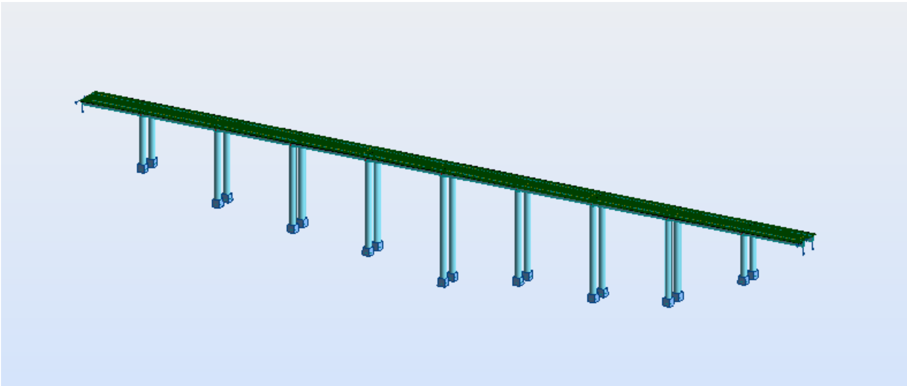
INSTITUTO SUPERIOR DE ENGENHARIA DE LISBOA

Área Departamental de Engenharia Civil



Preliminary Design of a Prestressed Concrete Viaduct

MARCIN ANDRZEJEWSKI

(Bachelor of science)

Project elaborated for the partial fulfilment of the requirements of the Master degree in Civil Engineering

Supervisor:
Doctor Luciano Alberto do Carmo Jacinto

Examination Board:
President: Master Cristina Ferreira Xavier Brito Machado
Members:
Master António Carlos Teles de Sousa Gorgulho
Doctor Luciano Alberto do Carmo Jacinto

July, 2016

Abstract

The viaduct is a structure of 10 spans. It is about to be constructed in accordance with span by span casting method. It is quite simple prestressed continuous beam with a doubled webbed cross section of the deck. There are two lanes with a width of 3,5 m each and two sidewalks with a width of 1,1 m. The viaduct is located in Poland so all loads that occur are in line with national standards and annexes in eurocodes. There are few basic dimensions of the structure below:

- The diameter of the piers - 2,5 m
- Total length - 288 m
- Length of single span 30 m (24 m)
- Total width – 11,20 m
- Length of the piers: 19,95 m; 26,8 m; 30,57 m; 33,59 m; 39,38 m; 39,14 m; 34,28 m; 30,36 m; 16,9 m.
- Length of the piles: 8,71 m; 17,68 m; 23,51 m; 21,72 m; 10,57 m;
- The number of spread foundations – 4
- The number of deep foundations - 5
- The diameter of the piles – 1,75 m

Materials:

- Bedding concrete C16/20
- Abutments and foundations C30/37
- Piers and deck C35/45
- Reinforcing steel A500 NR
- Prestressing steel Y1860 S7

Resumo

O presente Trabalho Final de Mestrado consiste na elaboração de um Estudo Prévio de um viaduto rodoviário, em betão armado pré-esforçado. O viaduto, com tabuleiro em laje vigada, é constituído por 10 tramos, prevendo-se que seja construído tramo a tramo, com juntas de betonagem a quintos de vão.

A plataforma do viaduto é constituída por duas vias de tráfego com 3.5m cada, duas bermas de 1.00 m e dois passeios laterais com 1.10 m cada, perfazendo uma largura total de 11.20. O viaduto localiza-se em Polónia e foi dimensionado de acordo com os Eurocódigos e os Anexos Nacionais desse país.

Algumas dimensões básicas incluem:

[*As in the abstract*]

Materiais:

[*As in the abstract*]

Acknowledgements

I would like to thank my thesis supervisor Doctor Luciano Alberto do Carmo Jacinto from Instituto Superior de Engenharia de Lisboa. He has always had time for me whenever I came with a question or trouble. There was no problem for him to reply for my frequent emails. He has always been friendly and open-minded. I really appreciate cooperation with dr Jacinto because I know that he put a lot of effort in this work, especially that there are few differences in design approach between Poland and Portugal.

I also would like to express my gratitude to all the university. It would be impossible to come here and write the thesis without your permission and support. I really appreciate that I could have finished my work at ISEL in Lisbon. I have to say it was really great experience for me, because I was able to study abroad for one semester. I have learnt many thinks during this period and I enjoyed exploring a city. Thank you.

Marcin Andrzejewski

TABLE OF CONTENTS

Index of figures 5

Index of tables 11

Abbreviations 12

1. **Introduction** 13

1.1. Scope 13
1.2. Objectives 13
1.3. Organization of the work 13

2. **Bridge description and design criteria** 13

3. **Calculations** 16

3.1. Actions 16

a) Longitudinal direction 16
b) Transverse direction 20
c) Columns 23

3.2. Deck 26

3.2.1. Transverse direction 26
3.2.2. Longitudinal direction 30

3.3. Columns 40

3.4. Foundations 131
3.4.1. Spread foundations and pile caps 131
3.4.2. Piles 201

3.5. Bearings 205
3.6. Expansion joints 206

4. **Conclusion** 206

Bibliography 207

Annex A1 208

Annex A2 209

Annex A3 212

Annex A4 213

Annex A5 214

INDEX OF FIGURES

Figure 2.1: The first calculative model – static scheme 15
Figure 2.2: The first calculative model – 3D view 15
Figure 2.3: The first calculative model – side view........ 15
Figure 2.4: The second calculative model 15
Figure 2.5: The third calculative model – static scheme 16
Figure 2.6: The third calculative model – 3D view........ 16
Figure 3.1.1: Self weight of first model 17
Figure 3.1.2: Additional permanent loads of first model........ 17
Figure 3.1.3: Distributed traffic's load of first model – first location 18
Figure 3.1.4: Distributed traffic's load of first model – second location........ 18
Figure 3.1.5: Concentrated traffic's load of first model 19
Figure 3.1.6: Positive temperature load of first model 19
Figure 3.1.7: Negative temperature load of first model 19
Figure 3.1.8: Prestressing loads of first model........20
Figure 3.1.9: Self weight of second model........20
Figure 3.1.10: Additional permanent loads of second model 21
Figure 3.1.11: Distributed traffic's load of second model – axonometric view 21
Figure 3.1.12: Distributed traffic's load of second model – front view 22
Figure 3.1.13: Concentrated traffic's loads of second model – first case 22
Figure 3.1.14: Concentrated traffic's loads of second model – second case........23
Figure 3.1.15: Concentrated traffic's loads of second model – third case 23
Figure 3.1.16: Self weight of third model........24
Figure 3.1.17: Breaking load........24
Figure 3.1.18: Wind 25
Figure 3.1.19: Support axial forces (ULS) 25
Figure 3.1.20: Support axial forces (SLS) 26
Figure 3.2.1: Load table of transverse direction model 26
Figure 3.2.2: Combination table of transverse direction model 27

Figure 3.2.3: Top bending moment envelope of transverse direction model 28
Figure 3.2.4: Bottom bending moment envelope of transverse direction model 28
Figure 3.2.5: Load table of longitudinal direction model 30
Figure 3.2.6: Combination table of longitudinal direction model 30
Figure 3.2.7: The bending moment envelope of longitudinal direction model 30
Figure 3.2.8: The shear force envelope of longitudinal direction model – first case 33
Figure 3.2.9: The axial force envelope of longitudinal direction model – first case 33
Figure 3.2.10: The shear force envelope of longitudinal direction model – second case...33
Figure 3.2.11: The axial force envelope of longitudinal direction model – second case.....34
Figure 3.2.12: The first step 36
Figure 3.2.13: The second step 36
Figure 3.2.14: The third step...36
Figure 3.2.15: The fourth step...37
Figure 3.2.16: The fifth step 37
Figure 3.2.17: The sixth step 37
Figure 3.2.18: The seventh step 37
Figure 3.2.19: The eight step 38
Figure 3.2.20: The ninth step 38
Figure 3.2.21: The tenth step 38
Figure 3.3.1: The numbering of the columns 40
Figure 3.3.2: The curve interaction for bar #36 – first case..44
Figure 3.3.3: The curve interaction for bar #36 – second case 46
Figure 3.3.4: The curve interaction for bar #37 – first case 49
Figure 3.3.5: The curve interaction for bar #37 – second case 51
Figure 3.3.6: The curve interaction for bar #34 – first case...54
Figure 3.3.7: The curve interaction for bar #34 – second case 56
Figure 3.3.8: The curve interaction for bar #35 – first case...59
Figure 3.3.9: The curve interaction for bar #35 – second case 61
Figure 3.3.10: The curve interaction for bar #38 – first case...64
Figure 3.3.11: The curve interaction for bar #38 – second case...66

Figure 3.3.12: The curve interaction for bar #39 – first case 69
Figure 3.3.13: The curve interaction for bar #39 – second case 71
Figure 3.3.14: The curve interaction for bar #40 – first case..74
Figure 3.3.15: The curve interaction for bar #40 – second case 76
Figure 3.3.16: The curve interaction for bar #41 – first case 79
Figure 3.3.17: The curve interaction for bar #41 – second case.. 81
Figure 3.3.18: The curve interaction for bar #42 – first case..84
Figure 3.3.19: The curve interaction for bar #42 – second case 86
Figure 3.3.20: The curve interaction for bar #43 – first case 89
Figure 3.3.21: The curve interaction for bar #43 – second case 91
Figure 3.3.22: The curve interaction for bar #44 – first case..94
Figure 3.3.23: The curve interaction for bar #44 – second case.......................................96
Figure 3.3.24: The curve interaction for bar #45 – first case..99
Figure 3.3.25: The curve interaction for bar #45 – second case 101
Figure 3.3.26: The curve interaction for bar #46 - first case 104
Figure 3.3.27: The curve interaction for bar #46 – second case......................................106
Figure 3.3.28: The curve interaction for bar #47 – first case..109
Figure 3.3.29: The curve interaction for bar #47 – second case...................................... 111
Figure 3.3.30: The curve interaction for bar #48 – first case 114
Figure 3.3.31: The curve interaction for bar #48 – second case 116
Figure 3.3.32: The curve interaction for bar #49 – first case...119
Figure 3.3.33: The curve interaction for bar #49 – second case......................................121
Figure 3.3.34: The curve interaction for bar #50 – first case 124
Figure 3.3.35: The curve interaction for bar #50 – second case......................................126
Figure 3.3.36: The curve interaction for bar #51 – first case 129
Figure 3.3.37: The curve interaction for bar #51 – second case.......................................131
Figure 3.4.1: Effective area of the foundation 132
Figure 3.4.2: The static model for the foundation P2 in the x-direction – first case 134
Figure 3.4.3: The bending moment for the foundation P2 in the x-direction –first case 134
Figure 3.4.4: The static model for the foundation P2 in the y-direction – first case 135

Figure 3.4.5: The bending moment for the foundation P2 in the y-direction –first case 135
Figure 3.4.6: The static model for the foundation P2 in the x-direction – second case... 137
Figure 3.4.7: The bending moment for the foundation P2 in the x-direction–second case 137
Figure 3.4.8: The static model for the foundation P2 in the y-direction – second case... 138
Figure 3.4.9: The bending moment for the foundation P2 in the y-direction – second case 138
Figure 3.4.10: The static model for the foundation P3 in the x-direction – first case...... 144
Figure 3.4.11: The bending moment for the foundation P3 in the x-direction – first case 144
Figure 3.4.12: The static model for the foundation P3 in the y-direction – first case...... 145
Figure 3.4.13: The bending moment for the foundation P3 in the y-direction – first case 145
Figure 3.4.14: The static model for the foundation P3 in the x-direction – second case . 147
Figure 3.4.15:The bending moment for the foundation P3 in the x-direction–second case 147
Figure 3.4.16: The static model for the foundation P3 in the y-direction – second case . 148
Figure 3.4.17: The bending moment for the foundation P3 in the y-direction – second case 148
Figure 3.4.18: The sketch of the pile cap 153
Figure 3.4.19: The relationship between the forces for piles #1,3,4,6 154
Figure 3.4.20: The relationship between the forces for piles #2,5 155
Figure 3.4.21: The relationship between the forces – side view 156
Figure 3.4.22: The static model for the foundation P9 in the x-direction – first case 183
Figure 3.4.23: The bending moment for the foundation P9 in the x-direction – first case 183
Figure 3.4.24: The static model for the foundation P9 in the y-direction – first case 184
Figure 3.4.25: The bending moment for the foundation P9 in the y-direction – first case 184
Figure 3.4.26: The static model for the foundation P9 in the x-direction –second case . 186
Figure 3.4.27: The bending moment for the foundation P9 in the x-direction–second case 186

Figure 3.4.28: The static model for the foundation P9 in the y-direction –second case . 187

Figure 3.4.29: The bending moment for the foundation P9 in the y-direction – second case 187

Figure 3.4.30: The static model for the foundation P10 in the x-direction – first case ... 193

Figure 3.4.31:The bending moment for the foundation P10 in the x-direction – first case 193

Figure 3.4.32: The static model for the foundation P10 in the y-direction – first case.... 194

Figure 3.4.33: The bending moment for the foundation P10 in the y-direction – first case 194

Figure 3.4.34: The static model for the foundation P10 in the x-direction – second case 196

Figure 3.4.35: The bending moment for the foundation P10 in the x-direction – second case 196

Figure 3.4.36: The static model for the foundation P10 in the y-direction – second case197

Figure 3.4.37: The bending moment for the foundation P10 in the y-direction – second case 197

Figure 3.4.38: The curve interaction for the most loaded pile – first case 203

Figure 3.4.39: The curve interaction for the most loaded pile – second case 203

Figure 3.4.40: The combination table (reactions) 212

Figure 3.4.41: The reactions (SLS) 212

INDEX OF TABLES

Table 1: Self weight 214
Table 2: Prestressing load 216
Table 3: Additional permanent loads 218
Table 4: Temperature load 220
Table 5: The bending moments (DLS) 223

Abbreviations

DLS – decompression limit state

ULS – ultimate limit state

SLS – serviceability limit state

EC – Eurocode

QP – quasi permanent

1. Introduction

1.1. Scope

The project focuses on a preliminary design of the prestressed concrete viaduct. It includes the calculations of the main structure like deck, columns and foundations. As the result of that work there are a few drawings showing the reinforcement of each element of the viaduct.

1.2. Objectives

The main goal of this project is to design a crossing through the valley located in Poland which makes the transport easier and it will allow road users to save time. The viaduct should have two lanes and sidewalks. There is no counter indications to occupy areas of the valley which will facilitate the construction method.

1.3. Organization of the work

The project consists of a few different chapters. At the beginning there is quite detailed description of the structure in the point #2: "Bridge description and design criteria". There is basic information about the viaduct like all the dimensions, type of materials or calculative models. Next chapter #3 is the most important part of the project and consists of the calculations. The safety of the deck and the columns was verified in this section. In addition the number of reinforcing bars was chosen. What's more the bearings and expansion joints were selected. In the last chapter #4 called "Conclusion" there is a summary of all the project. Furthermore there are two more points in this work – bibliography and annexes which are the additional materials of the thesis.

2. Bridge description and design criteria

The viaduct was designed as 10 spans structure. It will be constructed in accordance with span by span casting method.

The basic dimensions of the viaduct:

- The diameter of the piers - 2,5 m
- Total length - 288 m
- Length of single span 30 m (24 m)
- Total width – 11,20 m
- Height of the piers: 19,95 m; 26,8 m; 30,57 m; 33,59 m; 39,38 m; 39,14 m; 34,28 m; 30,36 m; 16,9 m.
- Length of the piles: 8,71 m; 17,68 m; 23,51 m; 21,72 m; 10,57 m;
- The number of spread foundations – 4

- The number of deep foundations - 5
- The diameter of the piles – 1,75 m

Materials:

- Bedding concrete C16/20
- Abutments and foundations C30/37
- Piers and deck C35/45
- Reinforcing steel A500 NR
- Prestressing steel Y1860 S7

There are three calculation models in order to simplify the structure. The first model was used to verify the ultimate limit state of the deck in the longitudinal direction. In this case the structure has been simplified to one beam model with 3 characteristic cross sections – support cross section, halfway cross section and middle span cross section. The support and middle span cross sections are placed in the drawings. The halfway cross section was adopted with averaged dimensions of the two remaining cross sections. The second model is two support beam and it was also used to verify the ULS of the deck but in transversal direction. The shell model was used to create it. The third model is the most advanced because it was created as 3 dimensions structure. It was needed to verify the piers which are loaded by actions in two directions (wind and breaking load). It consists of the piers which are fixed in the foundations and released in the top (bearings), two beams of dimensions 60 x 188 cm and the slab (20 cm).

Support cross section:
$A = 6{,}42\ m^2$
$V_t = 0{,}717\ m$
$I = 2{,}18\ m^4$
$V_b = 1{,}233\ m$

Halfway cross section:
$A = 5{,}46\ m^2$
$V_t = 0{,}64\ m$
$I = 1{,}76\ m^4$
$V_b = 1{,}31\ m$

Middle span cross section:
$A = 5{,}11\ m^2$
$V_t = 0{,}579\ m$
$I = 1{,}53\ m^4$
$V_b = 1{,}371\ m$

