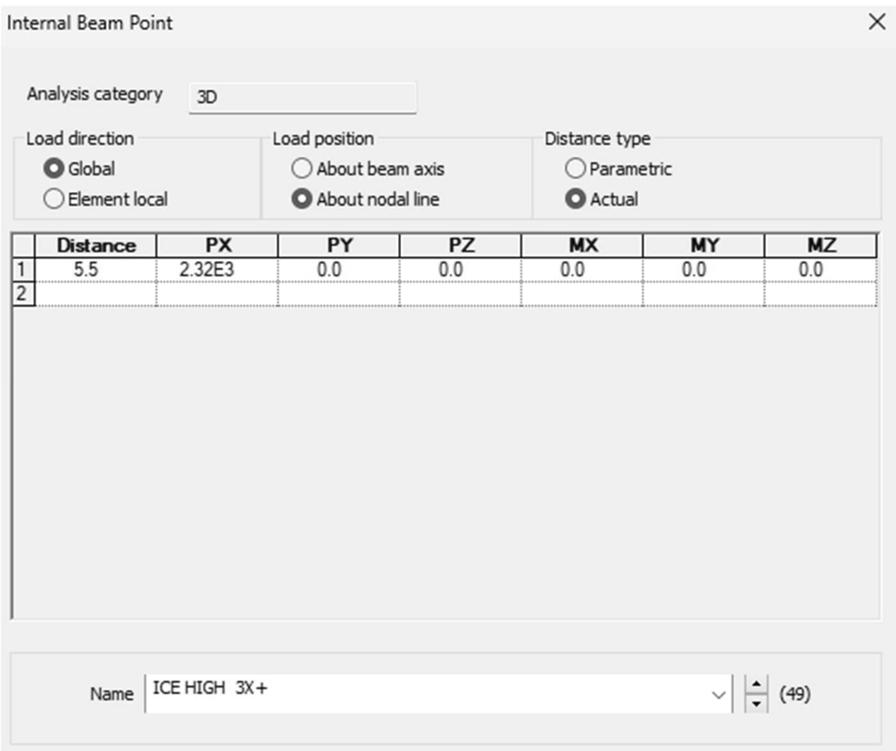
$P_y = \mp 378kN$

$P_z = 771kN$

Load : ICE HIGH 2X+



Load : ICE HIGH 3X+



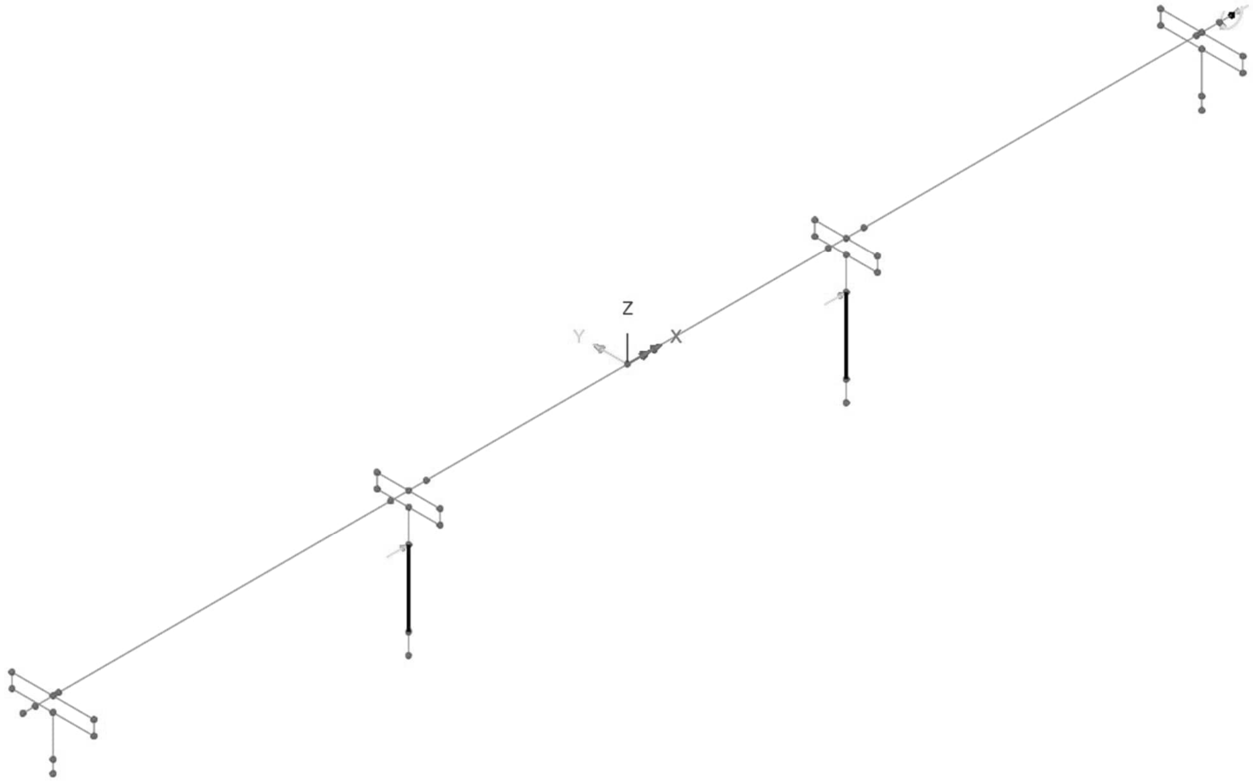
Loadcase: ICE HIGH X+

$\Delta_{is}(f=0) = 47.17mm$

$\Delta_{ice}(f=0.5903) = 9.445\ mm\ \text{assumed} \rightarrow \frac{v_{ice}}{v_p} = \frac{9.445mm}{16mm} = 0.5903$

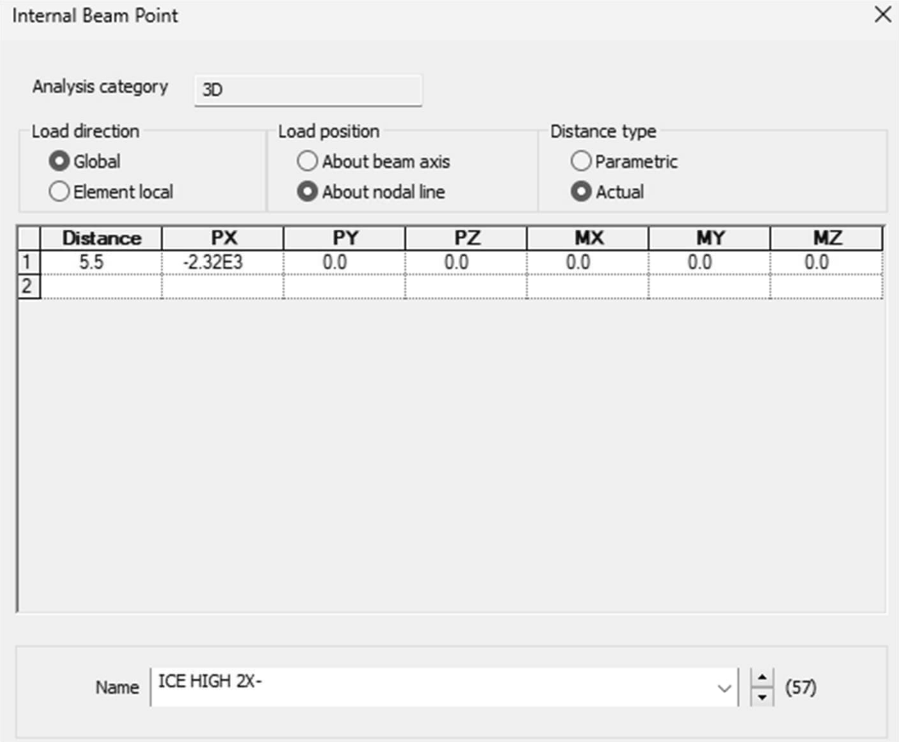
$v_{ice} = 47.17mm - f \cdot 63.9mm = 9.449\ mm \approx \Delta_{ice}(f=0.5903)$ which was to be proven !

Load	Factor
ICE HIGH 2X-	1
ICE HIGH 3X-	1
PASSIV 1X+	f = 0.5903



Overview 3D

Load : ICE HIGH 2X-


Internal Beam Point

Analysis category: 3D

Load direction: (•) Global ( ) Element local

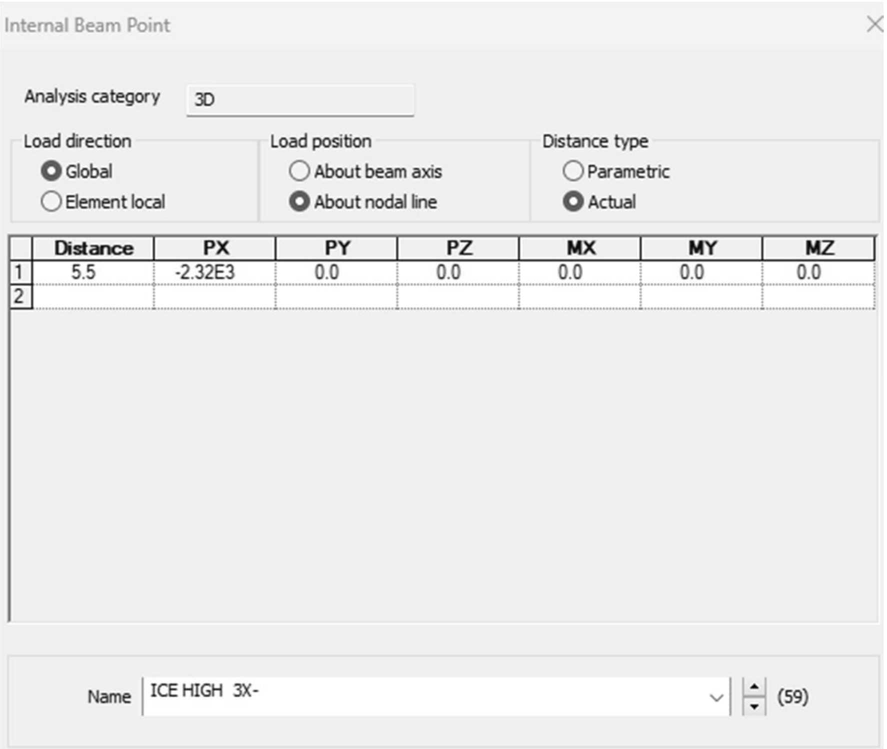
Load position: ( ) About beam axis (•) About nodal line

Distance type: ( ) Parametric (•) Actual

	Distance	PX	PY	PZ	MX	MY	MZ
1	5.5	-2.32E3	0.0	0.0	0.0	0.0	0.0
2							

Name: ICE HIGH 2X- (57)

Load : ICE HIGH 3X-


Internal Beam Point

Analysis category: 3D

Load direction: (•) Global ( ) Element local

Load position: ( ) About beam axis (•) About nodal line

Distance type: ( ) Parametric (•) Actual

	Distance	PX	PY	PZ	MX	MY	MZ
1	5.5	-2.32E3	0.0	0.0	0.0	0.0	0.0
2							

Name: ICE HIGH 3X- (59)

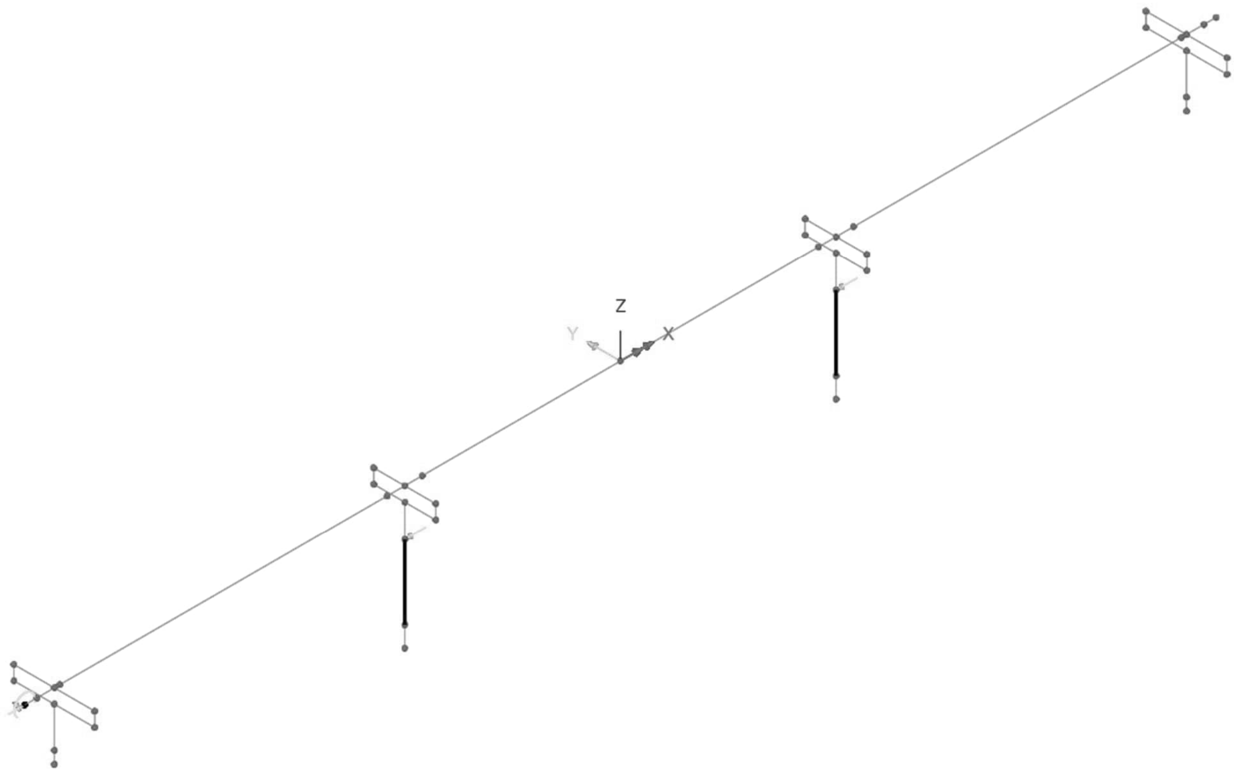
Loadcase: ICE HIGH X-

$\Delta_{is}(f=0)=47.17mm$

$\Delta_{ice}(f=0.5903)=9.445$ mm assumed$\rightarrow \frac{v_{ice}}{v_p}=\frac{9.445mm}{16mm}=0.5903$

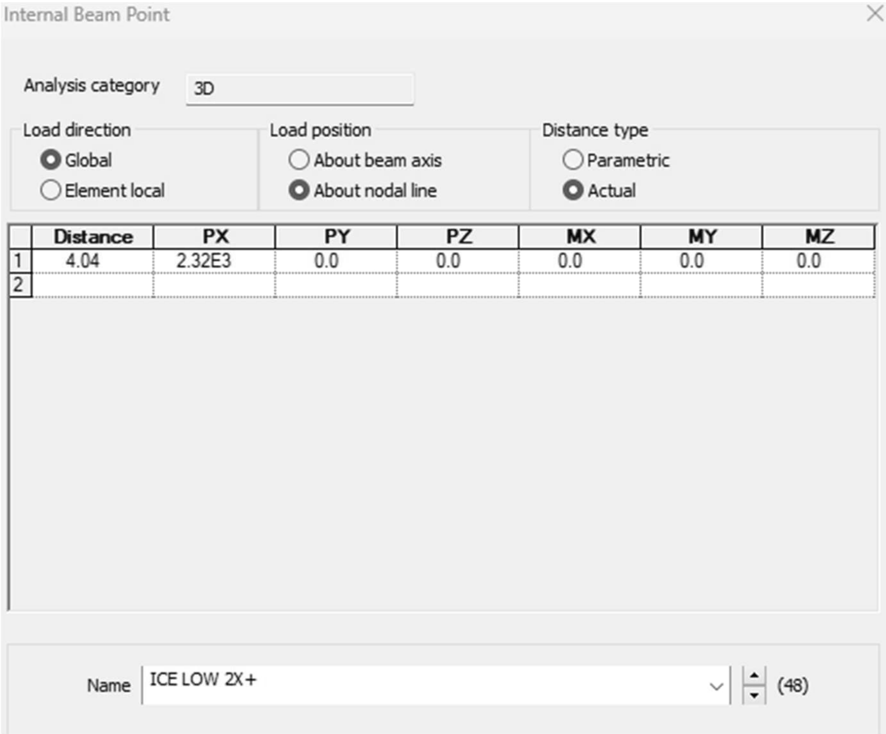
$v_{ice}=47.17mm - f \cdot 63.9mm=9.449$ mm $\approx \Delta_{ice}(f=0.5903)$which was to be proven !