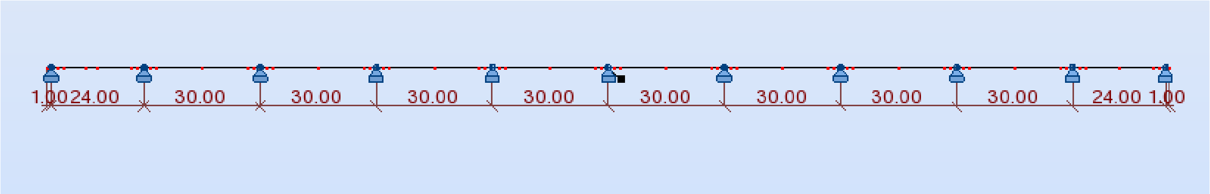


Figure 2.1: The first calculative model – static scheme

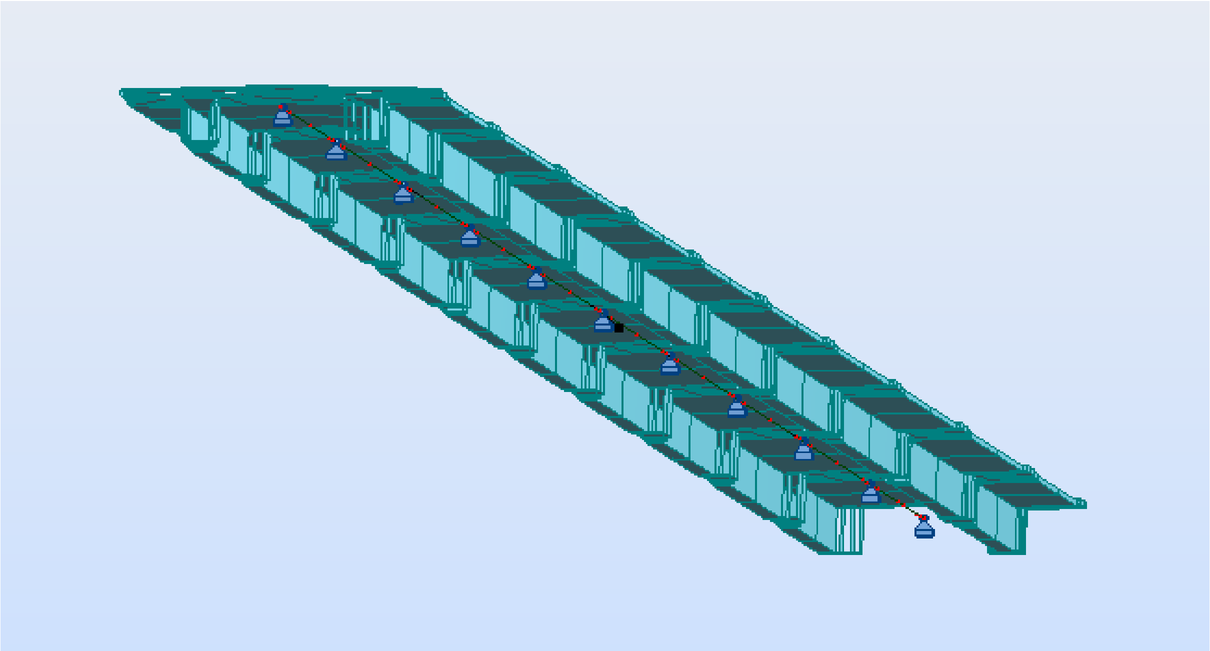


Figure 2.2: The first calculative model – 3D view

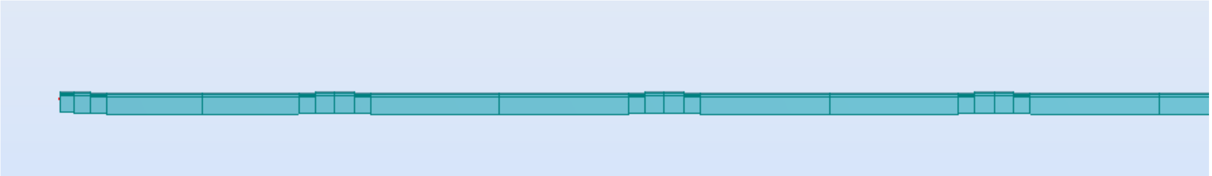


Figure 2.3: The first calculative model – side view

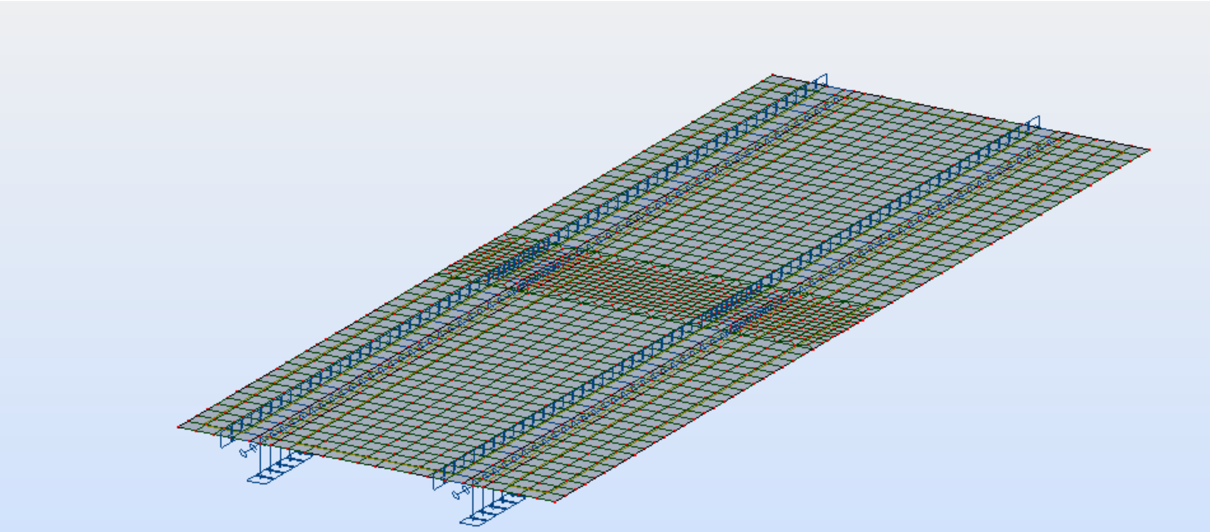


Figure 2.4: The second calculative model

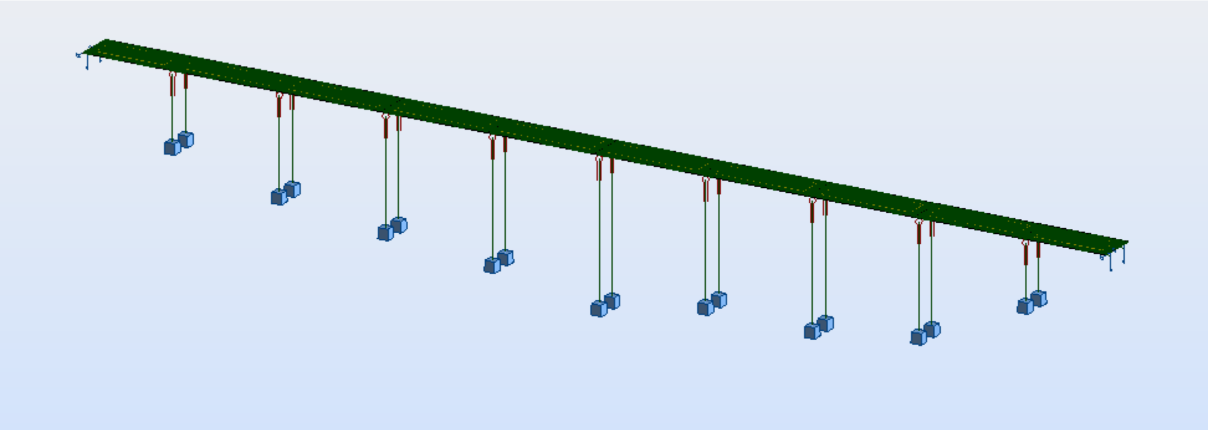


Figure 2.5: The third calculative model – static scheme

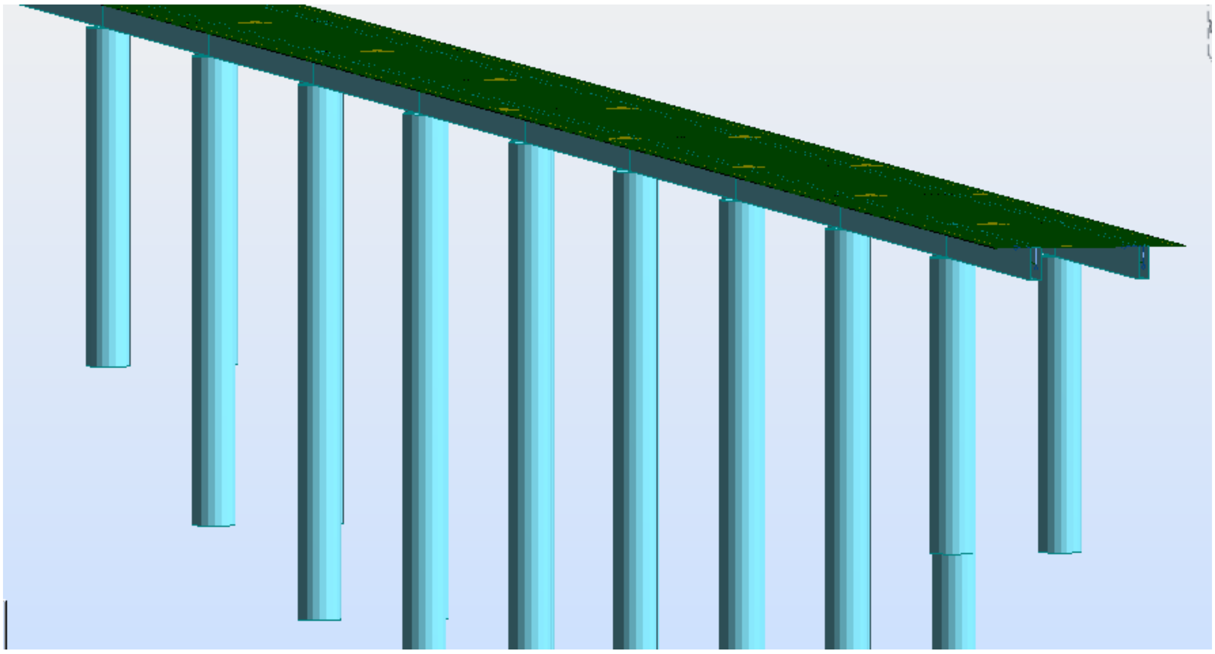


Figure 2.6: The third calculative model – 3D view

3. Calculations

3.1. Actions

a) Longitudinal direction

Self weight:

- Concrete C35/45

Figure 3.1.1: Self weight of first model

Additional permanent loads:

–	Edge beam	$25\ kN/m^3 \cdot 0{,}104\ m^2 = 2{,}60\ kN/m$
–	Parapet	$1{,}0\ kN/m$
–	Walkway filling	$24\ kN/m^3 \cdot 0{,}098\ m^2 = 2{,}35\ kN/m$
–	Kerb	$25 kN/m^3 \cdot 0{,}113\ m^2 = 2{,}83\ kN/m$
–	Rail	$1{,}0\ kN/m$
–	For every walkway side:	$2{,}6 + 1 + 2{,}352 + 2{,}825 + 1 = 9{,}78\ kN/m$
–	Asphalt	$24\ kN/m^3 \cdot 0{,}721\ m^2 = 17{,}30\ kN/m$

$$\Sigma = 36{,}86\ kN/m$$

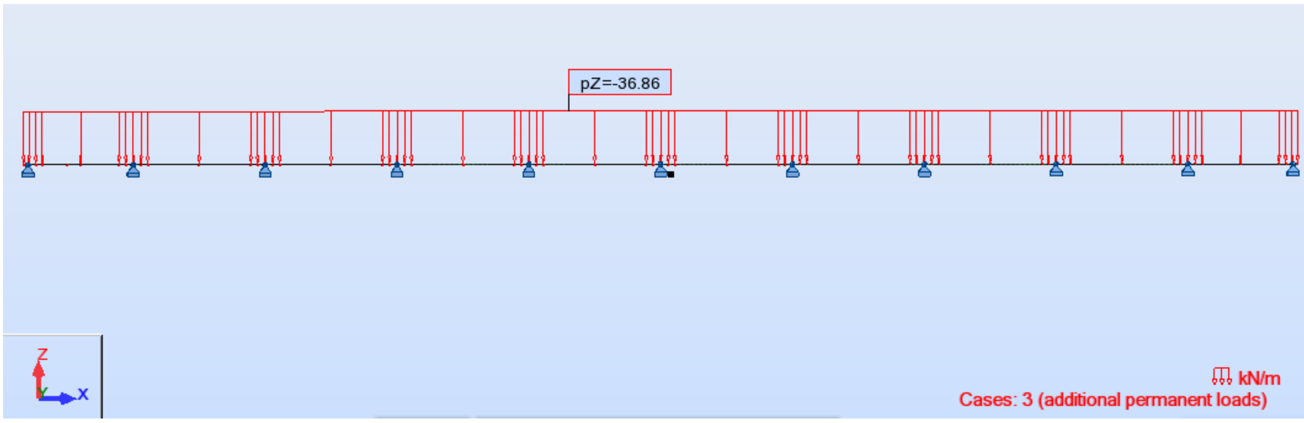


Figure 3.1.2: Additional permanent loads of first model

Distributed traffic's loads (UDL):

–	Lane #1	$9\ kN/m^2$
–	Lane #2	$2{,}5\ kN/m^2$
–	Lane #3	$2{,}5\ kN/m^2$
-	Average traffic's load	$\frac{(9{,}0+2{,}5+2{,}5)}{3} = 4{,}67\ kN/m2$
–	Sidewalk	$5{,}0\ kN/m^2$

$$\Sigma = \quad 5{,}0\ kN/m^2 \cdot 11{,}2\ m = 56{,}0\ kN/m$$

In view of simplified one beam model of the viaduct, it was assumed that there is the same average traffic load over the entire cross section and it is equal to 5,0 kN/m² - due to similar value of the sidewalk's load.

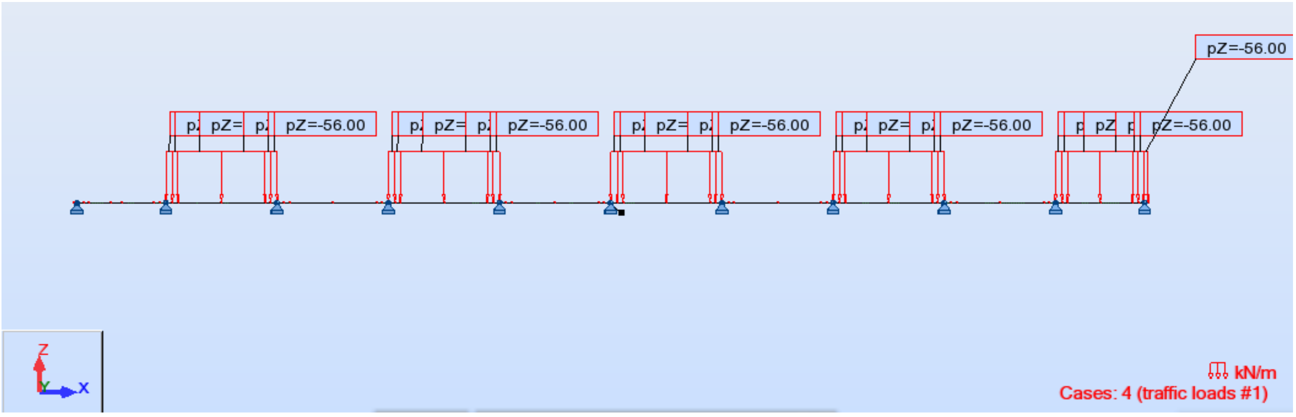


Figure 3.1.3: Distributed traffic's load of first model – first location

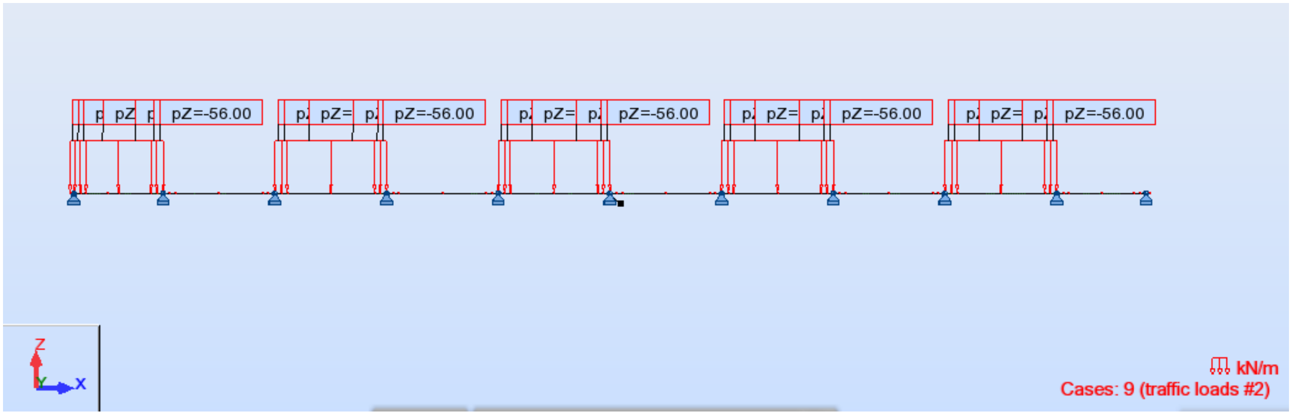


Figure 3.1.4: Distributed traffic's load of first model – second location

<u>Concentrated traffic's loads:</u>

– Lane #1	300 kN
– Lane #2	200 kN
– Lane #3	100 kN

$$\Sigma = \quad 2 \cdot (300+200+100) = 1200 \text{ kN}$$

In view of simplified one beam model of the viaduct, it was assumed that there is one single force (the sum of 3 lanes) in the middle of cross section. Because the length of a span is greater than 10 m, a tandem system is replaced by a one-axle concentrated load of weight of the two axis – 1200 kN.

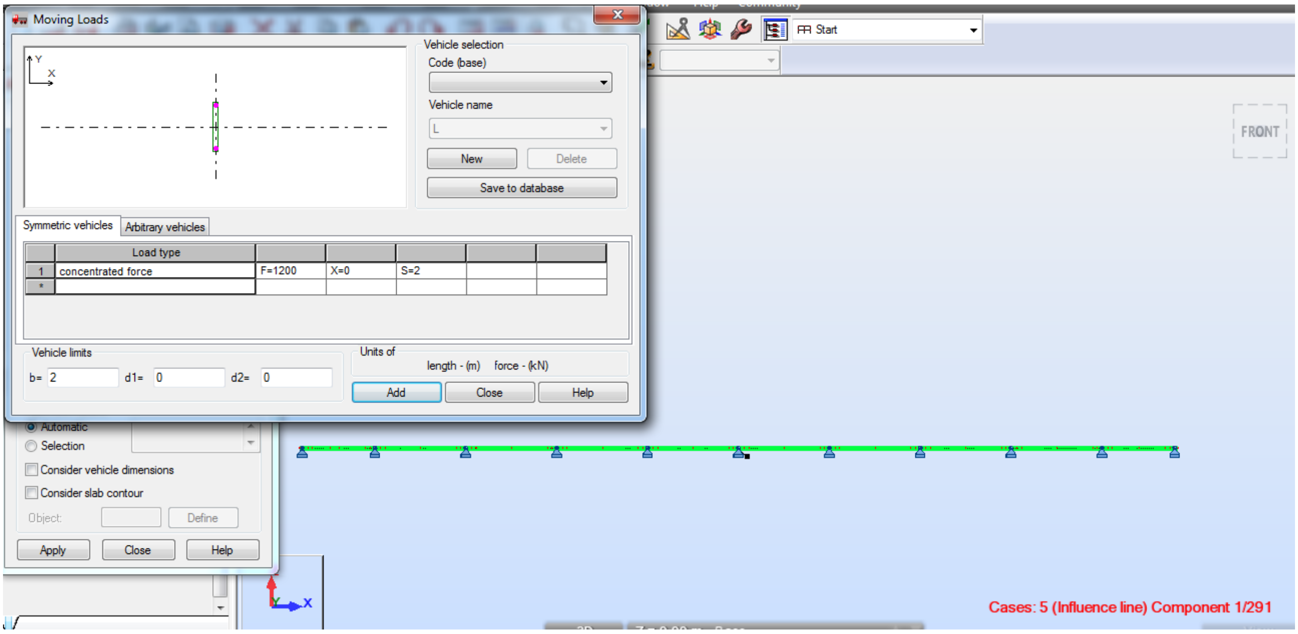


Figure 3.1.5: Concentrated traffic's load of first model

Temperature load #1 (+15°C):

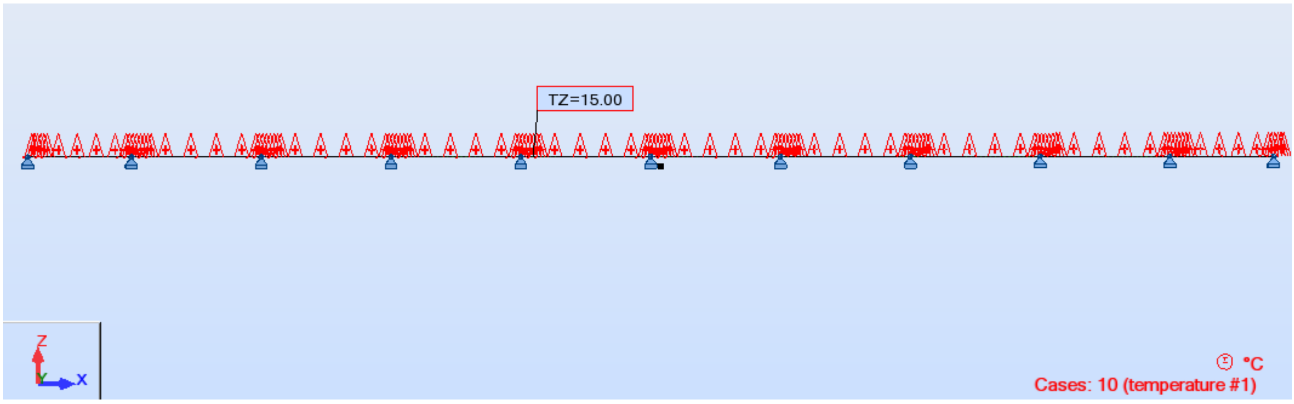


Figure 3.1.6: Positive temperature load of first model

Temperature load #2 (-8°C):

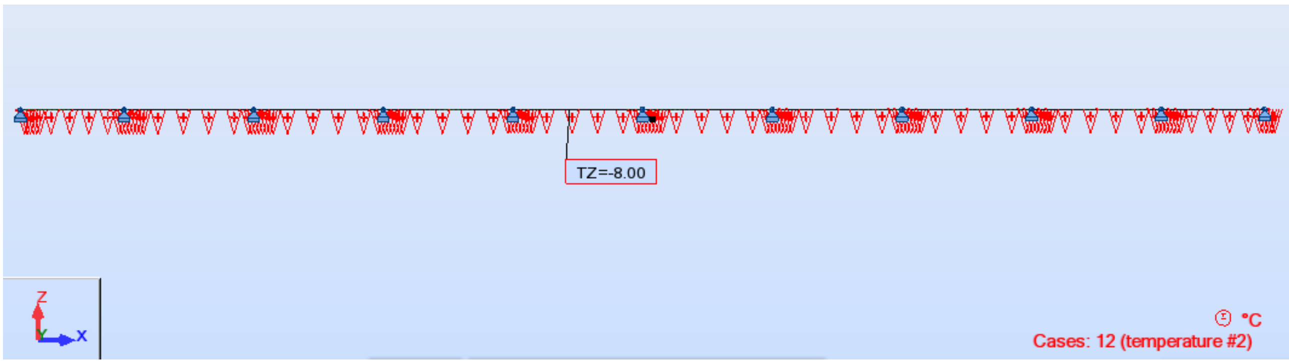


Figure 3.1.7: Negative temperature load of first model

Prestressing loads:

– Horizontal force P	+/-1000 kN
– Vertical force V	-218,89 kN
– Nodal bending moment M	+/- 84 kNm
– Uniformly distributed load for the extreme spans q1	24,32 kN/m
– Uniformly distributed load for the internal spans q2	16,03 kN/m
– Uniformly distributed load for the supports area q3	-64,13 kN/m
– Vertical internal force for span by span method V1	144,36 kN
– Nodal bending moment for span by span method M1	+/- 446 kNm

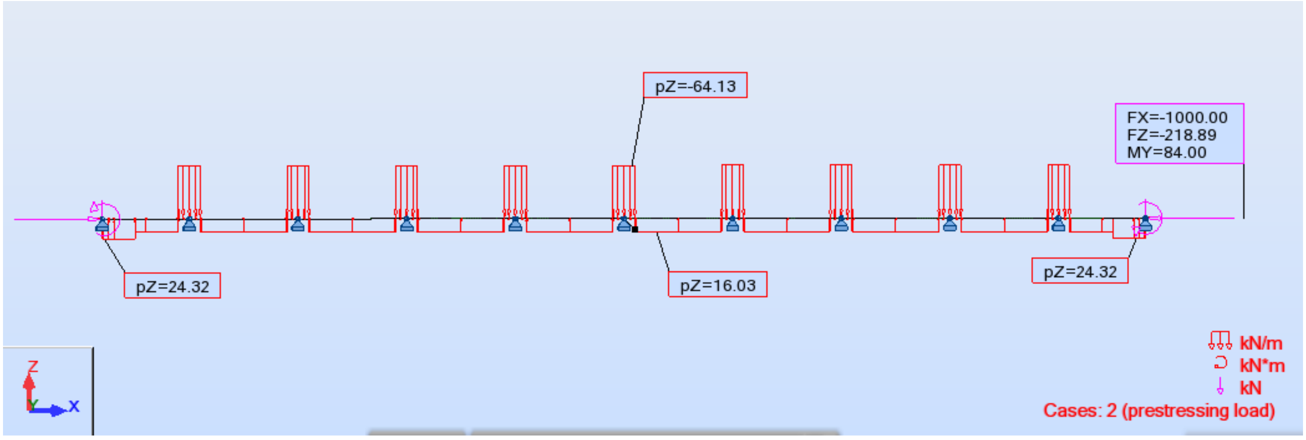


Figure 3.1.8: Prestressing loads of first model

b) Transverse direction

Self weight:

– Concrete C35/45

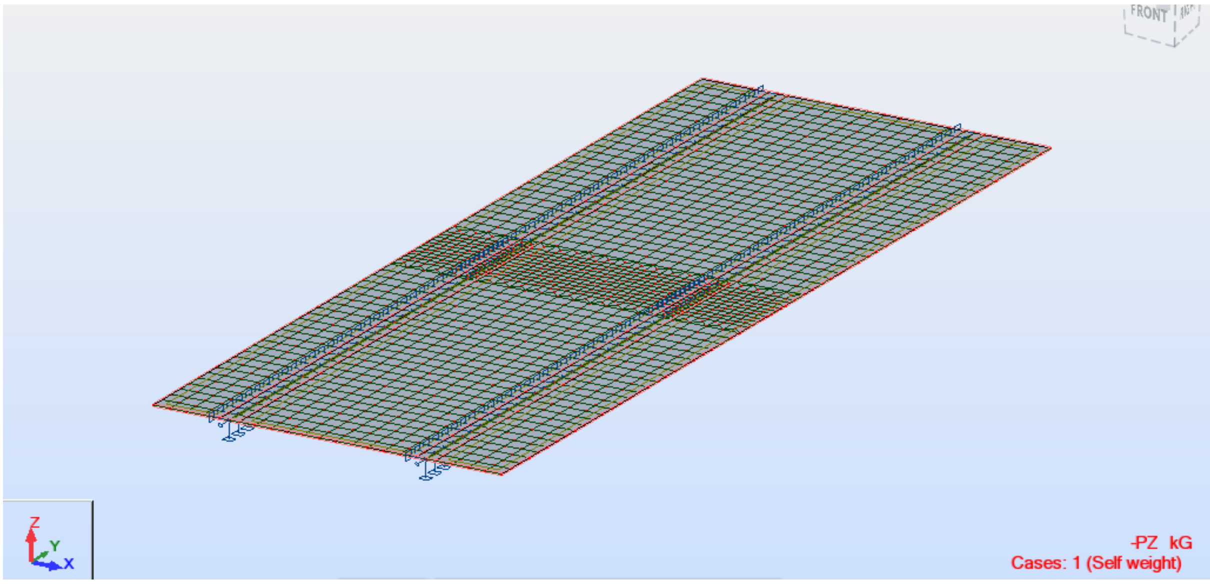


Figure 3.1.9: Self weight of second model

<u>Additional permanent loads:</u>

– Total load 36,86 kN/m : 11,2 m = 3,29 kN/m²

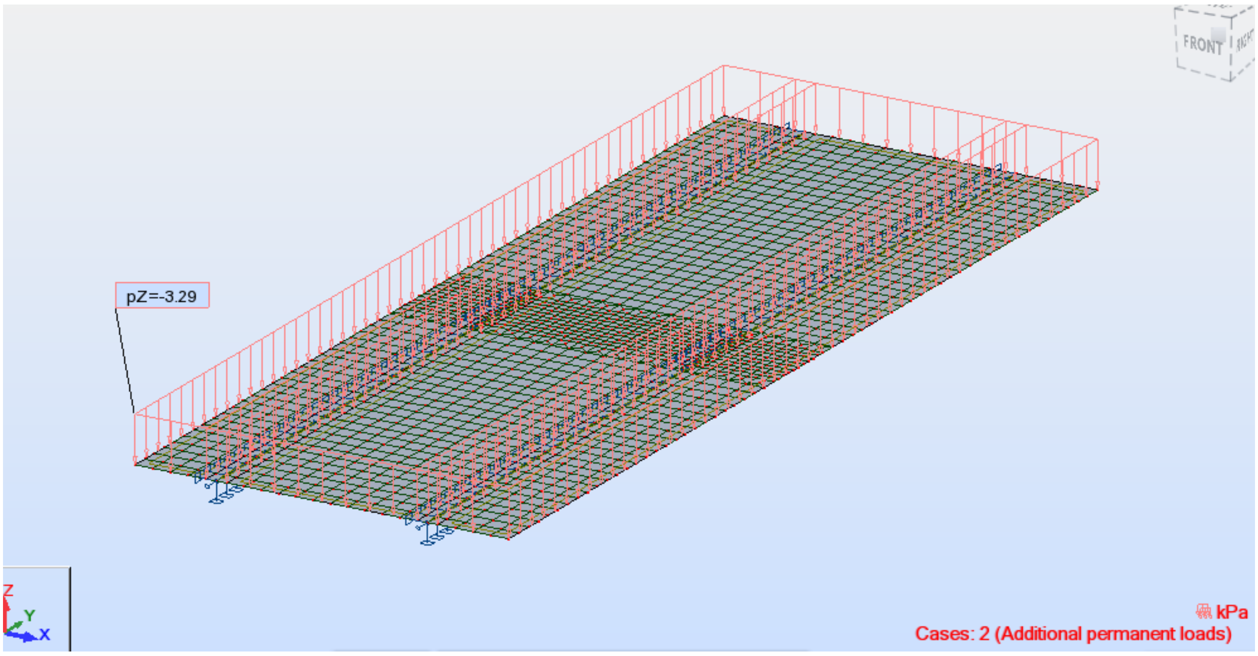


Figure 3.1.10: Additional permanent loads of second model

<u>Distributed traffic's loads (UDL):</u>

– Lane #1 9 kN/m²
– Lane #2 2,5 kN/m²
– Lane #3 2,5 kN/m
– Sidewalk 5,0 kN/m²

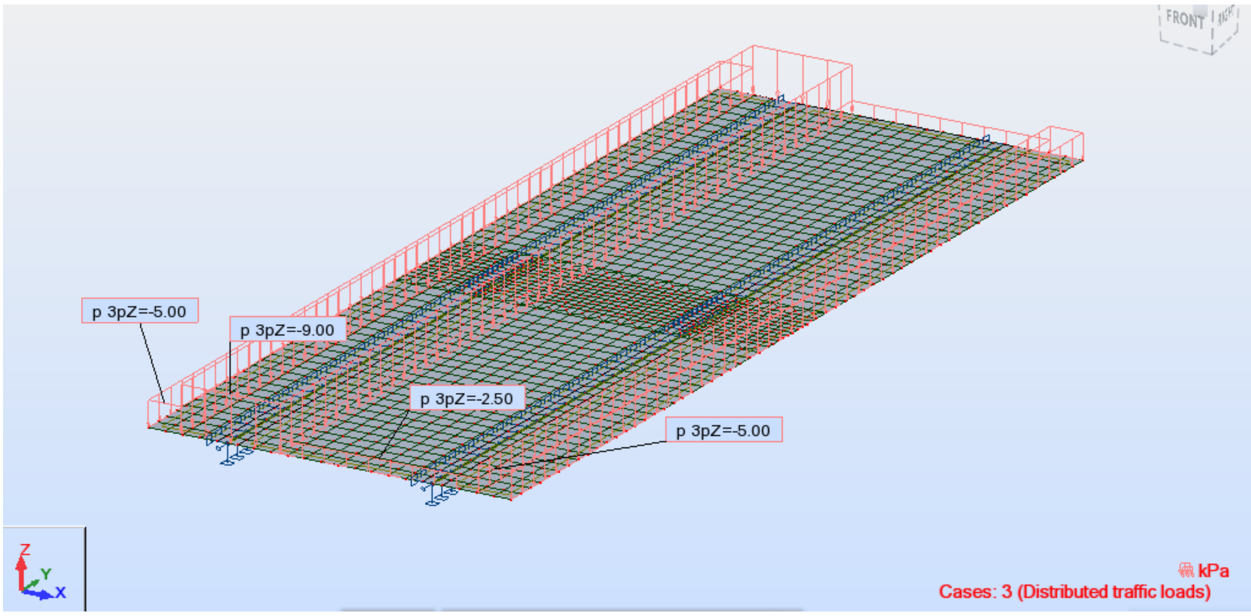


Figure 3.1.11: Distributed traffic's loads of second model – axonometric view

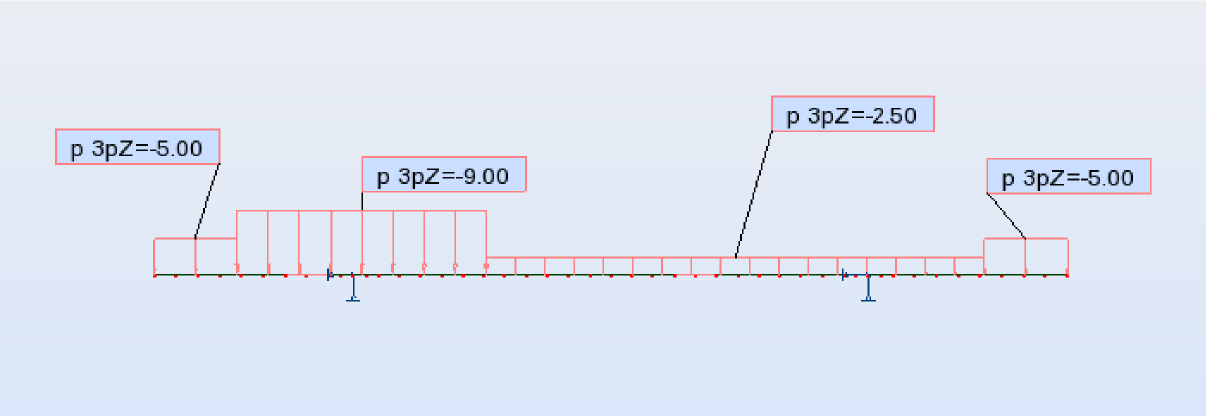


Figure 3.1.12: Distributed traffic's loads of second model – front view

<u>Concentrated traffic's loads:</u>

– Lane #1	300 kN per one axle (Tandem system)
– Lane #2	200 kN per one axle (Tandem system)
– Lane #3	100 kN per one axle (Tandem system)

On account of looking for the most dangerous case, three tandem system positions were considered. Because of that all lanes weren't put under load in the same time.

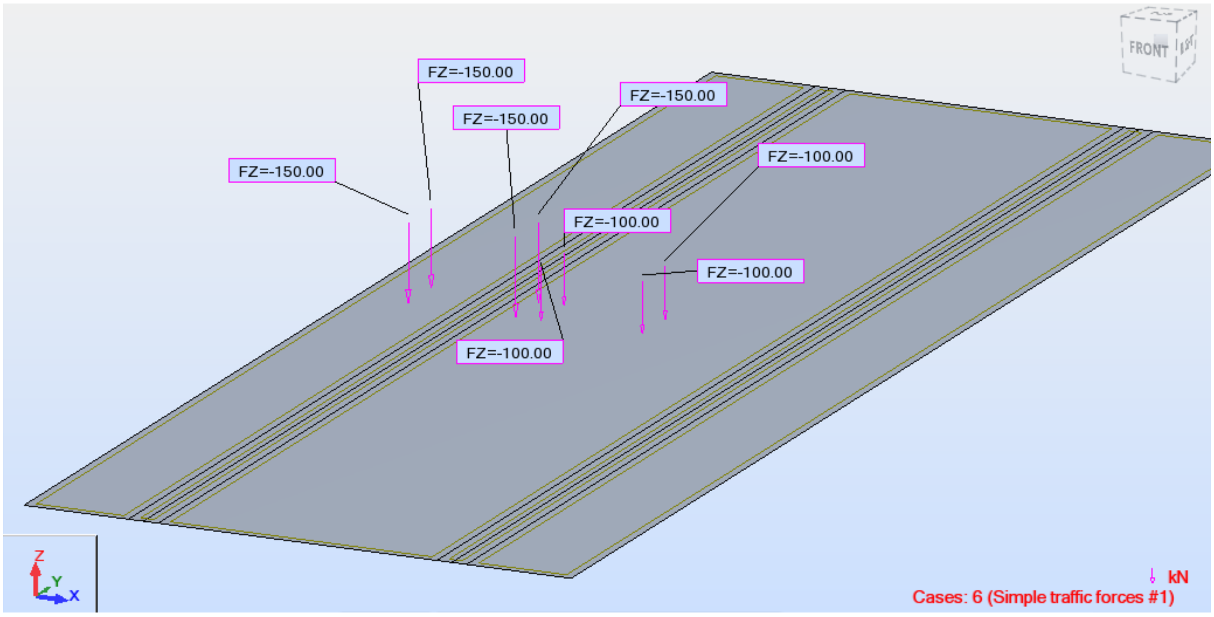


Figure 3.1.13: Concentrated traffic's loads of second model – first case

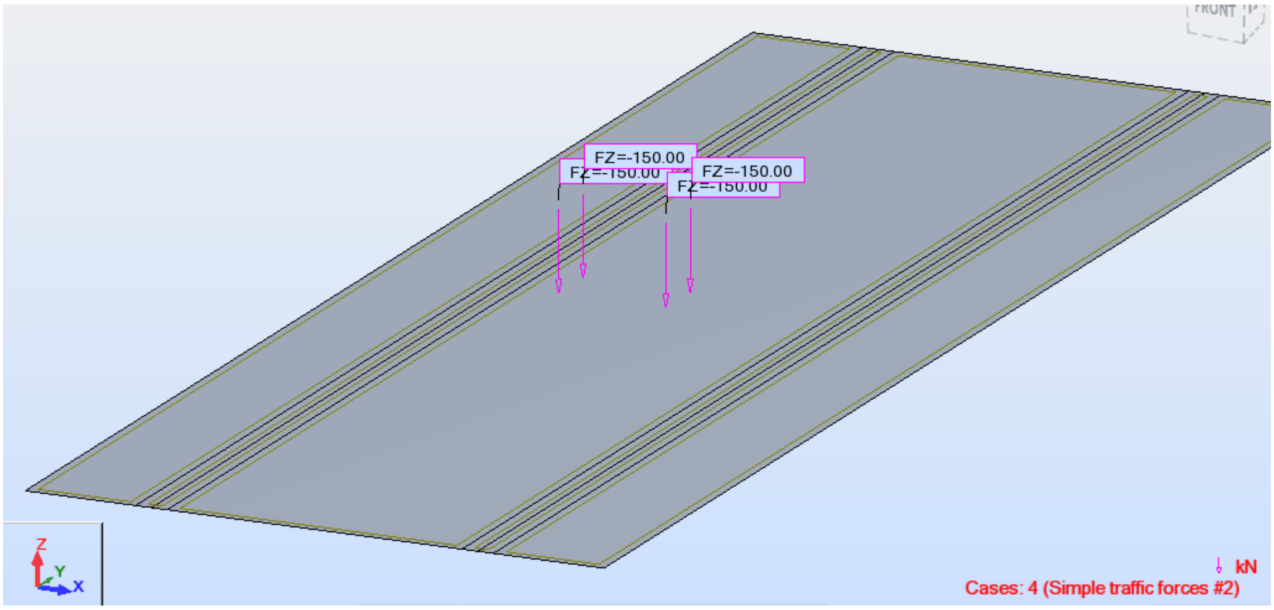


Figure 3.1.14: Concentrated traffic's loads of second model – second case

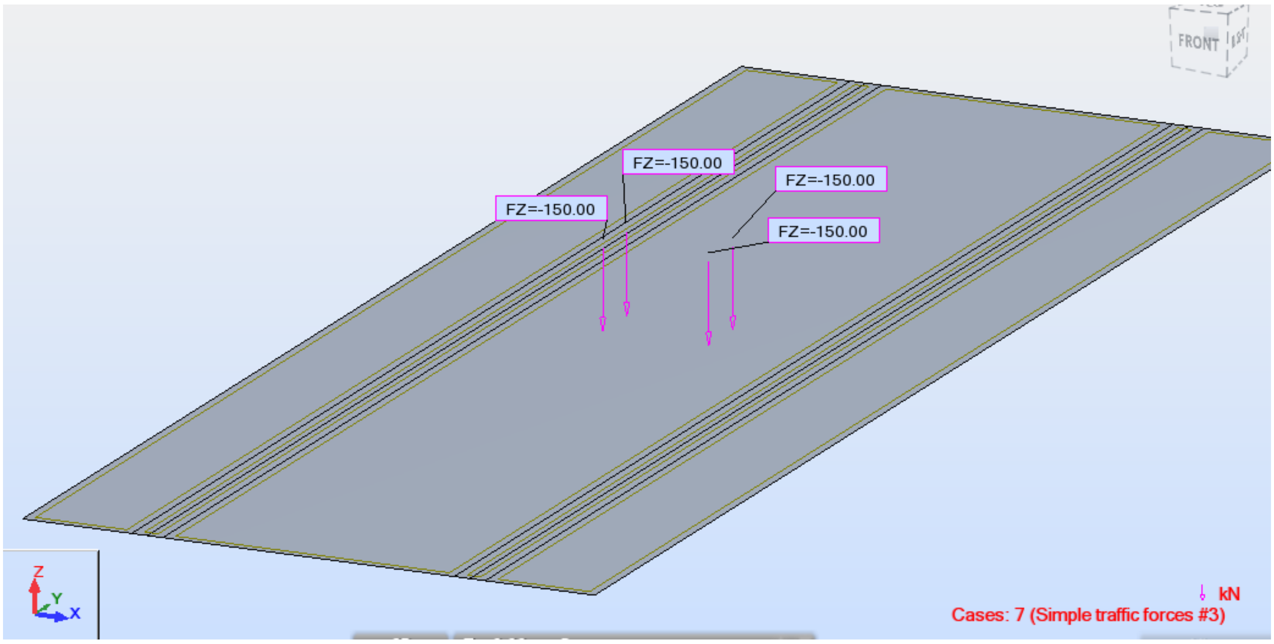


Figure 3.1.15: Concentrated traffic's loads of second model – third case

c) Columns

Self weight:

- Concrete C35/45

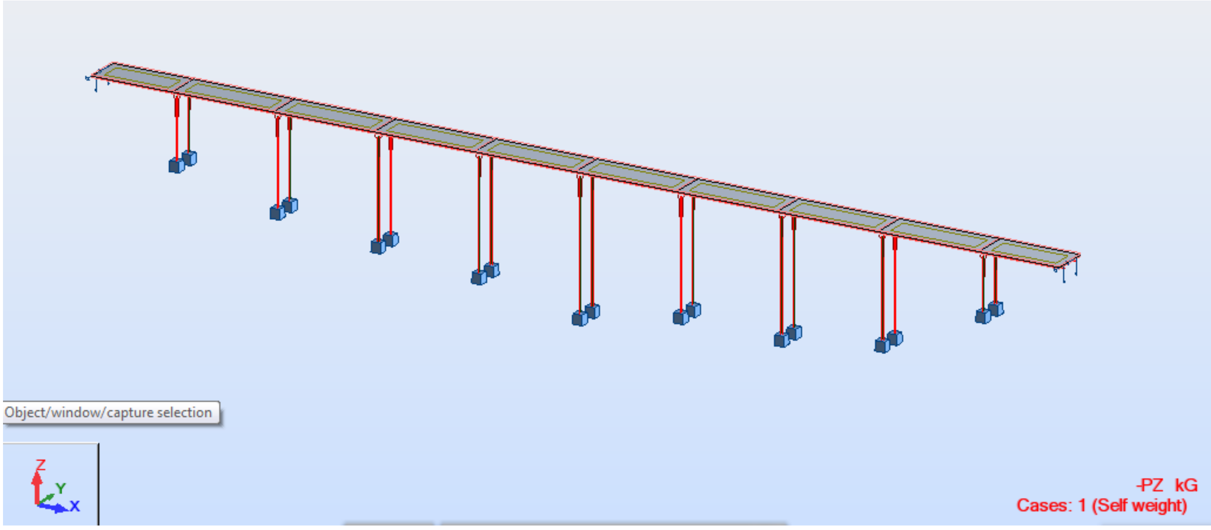


Figure 3.1.16: Self weight of third model

Breaking load:

– Concentrated horizontal force 900 kN

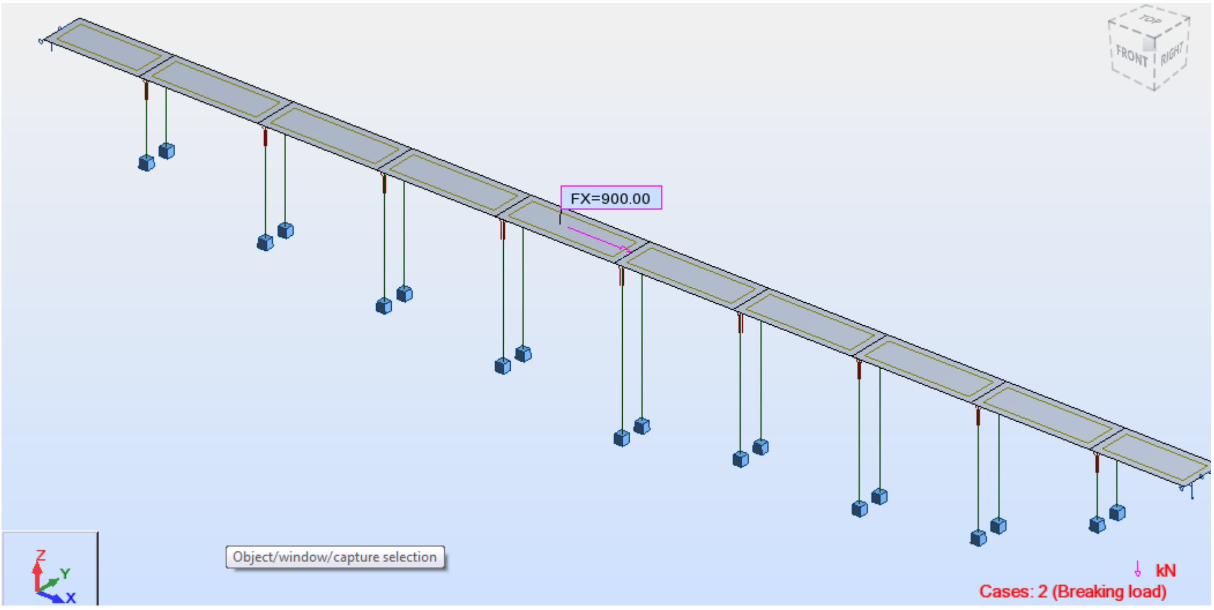


Figure 3.1.17: Breaking load

Wind:

– Uniformly distributed load 1,2 kPa

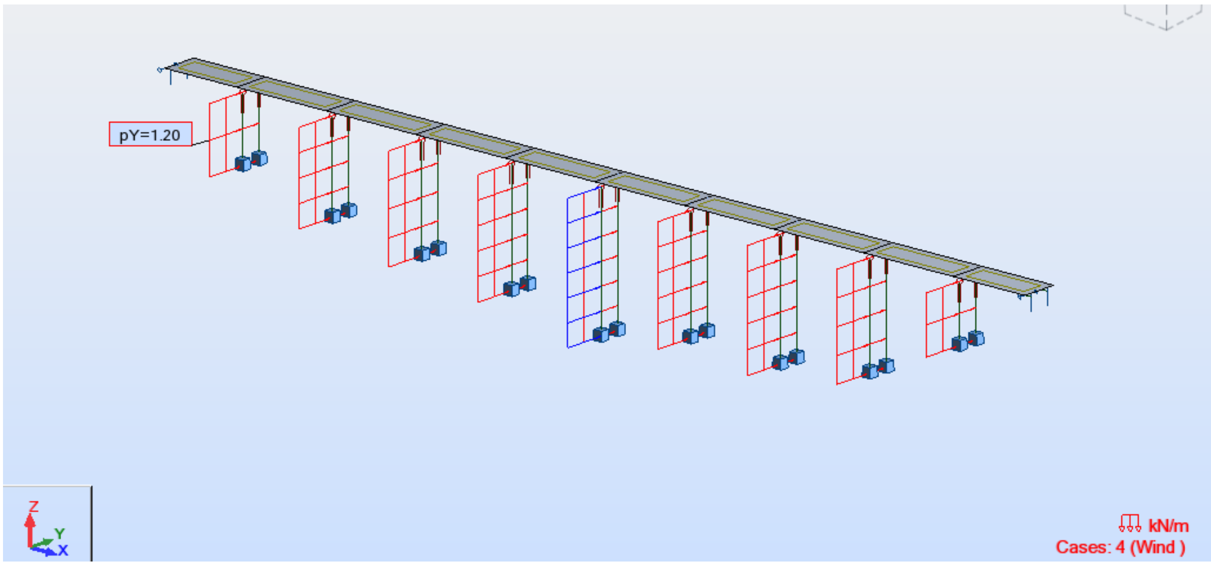


Figure 3.1.18: Wind

Support axial forces (ULS):

– The first row of the piers	2686 kN
– The second row of the piers	2696 kN
– The third row of the piers	2689 kN
– The fourth row of the piers	2691 kN
– The fifth row of the piers	2690 kN
– The sixth row of the piers	2691 kN
– The seventh row of the piers	2689 kN
– The eight row of the piers	2696 kN
– The ninth row of the piers	2686 kN