Load	Factor
ICE HIGH 2X-	1
ICE HIGH 3X-	1
PASSIV 1X+	f = 0.5903



Overview 3D

Load : ICE LOW 2X+



Internal Beam Point

Analysis category: 3D

Load direction: (•) Global ( ) Element local

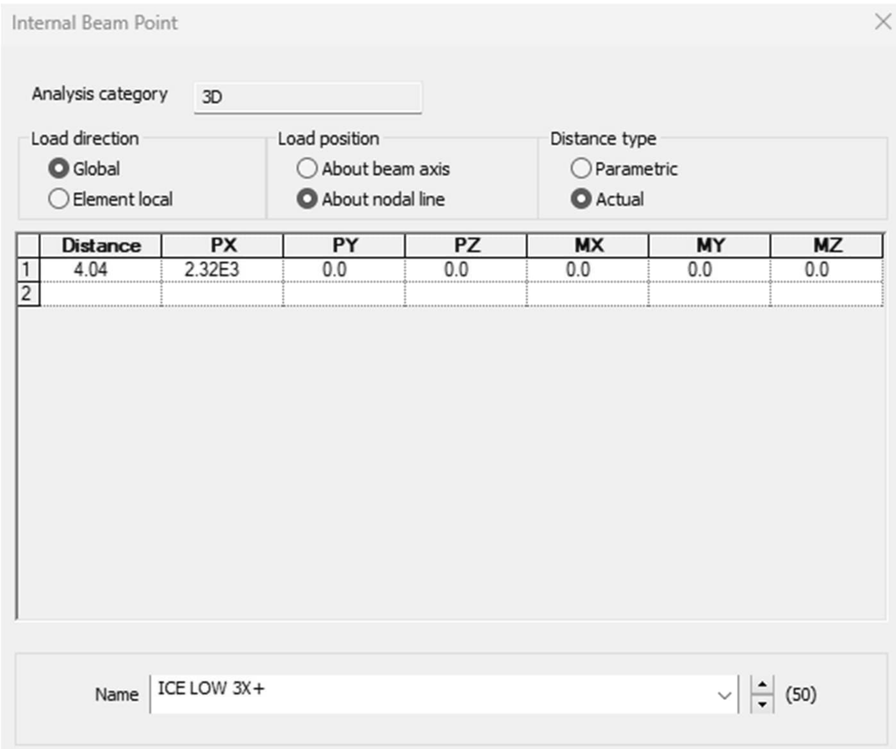
Load position: ( ) About beam axis (•) About nodal line

Distance type: ( ) Parametric (•) Actual

	Distance	PX	PY	PZ	MX	MY	MZ
1	4.04	2.32E3	0.0	0.0	0.0	0.0	0.0
2							

Name: ICE LOW 2X+ (48)

Load: ICE HIGH 3X+



Internal Beam Point

Analysis category: 3D

Load direction: (•) Global ( ) Element local

Load position: ( ) About beam axis (•) About nodal line

Distance type: ( ) Parametric (•) Actual

	Distance	PX	PY	PZ	MX	MY	MZ
1	4.04	2.32E3	0.0	0.0	0.0	0.0	0.0
2							

Name: ICE LOW 3X+ (50)

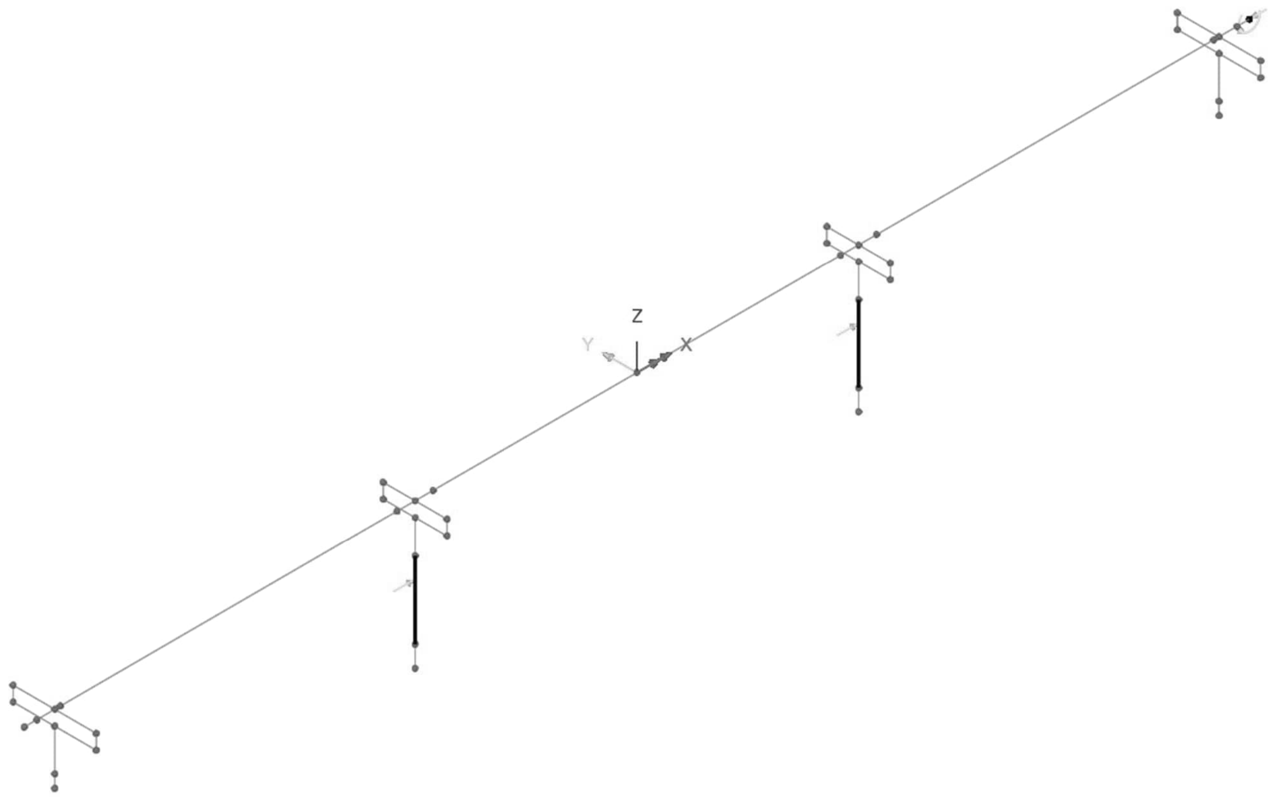
Loadcase: ICE LOW X+

$\Delta_{is}(f=0)=37.12mm$

$\Delta_{ice}(f=0.4646)=7.433\text{ mm assumed}\rightarrow \frac{v_{ice}}{v_p}=\frac{7.433mm}{16mm}=0.4646$

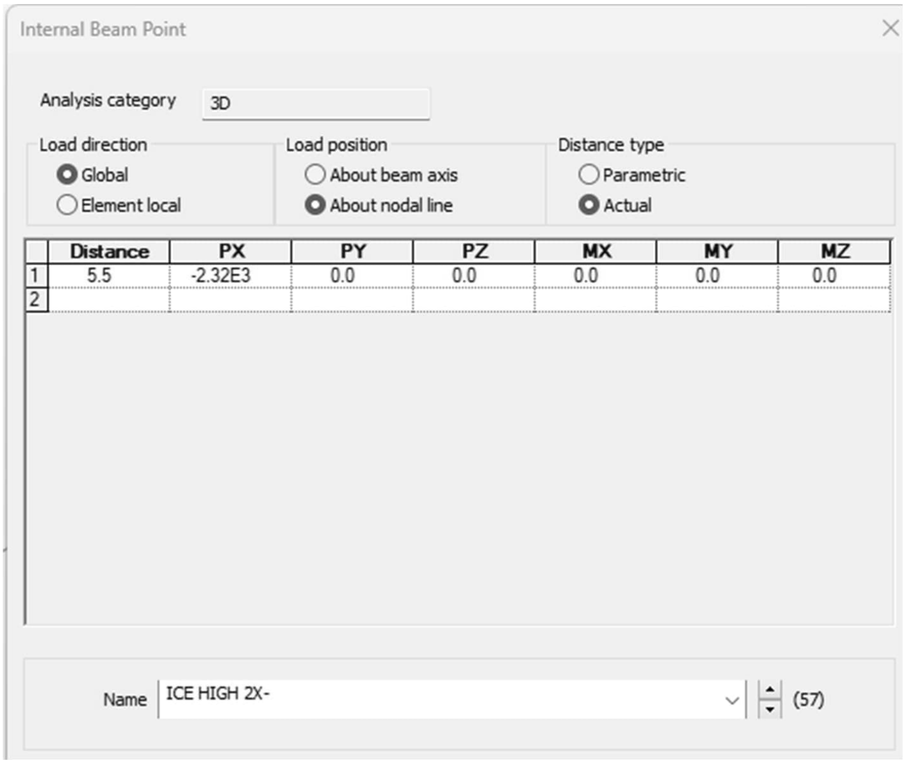
$v_{ice}=37.12\text{ mm - f}\cdot 63.9mm=97.434\text{ mm}\approx \Delta_{ice}(f=0.4646)\text{which was to be proven !}$

Load	Factor
ICE LOW 2X+	1
ICE HIGH 3X+	1
PASSIV 4X-	f = 0.4646



Overview 3D

Load : ICE HIGH 2X-


Internal Beam Point

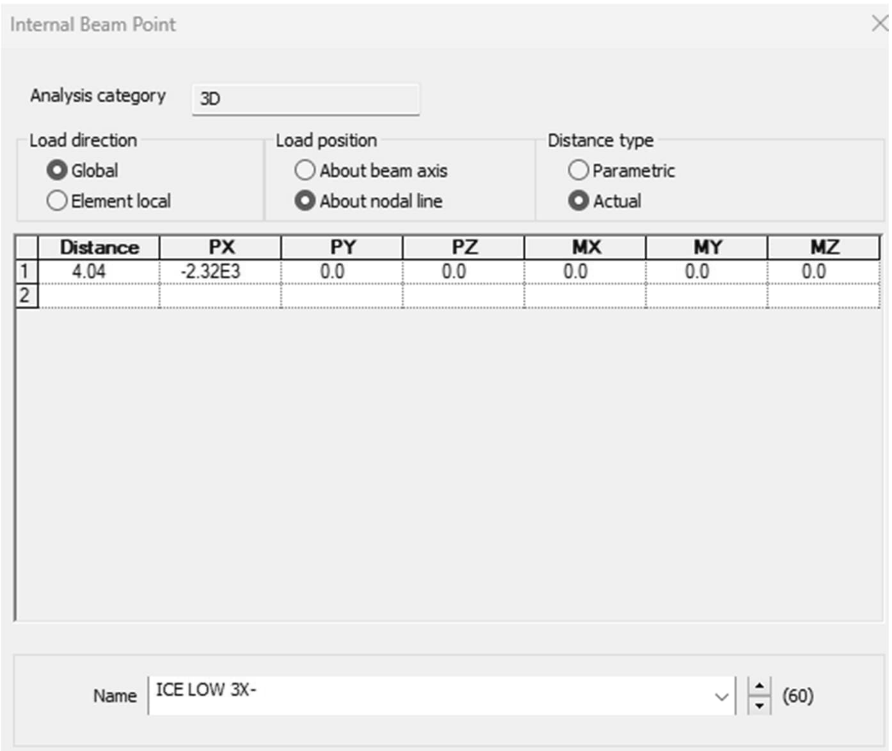
Analysis category: 3D

Load direction: (●) Global ( ) Element local
Load position: ( ) About beam axis (●) About nodal line
Distance type: ( ) Parametric (●) Actual

	Distance	PX	PY	PZ	MX	MY	MZ
1	5.5	-2.32E3	0.0	0.0	0.0	0.0	0.0
2							

Name: ICE HIGH 2X- (57)

Load : ICE LOW 3X-


Internal Beam Point

Analysis category: 3D

Load direction: (●) Global ( ) Element local
Load position: ( ) About beam axis (●) About nodal line
Distance type: ( ) Parametric (●) Actual

	Distance	PX	PY	PZ	MX	MY	MZ
1	4.04	-2.32E3	0.0	0.0	0.0	0.0	0.0
2							

Name: ICE LOW 3X- (60)

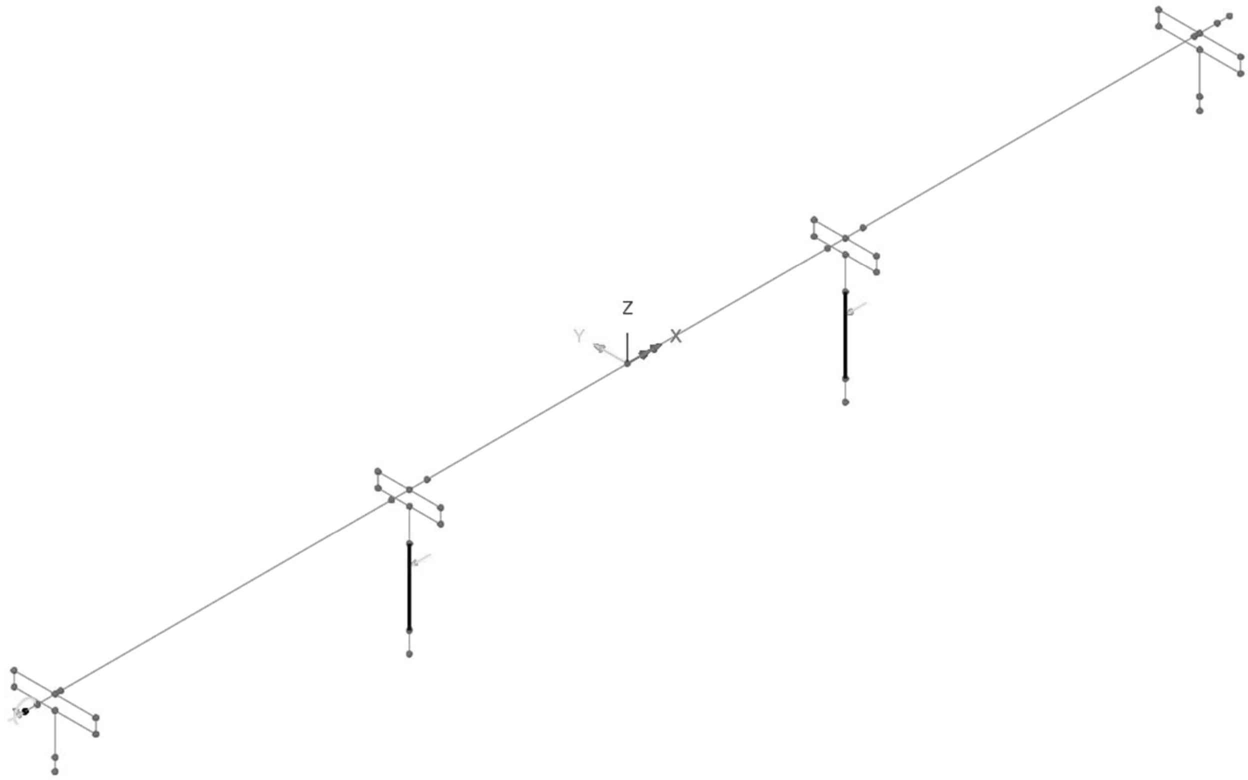
Loadcase: ICE LOW X-

$\Delta_{is}(f=0)=37.12mm$

$\Delta_{ice}(f=0.4646)=7.433\text{ mm assumed}\rightarrow\frac{v_{ice}}{v_p}=\frac{7.433mm}{16mm}=0.4646$

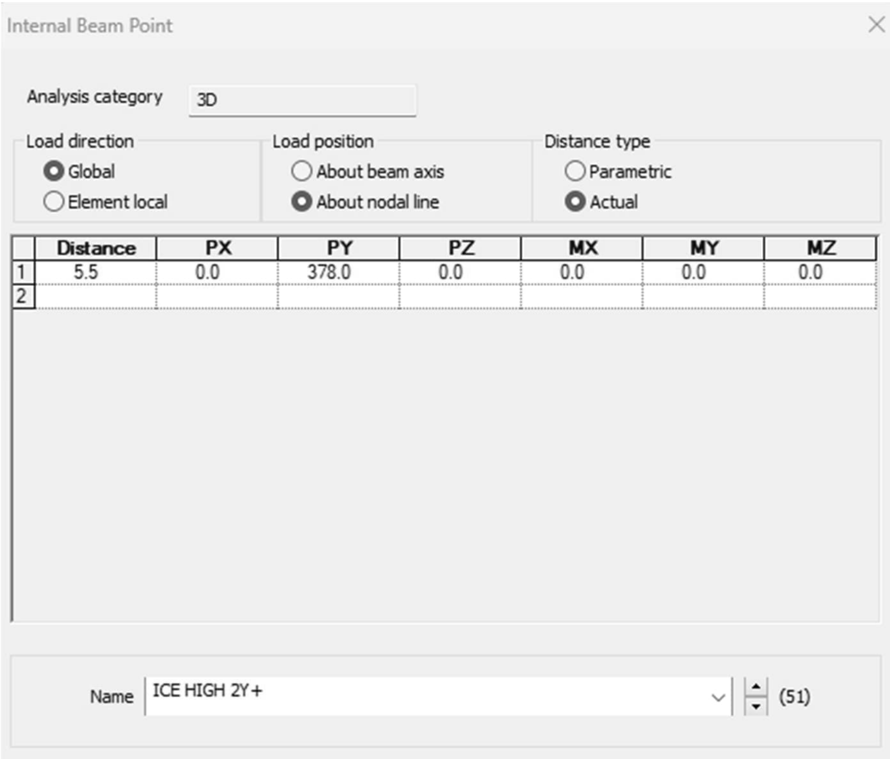
$v_{ice}=37.12\text{ mm - }f\cdot 63.9mm=97.434\text{ mm}\approx\Delta_{ice}(f=0.4646)$ which was to be proven !