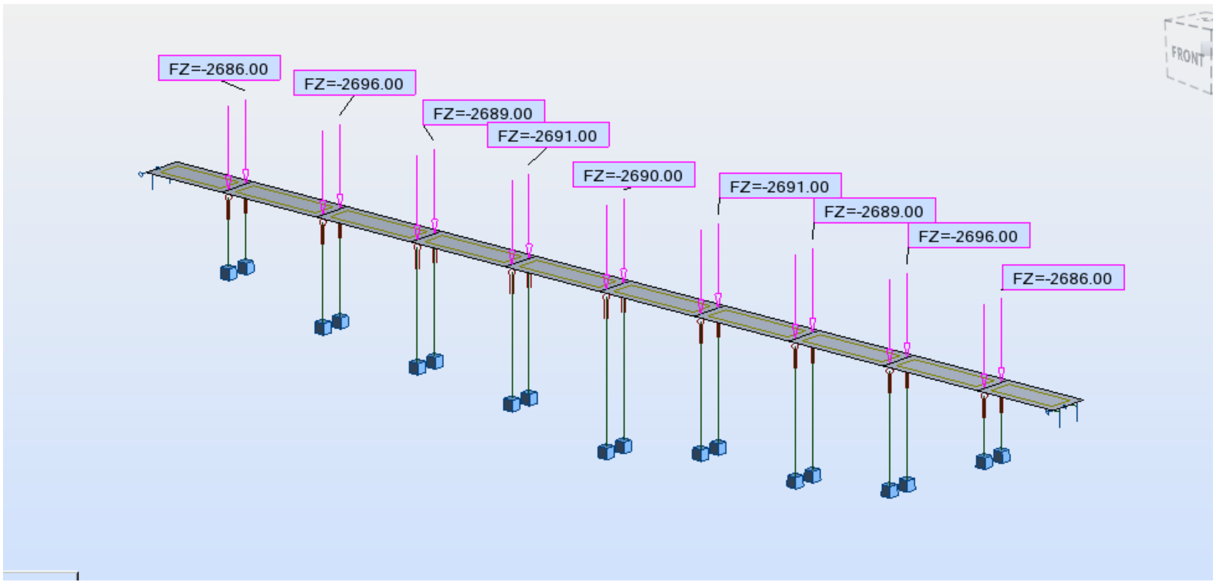


Figure 3.1.19: Support axial forces (ULS)

Support axial forces (SLS):

– The first row of the piers	1933 kN
– The second row of the piers	1922 kN
– The third row of the piers	1920 kN

- The fourth row of the piers 1921 kN
- The fifth row of the piers 1920 kN
- The sixth row of the piers 1921 kN
- The seventh row of the piers 1920 kN
- The eight row of the piers 1922 kN
- The ninth row of the piers 1933 kN

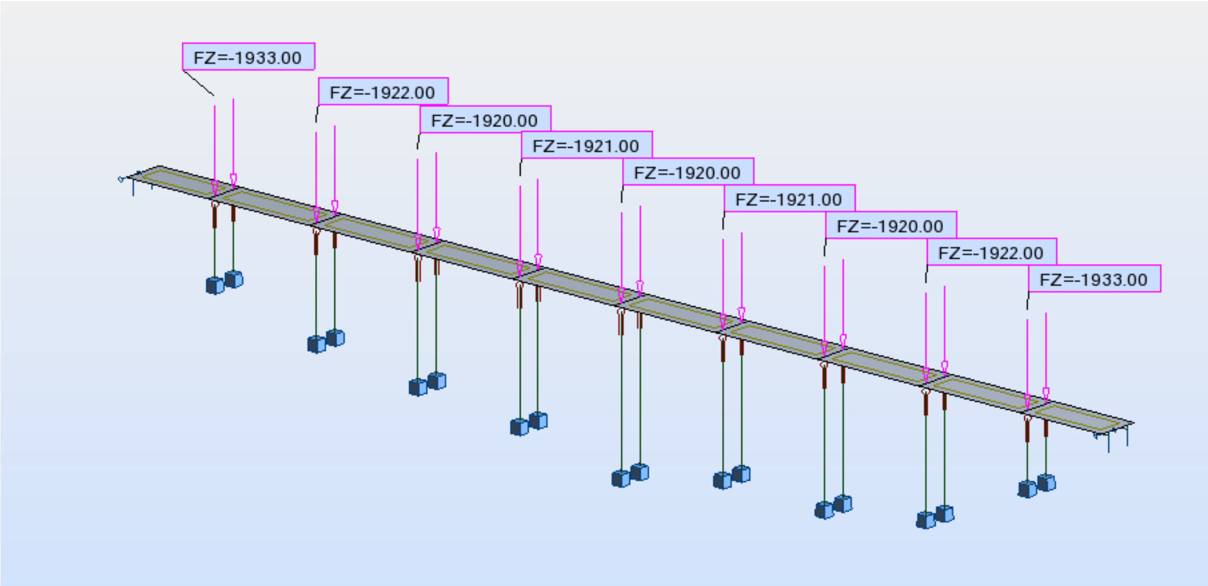


Figure 3.1.20: Support axial forces (SLS)

3.2. Deck

3.2.1. Transverse direction

Case	Label	Case name	Nature	Analysis type
1	DL1	Self weight	Structural	Static - Linear
2	DL1	Additional permanent loads	Non-structural	Static - Linear
3	DL3	Distributed traffic loads	UDL	Static - Linear
4	DL3	Simple traffic forces #2	TS	Static - Linear
6	DL3	Simple traffic forces #1	TS	Static - Linear
7	DL3	Simple traffic forces #3	TS	Static - Linear

Figure 3.2.1: Load table of transverse direction model

Combinations	Name	Analysis type	Combi nation	Case nature	Definition
8 (C)	*0.54 + 6*1.01	inear Combination		Structural	(1+2)*1.35+3*0.54+6*1.01
9 (C)	*0.54 + 4*1.01	inear Combination		Structural	(1+2)*1.35+3*0.54+4*1.01
10 (C)	*0.54 + 7*1.01	inear Combination		Structural	(1+2)*1.35+3*0.54+7*1.01
11 (C)	*0.54 + 6*1.01	inear Combination		Structural	(1+2)*1.00+3*0.54+6*1.01
12 (C)	*0.54 + 4*1.01	inear Combination		Structural	(1+2)*1.00+3*0.54+4*1.01
13 (C)	*0.54 + 7*1.01	inear Combination		Structural	(1+2)*1.00+3*0.54+7*1.01
14 (C)	*1.35 + 2*1.35	inear Combination		Structural	(1+2)*1.35
15 (C)	*1.35 + 3*0.54	inear Combination		Structural	(1+2)*1.35+3*0.54
16 (C)	*1.00 + 3*0.54	inear Combination		Structural	(1+2)*1.00+3*0.54
17 (C)	*1.00 + 2*1.00	inear Combination		Structural	(1+2)*1.00
18 (C)	*1.35 + 6*1.01	inear Combination		Structural	(1+2)*1.35+6*1.01
19 (C)	*1.35 + 4*1.01	inear Combination		Structural	(1+2)*1.35+4*1.01
20 (C)	*1.35 + 7*1.01	inear Combination		Structural	(1+2)*1.35+7*1.01
21 (C)	*1.00 + 6*1.01	inear Combination		Structural	(1+2)*1.00+6*1.01
22 (C)	*1.00 + 4*1.01	inear Combination		Structural	(1+2)*1.00+4*1.01
23 (C)	*1.00 + 7*1.01	inear Combination		Structural	(1+2)*1.00+7*1.01
24 (C)	*1.35 + 6*1.01	inear Combination		Structural	(1+2)*1.15+3*1.35+6*1.01
25 (C)	*1.35 + 4*1.01	inear Combination		Structural	(1+2)*1.15+3*1.35+4*1.01
26 (C)	*1.35 + 7*1.01	inear Combination		Structural	(1+2)*1.15+3*1.35+7*1.01
27 (C)	*1.35 + 6*1.01	inear Combination		Structural	(1+2)*1.00+3*1.35+6*1.01
28 (C)	*1.35 + 4*1.01	inear Combination		Structural	(1+2)*1.00+3*1.35+4*1.01
29 (C)	*1.35 + 7*1.01	inear Combination		Structural	(1+2)*1.00+3*1.35+7*1.01
30 (C)	*1.15 + 2*1.15	inear Combination		Structural	(1+2)*1.15
31 (C)	*1.15 + 3*1.35	inear Combination		Structural	(1+2)*1.15+3*1.35
32 (C)	*1.00 + 3*1.35	inear Combination		Structural	(1+2)*1.00+3*1.35
33 (C)	*1.00 + 2*1.00	inear Combination		Structural	(1+2)*1.00
34 (C)	*0.54 + 6*1.35	inear Combination		Structural	(1+2)*1.15+3*0.54+6*1.35
35 (C)	*0.54 + 4*1.35	inear Combination		Structural	(1+2)*1.15+3*0.54+4*1.35
36 (C)	*0.54 + 7*1.35	inear Combination		Structural	(1+2)*1.15+3*0.54+7*1.35
37 (C)	*0.54 + 6*1.35	inear Combination		Structural	(1+2)*1.00+3*0.54+6*1.35
38 (C)	*0.54 + 4*1.35	inear Combination		Structural	(1+2)*1.00+3*0.54+4*1.35
39 (C)	*0.54 + 7*1.35	inear Combination		Structural	(1+2)*1.00+3*0.54+7*1.35
40 (C)	*1.15 + 6*1.35	inear Combination		Structural	(1+2)*1.15+6*1.35
41 (C)	*1.15 + 4*1.35	inear Combination		Structural	(1+2)*1.15+4*1.35
42 (C)	*1.15 + 7*1.35	inear Combination		Structural	(1+2)*1.15+7*1.35
43 (C)	*1.00 + 6*1.35	inear Combination		Structural	(1+2)*1.00+6*1.35
44 (C)	*1.00 + 4*1.35	inear Combination		Structural	(1+2)*1.00+4*1.35
45 (C)	*1.00 + 7*1.35	inear Combination		Structural	(1+2)*1.00+7*1.35

Figure 3.2.2: Combination table of transverse direction model

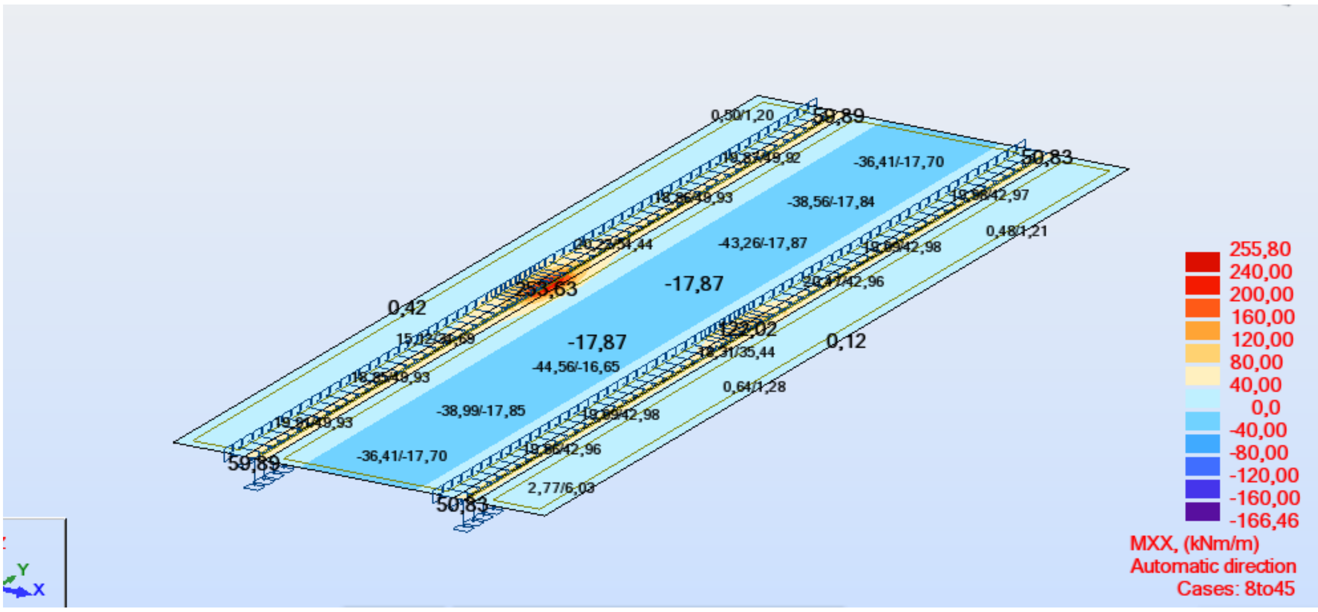


Figure 3.2.3: Top bending moment envelope of transverse direction model

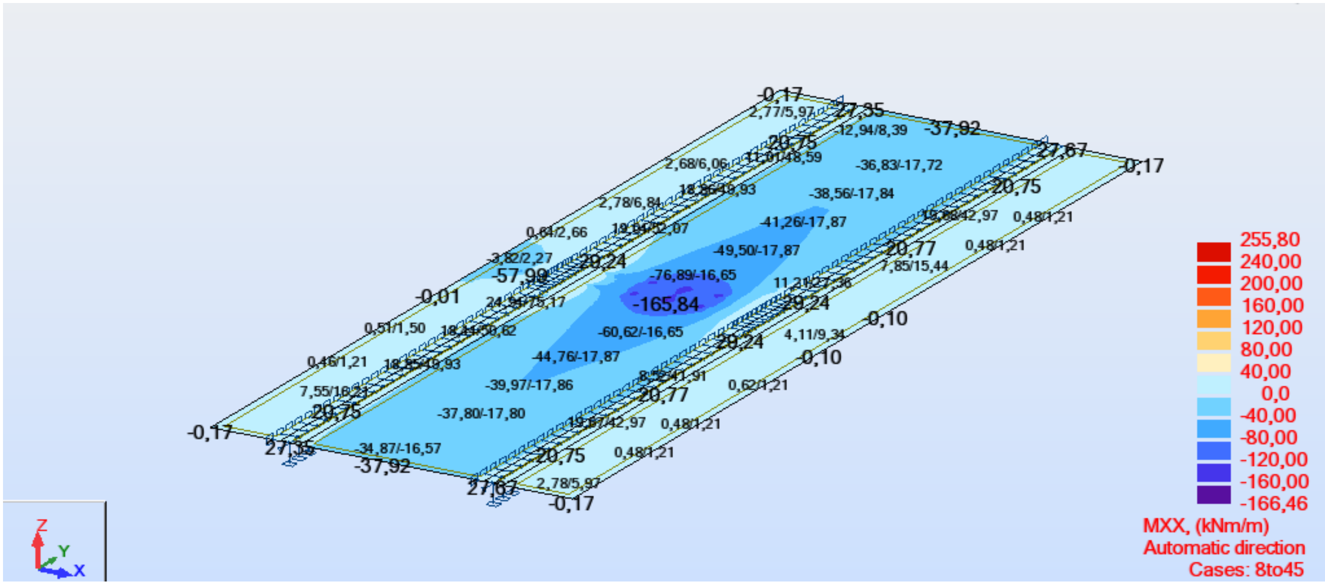


Figure 3.2.4 Bottom bending moment envelope of transverse direction model

Cantilever:

The bending moment is given by computer program Autodesk Robot Structural Analysis Professional 2014:

$M_{Ed} = 254 \ kNm/m$

The nominal concrete cover:

$C_{nom} = C_{min} + \Delta C_{dev}$

$\Delta C_{dev} = 10$ mm

$C_{min} = \max \{ C_{min,b}; C_{min,dur} + \Delta C_{dur,y} - \Delta C_{dur,st} - \Delta C_{dur,add}; 10 \text{ mm} \}$

$C_{min,b} =$ 20 mm

$C_{min,dur} = 10$ mm
$\Delta\ C_{dur,y} = \Delta\ C_{dur,st} = \Delta\ C_{dur,add} = 0$
$C_{nom} =$ 20 mm + 10 mm = 30 mm

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\emptyset}{2} = 0{,}30\ m - 0{,}03\ m - \frac{0{,}020}{2} m = 0{,}26\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{254\ kNm}{1{,}0\ m \cdot (0{,}26m)^2 \cdot 25\ kPa \cdot 10^3} = 0{,}150$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}150} = 0{,}163$$

$$A_{s,min} = 0{,}163 \cdot 1{,}0\ m \cdot 0{,}26\ m \cdot \frac{25\ MPa}{435\ MPa} = 24{,}4\ cm^2$$

That gives us #20/0,125 m with total area equal $A_s = 25{,}13\ cm^2$

Slab between beams:

The bending moment is given by computer program Autodesk Robot Structural Analysis Professional 2014:

$$M_{Ed} = 166\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\emptyset}{2} = 0{,}25\ m - 0{,}03\ m - \frac{0{,}020}{2} m = 0{,}21\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{166\ kNm}{1{,}0\ m \cdot (0{,}21\ m)^2 \cdot 25\ kPa \cdot 10^3} = 0{,}150$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}150} = 0{,}163$$

$$A_{s,min} = 0{,}163 \cdot 1{,}0\ m \cdot 0{,}21\ m \cdot \frac{25\ MPa}{435\ MPa} = 19{,}7\ cm^2$$

That gives us #20/0,15 m with total area equal $A_s = 20{,}94\ cm^2$

3.2.2. Longitudinal direction

Case	Label	Case name	Nature	Analysis type
1	STA1	self weight	Structural	Static - Linear
2	STA1	prestressing load	Structural	Static - Linear
3	STA1	additional permanent loads	Structural	Static - Linear
4	MOV1	traffic loads #1	live	Static - Linear
5	MOV1	Influence line		Analysis of moving l
6		Influence line +		Analysis of moving l
7		Influence line -		Analysis of moving l
9	MOV1	traffic loads #2	live	Static - Linear
10	STA1	temperature #1	temperature	Static - Linear
11		Decompression limit state		Linear Combination
12	STA1	temperature #2	temperature	Static - Linear

Figure 3.2.5 Load table of longitudinal direction model

Combinations	Name	Analysis type	Combi nation	Case nature	Definition
11 (C)	Decompression limit state	Linear Combination	S:QPR		(1+2+3)*1.00+10*0.50
13 (C)	Ultimate limit state of bending	Linear Combination	ULS		(1+3+4+5+9)*1.35+2*1.00
17 (C)	Ultimate limit state of bending - Ved (1,2)	Linear Combination	ULS		(1+3+4+5+9)*1.35+2*1.20
32 (C)	SLS:QPR/1=3*1.00 + 2*1.00	Linear Combination	S:QPR	dead	(3+2)*1.00
33 (C)	SLS:QPR/2=3*1.00 + 2*1.00 + 10*0.50	Linear Combination	S:QPR	dead	(3+2)*1.00+10*0.50
34 (C)	SLS:QPR/3=3*1.00 + 2*1.00 + 12*0.50	Linear Combination	S:QPR	dead	(3+2)*1.00+12*0.50
39 (C)	ULS (Reactions) withous self weight	Linear Combination	ULS		2*1.00+(3+4+5+9)*1.35
43 (C)	ULS (Reactions) without self weight P=1,2	Linear Combination	ULS		2*1.20+(3+4+5+9)*1.35

Figure 3.2.6 Combination table of longitudinal direction model

<u>Ultimate limit state of bending</u>

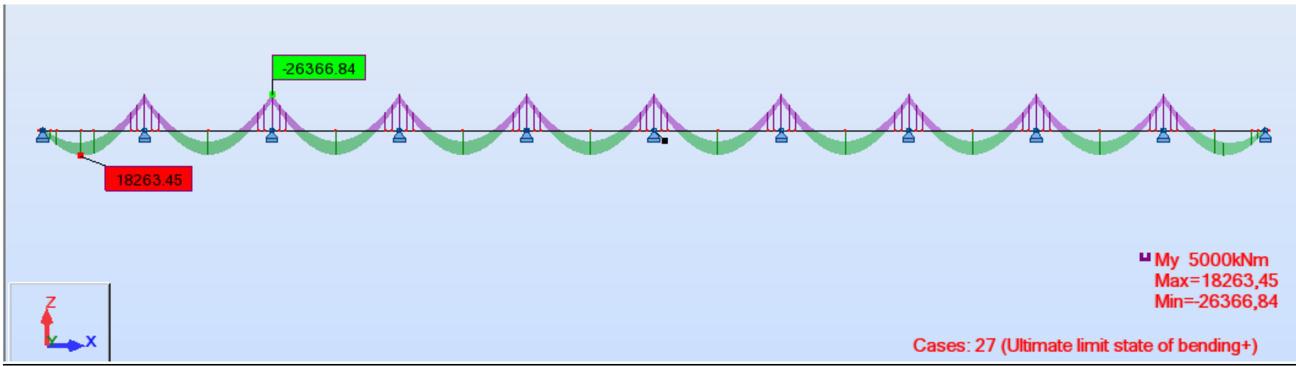


Figure 3.2.7 The bending moment envelope of longitudinal direction model

$M_{Ed} \leq M_{Rd}$

Support section:

The bending moment is given by computer program Autodesk Robot Structural Analysis Professional 2014:

$M_{Ed} = -26367\ kNm$

The nominal concrete cover:

$C_{nom} = C_{min} + \Delta C_{dev}$

$\Delta\ C_{dev} = 10\ mm$
$C_{min} = \max\{ C_{min,b};\ C_{min,dur} + \Delta\ C_{dur,y} - \Delta\ C_{dur,st} - \Delta\ C_{dur,add};\ 10\ mm \}$
$C_{min,b} = 25\ mm$
$C_{min,dur} = 10\ mm$
$\Delta\ C_{dur,y} = \Delta\ C_{dur,st} = \Delta\ C_{dur,add} = 0$
$C_{nom} = 25\ mm + 10\ mm = 35\ mm$

Minimum area of reinforcement:

$$A_{s,min} = 0{,}26 \cdot \frac{f_{ctm}}{f_{yk}} b_t d$$

Assuming bars #25:

$$d = h - c_{nom} - 0{,}02\ m - \frac{\emptyset}{2} = 1{,}86\ m - 0{,}035\ m - 0{,}02\ m - \frac{0{,}025}{2}\ m = 1{,}79\ m$$

Calculated minimum area of reinforcement:

$$A_{s,min} = 0{,}26 \cdot \frac{3{,}2\ MPa}{500\ MPa} \cdot 1{,}15\ m \cdot 1{,}79\ m = 34{,}2\ cm^2$$

That gives us 8 #25 with total area equal $A_s = 39{,}27\ cm^2$

Assuming that both steels have reached yielding stress:

$$F_s = f_{yd}A_s = 435\ MPa \cdot (2 \cdot 39{,}27\ cm^2\ ) = 3416\ kN$$

$$F_p = f_{pd}A_P = 1400\ MPa \cdot (2 \cdot 2 \cdot 19 \cdot 1{,}4\ cm^2) = 14896\ kN$$

$$F_s + F_P = 3416\ kN + 14896\ kN = 18312\ kN$$

$$F_c = f_{cd}A_c = 25 \cdot 10^3\ MPa \cdot (2 \cdot 1{,}05\ m \cdot y) = 52500y$$

Because

$$F_s + F_P = F_c$$

Then

$$18312\ kN = 52500y \Leftrightarrow y = 0{,}349\ m$$

$$y = 0{,}8x \Leftrightarrow x = 0{,}436\ m$$

Verification of the assumption:

$$\frac{\varepsilon_c}{x} = \frac{\varepsilon_s}{d-x} \Leftrightarrow \varepsilon_s = \frac{1{,}79\ m - 0{,}436\ m}{0{,}436\ m} \cdot 3{,}5 = 10{,}87 > \varepsilon_{yd} = 2{,}175$$

$$\frac{\varepsilon_c}{x} = \frac{\Delta\varepsilon_P}{h - x - 0{,}165} \Leftrightarrow \Delta\varepsilon_P = \frac{1{,}86\ m - 0{,}436\ m - 0{,}13\ m}{0{,}436\ m} \cdot 3{,}5 = 10{,}39$$

$$\varepsilon_P = \varepsilon_{P\infty} + \Delta\varepsilon_P = \frac{\sigma_{P\infty}}{E_p} + \Delta\varepsilon_P = \frac{1000}{195} + 10{,}39 = 15{,}39 > \varepsilon_{Pd} = 7{,}18$$

$$M_{Rd} = 14896\ kN \cdot 1{,}56\ m + 3416\ kN \cdot (1{,}56\ m + 0{,}06\ m) = 28771\ kNm > M_{Ed}$$

Mid span section:

The bending moment is given by computer program Autodesk Robot Structural Analysis Professional 2014:

$M_{Ed} = 18263\ kNm$

Minimum area of reinforcement:

$A_{s,min} = 0{,}26 \cdot \frac{f_{ctm}}{f_{yk}} b_t d$

Assuming bars #25:

$d = 1{,}79\ m$

Calculated minimum area of reinforcement:

$A_{s,min} = 0{,}26 \cdot \frac{3{,}2\ MPa}{500\ MPa} \cdot 0{,}70\ m \cdot 1{,}79\ m = 20{,}85\ cm^2$

That gives us 5 #25 with total area equal $A_s = 24{,}54\ cm^2$

Assuming that both steels have reached yielding stress:

$F_s = f_{yd} A_s = 435\ MPa \cdot (2 \cdot 24{,}54\ cm^2) = 2135\ kN$

$F_p = f_{pd} A_s = 1400 \cdot (2 \cdot 2 \cdot 19 \cdot 1{,}4\ cm^2) = 14896\ kN$

$F_s + F_P = 2135\ kN + 14896\ kN = 17031\ kN$

$F_c = f_{cd} A_c = 25 \cdot 10^3\ MPa \cdot (11{,}20\ m \cdot y) = 280000y$

Because

$F_s + F_P = F_c$

Then

$17031\ kN = 280000y \Leftrightarrow y = 0{,}061\ m$

$y = 0{,}8x \Leftrightarrow x = 0{,}076\ m$

Obviously steels have reached the yielding points.

$M_{Rd} = 14896\ kN \cdot 1{,}56\ m + 2135\ kN \cdot (1{,}56\ m + 0{,}2\ m) = 26995\ kNm > M_{Ed}$

Ultimate limit state of shearing

The first case

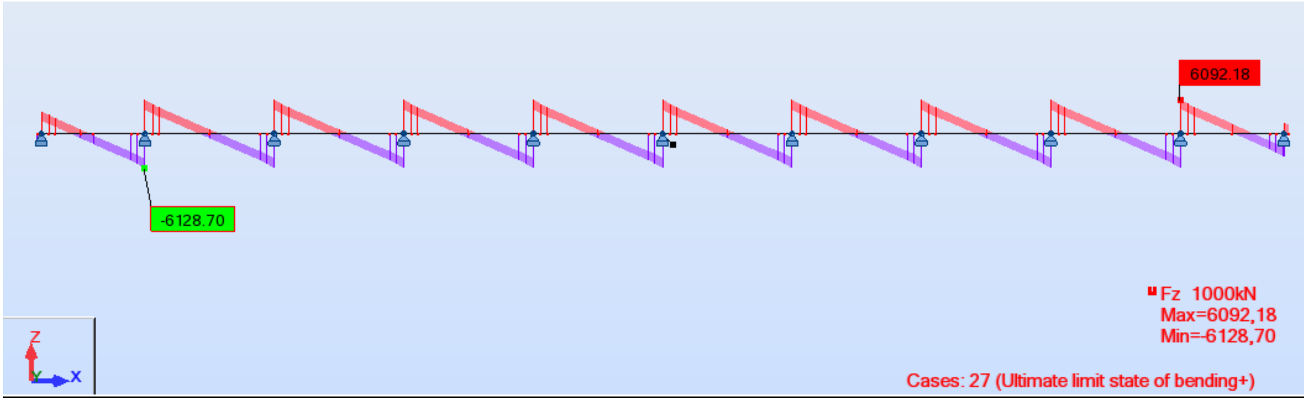


Figure 3.2.8 The shear force envelope of longitudinal direction model – first case

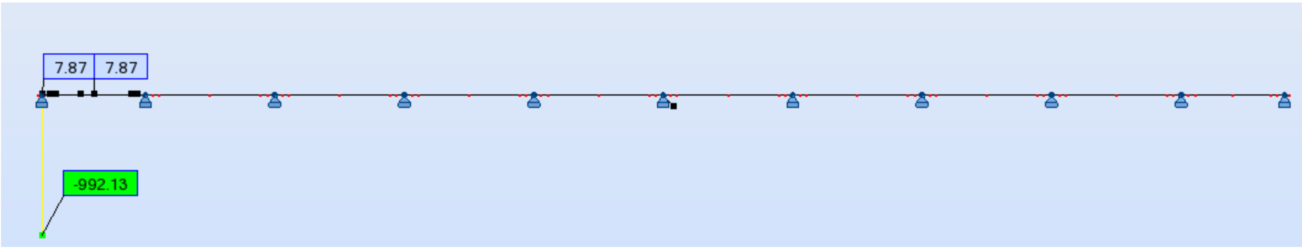


Figure 3.2.9 The axial force envelope of longitudinal direction model – first case

The second case

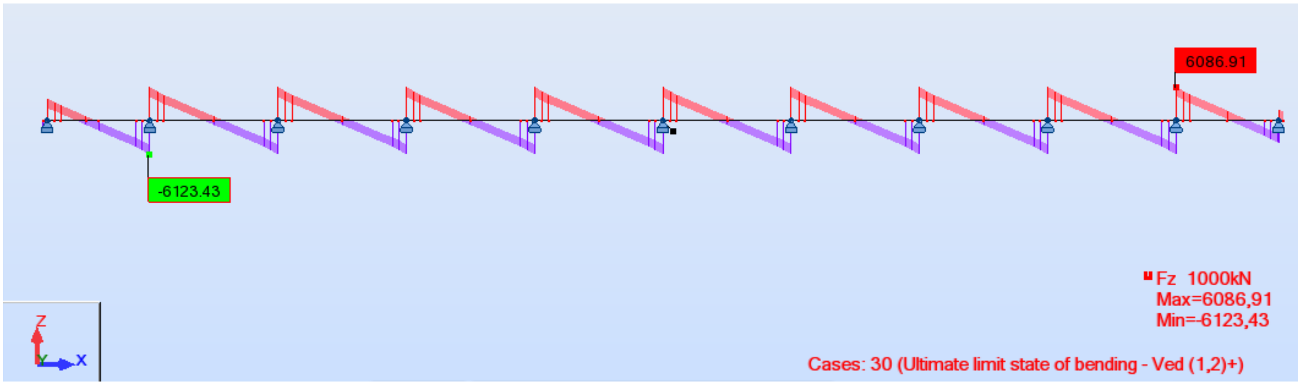


Figure 3.2.10 The shear force envelope of longitudinal direction model – second case

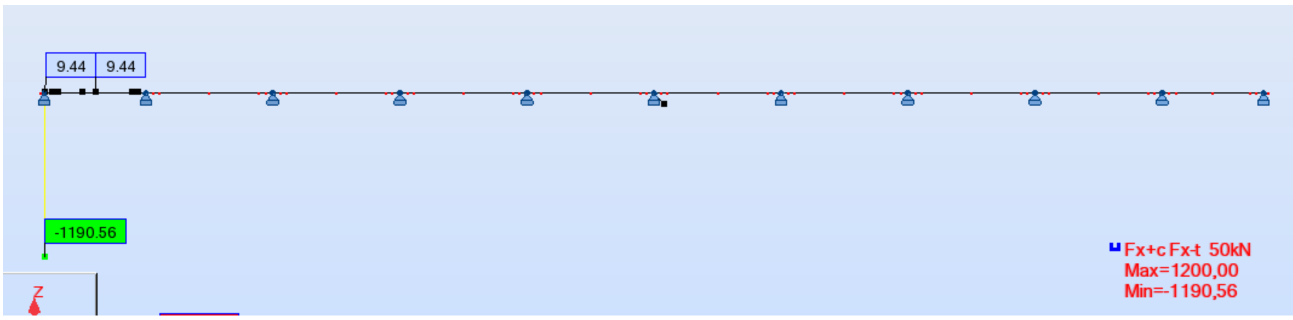


Figure 3.2.11 The axial force envelope of longitudinal direction model – second case

$V_{Ed} \leq V_{Rd,max}$

Support section (the highest value of the shear force)

There are two different situations which should be considered. The ultimate limit state of shearing is calculated for combination according to formula 6.10 (PN-EN 1990:2004). The design value of applied shear force must be checked in two cases:

1) Safety factor for prestressing loads is equal 1,0
2) Safety factor for prestressing loads is equal 1,2

The shear force is given by computer program Autodesk Robot Structural Analysis Professional 2014:

$V_{Ed,1} = 6129\ kN$

$N'_{Ed,1} = 992\ kN$

The final value of the axial force:

$N_{Ed,1} = 992\ kN \cdot 11{,}917 \approx 11822\ kN$

$V_{Ed,2} = 6123\ kN$

$N'_{Ed,2} = 1191\ kN$

The final value of the axial force:

$N_{Ed,2} = 1191\ kN \cdot 11{,}917 \approx 14193\ kN$

<u>The first case</u>

Minimum area of the shear reinforcement:

$$V_{Rd,s} = \frac{A_{sw}}{s} \cdot z \cdot f_{ywd} \cdot cot\theta \rightarrow \frac{A_{sw}}{s} = \frac{V_{Ed,1}}{z \cdot f_{ywd} \cdot cot\theta} = \frac{6129\ kN}{0{,}9 \cdot 1{,}79\ m \cdot 435\ MPa \cdot cot30°} = 50{,}5\ cm^2/m$$

Taking into consideration two beams of the deck (one stirrup in each cross section of a beam):

$$\frac{50{,}5\ cm^2/\text{m}}{8} = 6{,}3 \frac{cm^2}{m} \rightarrow \emptyset 16\ every\ 25\ cm\ (A_s = 8{,}04\ cm^2\ )$$

$$V_{Rd,max} = \frac{\alpha_{cw} \cdot b_w \cdot z \cdot \upsilon_1 \cdot f_{cd}}{cot\vartheta + tan\theta}$$

$b_w = 1{,}05\ m$

$z = 0{,}9 \cdot d = 0{,}9 \cdot 1{,}79\ m = 1{,}611\ m$

$$f_{cd} = \frac{f_{ck}}{\gamma_d} = \frac{35\ MPa}{1{,}4} = 25\ MPa$$

$$\upsilon_1 = \ \upsilon = 0{,}6 \cdot \left(1 - \frac{f_{ck}}{250}\right) = 0{,}6 \cdot \left(1 - \frac{35}{250}\right) = 0{,}516$$

$$\sigma_{cp} = \frac{N_{Ed,1}}{A_c} = \frac{11822\ kN}{6{,}42\ m^2} = 1{,}84\ MPa$$

Because $0 < \sigma_{cp} < 0{,}25f_{cd} = 6\ {,}25\ MPa$:

$$\propto_{cw} = 1 + \frac{\sigma_{cp}}{f_{cd}} = 1 + \frac{1{,}84\ MPa}{25\ MPa} \approx 1{,}07$$

$$V_{Rd,max} = \frac{1{,}07 \cdot 1{,}05\ m \cdot 1{,}611\ m \cdot 0{,}516 \cdot 25\ MPa}{cot30° + tan30°} = \frac{22260\ kN}{2{,}31} = 10107\ kN > \ V_{Ed,1}$$

The second case

Minimum area of the shear reinforcement:

$$V_{Rd,s} = \frac{A_{sw}}{s} \cdot z \cdot f_{ywd} \cdot cot\theta \rightarrow \ \frac{A_{sw}}{s} = \frac{V_{Ed,2}}{z \cdot f_{ywd} \cdot cot\theta} = \frac{6123\ kN}{0{,}9 \cdot 1{,}79\ m \cdot 435\ MPa \cdot cot30°} = 50{,}4 cm^2/m$$

Taking into consideration two beams of the deck (one stirrup in each cross section of a beam):

$$\frac{50{,}4\ cm^2/\text{m}}{8} = 6{,}3\frac{cm^2}{m} \rightarrow \ \emptyset 16\ every\ 25\ cm\ (A_s = 8{,}04\ cm^2\ )$$

$$V_{Rd,max} = \frac{\alpha_{cw} \cdot b_w \cdot z \cdot v_1 \cdot f_{cd}}{cot\vartheta + tan\theta}$$

$$b_w = 1{,}05\ m$$

$$z = 0{,}9 \cdot d = 0{,}9 \cdot 1{,}79\ m = 1{,}611\ m$$

$$f_{cd} = \frac{f_{ck}}{\gamma_d} = \frac{35\ MPa}{1{,}4} = 25\ MPa$$

$$v_1 = \ v = 0{,}6 \cdot \left(1 - \frac{f_{ck}}{250}\right) = 0{,}6 \cdot \left(1 - \frac{35}{250}\right) = 0{,}516$$

$$\sigma_{cp} = \frac{N_{Ed,2}}{A_c} = \frac{14193\ kN}{6{,}42\ m^2} = 2{,}21\ MPa$$

Because $0 < \sigma_{cp} < 0{,}25f_{cd} = 6\ {,}25\ MPa$:

$$\propto_{cw} = 1 + \frac{\sigma_{cp}}{f_{cd}} = 1 + \frac{2{,}21\ MPa}{25\ MPa} \approx 1{,}09$$

$$V_{Rd,max} = \frac{1{,}09 \cdot 1{,}05\ m \cdot 1{,}611\ m \cdot 0{,}516 \cdot 25\ MPa}{cot30° + tan30°} = \frac{22470\ kN}{2{,}31} = 10296\ kN > \ V_{Ed,2}$$

Decompression limit state

There are ten steps of span by span construction method. Each newly constructed span has been loaded according to the reality by self-weight and prestressing load. The results (bending moments) were used in formulas to make a bending moment envelope.