Load	Factor
ICE HIGH 2X-	1
ICE HIGH 3X-	1
PASSIV 1X+	0.4646

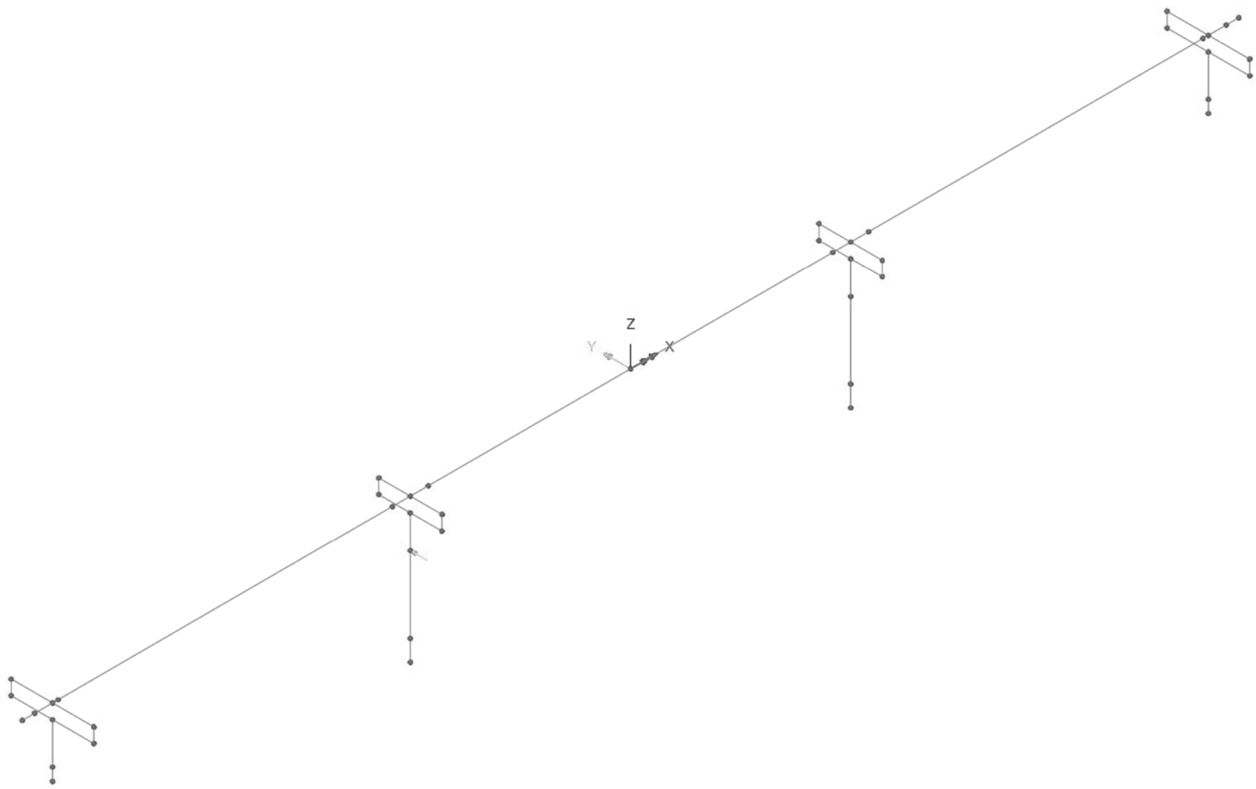


Overview 3D

Load case : ICE HIGH 2Y+

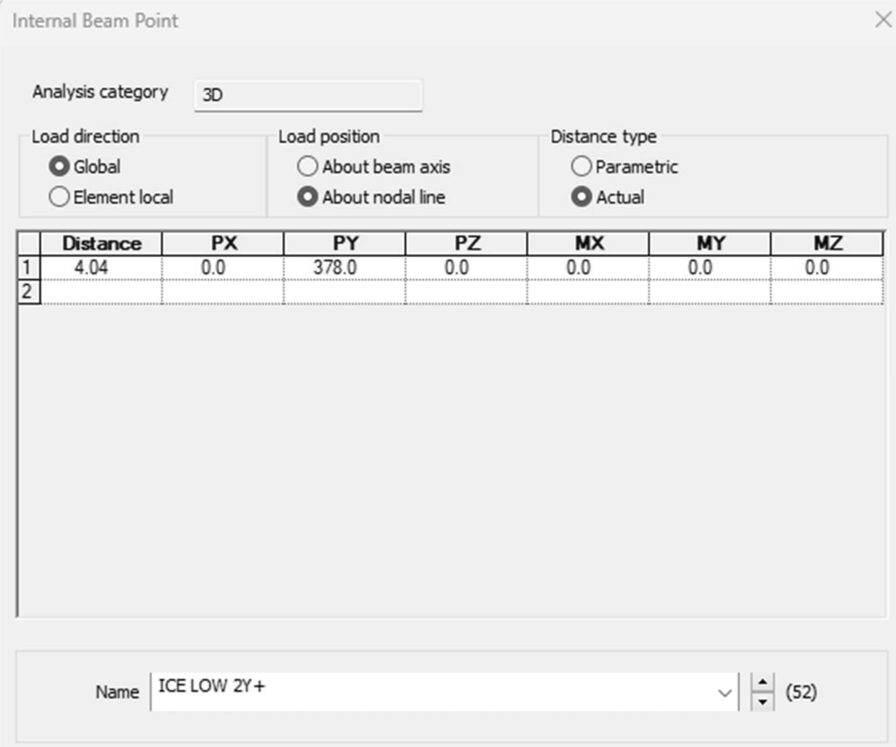


	Distance	PX	PY	PZ	MX	MY	MZ
1	5.5	0.0	378.0	0.0	0.0	0.0	0.0
2							

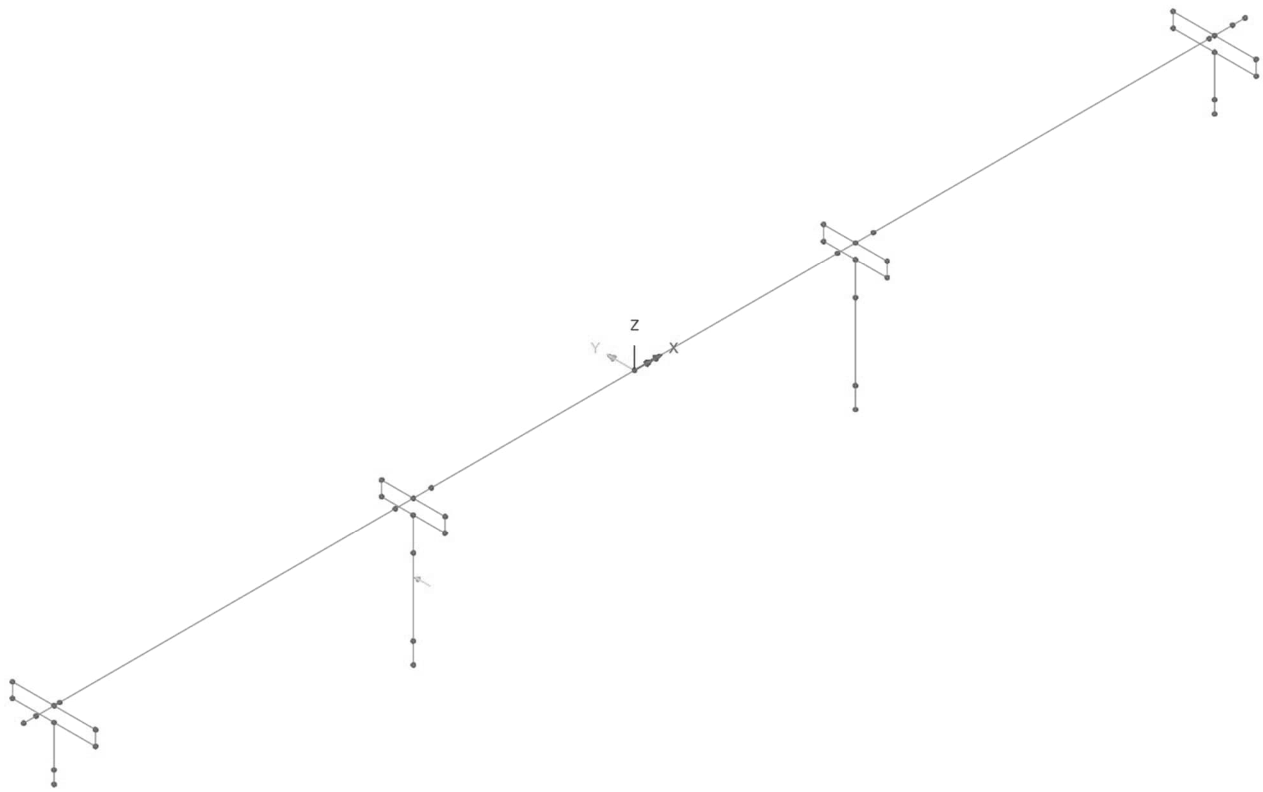


Overview 3D

Load case : ICE LOW 2Y+

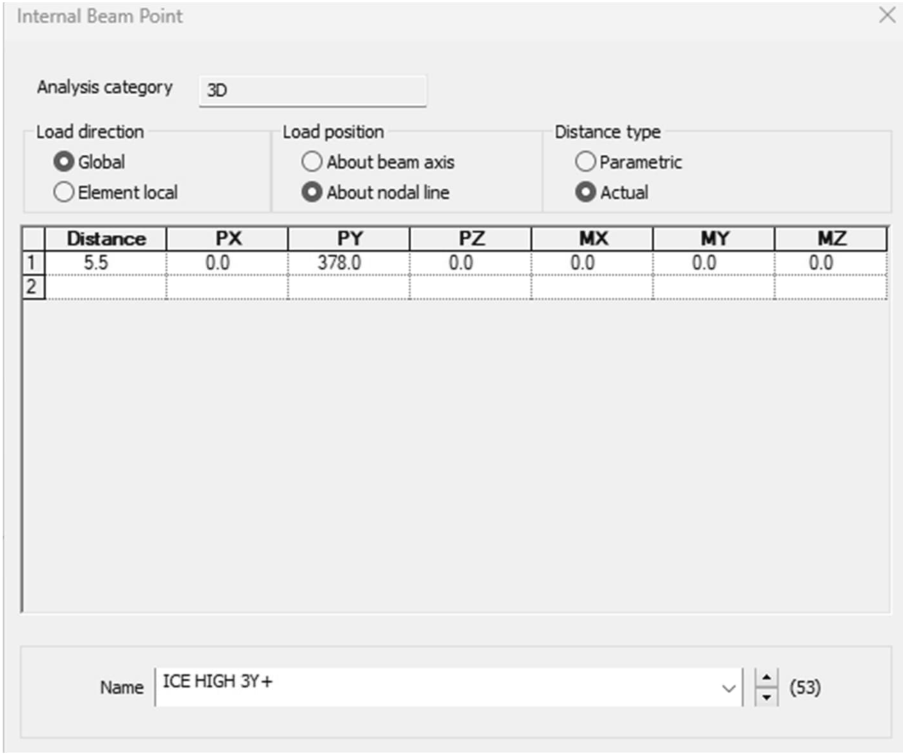


	Distance	PX	PY	PZ	MX	MY	MZ
1	4.04	0.0	378.0	0.0	0.0	0.0	0.0
2							



Overview 3D

Load case : ICE HIGH 3Y+



Internal Beam Point

Analysis category: 3D

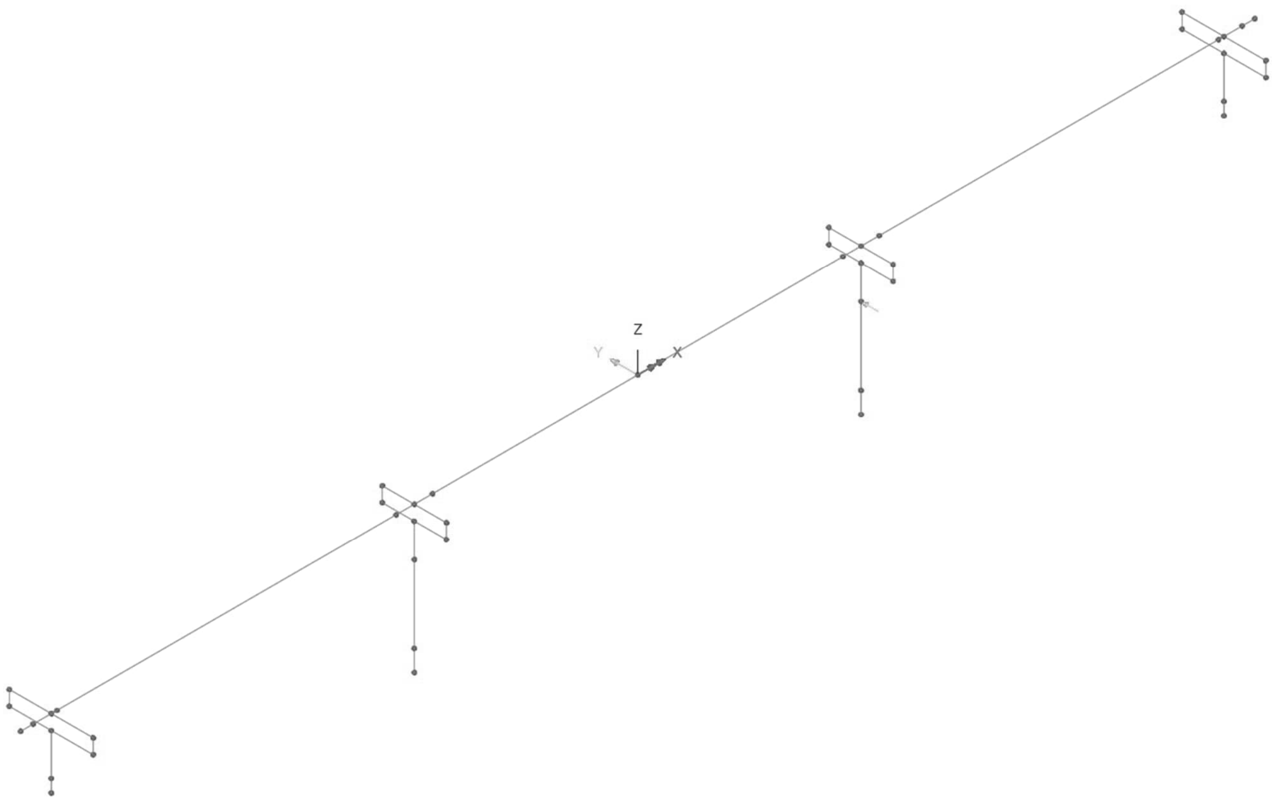
Load direction: (•) Global ( ) Element local

Load position: ( ) About beam axis (•) About nodal line

Distance type: ( ) Parametric (•) Actual

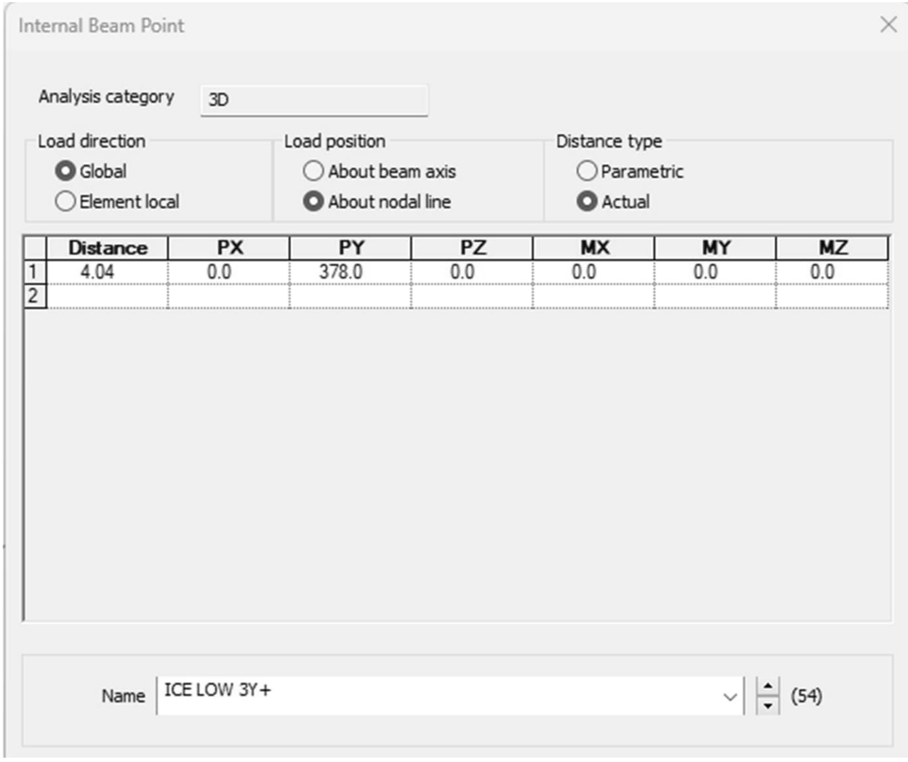
	Distance	PX	PY	PZ	MX	MY	MZ
1	5.5	0.0	378.0	0.0	0.0	0.0	0.0
2							

Name: ICE HIGH 3Y+ (53)



Overview 3D

Load case : ICE LOW 3Y+



Internal Beam Point

Analysis category: 3D

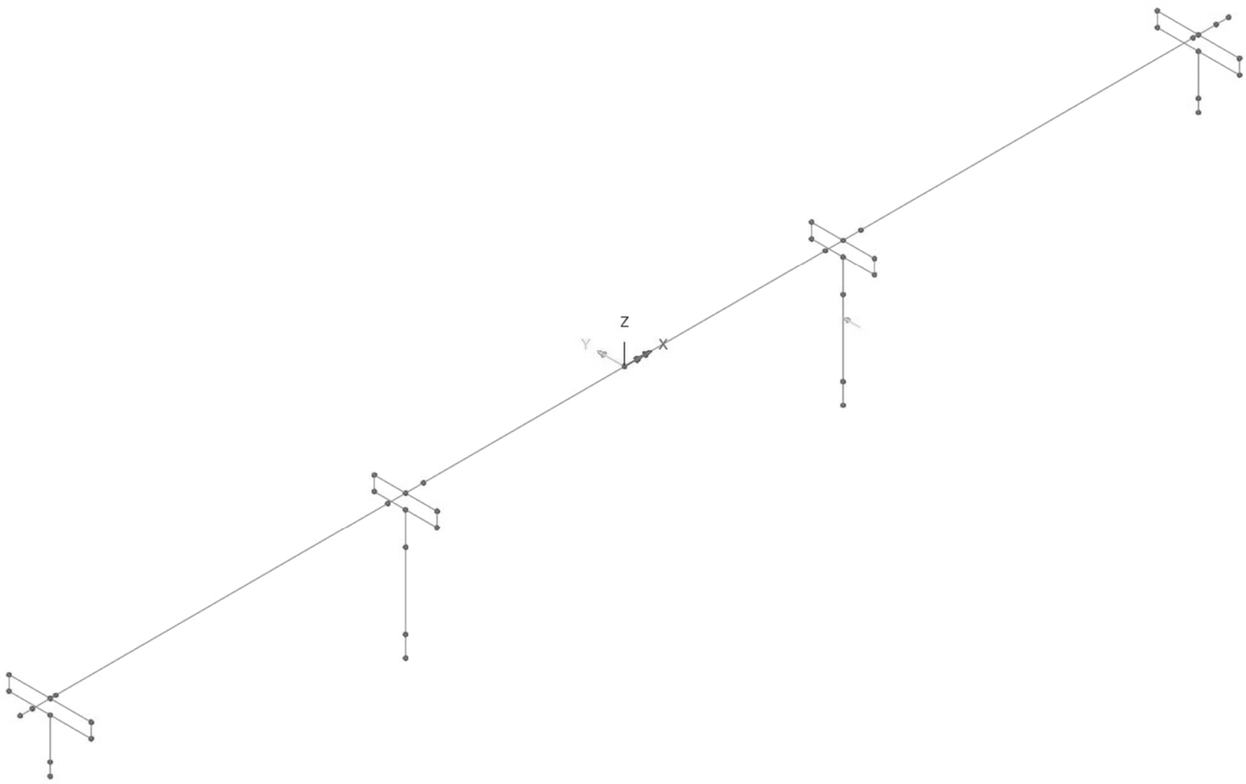
Load direction: (•) Global ( ) Element local

Load position: ( ) About beam axis (•) About nodal line

Distance type: ( ) Parametric (•) Actual

	Distance	PX	PY	PZ	MX	MY	MZ
1	4.04	0.0	378.0	0.0	0.0	0.0	0.0
2							

Name: ICE LOW 3Y+ (54)



Overview 3D

Load case : ICE 2Z

Internal Beam Point

Analysis category: 3D

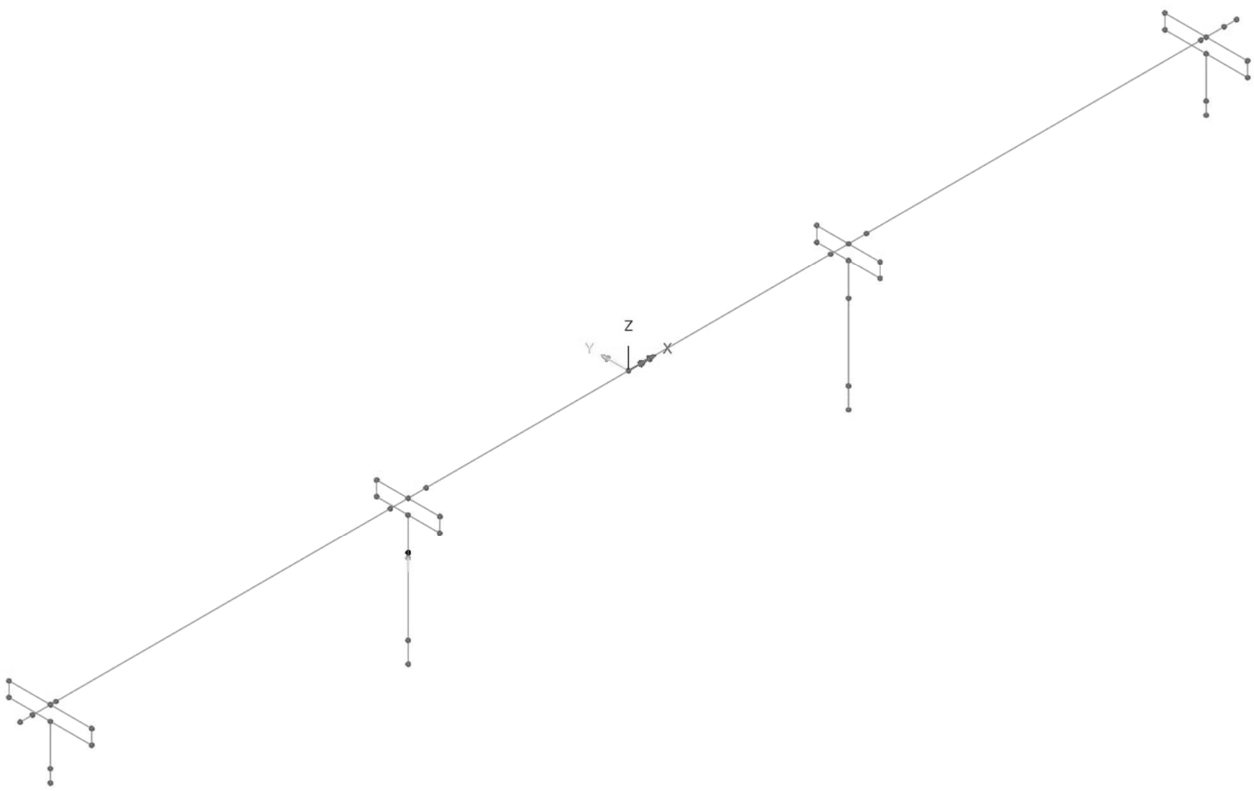
Load direction: (●) Global ( ) Element local