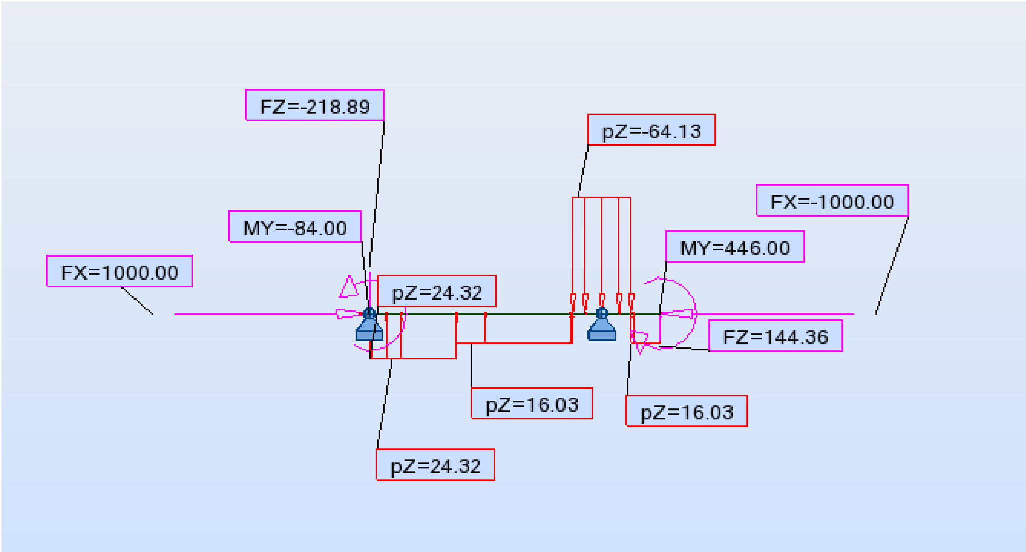


Figure 3.2.12 The first step

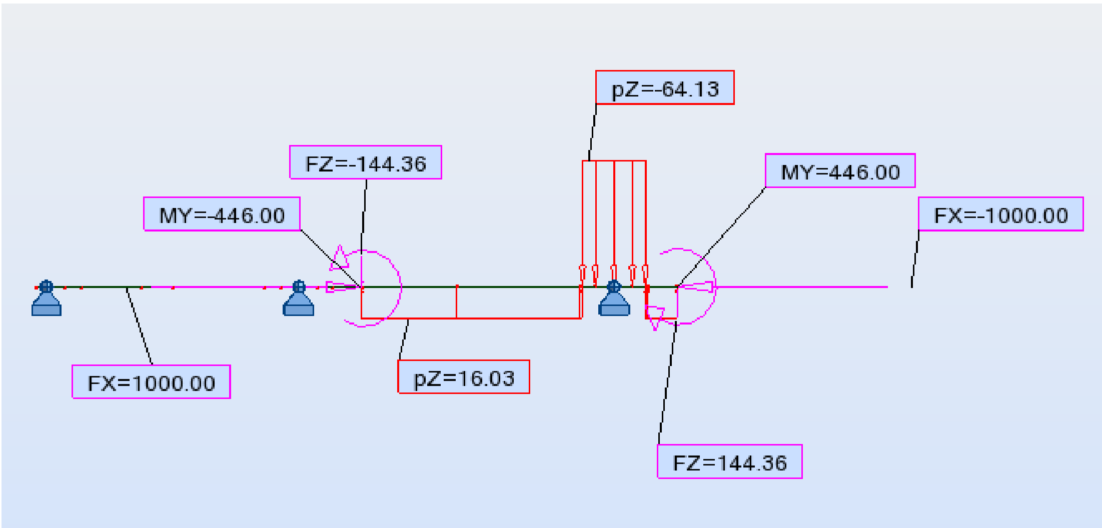


Figure 3.2.13 The second step

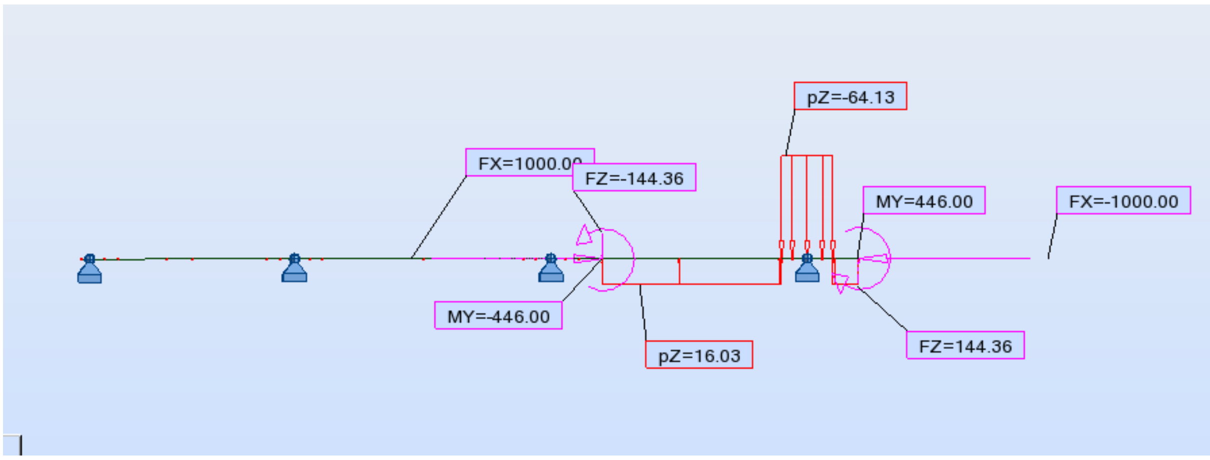


Figure 3.2.14 The third step

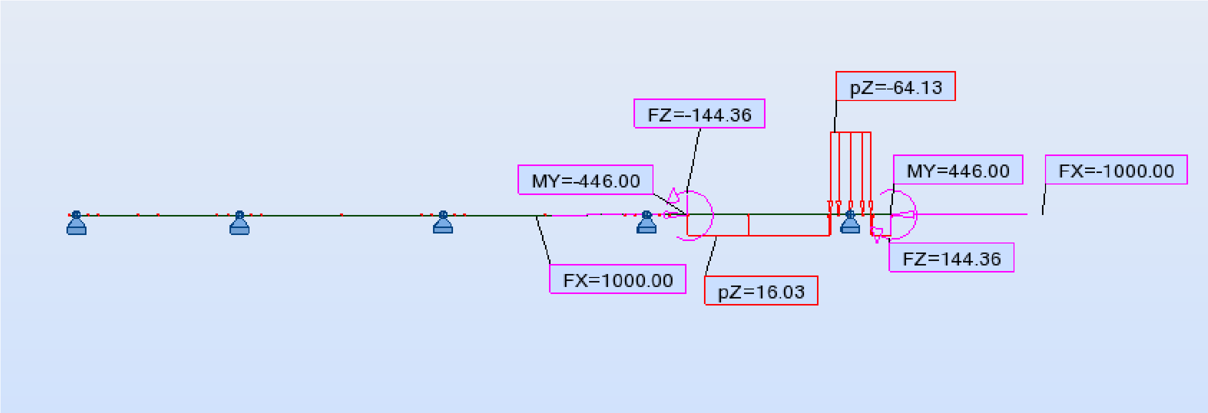


Figure 3.2.15 The fourth step

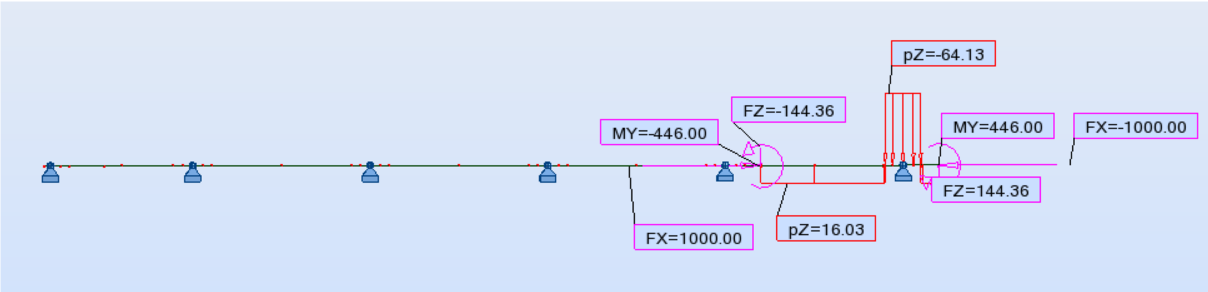


Figure 3.2.16 The fifth step

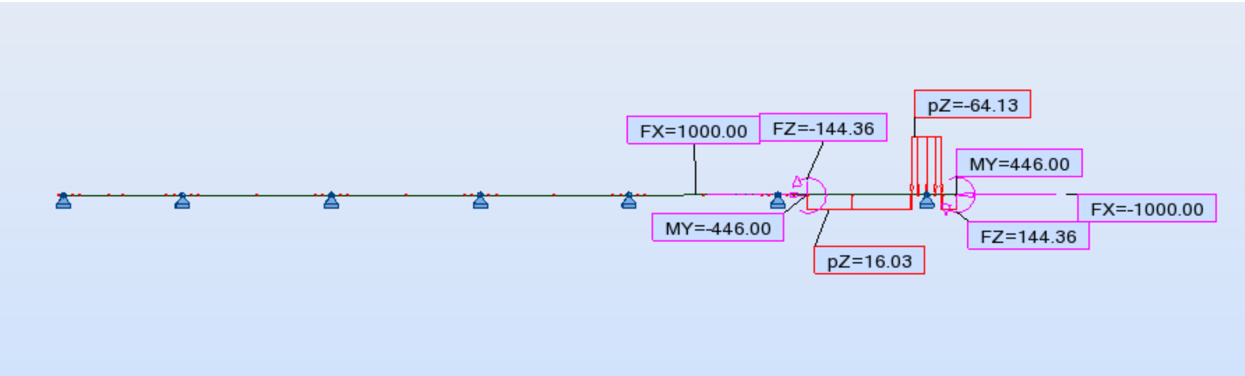


Figure 3.2.17 The sixth step

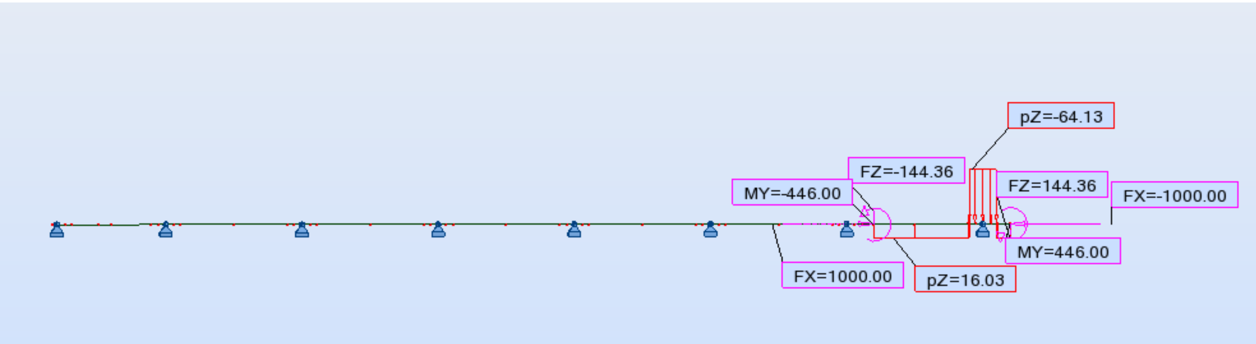


Figure 3.2.18 The seventh step

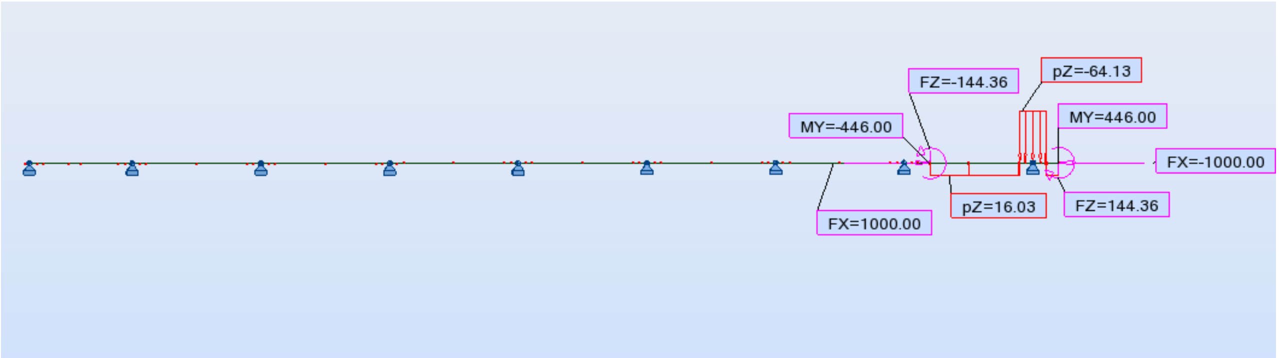


Figure 3.2.19 The eighth step

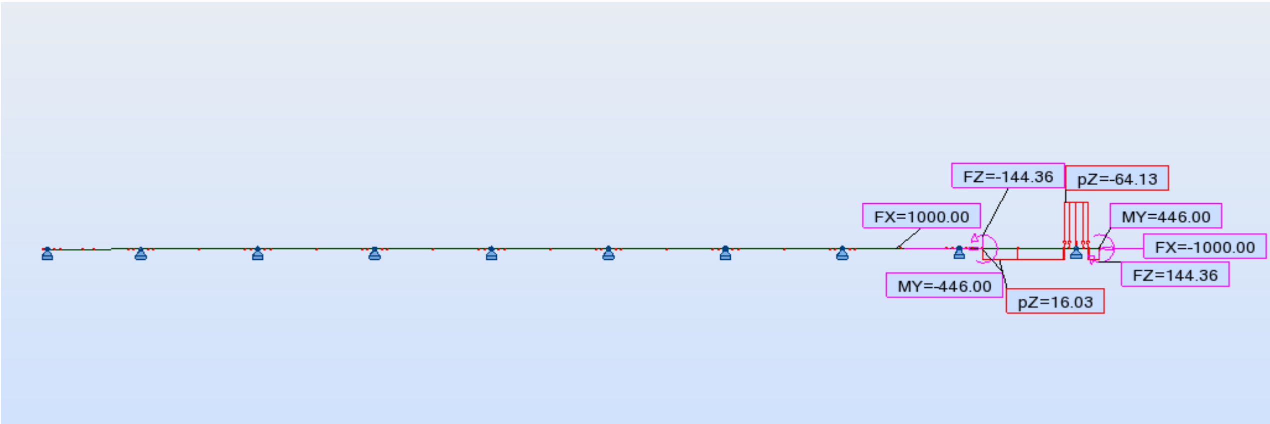


Figure 3.2.20 The ninth step

Figure 3.2.21 The tenth step

There are two formulas below which were used to calculate the values of bending moment – for self-weight and prestressing load. Both cases include calculations for two phases of the construction – the beginning of the service and after 10000 days (long-term situation). Besides self-weight and prestressing load there were used additional permanent loads and temperature load.

$$Mg(x,t) = \sum_{i=1}^{9} M_{g,i}(x) + \left(M_{g,e}(x) - \sum_{i=1}^{9} M_{g,i}(x)\right) \cdot \frac{\varphi(t,3)}{1+\varphi(t,3)}$$

$$Mp(x,t) = \left(\sum_{i=1}^{9} M_{p,i}(x) + \left(M_{p,e}(x) - \sum_{i=1}^{9} M_{p,i}(x)\right) \cdot \frac{\varphi(t,3)}{1+\varphi(t,3)}\right) \cdot \frac{\sigma \cdot A}{1000\ kN}$$

Decompression limit state consists of verifying that (calculated for quasi-permanent combination of actions):

$$\sigma_t \leq 0$$

$$\sigma_b \leq 0$$

Support section:

t = 0 days

$A = 6{,}42\ m^2$

$I = 2{,}18\ m^4$

$v_t = 0{,}717\ m$

$v_b = 1{,}233\ m$

$P_0 = 11917 kN$

$M_{qp} = -2998{,}42\ kNm$

$$\sigma_t = -\frac{M_{qp}}{I} v_t - \frac{P_\infty}{I}$$

$$\sigma_t = -\frac{-2998{,}42\ kNm}{2{,}18\ m^4} \cdot 0{,}717\ m - \frac{11917\ kN}{6{,}42\ m^2} = -870\ kPa \approx -0{,}9\ MPa \quad \boldsymbol{Verified}!$$

t = 10000 days

$A = 6{,}42\ m^2$

$I = 2{,}18\ m^4$

$v_t = 0{,}717\ m$

$v_b = 1{,}233\ m$

$P_\infty = 10640\ kN$

$M_{qp} = -4138{,}57\ kNm$

$$\sigma_t = -\frac{M_{qp}}{I} v_t - \frac{P_\infty}{I}$$

$$\sigma_t = -\frac{-4138{,}57\ kNm}{2{,}18\ m^4} \cdot 0{,}717\ m - \frac{10640\ kN}{6{,}42\ m^2} = -296{,}14\ kPa \approx -0{,}29\ MPa \quad \boldsymbol{Verified}!$$

Mid span section:

t = 0 days

$A = 5{,}11\ m^2$

$I = 1{,}53\ m^4$

$v_t = 0{,}579\ m$

$v_b = 1{,}371\ m$

$P_0 = 11917\ kN$

$M_{qp} = 1985{,}55\ kNm$

$$\sigma_t = \frac{M_{qp}}{I} v_b - \frac{P_\infty}{I}$$

$$\sigma_b = \frac{1985{,}55\ kNm}{1{,}53\ m^4} \cdot 1{,}371\ m - \frac{11917\ kN}{5{,}11\ m^2} = -553\ kPa \approx -0{,}55\ MPa\ \ \boldsymbol{Verified}!$$

t = 10000 days

$A = 5{,}11\ m^2$

$I = 1{,}53\ m^4$

$v_t = 0{,}579\ m$

$v_b = 1{,}371\ m$

$P_\infty = 10640\ kN$

$M_{qp} = 2643{,}17\ kNm$

$$\sigma_t = \frac{M_{qp}}{I} v_b - \frac{P_\infty}{I}$$

$$\sigma_b = \frac{2643{,}17\ kNm}{1{,}53\ m^4} \cdot 1{,}371\ m - \frac{10640\ kN}{5{,}11\ m^2} = 286\ kPa \approx 0{,}3\ MPa\ \ \boldsymbol{Verified}!$$

3.3. Columns

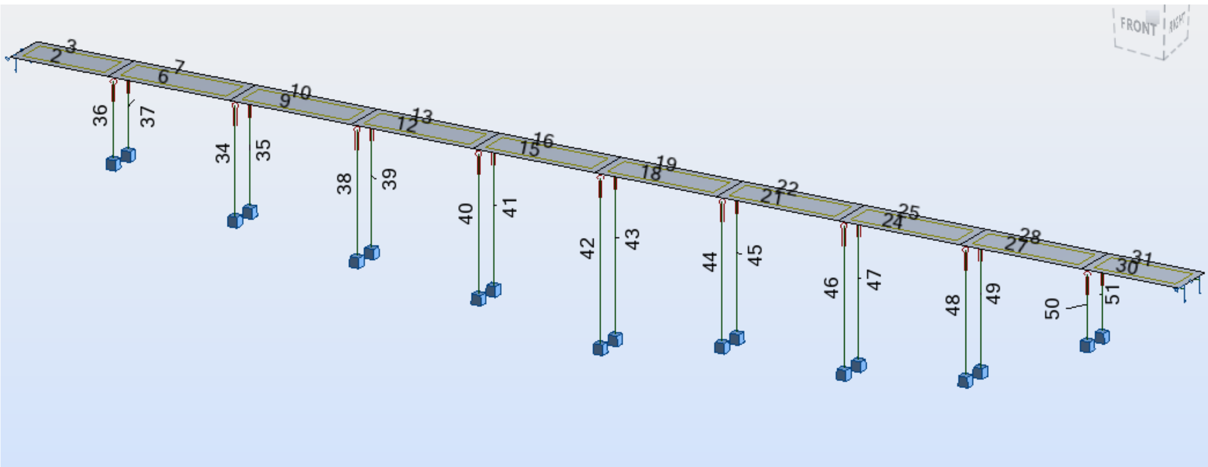


Figure 3.3.1 The numbering of the columns

Minimum area of reinforcement:

$$A_{s,min} = 0{,}10 \cdot \frac{N_{Ed}}{f_{yk}} \geq 0{,}002\ A_c$$

Calculated minimum area of reinforcement:

$$A_{s,min} = 0{,}10 \cdot \frac{11602\ kN}{435000\ kPa} = 26{,}7\ cm^2 < 0{,}002\ A_c$$

$$0{,}002 A_c = 0{,}002 \cdot 4{,}91\ \cdot 10^4\ cm^2 = 98{,}2\ cm^2$$

$$A_{s,min} = 98{,}2\ cm^2$$

That gives us 20#25 with total area equal $A_s = 98{,}2\ cm^2$

Two cases should be considered for each column in the calculations - the maximum bending moment and the corresponding axial force to it and the maximum axial force and the corresponding bending moment to it.

The nominal concrete cover:

$C_{nom} = C_{min} + \Delta\ C_{dev}$

$\Delta\ C_{dev} = 10$ mm
$C_{min} = \max \{ C_{min,b};\ C_{min,dur} + \Delta\ C_{dur,y} - \Delta\ C_{dur,st} - \Delta\ C_{dur,add};\ 10\ mm \}$
$C_{min,b} =$ 25 mm
$C_{min,dur} =$ 25 mm
$\Delta\ C_{dur,y} = \Delta\ C_{dur,st} = \Delta\ C_{dur,add} = 0$
$C_{nom} =$ 25 mm + 10 mm = 35 mm

The bar #36

First case

$N_{Ed,max} = 8340$ kN

$M_{Ed,cor.} = M_y = 60$ kNm

Length of the column = 19,35 m

Geometric imperfections:

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{19{,}35}} = 0{,}455 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 8340\ kN \cdot \frac{1}{300} = 27{,}8\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 60\ kNm + 27{,}8\ kN \cdot 19{,}35\ m \approx 598\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 598\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{8340\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}068$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}068}{1{,}014 - 0{,}4} = 1{,}54 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 19{,}35\ m}{0{,}625\ m} = 61{,}9$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{61{,}9}{150} = 0{,}11$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 $for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal$ 0.

ψ_2 $for\ wind\ load\ is\ equal$ 0,5.

$$M_{0Eqp} = M_y = 1232\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{1232\ kNm}{598\ kNm} = 3{,}71$$

$$K_\varphi = 1 + 0{,}11 \cdot 3{,}71 \approx 1{,}41$$

$$\frac{1}{r} = 1 \cdot 1{,}41 \cdot 0{,}00198\frac{1}{m} = 0{,}0028\frac{1}{m}$$

$$e_2 = 0{,}0028\frac{1}{m} \cdot \frac{(2 \cdot 19{,}35\ m)^2}{10} = 0{,}42\ m$$

$$M_{Ed} = 598\ kNm + 8340\ kN \cdot 0{,}42\ m = 4101\ kNm$$

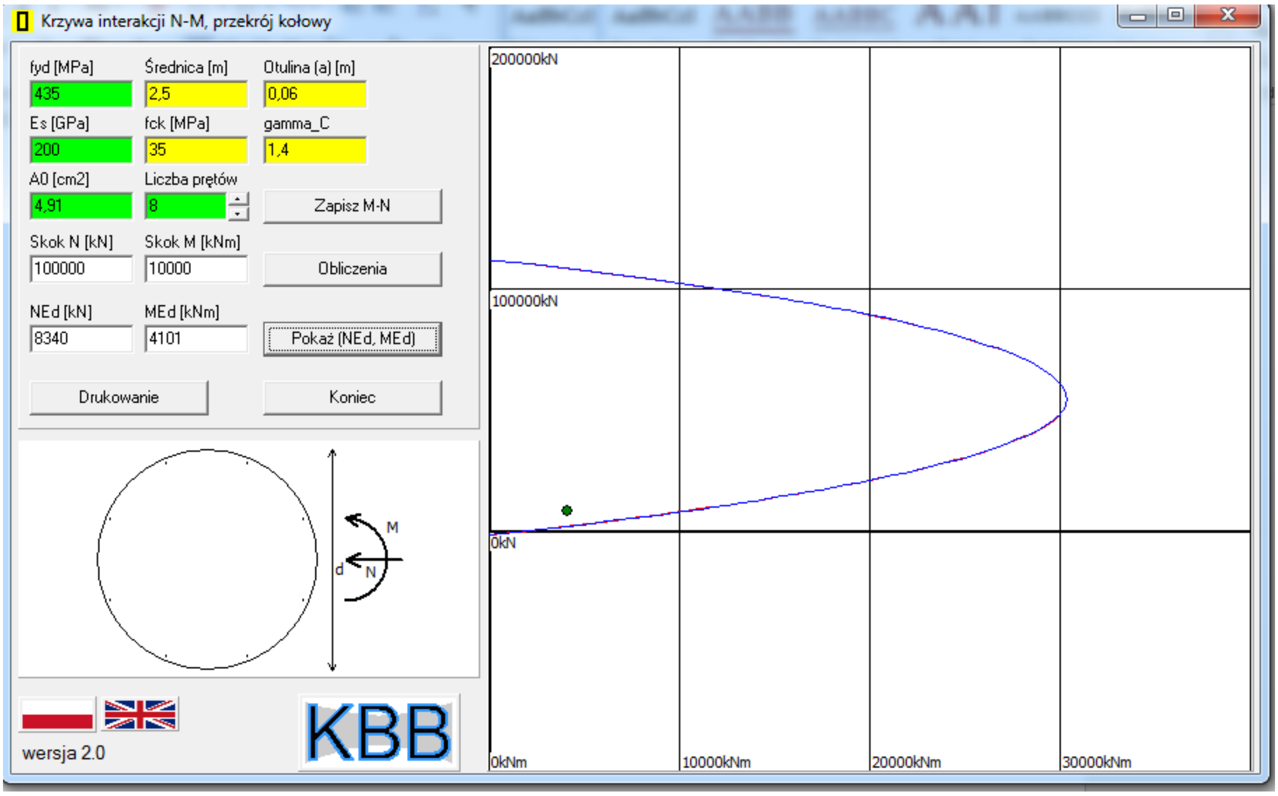


Figure 3.3.2 The curve interaction for bar #36 – first case

Second case

$M_{Ed,max} = M_y = 2871$ kNm

$N_{Ed,cor.} = 4184$ kN

Geometric imperfections:

$$H_i = \theta_i \cdot N = 4184\ kN \cdot \frac{1}{300} = 13{,}9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 2871\ kNm + 13{,}9\ kN \cdot 19{,}35\ m \approx 3140\ kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 3140\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{4184\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}034$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}034}{1{,}014 - 0{,}4} \approx 1{,}60 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta \varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0) \frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 325{,}75\ kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{325{,}75\ kNm}{3140\ kNm} = 0{,}19$$

$K_\varphi = 1 + 0{,}11 \cdot 0{,}19 = 1{,}02$

$$\frac{1}{r} = 1 \cdot 1{,}02 \cdot 0{,}00198 \frac{1}{m} = 0{,}002 \frac{1}{m}$$

$$e_2 = 0{,}002 \frac{1}{m} \cdot \frac{(2 \cdot 19{,}35\ m)^2}{10} = 0{,}30\ m$$

$M_{Ed} = 3140\ kNm + 4184\ kN \cdot 0{,}30\ m \approx 4395\ kNm$

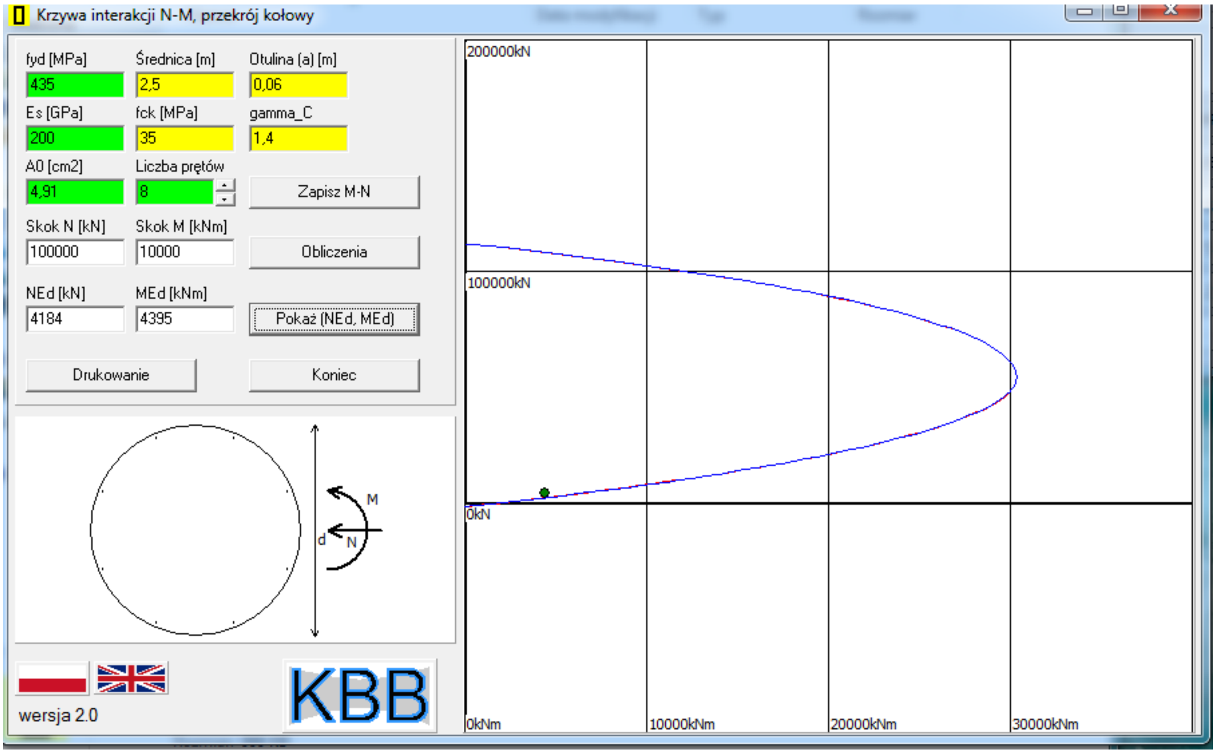


Figure 3.3.3 The curve interaction for bar #36 – second case

The bar #37

First case

$N_{Ed,max} = 8343$ kN

$M_{Ed,cor.} = M_z = 302$ kNm

Length of the column = 19,35 m

Geometric imperfections:

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{19{,}35}} = 0{,}455 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 8343\ kN \cdot \frac{1}{300} = 27{,}8\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 302\ kNm + 27{,}8\ kN \cdot 19{,}35\ m \approx 840\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 840\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198\frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{8343\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}068$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}068}{1{,}014 - 0{,}4} = 1{,}54 > 1{,}0$$

$$K_r = 1{,}0$$

$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$

$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$

$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 19{,}35\ m}{0{,}625\ m} = 61{,}9$

$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{61{,}9}{150} = 0{,}11$

$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_z = 2{,}0\ kNm$

$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$

$\varphi(\infty, t_0) = 1{,}8$

$\varphi_{ef} = 1{,}8 \cdot \frac{2{,}0\ kNm}{840\ kNm} = 0{,}004$

$K_{\varphi} = 1 + 0{,}11 \cdot 0{,}004 \approx 1{,}0$

$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$

$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 19{,}35\ m)^2}{10} = 0{,}30\ m$

$M_{Ed} = 840\ kNm + 8343\ kN \cdot 0{,}30\ m = 3343\ kNm$

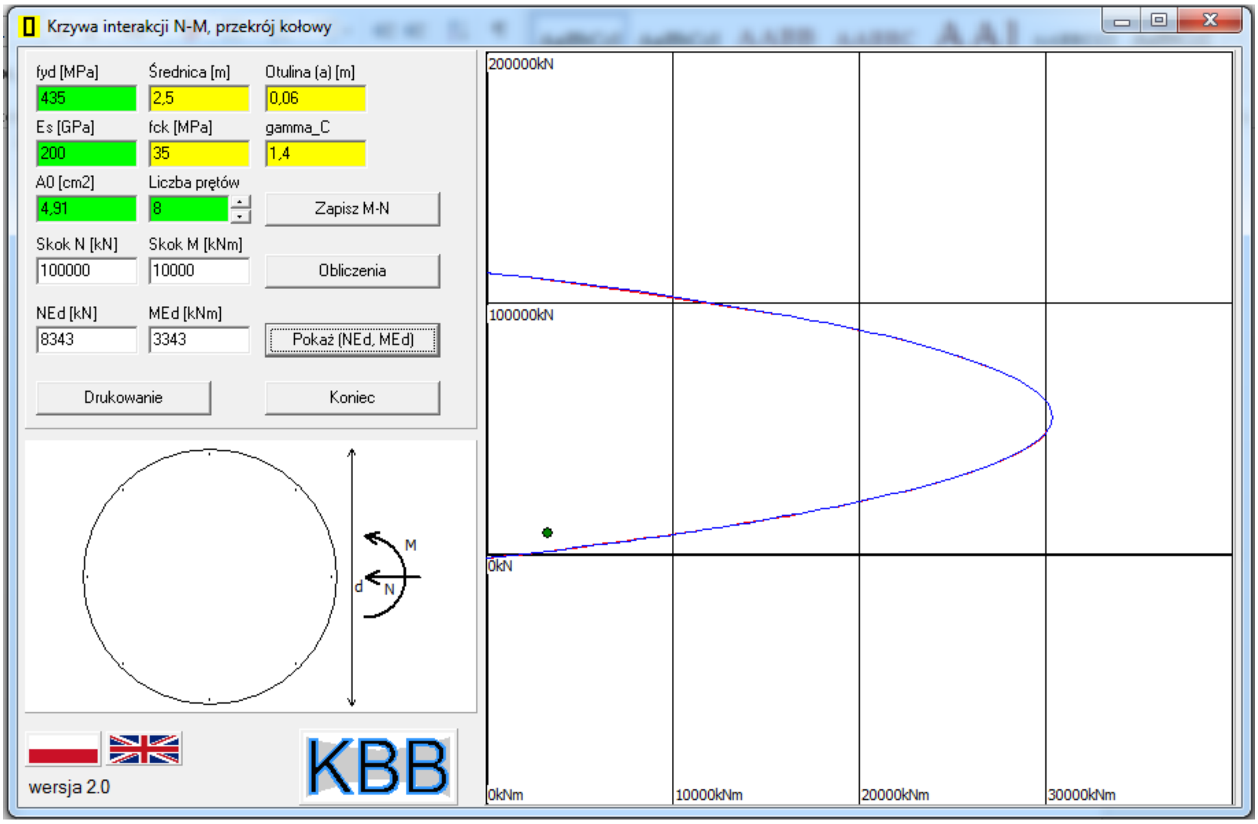


Figure 3.3.4 The curve interaction for bar #37 – first case

Second case

$M_{Ed,max} = M_y = 2834\text{kNm}$

$N_{Ed,cor.} = 4187\text{ kN}$

<u>Geometric imperfections:</u>

$$H_i = \theta_i \cdot N = 4187\ kN \cdot \frac{1}{300} = 13{,}9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 2834\ kNm + 13{,}9\ kN \cdot 19{,}35\ m \approx 3219\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 3140\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{4187\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}034$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}034}{1{,}014 - 0{,}4} = 1{,}60 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 1232\ kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{1232\ kNm}{3219\ kNm} = 0{,}69$$

$K_\varphi = 1 + 0{,}11 \cdot 0{,}69 = 1{,}07$

$$\frac{1}{r} = 1 \cdot 1{,}07 \cdot 0{,}00198 \frac{1}{m} = 0{,}0021 \frac{1}{m}$$

$$e_2 = 0{,}0021 \frac{1}{m} \cdot \frac{(2 \cdot 19{,}35\ m)^2}{10} = 0{,}31\ m$$

$M_{Ed} = 3219\ kNm + 4187\ kN \cdot 0{,}31\ m = 4517\ kNm$

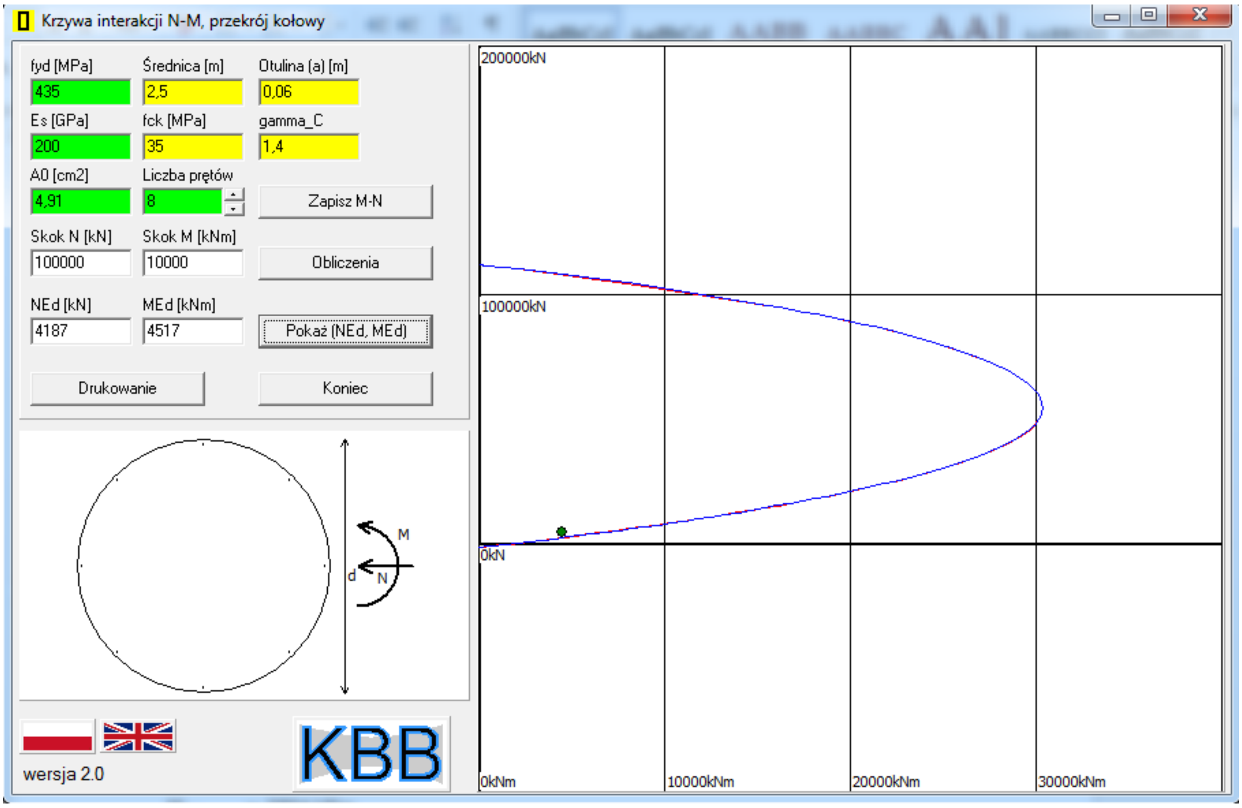


Figure 3.3.5 The curve interaction for bar #37 – second case

The bar #34

First case

$N_{Ed,max} = 9572$ kN

$M_{Ed,cor.} = M_y = 1{,}3$ kNm

Length of the column = 26,8 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{26{,}8}} = 0{,}386 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 9572\ kN \cdot \frac{1}{300} = 31{,}9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1{,}3\ kNm + 31{,}9\ kN \cdot 26{,}8\ m \approx 856\ kNm$$

The piers verification – method based on nominal curvature

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 856\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{9572\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}078$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}078}{1{,}014 - 0{,}4} = 1{,}52 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 26{,}8\ m}{0{,}625\ m} = 85{,}8$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{85{,}8}{150} = -0{,}05$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$$M_{0Eqp} = M_y = 677\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{677\ kNm}{856\ kNm} = 1{,}42$$

$$K_{\varphi} = 1 - 0{,}05 \cdot 1{,}42 = 0{,}93 < 1 \rightarrow K_{\varphi} = 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 26{,}8\ m)^2}{10} = 0{,}57\ m$$

$$M_{Ed} = 856\ kNm + 9572\ kN \cdot 0{,}57\ m = 6312\ kNm$$

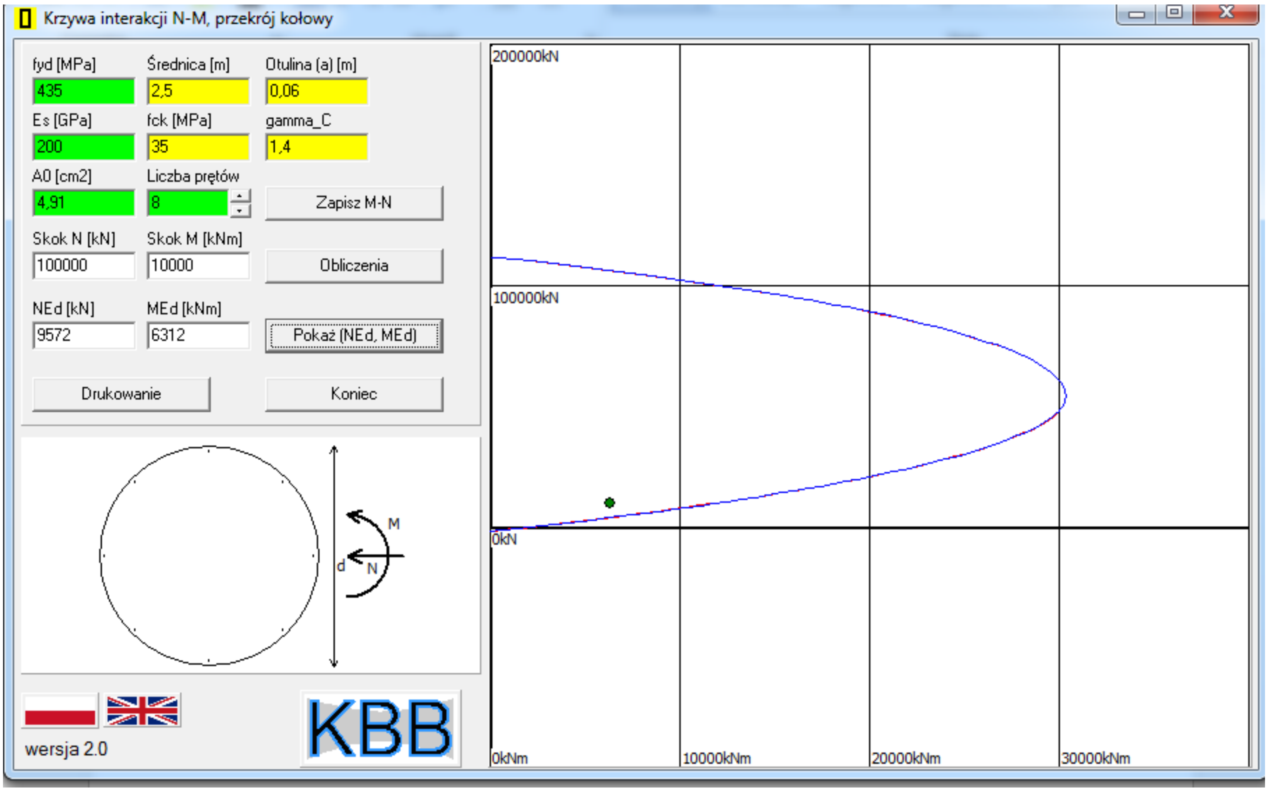


Figure 3.3.6 The curve interaction for bar #34 – first case

Second case

$M_{Ed,max} = M_y = 1547$ kNm

$N_{Ed,cor.} = 5096$ kN

Geometric imperfections:

$$H_i = \theta_i \cdot N = 5096\, kN \cdot \frac{1}{300} = 17{,}0\, kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1547\, kNm + 17{,}0\, kN \cdot 26{,}8\, m \approx 2003\, kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 2003\, kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{5096\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}041$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}041}{1{,}014 - 0{,}4} = 1{,}58 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 677\ kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{677\ kNm}{2003\ kNm} = 0{,}61$$

$K_\varphi = 1 - 0{,}05 \cdot 0{,}61 = 0{,}97 < 1 \rightarrow K_\varphi = 1$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 26{,}8\ m)^2}{10} = 0{,}57\ m$$

$M_{Ed} = 2003\ kNm + 5096\ kN \cdot 0{,}57\ m = 4908\ kNm$

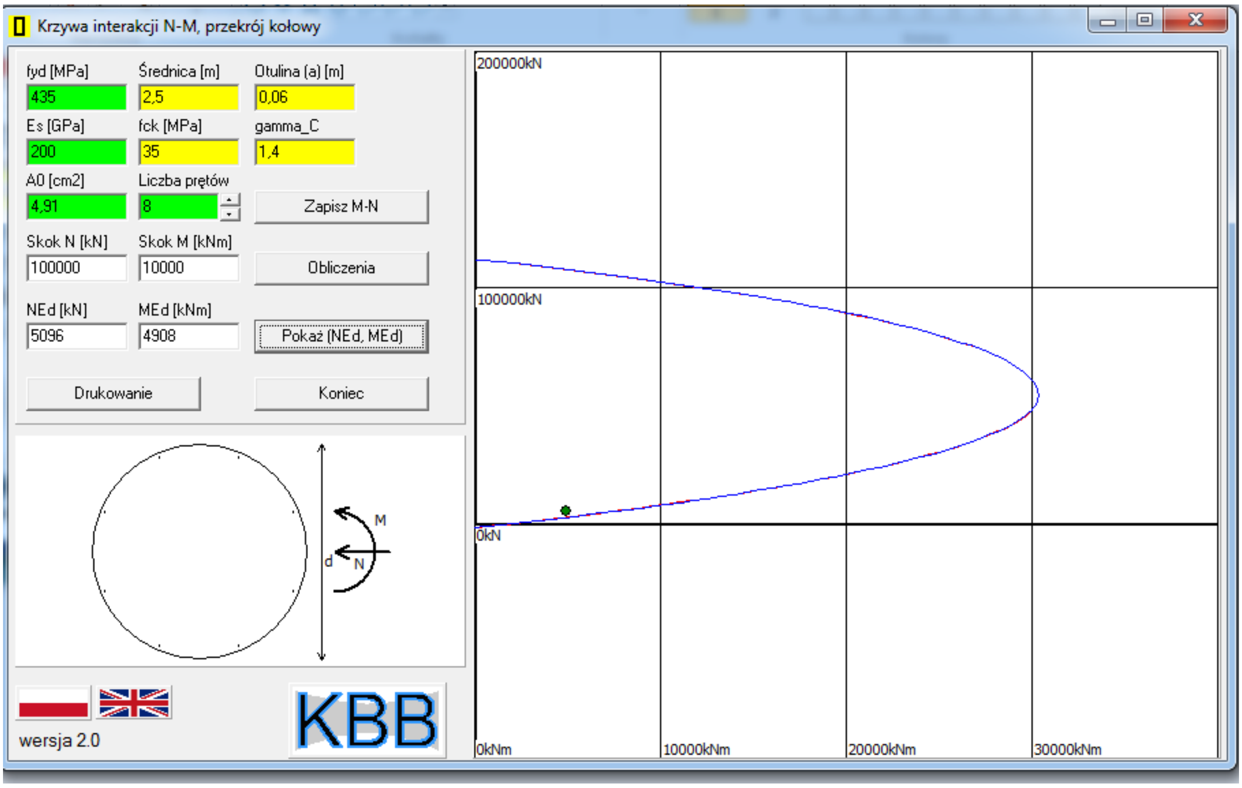


Figure 3.3.7 The curve interaction for bar #34 – second case

The bar #35

First case

$N_{Ed,max} = 9574$ kN

$M_{Ed,cor.} = M_z = 431$ kNm

Length of the column = 26,8 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{26{,}8}} = 0{,}386 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 9574\ kN \cdot \frac{1}{300} = 31{,}9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 431\ kNm + 31{,}9\ kN \cdot 26{,}8\ m \approx 1286\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1286\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{9574\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}078$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}078}{1{,}014 - 0{,}4} = 1{,}52 > 1{,}0$$

$K_r = 1{,}0$

$$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 26{,}8\ m}{0{,}625\ m} = 85{,}8$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{85{,}8}{150} = -0{,}05$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$$M_{0Eqp} = M_z = 0{,}81\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}81\ kNm}{1286\ kNm} = 0{,}001$$

$$K_{\varphi} = 1 - 0{,}05 \cdot 0{,}001 \approx 1{,}0$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 26{,}8\ m)^2}{10} = 0{,}57\ m$$

$$M_{Ed} = 1286\ kNm + 9574\ kN \cdot 0{,}57\ m = 6743\ kNm$$

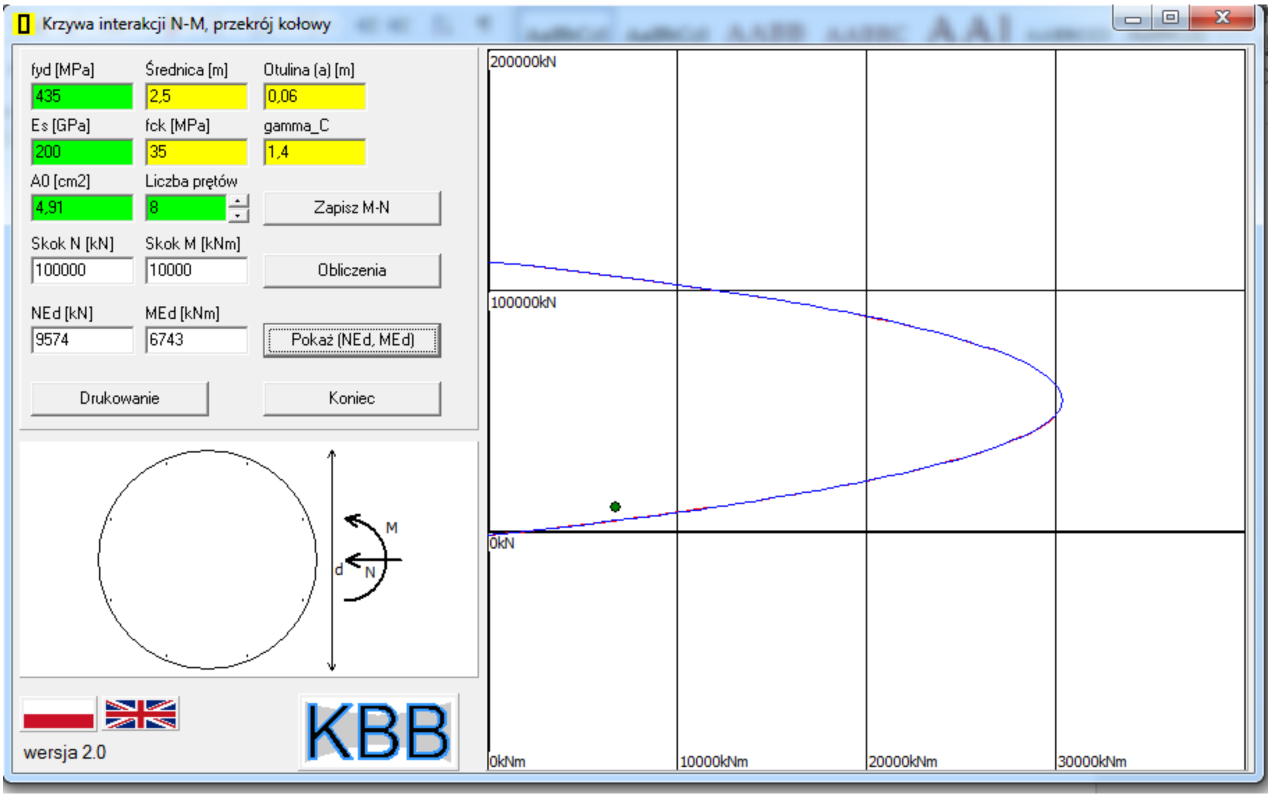


Figure 3.3.8 The curve interaction for bar #35 – first case

Second case

$M_{Ed,max} = M_y = 1526 \text{ kNm}$

$N_{Ed,cor.} = 5097 \text{ kN}$

Geometric imperfections:

$$H_i = \theta_i \cdot N = 5097\ kN \cdot \frac{1}{300} = 17{,}0\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1526\ kNm + 17{,}0\ kN \cdot 26{,}8\ m \approx 1982\ kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1982\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{5097\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}041$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}041}{1{,}014 - 0{,}4} = 1{,}58 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 677\ kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{677\ kNm}{1982\ kNm} = 0{,}61$$

$K_\varphi = 1 - 0{,}05 \cdot 0{,}61 = 0{,}97 < 1 \rightarrow K_\varphi = 1$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198 \frac{1}{m} = 0{,}00198 \frac{1}{m}$$

$$e_2 = 0{,}00198 \frac{1}{m} \cdot \frac{(2 \cdot 26{,}8\ m)^2}{10} = 0{,}57\ m$$