Load position: ( ) About beam axis (●) About nodal line

Distance type: ( ) Parametric (●) Actual

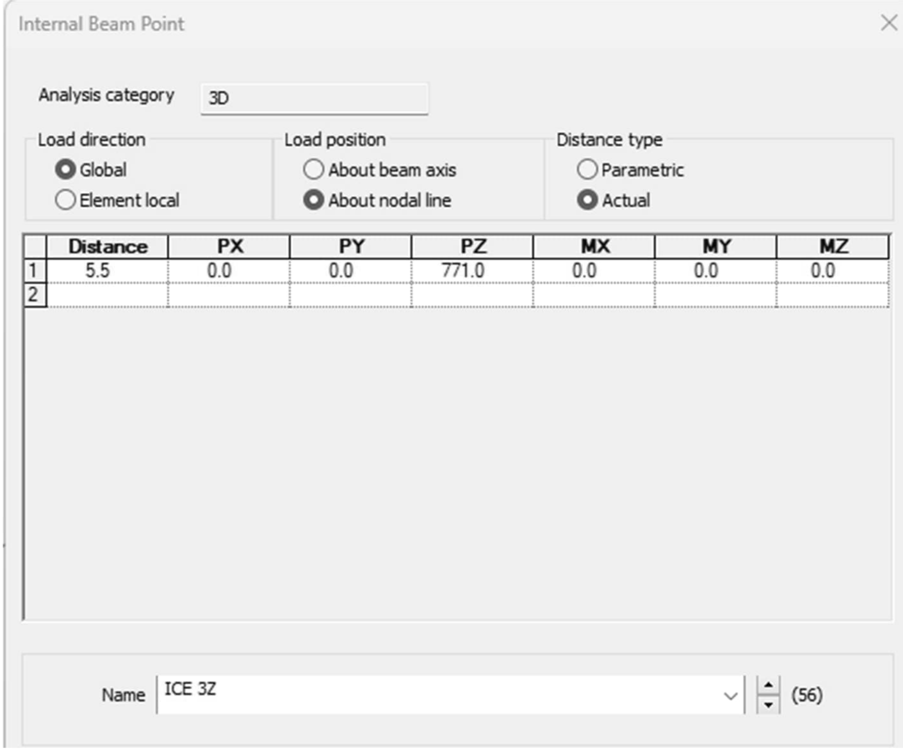
	Distance	PX	PY	PZ	MX	MY	MZ
1	5.5	0.0	0.0	771.0	0.0	0.0	0.0
2							

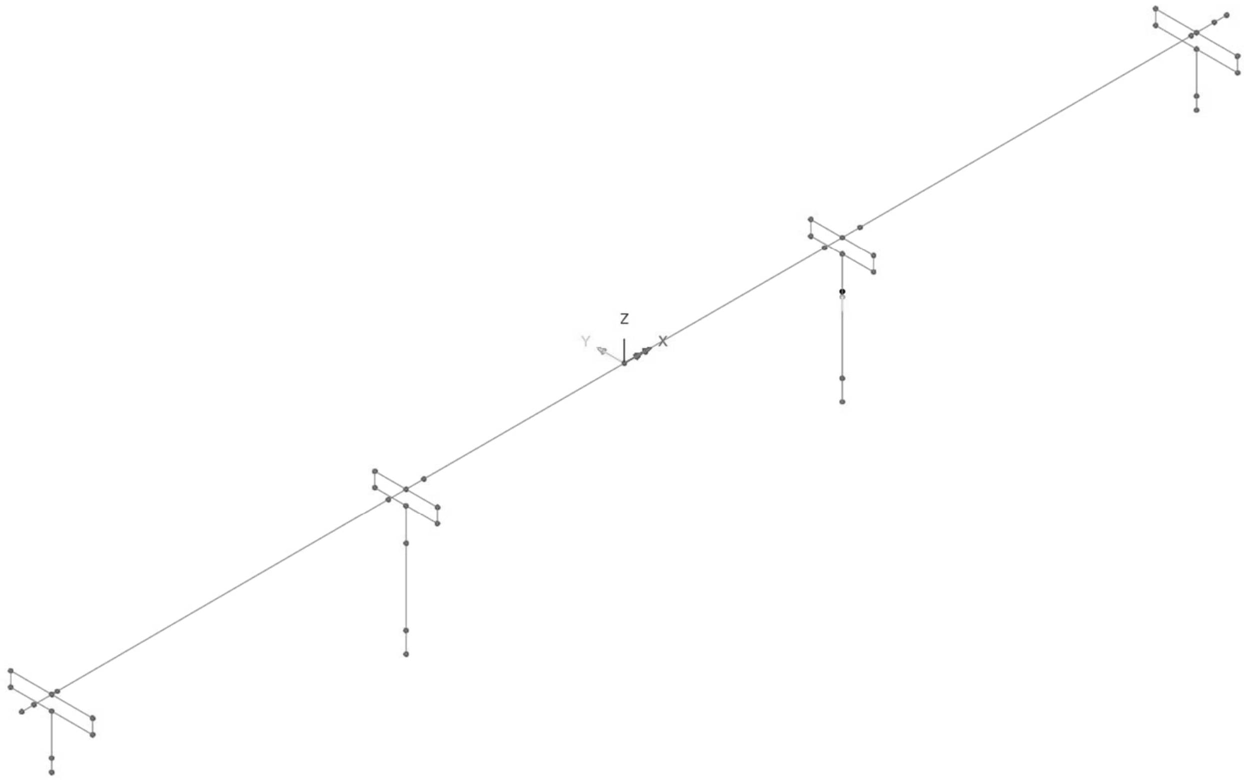
Name: ICE 2Z (55)



Overview 3D

Load case : ICE 3Z





Overview 3D

3.13.2 Load combination

Load combination smart ICE HIGH Y :

Loadcase	Permanent factor	Variable factor
ICE HIGH 2Y+	0	+1
ICE HIGH 2Y+	0	-1
ICE HIGH 3Y+	0	+1
ICE HIGH 3Y+	0	-1

Load combination smart ICE LOW Y :

Loadcase	Permanent factor	Variable factor
ICE LOW 2Y+	0	+1
ICE LOW 2Y+	0	-1
ICE LOW 3Y+	0	+1
ICE LOW 3Y+	0	-1

Load combination smart ICE Z :

Loadcase	Permanent factor	Variable factor
ICE Z	0	+1
ICE Z	0	+1

Envelope ICE :

Load case
ICE HIGH X+
ICE LOW X+
ICE HIGH X-
ICE LOW X
ICE HIGH Y
ICE LOW Y
ICE Z

3.14 PRESTESS

Analysis of pre tensioned cable is studied at times : t_0 (5 days), t_1(30 days) and t_2 (120 years).

The preliminary location of cables is determined with program PROG B2.001.

The location is imported as a spread sheet into LUSAS as a tension profile. The location is defined with to nodal lines.

Initial prestress loss at time t0 is only due to friction. This is determined with LUSAS and program PROG B2.001.

Determination of time loses (η_t) is made in separate program PROG B2.002. Preliminary analysis will use losses seen below. They will be verified later during detailed design.

Time	η_t	Load combination	Load case
t0	0 %	PT-T0	1.00 x PT-T0
t1	6 %	PT-T1	0.94 x PT-T0
t2	16 %	PT-T2	0.84 x PT-T0

3.14.1 General

Pre tensions system VSL 6-15 (d = 15.7 mm; Y1860S7). Externally grouted anchorage type GC.

Material :

$f_{p0.1k} = 1640\,MPa$

$f_{pk} = 1860 MPa$

$E_{sk} = 195 GPa$

$\mu = 0.18$

$k = 0.005 \cdot \frac{1}{m}$

Casting tube :
80 mm / 86 mm

Slip during locking:
6 mm

Permissible curvature :
$R_{\min} = 5.7 m$

Cabel area :
$A_p = 15 \cdot 150\,mm^2 = 2250\,mm^2$

Anchor plate :
290 mm x 290 mm (same for both passiv and active anchorage)

Ultimate load :
$F_u = 2250 mm^2 \cdot 1860\,MPa = 4185 kN$

Permissible stress before locking :
See SS-EN 1992-1-1 section 5.10.2.1

$$\sigma_{p,\max}^{före} = \min(0.8\,f_{pk};0.9\,f_{p0.1k}) = \min(1488\,MPa;1476\,MPa) = 1476\,MPa$$

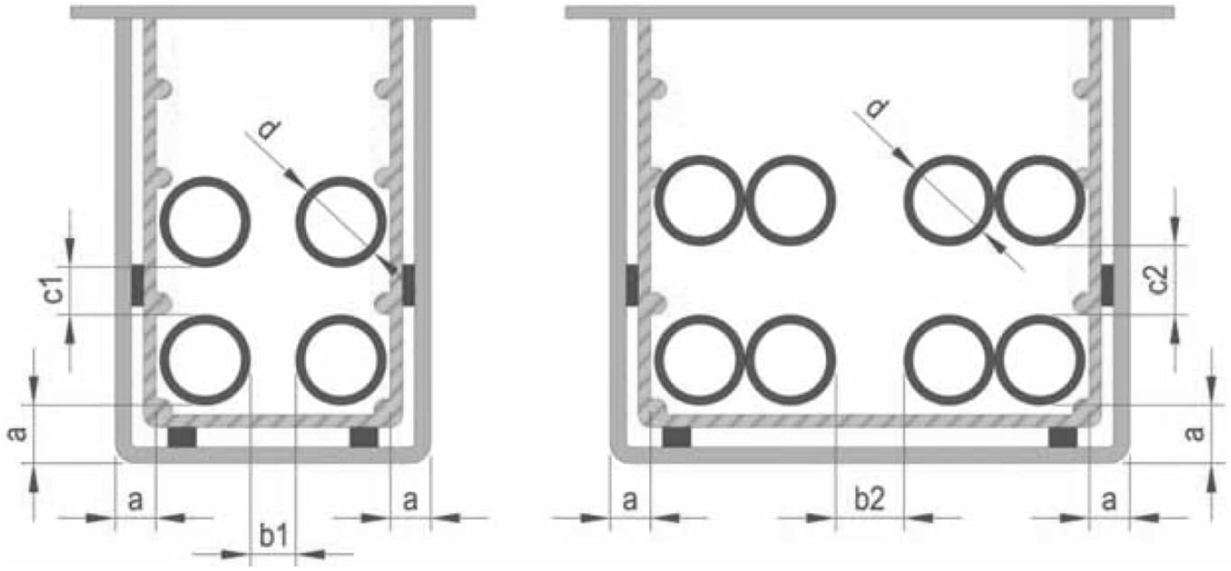
Permissible stress after locking :
See SS-EN 1992-1-1 section 5.10.3

$$\sigma_{p,\max}^{efter} = \min(0.75\,f_{pk};0.85\,f_{p0.1k}) = \min(1395\,MPa;1394\,MPa) = 1394\,MPa$$

3.14.2 Execution

Associated to pre tension system VSL 6-15.

Recommended measurements :



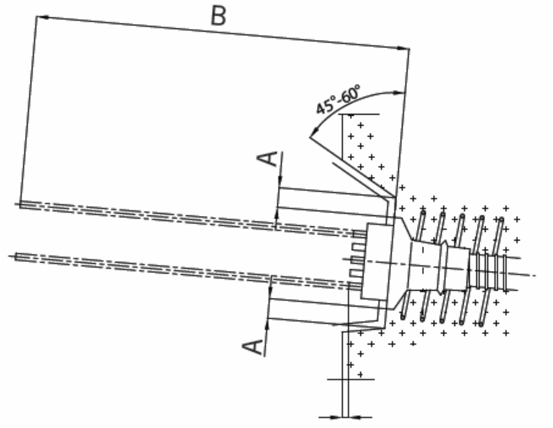
d = 90 mm

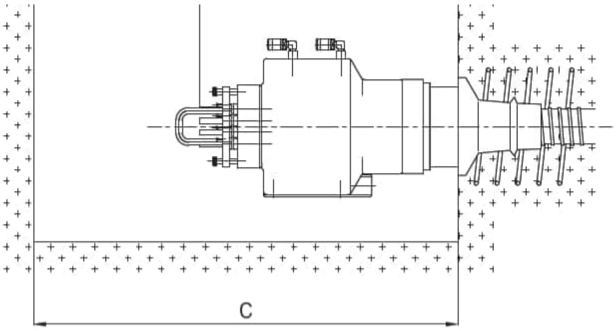
a > 50 mm

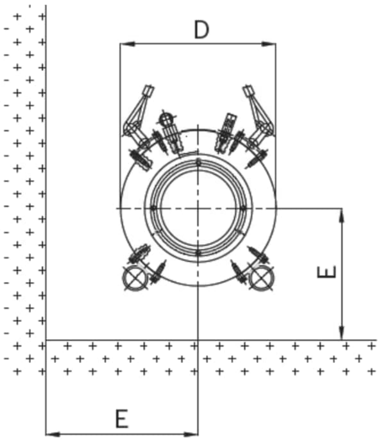
b1, c1 > 0.7d = 63 mm but 100 chosen !

b2, c2 > 1.0d = 90 mm but 100 mm chosen !

Demand for space during tensioning :





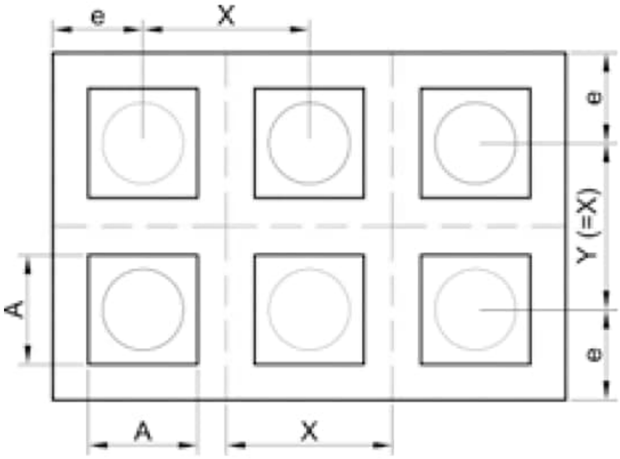


A = 70 mm

B = 1200 mm

C = 1700 mm

Measurements of cables VSL 6-15 :



A = 290 mm

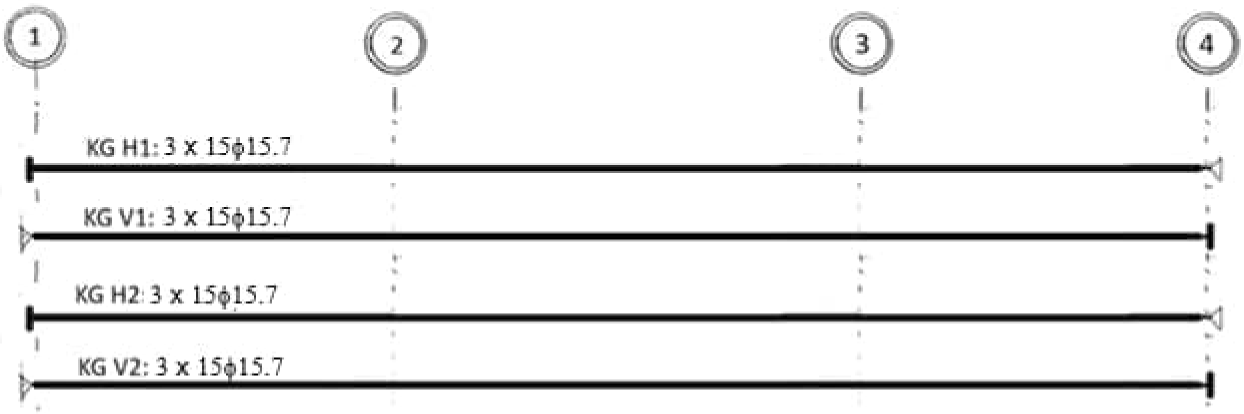
e ≥ 175 mm + TB

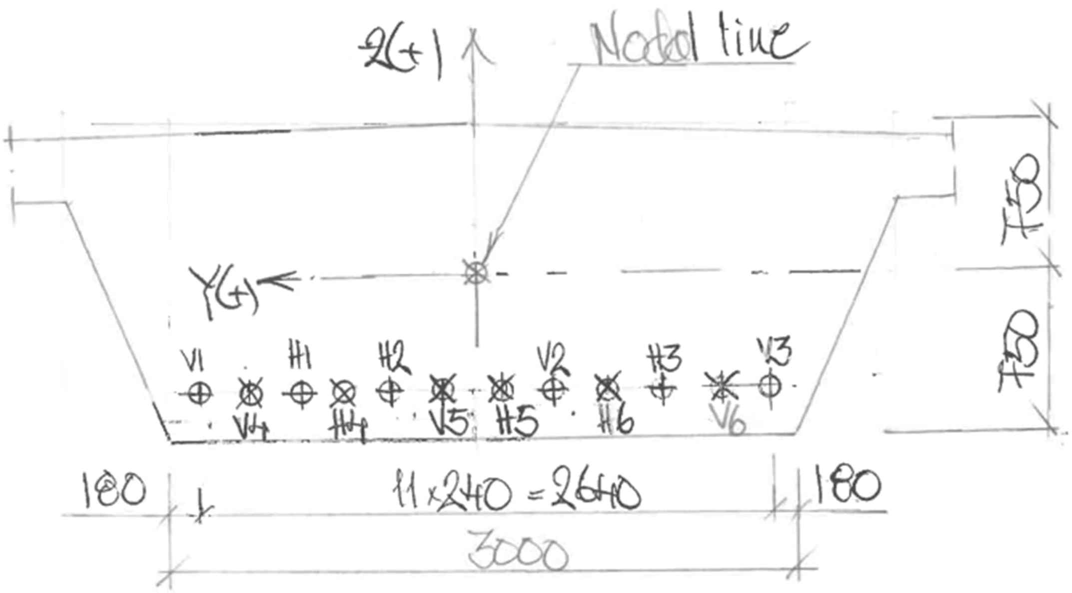
X ≥ 400 mm

3.14.3 Preliminary cable location

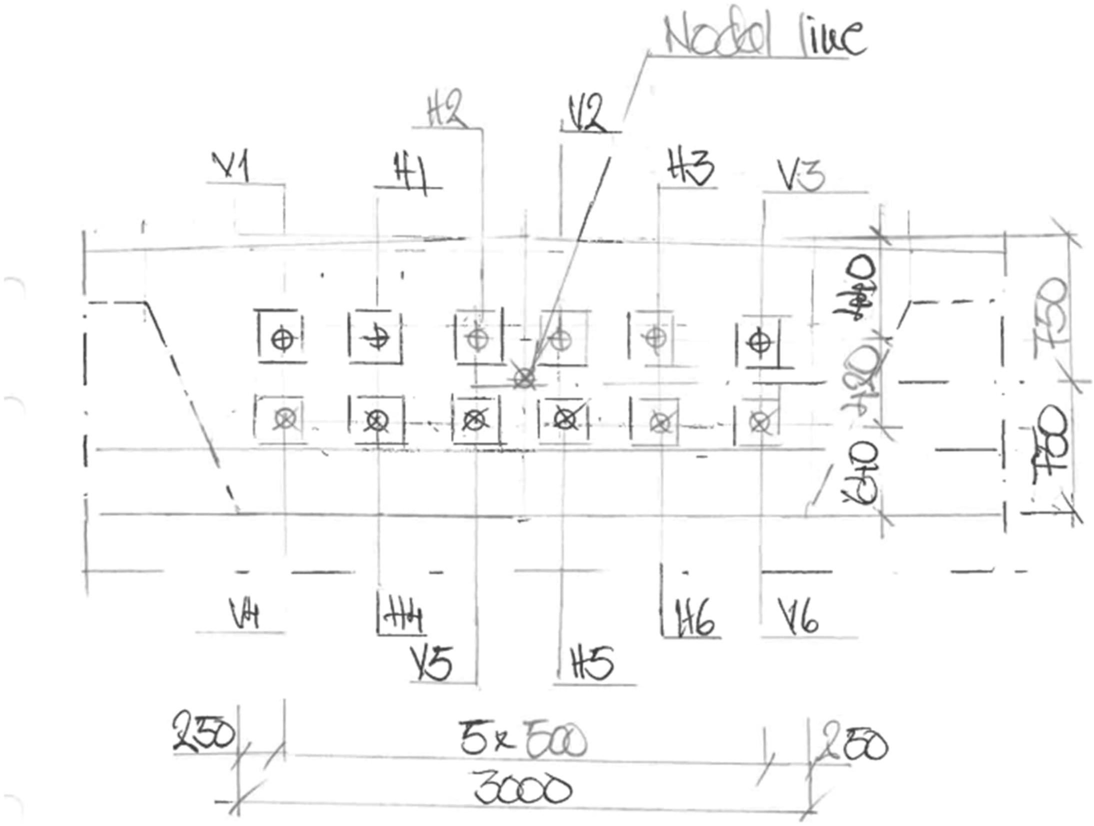
In the static model cables are simplified (= 3 cables are modelled as one fictive cable as seen below).

Profiles can be defined using “global coordinates” or as “local coordinates mapped to lines”. The later of this method is used.

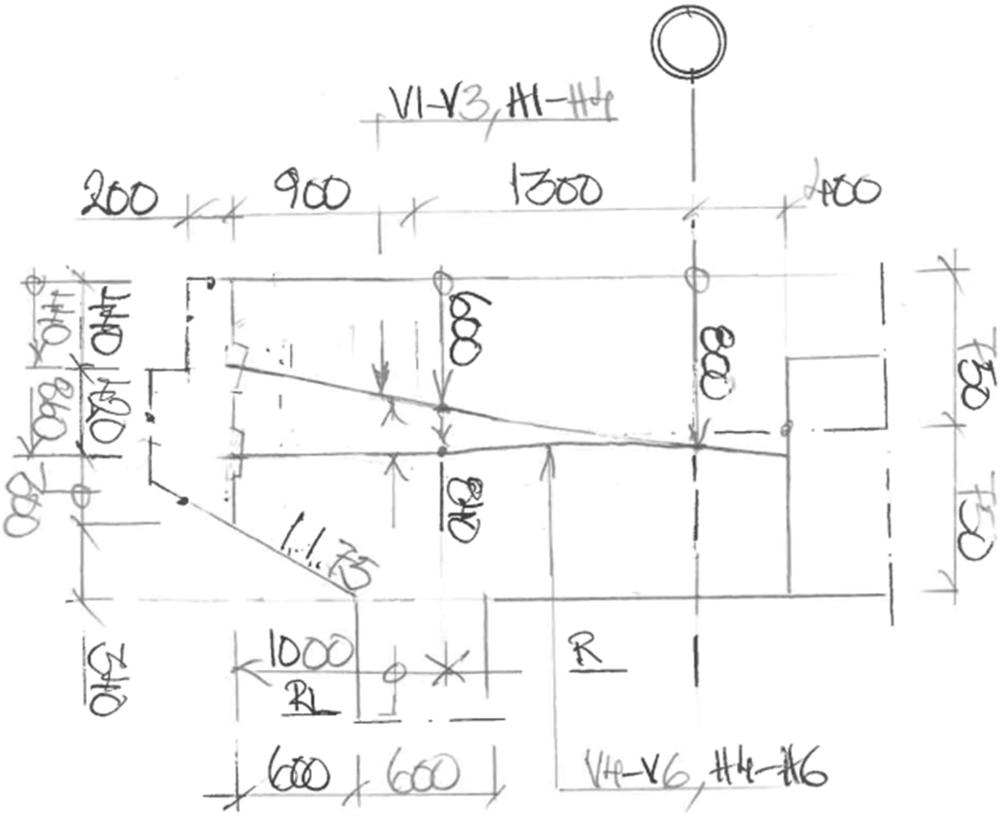




Cross section

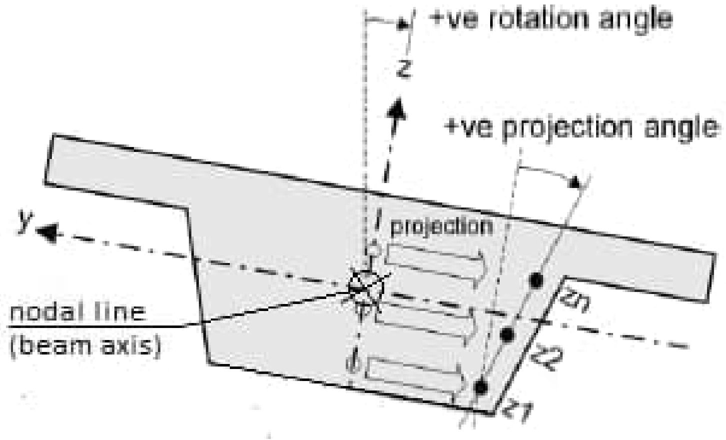


Detail 1
Cross section at end of tendon.



Detail 2,
Longitudinal section at end of tendon.

Principle sketch:



Summary input - pretensioned cables:

Cable	Area	Slip	Left side	Right side	Max. prestress before	Min. prestress after	Pretension force	Location y(+)
KG-V1	2250	6	Active	Passive	1476	1394	3150*	0
KG-H1	2250	6	Passive	Active	1476	1394	3150*	0
KG-V2	2250	6	Active	Passive	1476	1394	3150*	0
KG-H2	2250	6	Passive	Active	1476	1394	3150*	0
-	mm^2	mm	-	-	MPa	MPa	kN	m

* = chosen prestress 1400 MPa

Loadcase	Cables	Fictive load
KG V1	3	3 x KG-V1
KG H1	3	3 x KG-H1
KG V2	3	3 x KG-V2
KG H2	3	3 x KG-H2

Tendon profile KG V1 & KG 1:
See spread sheet input see page A3:144.

x(+) : $x_p(+)$

y(+) : 0 m

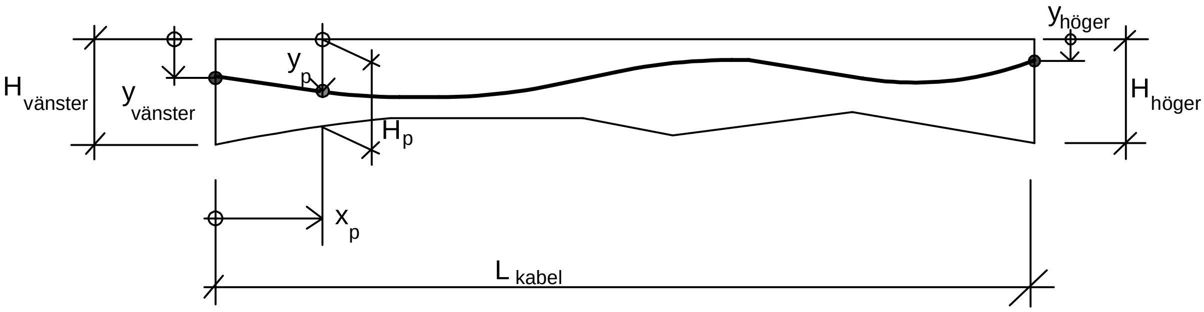
z(+): 0.75 m - $y_p(+)$

x(+)	z(+)	
0	0.31	← 0.75 m – 0.44 m
1.00	0.15	
2.20	-0.05	
7.20	-0.50	
12.20	-0.55	
21.20	0.15	
28.20	0.55	
34.20	0.25	
44.20	-0.65	
54.20	0.15	
60.20	0.55	
67.20	0.15	
76.20	-0.55	
81.20	-0.50	
86.20	-0.05	
87.40	0.15	
88.40	0.31	← 0.75 m – 0.44 m
m	m	

Remark
Profile used for tendons V1-V3 & H1-H3. Cables are placed at nodal line in transversal direction.

Object: Cables V1-V3 (H1-H3)

PRINCIPFIGUR



INDATA

Total kabellängd: $L_{kabel} = 2.2m + 26m + 32m + 26m + 2.2m = 88.4\,m$

Ange antalet kända brytpunkter: $N = 17 \cdot st$

Fiktionskoefficienter spännarmering: $\mu = 0.18$ $k = 0.005 \cdot \frac{rad}{m}$

Draghållfasthet spännarmering : $f_{p0.1k} = 1640MPa$

$f_{pk} = 1860MPa$

E-modul spännarmering: $E_s = 195 \cdot GPa$

Area spännarmering : $A_s = 2250mm^2$

Största tillåtna spännkraft före låsning enligt SS-EN 1992-1-1 avsnitt 5.10.2.1 :

$$\min\left(0.8 \cdot f_{pk}, 0.9 \cdot f_{p0.1k}\right) \cdot A_s = 3321 \cdot kN$$

Vald uppspänningskraft:

$$V_{ö} = 3320kN = 3320 \cdot kN$$

Största tillåtna spännkraft efter låsning enligt SS-EN 1992-1-1 avsnitt 5.10.3 :

$$\min\left(0.75 \cdot f_{pk}, 0.85 \cdot f_{p0.1k}\right) \cdot A_s = 3136 \cdot kN$$

Typ av förankring ("Passiv" eller "Aktiv") / vald maximal kabelkraft efter låsning :

Snitt	Typ	V_{max} [kN]
Vänster	Aktiv	3130
Höger	Passiv	3130

<u>Ge brytpunkter i kabelföring :</u>

Snitt	x_p (m)	y_p (mm)	H_p (mm)
1	0	440	1500
2	1.000	600	1500
3	2.200	800	1500
4	7.200	1250	1500
5	12.200	1300	1500
6	21.200	600	1500
7	28.200	200	1500
8	34.200	500	1500
9	44.200	1400	1500
10	54.200	600	1500
11	60.200	200	1500
12	67.200	600	1500
13	76.200	1300	1500
14	81.200	1250	1500
15	86.200	800	1500
16	87.400	600	1500
17	88.400	440	1500

STEP 2 ⇒

x	w
0	0.31
1.00	0.15
2.20	-0.05
7.20	-0.50
12.20	-0.55
21.20	0.15
28.20	0.55
34.20	0.25
44.20	-0.65
54.20	0.15
60.20	0.55
67.20	0.15
76.20	-0.55
81.20	-0.50
86.20	-0.05
87.40	0.15
88.40	0.31

LUSAS ⇒

x(+)	z(+)
0	0.31
1.00	0.15
2.20	-0.05
7.20	-0.50
12.20	-0.55
21.20	0.15
28.20	0.55
34.20	0.25
44.20	-0.65
54.20	0.15
60.20	0.55
67.20	0.15
76.20	-0.55
81.20	-0.50
86.20	-0.05
87.40	0.15
88.40	0.31

BERÄKNING

Skapa matematiska funktioner för balk och kabel

$C = \text{pspline}(x_p, y_p)$: bestämning av koefficienter parabel splinefunktioner

$y(x) = \text{interp}(C, x_p, y_p, x)$: kabelföring (= splinefunktioner)

$y'(x) = \frac{d}{dx} y(x)$: lutning kabelföring

$y''(x) = \frac{d^2}{dx^2} y(x)$: lutningsförändring kabelföring

$R_{min} = \frac{1}{\max(y''(x))}$: minsta kökningsradie

Friktionsförlust funktion mät ifrån "vänster" sida

$$\alpha_v = \text{if}\left(i > 1, \sum_{j=2}^{i} \left|y'(x_j) - y'(x_{j-1})\right|, 0\right)$$

: ackumulerade vinkeländringar

$$\beta_v = \mu\cdot(\alpha_v + k\cdot X)$$

: exponent friktionsförluster

$$\beta_v = \mu\cdot(\alpha_v + k\cdot x)$$

: exponent friktionsförluster

$$\eta_{vf} = e^{-\beta_v}$$

: friktionsförluster före låsning

$$\eta_{ve} = e^{\beta_v}$$

: friktionsförlust efter låsning

Bestämning av läge för maximal kabelkraft **efter** låsning :

$$X_{mv} = \left| \begin{array}{l} x_{skär} \leftarrow 0m \quad \text{if} \quad Typ = \text{"Passiv"} \\ \text{if} \quad Typ = \text{"Aktiv"} \\ \quad \left| \begin{array}{l} x_{start} \leftarrow 2m \\ x_{skär} \leftarrow \text{root}\left(V_{max} - V_ö\cdot\text{linterp}\left(X, \eta_{vf}, x_{start}\right), x_{start}\right) \end{array} \right. \end{array} \right.$$

Friktionsförlust funktion mät ifrån "höger" sida

$$\alpha_h = \text{if}\left(i < n, \sum_{j=i+1}^{n} \left|y'(x_j) - y'(x_{j-1})\right|, 0\right)$$: ackumulerade vinkeländringar

$$\beta_h = \mu \cdot \left[\alpha_h + k \cdot \left(L_{kabel} - x\right)\right]$$: exponent friktionsförluster

$$\eta_{hf} = e^{-\beta_h}$$: friktionsförluster före låsning

$$\eta_{he} = e^{\beta_h}$$: friktionsförlust efter låsning

Bestämning av läge för maximal kabelkraft **efter** låsning :

$$X_{mh} = \begin{array}{|l} x_{skär} \leftarrow L_{kabel} \;\; \text{if} \;\; Typ = \text{"Passiv"} \\ \text{if} \;\; Typ = \text{"Aktiv"} \\ \quad \begin{array}{|l} x_{start} \leftarrow L_{kabel} - 2m \\ x_{skär} \leftarrow \text{root}\left(V_{max} - V_{ö} \cdot \text{linterp}\left(X, \eta_{hf}, x_{start}\right), x_{start}\right) \end{array} \end{array}$$

Bestämning skärning mellan kurva kabelkraft vänster resp. höger

$$X_m = \begin{array}{|l} x_{skär} \leftarrow L_{kabel} \;\; \text{if} \;\; Typ = \text{"Aktiv"} \wedge Typ = \text{"Passiv"} \\ x_{skär} \leftarrow 0m \;\; \text{if} \;\; Typ = \text{"Passiv"} \wedge Typ = \text{"Aktiv"} \\ \text{if} \;\; Typ = \text{"Aktiv"} \wedge Typ = \text{"Aktiv"} \\ \quad \begin{array}{|l} x_{start} \leftarrow 0.5 \cdot L_{kabel} \\ x_{skär} \leftarrow \text{root}\left(V_{ö} \cdot \text{linterp}\left(X, \eta_{vf}, x_{start}\right) - V_{ö} \cdot \text{linterp}\left(X, \eta_{hf}, x_{start}\right), x_{start}\right) \end{array} \end{array}$$

Bestämning av kabelkraft efter låsning i resp. balkände

Kabelkraft på vänster sida :

$$P_{ve} = \begin{cases} V_{max} \cdot \text{linterp}\left(X, \eta_{hf}, 0m\right) & \text{if } \text{Typ} = \text{"Passiv"} \\ \dfrac{V_{max}}{\text{linterp}\left(X, \eta_{ve}, X_{mv}\right)} & \text{if } \text{Typ} = \text{"Aktiv"} \end{cases}$$

Kabelkraft på höger sida :

$$P_{he} = \begin{cases} V_{max} \cdot \text{linterp}\left(X, \eta_{vf}, L_{kabel}\right) & \text{if } \text{Typ} = \text{"Passiv"} \\ \dfrac{V_{max}}{\text{linterp}\left(X, \eta_{he}, X_{mh}\right)} & \text{if } \text{Typ} = \text{"Aktiv"} \end{cases}$$

Bestämning av eftersläppning / "låsglidning"

Vänster sida :

$$\Delta L_v = \text{if}\left[\text{Typ} = \text{"Aktiv"}, \frac{1}{A_s \cdot E_s}\int_0^{X_{mv}} \left(V_ö \cdot \text{linterp}(X, \eta_{vf}, x) - P_{ve} \cdot \text{linterp}(X, \eta_{ve}, x)\right) dx, 0\right]$$

Höger sida :

$$\Delta L_h = \text{if}\left[\text{Typ} = \text{"Aktiv"}, \frac{1}{A_s \cdot E_s}\int_{X_{mh}}^{L_{kabel}} \left(V_ö \cdot \text{linterp}(X, \eta_{hf}, x) - P_{ve} \cdot \text{linterp}(X, \eta_{he}, x)\right) dx, 0\right]$$

Bestämning kabelförlängning före låsning

Vänster sida :

$$L_v = \frac{1}{A_s \cdot E_s}\int_0^{X_m} \left(V_ö \cdot \text{linterp}(X, \eta_{vf}, x)\right) dx$$

Höger sida :

$$L_h = \frac{1}{A_s \cdot E_s}\int_{X_m}^{L_{kabel}} \left(V_ö \cdot \text{linterp}(X, \eta_{hf}, x)\right) dx$$

Bestäm funktion för bestämning av godtycklig kabelkraft före låsning

$$P_{före} = \begin{vmatrix} V_{ö} \cdot \text{linterp}(X, \eta_{lvf}, x) & \text{if } x \le X_m \\ V_{ö} \cdot \text{linterp}(X, \eta_{lhf}, x) & \text{if } x > X_m \end{vmatrix}$$

Bestäm funktion för bestämning av godtycklig kabelkraft efter låsning

$$P_{efter} = \begin{vmatrix} P_{ve} \cdot \text{linterp}(X, \eta_{lve}, x) & \text{if } x \le X_{mv} \\ V_{ö} \cdot \text{linterp}(X, \eta_{lvf}, x) & \text{if } X_{mv} < x < X_m \\ V_{ö} \cdot \text{linterp}(X, \eta_{lhf}, x) & \text{if } X_m \le x \le X_{mh} \\ P_{he} \cdot \text{linterp}(X, \eta_{lhe}, x) & \text{if } x > X_{mh} \end{vmatrix}$$

Utstättningsdata kabelläge i tabellform
(Godtyckliga punkter väljs nedan)

Punkter :

Punkt	x´ (m)	Anm.
1	0.00	-
2	1.00	-
3	8.70	-
4	12.00	-
5	15.20	-
6	18.50	-
6	21.70	-
8	25.00	-
9	28.20	-
10	32.20	-
11	36.20	-
12	40.20	-
13	44.20	-

Kabeläge :

Punkt	y´ (m)	Anm.
1	0.440	Förankringar
2	0.600	-
3	1.302	-
4	1.306	-
5	1.140	-
6	0.856	-
7	0.555	-
8	0.305	-
9	0.200	-
10	0.334	-
11	0.714	-
12	1.162	-
13	1.400	-

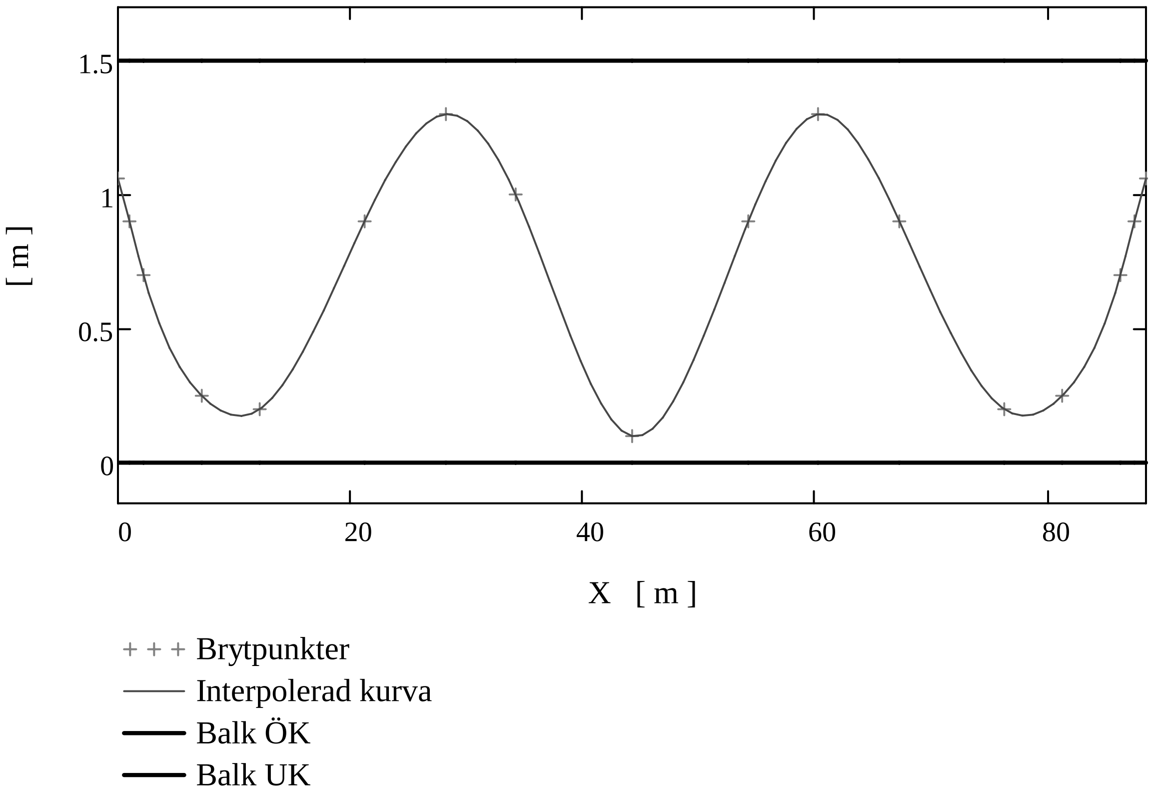
ger

q_{sp} (m)
1.060
0.900
0.198
0.194
0.360
0.644
0.945
1.195
1.300
1.166
0.786
0.338
0.100

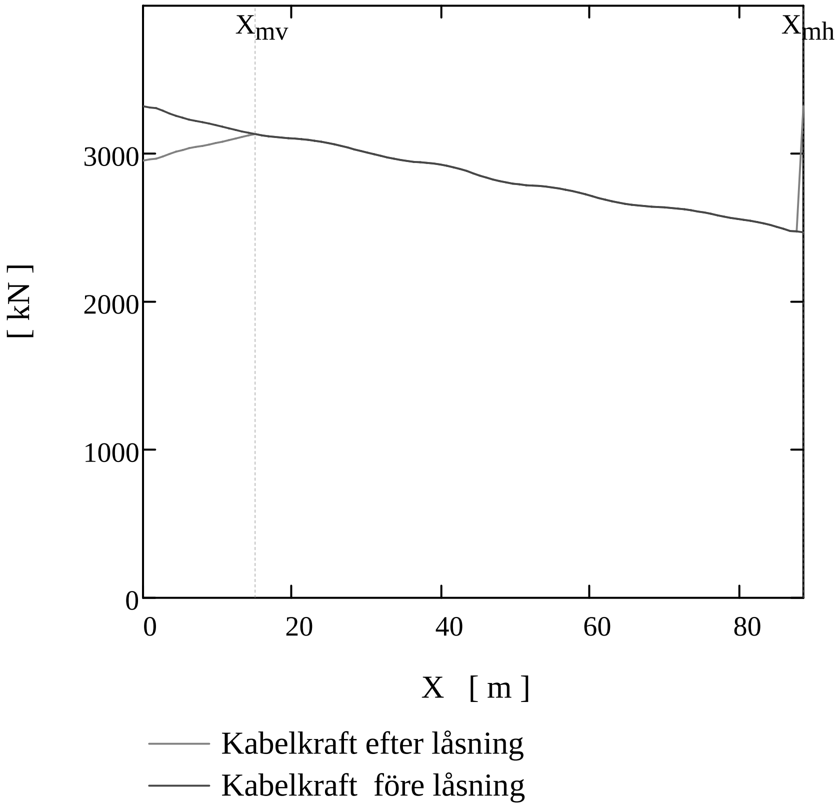
$q_{sp} = H - y´$

RESULTAT

Grafisk uppritning av balk och kabelföring



Grafisk uppritning av kabelkrafter



Minsta krökningsradie

$R_{min} = 38.8 \cdot m$

Kabelförlängning före låsning

$L_v = 579 \cdot mm$: vänster sida

$L_h = 0 \cdot mm$: högers sida

Låsglidning

$\Delta L_v = 6 \cdot mm$: vänster sida

$\Delta L_h = 0 \cdot mm$: högers sida

Kabelkraft i balkände efter låsning

$P_{ve} = 2951 \cdot kN$: vänster sida

$P_{he} = 2325 \cdot kN$: högers sida

Läge för maximal kabelkraft efter låsning

$X_{mv} = 15.005\,m$: vänster sida

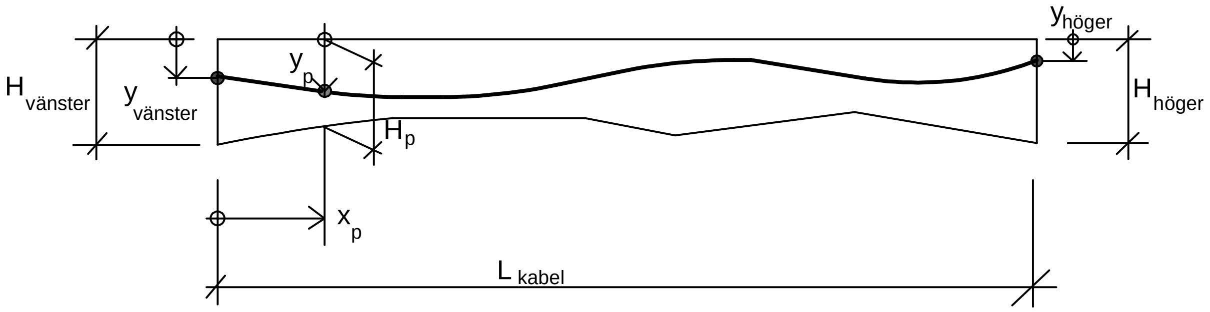
$X_{mh} = 88.4 \cdot m$: högers sida

Läge för lägsta kabelkraft

$X_m = 88.4\,m$

Object: Cables V4-V6 (H4-H6)

PRINCIPFIGUR



INDATA

Total kabellängd: $L_{kabel} = 2.2m + 26m + 32m + 26m + 2.2m = 88.4\,m$

Ange antalet kända brytpunkter: $N = 17 \cdot st$

Fiktionskoefficienter spännarmering: $\mu = 0.18$ $k = 0.005 \cdot \frac{rad}{m}$

Draghållfasthet spännarmering : $f_{p0.1k} = 1640MPa$

$f_{pk} = 1860MPa$

E-modul spännarmering: $E_s = 195 \cdot GPa$

Area spännarmering : $A_s = 2250mm^2$

Största tillåtna spännkraft före låsning enligt SS-EN 1992-1-1 avsnitt 5.10.2.1 :

$$\min\left(0.8 \cdot f_{pk}, 0.9 \cdot f_{p0.1k}\right) \cdot A_s = 3321 \cdot kN$$

Vald uppspänningskraft:

$$V_{ö} = 3320kN = 3320 \cdot kN$$

Största tillåtna spännkraft efter låsning enligt SS-EN 1992-1-1 avsnitt 5.10.3 :

$$\min\left(0.75 \cdot f_{pk}, 0.85 \cdot f_{p0.1k}\right) \cdot A_s = 3136 \cdot kN$$

Typ av förankring ("Passiv" eller "Aktiv") / vald maximal kabelkraft efter låsning :

Snitt	Typ	V_{max} [kN]
Vänster	Aktiv	3080
Höger	Passiv	3080

Ge brytpunkter i kabelföring :

Snitt	x_p (m)	y_p (mm)	H_p (mm)
1	0	860	1500
2	1.000	840	1500
3	2.200	800	1500
4	7.200	1250	1500
5	12.200	1300	1500
6	21.200	600	1500
7	28.200	200	1500
8	34.200	500	1500
9	44.200	1400	1500
10	54.200	600	1500
11	60.200	200	1500
12	67.200	600	1500
13	76.200	1300	1500
14	81.200	1250	1500
15	86.200	800	1500
16	87.400	840	1500
17	88.400	860	1500

STEP 2 ⇒

x	w
0	-0.11
1.00	-0.09
2.20	-0.05
7.20	-0.50
12.20	-0.55
21.20	0.15
28.20	0.55
34.20	0.25
44.20	-0.65
54.20	0.15
60.20	0.55
67.20	0.15
76.20	-0.55
81.20	-0.50
86.20	-0.05
87.40	-0.09
88.40	-0.11

LUSAS ⇒

x(+)	z(+)
0	-0.11
1.00	-0.09
2.20	-0.05
7.20	-0.50
12.20	-0.55
21.20	0.15
28.20	0.55
34.20	0.25
44.20	-0.65
54.20	0.15
60.20	0.55
67.20	0.15
76.20	-0.55
81.20	-0.50
86.20	-0.05
87.40	-0.09
88.40	-0.11

BERÄKNING

Skapa matematiska funktioner för balk och kabel

$C = \text{pspline}(x_p, y_p)$: bestämning av koefficienter parabel splinefunktioner

$y(x) = \text{interp}(C, x_p, y_p, x)$: kabelföring (= splinefunktioner)

$y'(x) = \frac{d}{dx} y(x)$: lutning kabelföring

$y''(x) = \frac{d^2}{dx^2} y(x)$: lutningsförändring kabelföring

$R_{min} = \frac{1}{\max(y''(x))}$: minsta kökningsradie

Friktionsförlust funktion mät ifrån "vänster" sida

$$\alpha_v = \text{if}\left(i > 1, \sum_{j=2}^{i} \left|y'(x_j) - y'(x_{j-1})\right|, 0\right)$$: ackumulerade vinkeländringar

$$\beta_v = \mu \cdot (\alpha_v + k \cdot X)$$: exponent friktionsförluster

$$\beta_v = \mu \cdot (\alpha_v + k \cdot x)$$: exponent friktionsförluster

$$\eta_{vf} = e^{-\beta_v}$$: friktionsförluster före låsning

$$\eta_{ve} = e^{\beta_v}$$: friktionsförlust efter låsning

Bestämning av läge för maximal kabelkraft **efter** låsning :

$$X_{mv} = \begin{vmatrix} x_{skär} \leftarrow 0m \text{ if } Typ = \text{"Passiv"} \\ \text{if } Typ = \text{"Aktiv"} \\ \quad \begin{vmatrix} x_{start} \leftarrow 2m \\ x_{skär} \leftarrow \text{root}\left(V_{max} - V_{ö} \cdot \text{linterp}\left(X, \eta_{vf}, x_{start}\right), x_{start}\right) \end{vmatrix} \end{vmatrix}$$

Friktionsförlust funktion mät ifrån "höger" sida

$$\alpha_h = \text{if}\left(i < n, \sum_{j=i+1}^{n} \left|y'(x_j) - y'(x_{j-1})\right|, 0\right)$$: ackumulerade vinkeländringar

$$\beta_h = \mu \cdot \left[\alpha_h + k \cdot (L_{kabel} - x)\right]$$: exponent friktionsförluster

$$\eta_{hf} = e^{-\beta_h}$$: friktionsförluster före låsning

$$\eta_{he} = e^{\beta_h}$$: friktionsförlust efter låsning

Bestämning av läge för maximal kabelkraft **efter** låsning :

$$X_{mh} = \left| \begin{array}{l} x_{skär} \leftarrow L_{kabel} \ \text{ if } \ Typ = \text{"Passiv"} \\ \text{if } \ Typ = \text{"Aktiv"} \\ \quad \left| \begin{array}{l} x_{start} \leftarrow L_{kabel} - 2m \\ x_{skär} \leftarrow \text{root}\left(V_{max} - V_ö \cdot \text{linterp}\left(X, \eta_{hf}, x_{start}\right), x_{start}\right) \end{array} \right. \end{array} \right.$$

Bestämning skärning mellan kurva kabelkraft vänster resp. höger

$$X_m = \left| \begin{array}{l} x_{skär} \leftarrow L_{kabel} \ \text{ if } \ Typ = \text{"Aktiv"} \wedge Typ = \text{"Passiv"} \\ x_{skär} \leftarrow 0m \ \text{ if } \ Typ = \text{"Passiv"} \wedge Typ = \text{"Aktiv"} \\ \text{if } \ Typ = \text{"Aktiv"} \wedge Typ = \text{"Aktiv"} \\ \quad \left| \begin{array}{l} x_{start} \leftarrow 0.5 \cdot L_{kabel} \\ x_{skär} \leftarrow \text{root}\left(V_ö \cdot \text{linterp}\left(X, \eta_{vf}, x_{start}\right) - V_ö \cdot \text{linterp}\left(X, \eta_{hf}, x_{start}\right), x_{start}\right) \end{array} \right. \end{array} \right.$$

Bestämning av kabelkraft efter låsning i resp. balkände

Kabelkraft på vänster sida :

$$P_{ve} = \left| \begin{array}{ll} V_{max} \cdot \mathrm{linterp}\left(X, \eta_{hf}, 0m\right) & \text{if } Typ = \text{"Passiv"} \\ \dfrac{V_{max}}{\mathrm{linterp}\left(X, \eta_{ve}, X_{mv}\right)} & \text{if } Typ = \text{"Aktiv"} \end{array} \right.$$

Kabelkraft på höger sida :

$$P_{he} = \left| \begin{array}{ll} V_{max} \cdot \mathrm{linterp}\left(X, \eta_{vf}, L_{kabel}\right) & \text{if } Typ = \text{"Passiv"} \\ \dfrac{V_{max}}{\mathrm{linterp}\left(X, \eta_{he}, X_{mh}\right)} & \text{if } Typ = \text{"Aktiv"} \end{array} \right.$$

Bestämning av eftersläppning / "låsglidning"

Vänster sida :

$$\Delta L_v = \mathrm{if}\left[Typ = \text{"Aktiv"}, \frac{1}{A_s \cdot E_s} \int_0^{X_{mv}} \left(V_{ö} \cdot \mathrm{linterp}\left(X, \eta_{vf}, x\right) - P_{ve} \cdot \mathrm{linterp}\left(X, \eta_{ve}, x\right)\right) dx, 0\right]$$

Höger sida :

$$\Delta L_h = \mathrm{if}\left[Typ = \text{"Aktiv"}, \frac{1}{A_s \cdot E_s} \int_{X_{mh}}^{L_{kabel}} \left(V_{ö} \cdot \mathrm{linterp}\left(X, \eta_{hf}, x\right) - P_{ve} \cdot \mathrm{linterp}\left(X, \eta_{he}, x\right)\right) dx, 0\right]$$

Bestämning kabelförlängning före låsning

Vänster sida :

$$L_v = \frac{1}{A_s \cdot E_s} \int_0^{X_m} \left(V_{ö} \cdot \mathrm{linterp}\left(X, \eta_{vf}, x\right)\right) dx$$

Höger sida :

$$L_h = \frac{1}{A_s \cdot E_s} \int_{X_m}^{L_{kabel}} \left(V_{ö} \cdot \mathrm{linterp}\left(X, \eta_{hf}, x\right)\right) dx$$

Bestäm funktion för bestämning av godtycklig kabelkraft före låsning

$$P_{före} = \begin{cases} V_{ö} \cdot \text{linterp}(X, \eta_{vf}, x) & \text{if } x \le X_m \\ V_{ö} \cdot \text{linterp}(X, \eta_{hf}, x) & \text{if } x > X_m \end{cases}$$

Bestäm funktion för bestämning av godtycklig kabelkraft efter låsning

$$P_{efter} = \begin{cases} P_{ve} \cdot \text{linterp}(X, \eta_{ve}, x) & \text{if } x \le X_{mv} \\ V_{ö} \cdot \text{linterp}(X, \eta_{vf}, x) & \text{if } X_{mv} < x < X_m \\ V_{ö} \cdot \text{linterp}(X, \eta_{hf}, x) & \text{if } X_m \le x \le X_{mh} \\ P_{he} \cdot \text{linterp}(X, \eta_{he}, x) & \text{if } x > X_{mh} \end{cases}$$

Utstättningsdata kabelläge i tabellform
(Godtyckliga punkter väljs nedan)

Punkter :

Punkt	x´ (m)	Anm.
1	0.00	-
2	1.00	-
3	8.70	-
4	12.00	-
5	15.20	-
6	18.50	-
6	21.70	-
8	25.00	-
9	28.20	-
10	32.20	-
11	36.20	-
12	40.20	-
13	44.20	-

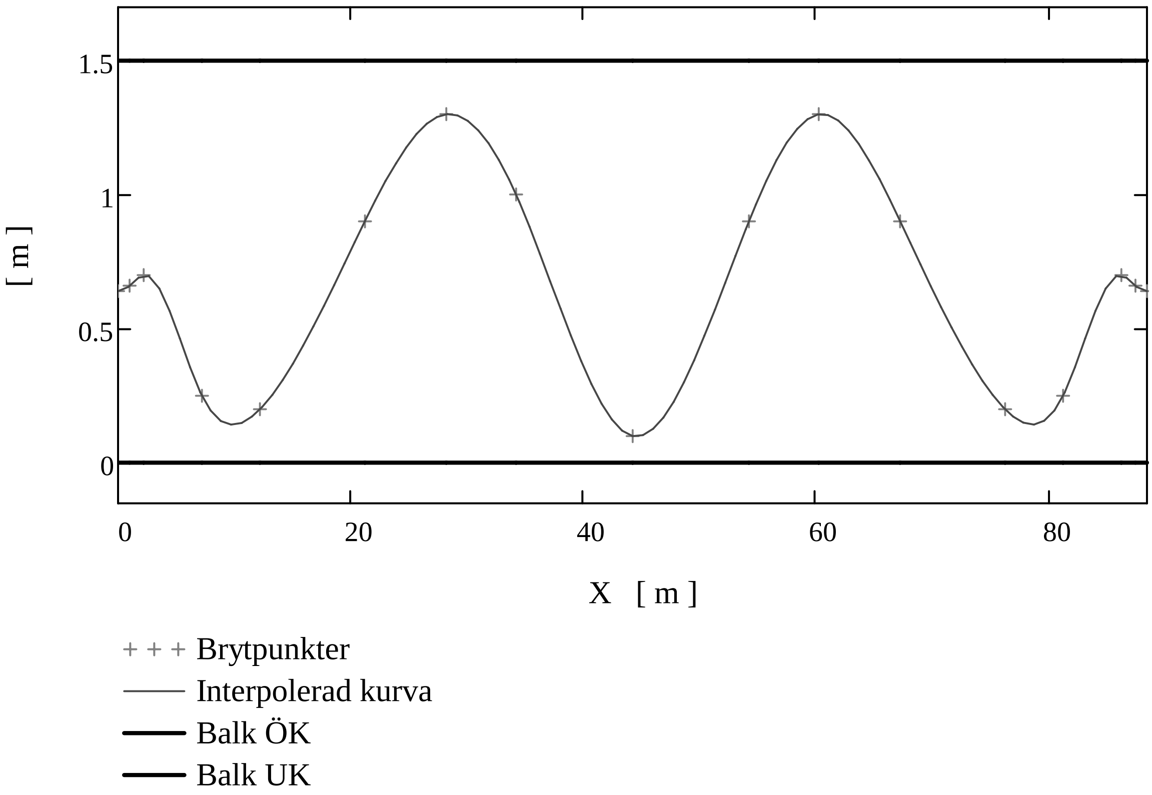
Kabeläge :

Punkt	y´ (m)	Anm.		q_{sp} (m)
1	0.860	Förankringar		0.640
2	0.840	-		0.660
3	1.340	-		0.160
4	1.309	-		0.191
5	1.118	-		0.382
6	0.842	-	ger	0.658
7	0.556	-		0.944
8	0.309	-		1.191
9	0.200	-		1.300
10	0.334	-		1.166
11	0.715	-		0.785
12	1.162	-		0.338
13	1.400	-		0.100

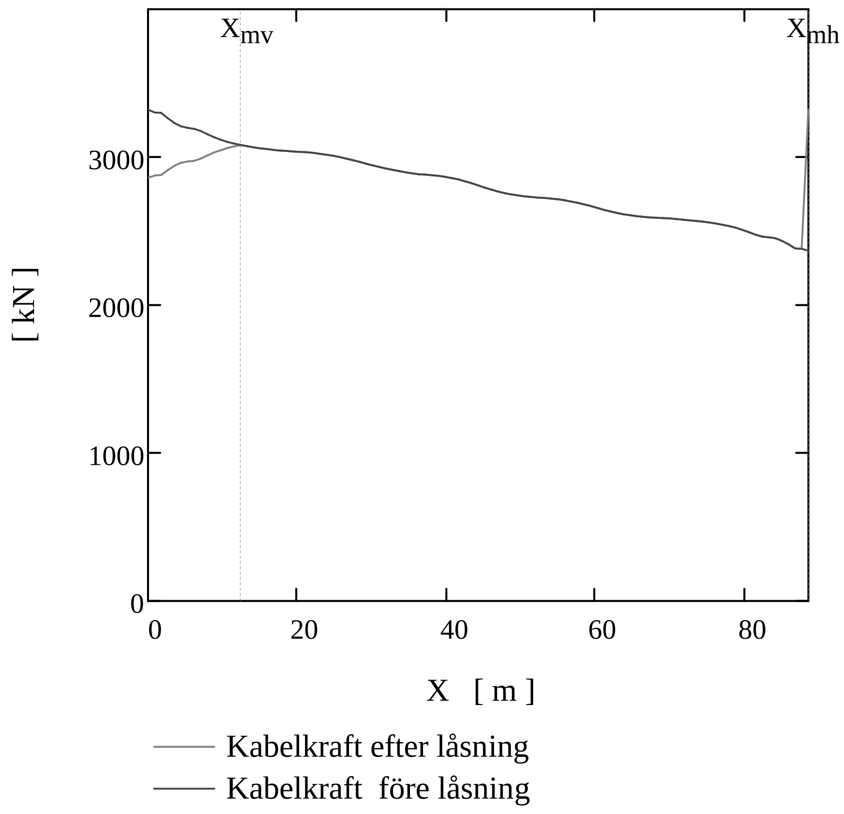
$q_{sp} = H - y´$

RESULTAT

Grafisk uppritning av balk och kabelföring



Grafisk uppritning av kabelkrafter



Minsta krökningsradie

$R_{min} = 14.6 \cdot m$

Kabelförlängning före låsning

$L_v = 567 \cdot mm$: vänster sida

$L_h = 0 \cdot mm$: högers sida

Låsglidning

$\Delta L_v = 6 \cdot mm$: vänster sida

$\Delta L_h = 0 \cdot mm$: högers sida

Kabelkraft i balkände efter låsning

$P_{ve} = 2857 \cdot kN$: vänster sida

$P_{he} = 2194 \cdot kN$: högers sida

Läge för maximal kabelkraft efter låsning

$X_{mv} = 12.384\,m$: vänster sida

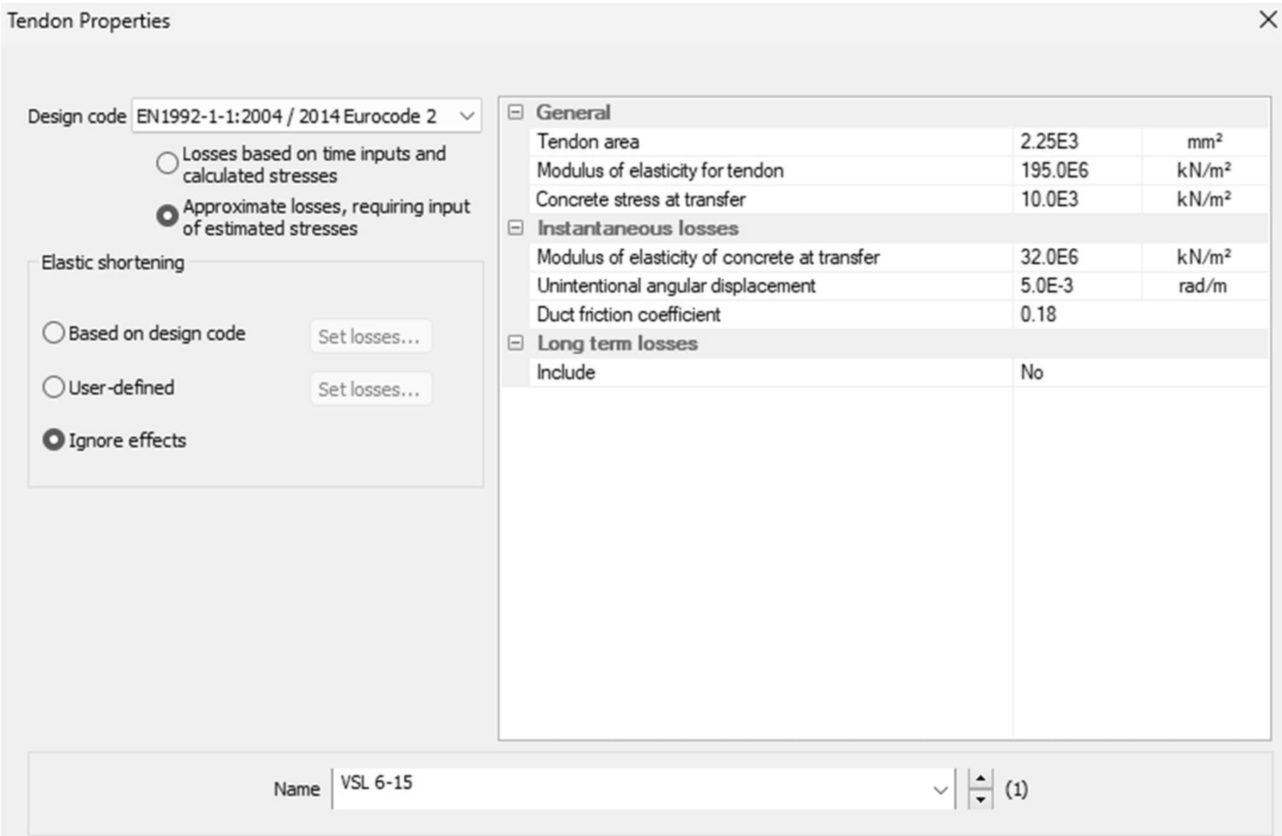
$X_{mh} = 88.4 \cdot m$: högers sida

Läge för lägsta kabelkraft

$X_m = 88.4\,m$

Tendon properties:

Beräkning av ”long term losses” sker inte med LUSAS utan separat. Därav ”Include: No” i tabell nedan.



Friktionskoefficienter VSL

$$P_{(x)} = P_o \cdot e^{-\mu(\alpha + k \cdot x)}$$

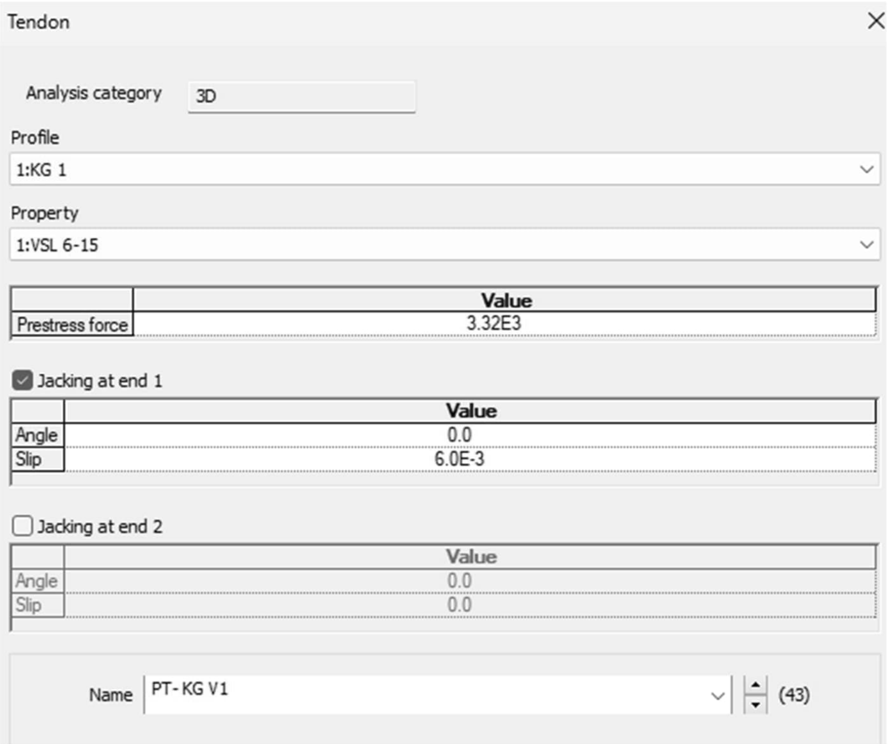
Type of tendon and duct	Range	Recommended value
Internal bonded tendon with corrugated steel duct (bare strand)	μ = 0.16 - 0.22 k = 0.004 - 0.008	μ = 0.18 k = 0.005 (k* = 9 x 10⁻⁴)

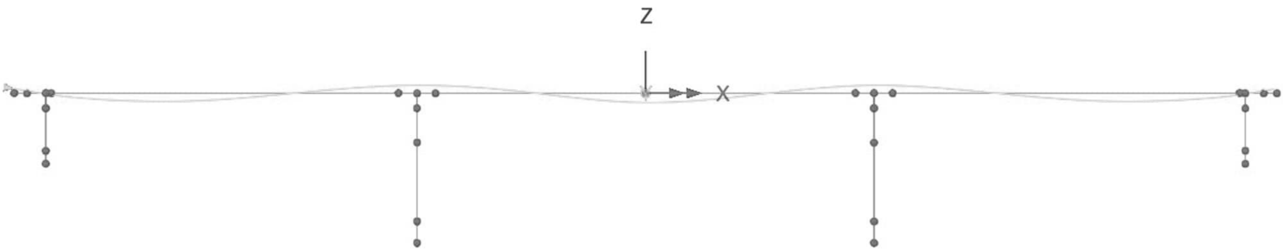
μ = 0.18

$$k = 0.005\,\frac{rad}{m}$$

3.14.4 Load definition

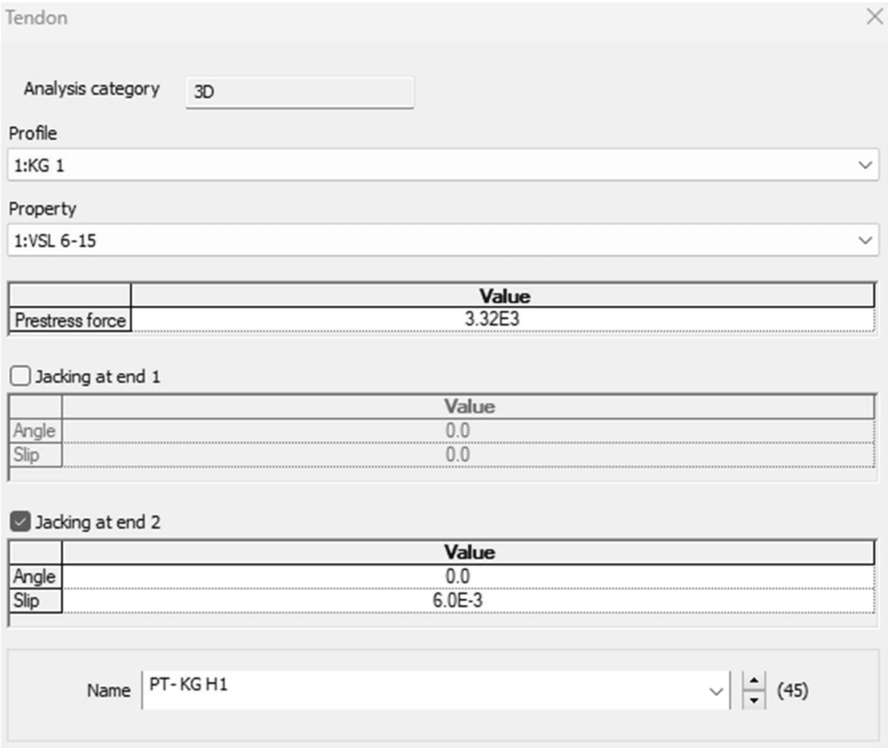
KG V1: Cables V1, V2 & V3





ELEVATION

KG H1: Cables H1, H2 & H3



Tendon

Analysis category: 3D

Profile: 1:KG 1

Property: 1:VSL 6-15

	Value
Prestress force	3.32E3

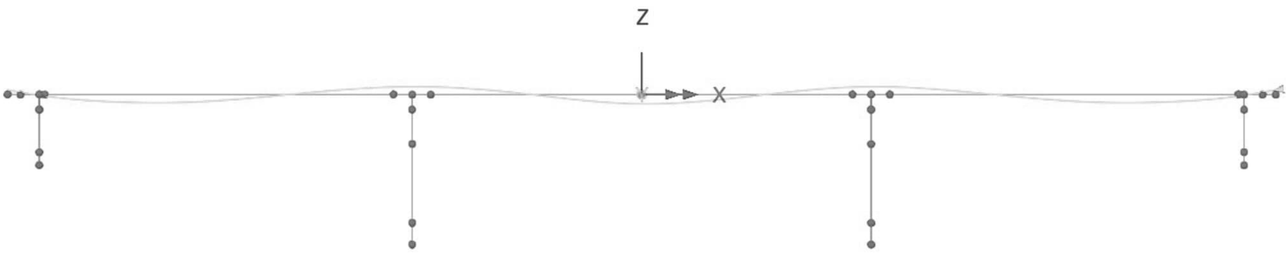
☐ Jacking at end 1

	Value
Angle	0.0
Slip	0.0

☑ Jacking at end 2

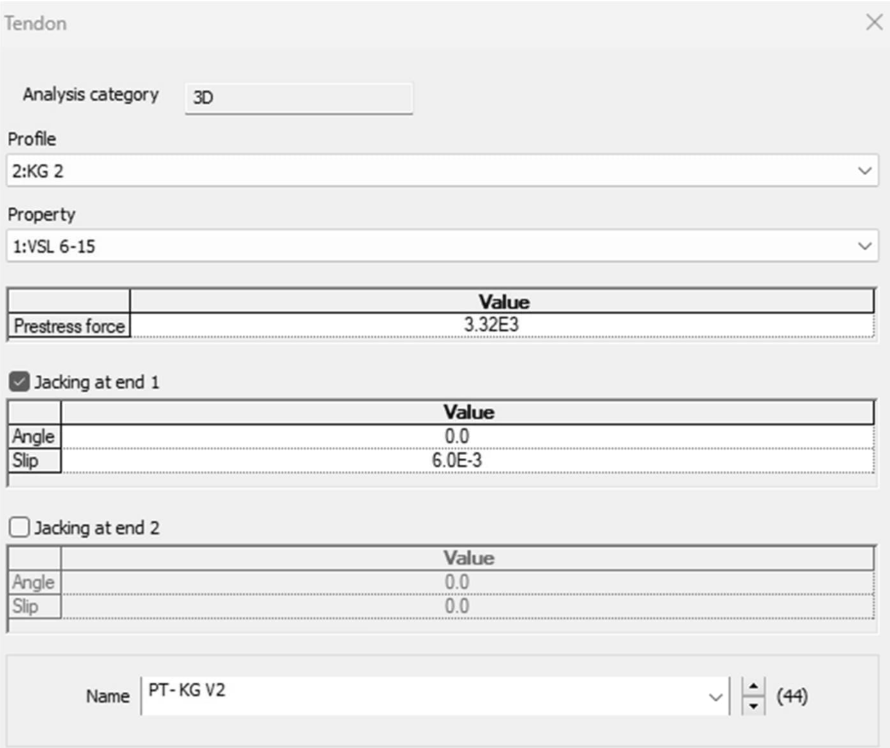
	Value
Angle	0.0
Slip	6.0E-3

Name: PT- KG H1 (45)



ELEVATION

KG V2: Cables V4, V5 & V6



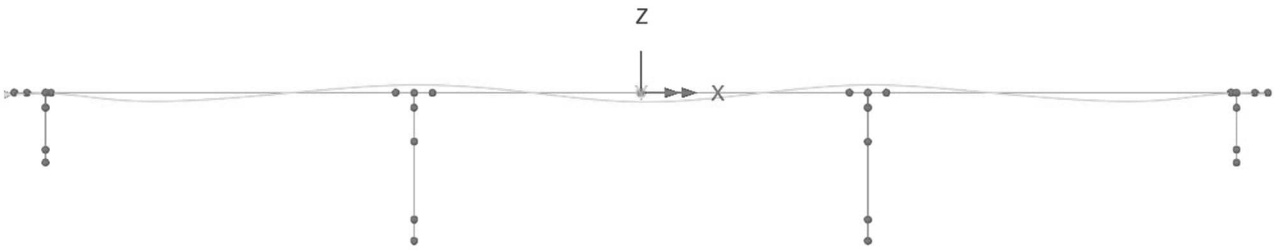
	Value
Prestress force	3.32E3

Jacking at end 1

	Value
Angle	0.0
Slip	6.0E-3

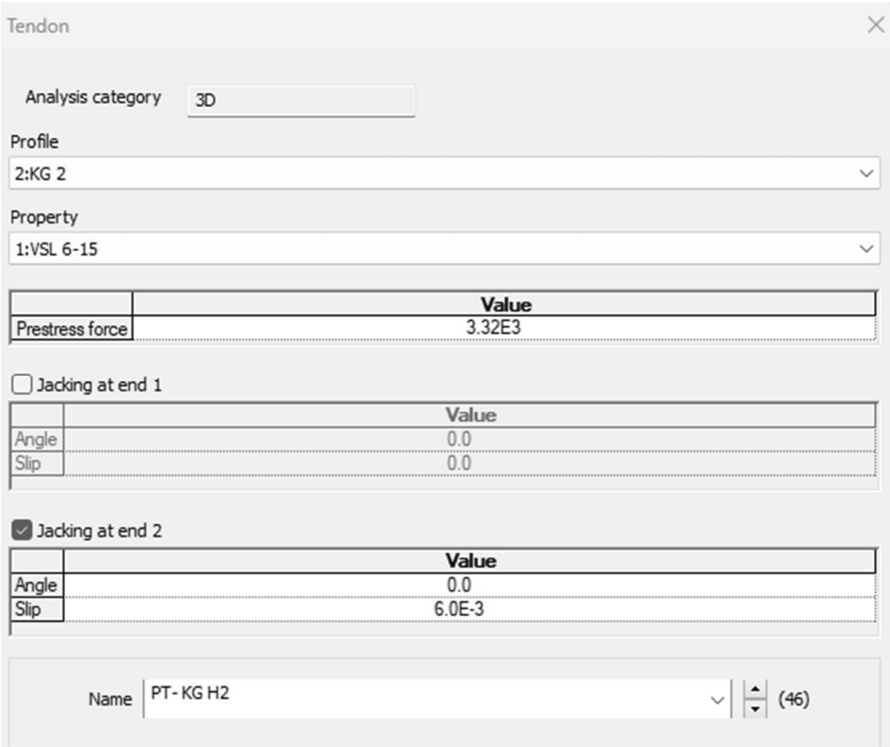
Jacking at end 2

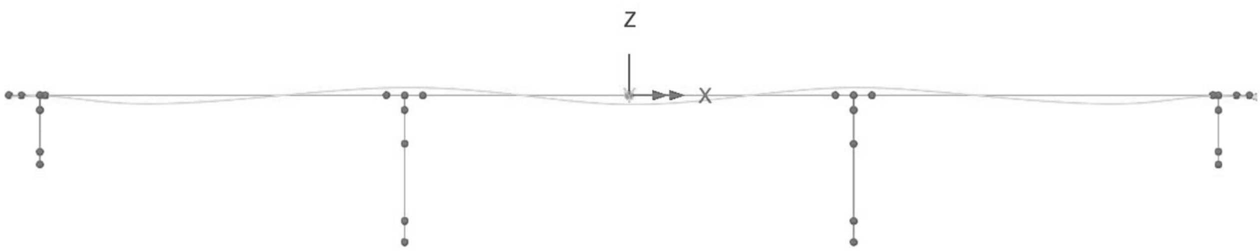
	Value
Angle	0.0
Slip	0.0



ELEVATION

KG H2: Cables H4, H5 & H6





ELEVATION

3.14.4 Load combination

Load combination basis PT-t0:

Load case	Factor
KG V1	3.00
KG H1	3.00
KG V2	3.00
KG H2	3.00

Load combination basis PT-t1:

Load case	Factor
PT – t0	0.94

Load combination basis PT-t2:

Load case	Factor
PT – t0	0.84

3.15 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.

3.15.1 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:
  $\Psi\gamma_{ULS-A} = \gamma_d \cdot 1.35 \cdot \eta_{sup.G} = 1.0 \cdot 0.89 \cdot 1.35 \cdot 1.1 = 1.49$ ← dimensioning
  $\Psi\gamma_{ULS-B} = \gamma_d \cdot 0.89 \cdot 1.35 \cdot \eta_{sup.G} = 1.0 \cdot 0.89 \cdot 1.35 \cdot 1.1 = 1.33$

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

Design method D3 (set C):

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.

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

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

Equation 6.10a refers to the (ULS-GA) case where the permanent loads are dominant, usually during the construction phase.
Equation 6.10b (ULS-GB) 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: $\psi\gamma_{\text{över}} = \gamma_d \cdot 1.40 = 0.91 \cdot 1.40 = 1.27$

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.

Check load coefficients associated with the geotechnical loads

$$K_o(D2) = 1 - sin(\varphi_d) = 1 - sin45^\circ = 0.29$$

$$K_o(D3) = 1 - sin(\varphi_d) = 1 - sin38^\circ = 0.39$$

Earth pressure→ 1.48[1.)] $\cdot K_0(D2) = 0.43 \equiv 1.10 \cdot K_0(D3) = 0.43$ i.e. OK!

Surcharge → 1.71[2.)] $\cdot K_0(D2) = 0.50 \equiv 1.27 \cdot K_0(D3) = 0.50$ i.e. OK!

Footnote

[1.)] Last coefficient $\psi\gamma_{ULS} = 1.48$ is applied instead of 1.33.

[2.)] Last coefficient $\psi\gamma_{ULS} = 1.71$ is applied instead of 1.50.

Permanent loads:
(Refers to RKFM appendix 2, page 22)

Nr	Load		$\psi\gamma_{ULS-A}$	$\psi\gamma_{ULS-B}$		$\psi\gamma_{ULS}$
1	Egentyngd	max	1.35	1.20		1.20
		min	1.00	1.00		1.00
2	Beläggning	max	1.49	1.33		1.33
		min	0.90	0.90		0.90
3	Överfyllnad	max	1.49	1.33		1.33
		min	0.90	0.90		0.90
4	Jordtryck	max	1.49	1.33	⇒	1.48[1.)]
		min	0.90	0.90		0.90
5	Vattentryck	max	1.35	1,09		1,09
		min	1.00	1.00		1.00
6	Stödförskjutning	max	1.35	1.20		1.20
		min	1.00	1.00		1.00
7	Krympning	max	1.35	1.20		1.20
		min	1.00	1.00		1.00
8	Spännkraft	max	1.35	1.35		1.35
		min	1.00	1.00		1.00

Remark
ULS-A is not considered critical during operational use. Instead ULS-B is used as design values.

Variable loads:
(Refers to RKFM appendix 2, page 22)

Nr	Load	$\psi\gamma_{ULS-A}$	$\psi\gamma_{ULS-B}$		$\psi\gamma_{ULS}$
	Lastmodell LM 1 :				
9	Boggiesystem	1.13	1.03/1.50		1.03/1.50
10	Utbredd last	0.60	0.60/1.50		0.60/1.50
11	Bromskraft	0.84	0.84/1.13		0.84/1.13
12	Sidokraft	0.84	0.84/1.13		0.84/1.13
13	Centrifugalkraft	0.84	0.84/1.13		0.84/1.13
	Lastmodell LM 2 :				
14	Enstaka axellast	0	0/1.50		0/1.50
	Typfordon EG A/B :				
15	Typfordon EG A/B	1.13	1.13/1.50		1.13/1.50
16	Bromskraft	0.84	0.84/1.13		0.84/1.13
17	Sidokraft	0.84	0.84/1.13		0.84/1.13
18	Centrifugalkraft	0.84	0.84/1.13	⇒	0.84/1.13
19	Temperatur	0.90	0.90/1.50		0.90/1.50
	Vindlaster:				
20	Vindlast mot bro	0.45	0.45/1.50		0.45/1.50
21	Vindlast mot trafik	0.45	0.45/1.50		0.45/1.50
22	Överlast	1.13	1.13/1.50		1.13/1.71 [2.)]
23	Istryck	0.60	0.60/1.50		0.60/1.50

Remark
ULS-A is not considered critical during operational use. Instead ULS-B is used as design values.

Load combination smart *ULS-PERM :*
(ULS-PERM_0 is identical but does not contain load case PT-t0)

Load case	Permanent factor	Variable factor
EGEN	1.00	0.20
BELÄGG	0.90	0.43
JORD	0.90	0.58
STOD	0	0.41 = (1.20 x 0.34 [4.)])
KRYMP	0	0.41 = (1.20 x 0.34[4.)])
PT-t0	0.84 (= 0.84·1.00) [3.)]	0.51 (= 1.35 - 0.84) [5.)]

Footnotes:
[4.)] The effect of creep results in reduced stiffness; see page A3:43.
[5.)] Load case pretension varies from PT-t0 to PT-t2 (= 0.84·PT-t0) is applied.

Although the load cases STOD and KRYMP do not need to be considered according to SS-EN 1992-1-1, this is done on the safe side.

Envelope ALT :

Load case
ICE
TEMP

Load combination smart *ULS-VAR :*
(Load cases to consider : 6 / Variable load cases : 1)

Load case	Permanent factor	Variable factor
TRAFIK	1.03	0.47
BROMS	0.84	0.29
SIDO	0.84	0.29
OVER	1.13	0.58
VIND	0.45	1.05
ALT	0.90	0.60

Load combination smart *ULS :*
(ULS-0 is identical but does not contain load case PT-t0)

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

3.16.2 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.

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

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

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

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

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

When designing, load coefficients according to equations 6.14a, 6.15b, and 6.16b are applied. Refer to the derivation in Appendix 2.

Adjustment of load coefficients for geotechnical loads:

$K_o(D2) = 1 - sin(\varphi_d) = 1 - sin45^\circ = 0.29$

$K_o(D3) = 1 - sin(\varphi_d) = 1 - sin38^\circ = 0.39$

LC	Earth pressue
SLS-K	$\frac{K0(D3)}{K0(D2)} \cdot 1.1 = \frac{0.39}{0.29} \cdot 1.1 = 1.48$
SLS-F	$\frac{K0(D3)}{K0(D2)} \cdot 1.1 = \frac{0.39}{0.29} \cdot 1.1 = 1.48$
SLS-Q	$\frac{K0(D3)}{K0(D2)} \cdot 1.0 = \frac{0.39}{0.29} \cdot 1.0 = 1.34$

LC	Temparature
SLS-K	$\frac{K0(D3)}{K0(D2)} \cdot 1.0 = \frac{0.39}{0.29} \cdot 1.00 = 1.34$
SLS-F	$\frac{K0(D3)}{K0(D2)} \cdot 0.60 = \frac{0.39}{0.29} \cdot 0.60 = 0.81$
SLS-Q	0

LC	Surcharge
SLS-K	$\frac{K0(D3)}{K0(D2)} \cdot 1.0 = \frac{0.39}{0.29} \cdot 1.00 = 1.34$
SLS-F	$\frac{K0(D3)}{K0(D2)} \cdot 0.75 = \frac{0.39}{0.29} \cdot 0.75 = 1.01$
SLS-Q	0

Permanent loads:
(Refers to RKFM appendix 2, page 40)

Nr	Load		$\psi\gamma_{SLS-K}$	$\psi\gamma_{SLS-F}$	$\psi\gamma_{SLS-Q}$
1	Egentyngd	max	1.00	1.00	1.00
		min	1.00	1.00	1.00
2	Beläggning	max	1.10	1.10	1.00
		min	0.90	0.90	1.00
3	Överfyllnad	max	1.10	1.10	1.00
		min	0.90	0.90	1.00
4	Jordtryck	max	1.48[6.)]	1.48[6.)]	1.34[6.)]
		min	0.90	0.90	1.00
5	Vattentryck	max	1.00	1.00	1,00
		min	1.00	1.00	1.00
6	Stödförskjutning	max	1.00	1.00	1.00
		min	1.00	1.00	1.00
7	Krympning	max	1.00	1.00	1.00
		min	1.00	1.00	1.00
8	Spännkraft	max	1.00	1.00	1.00
		min	1.00	1.00	1.00

← 1.48 is used on all safe side !

Footnote:
[6.)] Load coefficient page A3:182 is applied.

Variable loads:
(Refers to RKFM appendix 2, page 40)

Nr	Load	$\psi\gamma_{SLS-K}$	$\psi\gamma_{SLS-F}$	$\psi\gamma_{SLS-Q}$
	Lastmodell LM 1 :			
9	Boggiesystem	0.75/1.00	0/0.75	0
10	Utbredd last	0.40/1.00	0/0.40	0
11	Bromskraft	0.56/0.75	0/0.56	0
12	Sidokraft	0.56/0.75	0/0.56	0
13	Centrifugalkraft	0.56/0.75	0/0.56	0
	Lastmodell LM 2 :			
14	Enstaka axellast	0.75/1.00	0/0.75	0
	Typfordon EG A/B :			
15	Typfordon EG A/B	0.75/1.00	0/0.75	0
16	Bromskraft	0.56/0.75	0/0.56	0
17	Sidokraft	0.56/0.75	0/0.56	0
18	Centrifugalkraft	0.56/0.75	0/0.56	0
19	Temperatur	0.60/1.00	0.50/0.60	0.50
	Vindlaster:			
20	Vindlast mot bro	0.30/1.00	0/0.30	0
21	Vindlast mot trafik	0.30/1.00	0/0.30	0
22	Överlast	0.75/1.34[7.)]	0/1.01 [7.)]	0
23	Istryck	0.40/1.00	0/0.40	0

Footnote:
[7.)] Load coefficients according to page A3:182 is applied.

Load combination smart SLS-PERM :

Loadcase	Permanent factor	Variable factor
EGEN	1.00	0
BELÄGG	0.90	0.20
JORD	0.90	0.58
STOD	0	0.34 = (1.0 x 0.34[8.)])
KRYMP	0	0.34 = (1.0 x 0.34[8.)])
PT-t0	0.84[9.)]	0.16[9.)]

Footnotes:

[8.)] The effect of creep results in reduced stiffness; see page A3:43

[9.)] Load case pretension varies from PT-t0 to PT-t2 (= 0.84·PT-t0) is applied.

Envelope ALT :

Load case
ICE
TEMP

Load combination smart *SLS-K-VAR :*

(Load cases to consider : 6 / Variable load cases : 1)

Load case	Permanent factor	Variable factor
TRAFIK	0.75	0.25
BROMS	0.56	0.19
SIDO	0.56	0.19
OVER	0.75	0.59
VIND	0.30	0.70
ALT	0.60	0.40

Load combination smart *SLS-F-VAR :*

Load case	Permanent factor	Variable factor
TRAFIK	0	0.75
BROMS	0	0.56
SIDO	0	0.56
OVER	0	0.95
VIND	0	0.30
ALT	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
EGEN	1.00	0
BELÄGG	1.00	0.20
JORD	1.00	0.34
STOD	0	0.34 = (1.0 x 0.34[10.)])
KRYMP	0	0.34 = (1.0 x 0.34[10.)])
PT-t0	0.84[11.)]	0
TEMP	0	0.50

Footnotes:

[10.)] The effect of creep results in reduced stiffness; see page A3:43

[11.)] Load case pretension PT-t2 (= 0.84·PT-t0) is assumed.

3.15.3 Accidental load combination

The accidental load case is also designated as exceptional load combination EXC according to SS-EN 1990 section 6.4.3.3 equation 6.11a as shown below.
The accidental load case is denoted as A_d and consists of cable loss or impact load.

$$E_{Sd} = \sum_{j\geq 1} G_{k,j} + P + A_d + \psi_{1,1} \cdot Q_{k,1} + \sum_{i>1} \psi_{2,i} \cdot Q_{k,i} = \cdots$$

$$\psi\gamma_{EXC} \cdot \left(\sum_{j\geq 1} G_{k,j} + P + A_d + \sum_{i\geq 1} Q_{k,j}\right)$$

3.15.4 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.

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

Permanent loads:
(Refers to RKFM appendix 2, page 42)

Nr	Load		$\psi\gamma_{UTM}$
1	Egentyngd	max	1.00
		min	1.00
2	Beläggning	max	1.10
		min	0.90
3	Överfyllnad	max	1.10
		min	0.90
4	Jordtryck	max	1.48
		min	0.90
5	Vattentryck	max	1.00
		min	1.00
6	Stödförskjutning	max	1.00
		min	1.00
7	Krympning	max	1.00
		min	1.00
8	Spännkraft	max	1.00
		min	1.00

Variable loads:
(Refers to RKFM appendix 2, page 42)

Nr	Load	$\psi\gamma_{UTM}$
	Lastmodell LM 1 :	
9	Boggiesystem	-
10	Utbredd last	-
11	Bromskraft	-
12	Sidokraft	-
13	Centrifugalkraft	-
	Lastmodell LM 2 :	
14	Enstaka axellast	-
	Typfordon EG A/B :	
15	Typfordon EG A/B	-
16	Bromskraft	-
17	Sidokraft	-
18	Centrifugalkraft	-
19	Temperatur	0.60
	Vindlaster:	
20	Vindlast mot bro	0.30
21	Vindlast mot trafik	0.30
22	Överlast	1.01
23	UTM3	1.00

Load combination smart FAT :

Load case	Permanent factor	Variable factor
EGEN	1.00	0
BELÄGG	1.00	0
JORD	1.48	0
STOD	-	-
KRYMP	-	-
PT-t0	0.84	-
VIND	-	-
UTM	-	1.00
OVER	-	-
TEMP	-	-

Load cases BELÄGG, STOD and KRYMP are not fatigue loads, thus load coefficient 1.0 is applied.

Load cases pretension is not a fatigue loads, thus load coefficient lowest load value of value is assumed PT-t2 (= 0.84·PT-t0) is applied.

Load case JORD is not a fatigue load, thus load coefficient highest load coefficient is applied.

Load cases TEMP, VIND and OVER are not fatigue loads, thus load is not considered.

During verification STR, the load case TEMP can be neglected according to SS-EN 1992-1-1 section 2.3.1.2(2).