$M_{Ed} = 1982\ kNm + 5097\ kN \cdot 0{,}57\ m = 4887\ kNm$

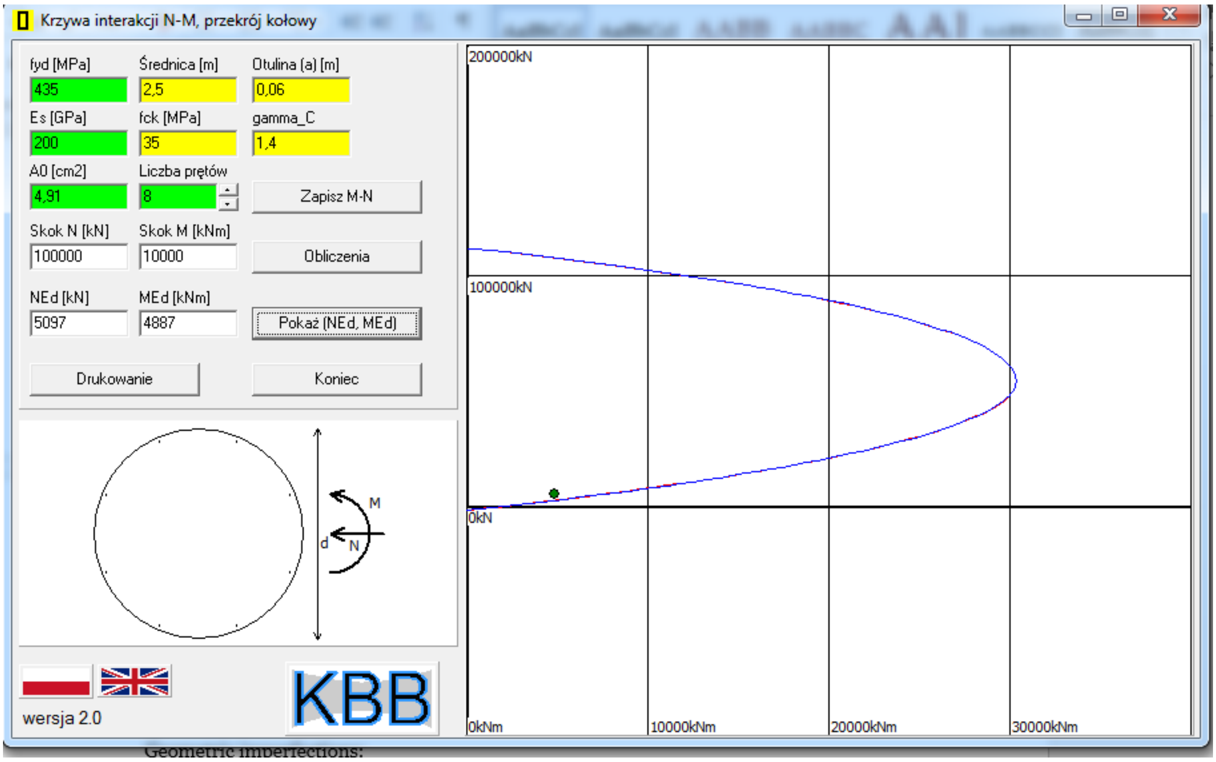


Figure 3.3.9 The curve interaction for bar #35 – second case

The bar #38

First case

$N_{Ed,max} = 10167$ kN

$M_{Ed,cor.} = M_y = 5{,}0$ kNm

Length of the column = 30,57 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{30{,}57}} = 0{,}362 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10167\ kN \cdot \frac{1}{300} = 33{,}9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 5{,}0\ kNm + 33{,}9\ kN \cdot 30{,}57\ m \approx 1041\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1041\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10167\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}083$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}083}{1{,}014 - 0{,}4} = 1{,}52 > 1{,}0$$

$$K_r = 1{,}0$$

$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$

$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$

$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 30{,}57\ m}{0{,}625\ m} = 97{,}8$

$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{97{,}8}{150} = -0{,}13$

$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 524\ kNm$

$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$

$\varphi(\infty, t_0) = 1{,}8$

$\varphi_{ef} = 1{,}8 \cdot \frac{524\ kNm}{1041\ kNm} = 0{,}91$

$K_{\varphi} = 1 - 0{,}13 \cdot 0{,}91 = 0{,}88 < 1 \rightarrow K_{\varphi} = 1$

$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$

$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 30{,}57\ m)^2}{10} = 0{,}74\ m$

$M_{Ed} = 1041\ kNm + 10167\ kN \cdot 0{,}74\ m = 8565\ kNm$

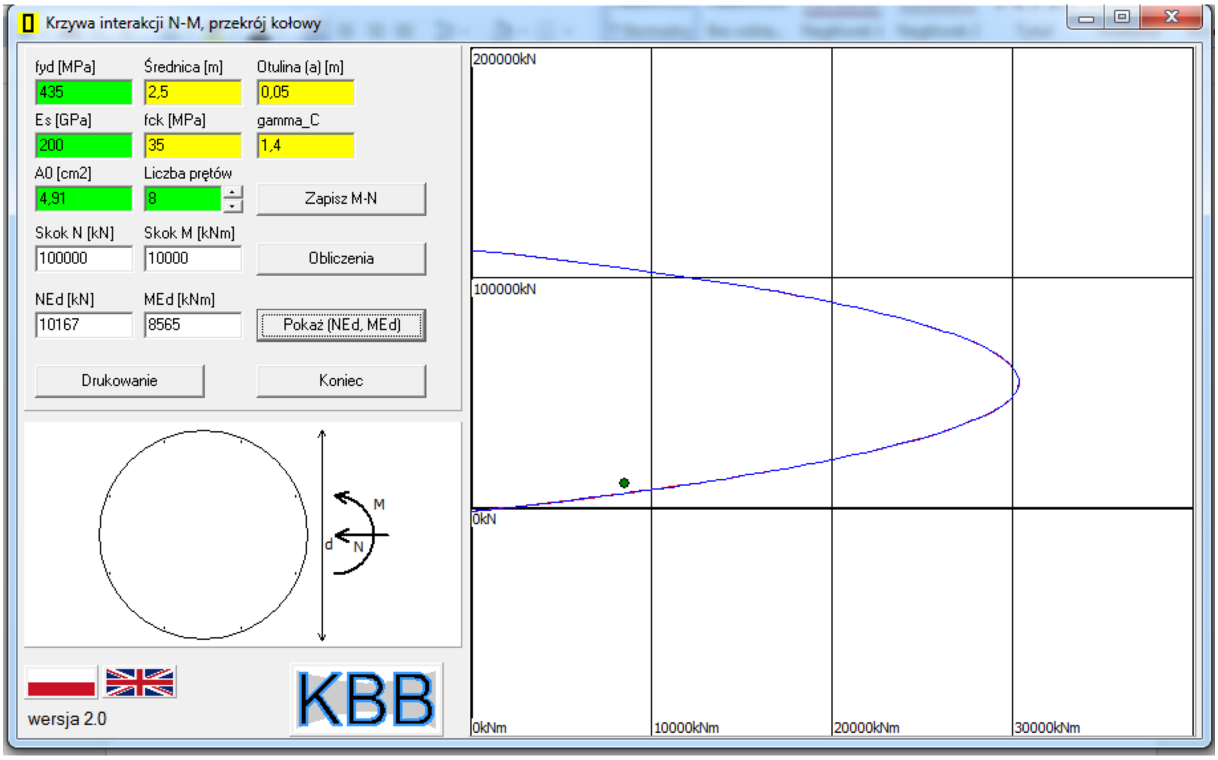


Figure 3.3.10 The curve interaction for bar #38 – first case

Second case

$M_{Ed,max} = M_y = 1199$ kNm

$N_{Ed,cor.} = 5540$ kN

Geometric imperfections:

$$H_i = \theta_i \cdot N = 5540\ kN \cdot \frac{1}{300} = 18{,}5\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1199\ kNm + 18{,}5\ kN \cdot 30{,}57\ m \approx 1764\ kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1764\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{5540\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}045$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}045}{1{,}014 - 0{,}4} = 1{,}58 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)\colon \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal$ 0.

$\psi_2\ for\ wind\ load\ is\ equal$ 0,5.

$$M_{0Eqp} = M_y = 524\ kNm$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{524\ kNm}{1764\ kNm} = 0{,}53$$

$$K_\varphi = 1 - 0{,}13 \cdot 0{,}53 = 0{,}93 < 1 \rightarrow K_\varphi = 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198 \frac{1}{m} = 0{,}00198 \frac{1}{m}$$

$$e_2 = 0{,}00198 \frac{1}{m} \cdot \frac{(2 \cdot 30{,}57\ m)^2}{10} = 0{,}74\ m$$

$$M_{Ed} = 1764\ kNm + 5540\ kN \cdot 0{,}74\ m = 5864\ kNm$$

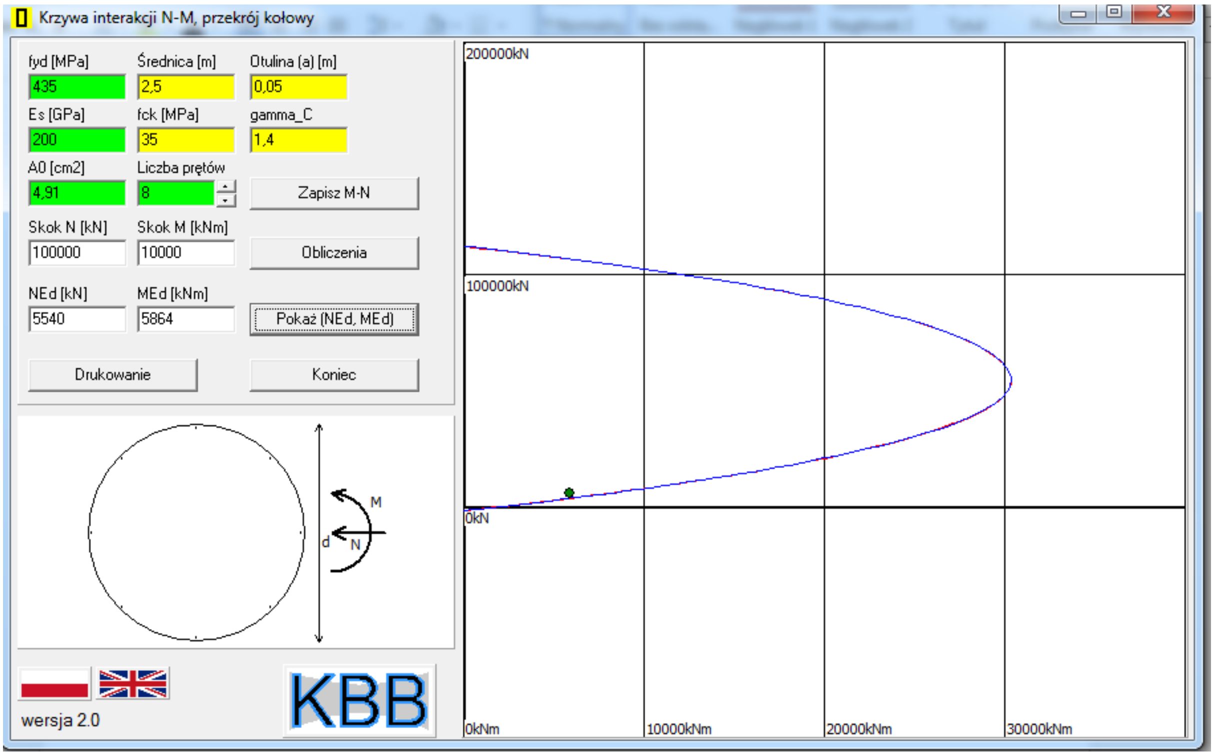


Figure 3.3.11 The curve interaction for bar #38 – second case

The bar #39

First case

$N_{Ed,max} = 10167$ kN

$M_{Ed,cor.} = M_z = 533$ kNm

Length of the column = 30,57 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{30{,}57}} = 0{,}362 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10167\ kN \cdot \frac{1}{300} = 33{,}9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 533\ kNm + 33{,}9\ kN \cdot 30{,}57\ m \approx 1569\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1569\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \le 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10167\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}083$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}083}{1{,}014 - 0{,}4} = 1{,}52 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 30{,}57\ m}{0{,}625\ m} = 97{,}8$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{97{,}8}{150} = -0{,}13$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 $for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal$ 0.

ψ_2 $for\ wind\ load\ is\ equal$ 0,5.

$$M_{0Eqp} = M_z = 0{,}7\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}7\ kNm}{1569\ kNm} = 0{,}0008$$

$$K_{\varphi} = 1 - 0{,}13 \cdot 0{,}0008 \approx 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 30{,}57\ m)^2}{10} = 0{,}74\ m$$

$$M_{Ed} = 1569\ kNm + 10167\ kN \cdot 0{,}74\ m = 9092\ kNm$$

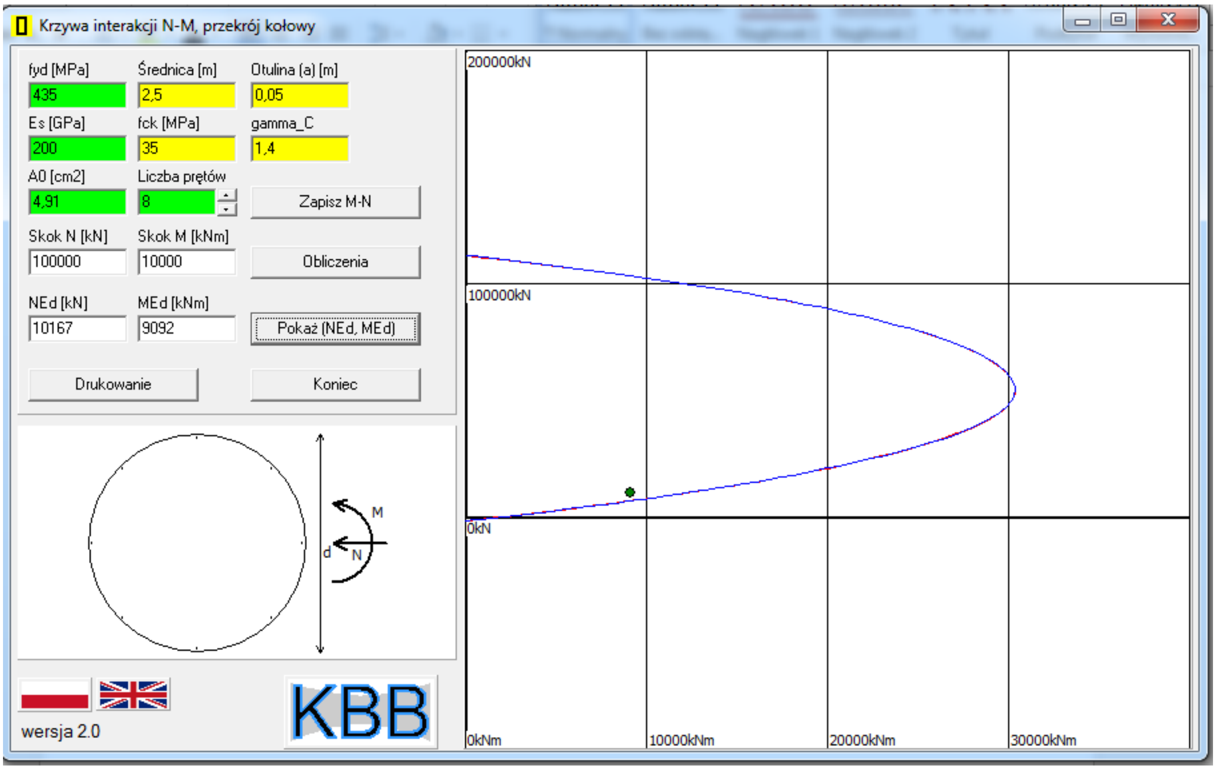


Figure 3.3.12 The curve interaction for bar #39 – first case

Second case

$M_{Ed,max} = M_y = 1184$ kNm

$N_{Ed,cor.} = 5540$ kN

Geometric imperfections:

$$H_i = \theta_i \cdot N = 5540\ kN \cdot \frac{1}{300} = 18{,}5\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1184\ kNm + 18{,}5\ kN \cdot 30{,}57\ m \approx 1749\ kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1749\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{5540\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}045$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}045}{1{,}014 - 0{,}4} = 1{,}58 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 524\ kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{524\ kNm}{1749\ kNm} = 0{,}54$$

$K_\varphi = 1 - 0{,}13 \cdot 0{,}54 = 0{,}93 < 1 \rightarrow K_\varphi = 1$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198 \frac{1}{m} = 0{,}00198 \frac{1}{m}$$

$$e_2 = 0{,}00198 \frac{1}{m} \cdot \frac{(2 \cdot 30{,}57\ m)^2}{10} = 0{,}74\ m$$

$M_{Ed} = 1749\ kNm + 5540\ kN \cdot 0{,}74\ m = 5849\ kNm$

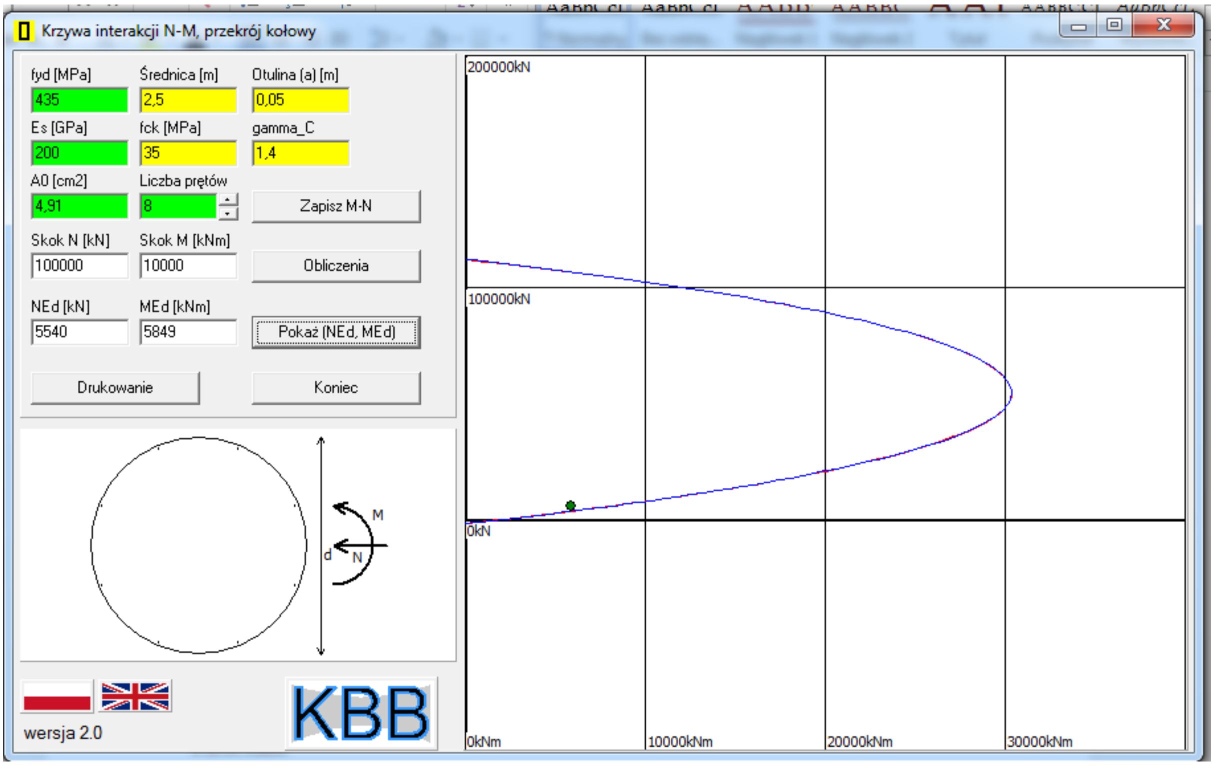


Figure 3.3.13 The curve interaction for bar #39 – second case

The bar #40

First case

$N_{Ed,max} = 10667$ kN

$M_{Ed,cor.} = M_z = 589$ kNm

Length of the column = 33,59 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{33{,}59}} = 0{,}345 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10667\ kN \cdot \frac{1}{300} = 35{,}5\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 589\ kNm + 35{,}5\ kN \cdot 33{,}59\ m \approx 1781\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1781\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10667\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}087$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}087}{1{,}014 - 0{,}4} = 1{,}51 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_{\varphi} = 1 + \beta \varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 33{,}59\ m}{0{,}625\ m} = 107{,}5$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{107{,}5}{150} = -0{,}19$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP): \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal$ 0.

$\psi_2\ for\ wind\ load\ is\ equal$ 0,5.

$$M_{0Eqp} = M_z = 0{,}61\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}61\ kNm}{1781\ kNm} = 0{,}0006$$

$$K_{\varphi} = 1 - 0{,}19 \cdot 0{,}0006 \approx 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 33{,}59\ m)^2}{10} = 0{,}89\ m$$

$$M_{Ed} = 1781\ kNm + 10667\ kN \cdot 0{,}89\ m = 11275\ kNm$$

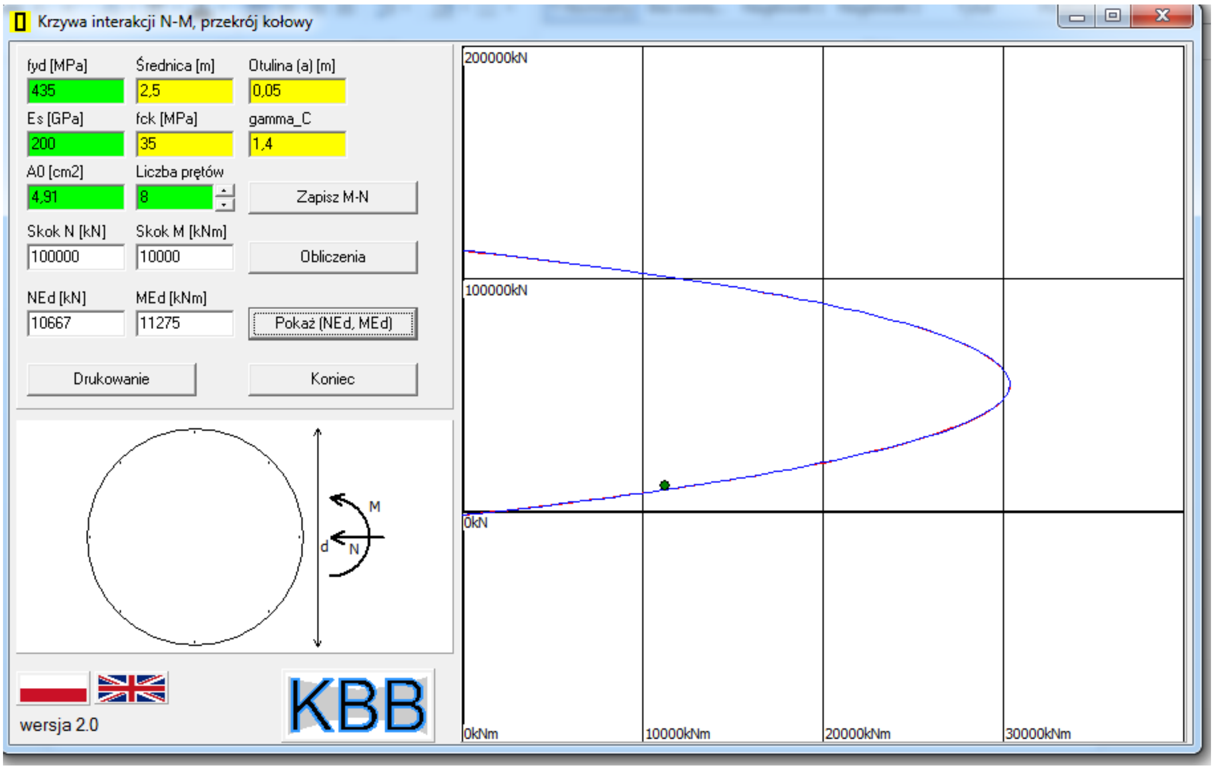


Figure 3.3.14 The curve interaction for bar #40 – first case

Second case

$M_{Ed,max} = M_y = 1008$ kNm

$N_{Ed,cor.} = 5903$ kN

<u>Geometric imperfections:</u>

$$H_i = \theta_i \cdot N = 5903\ kN \cdot \frac{1}{300} = 19{,}7\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1008\ kNm + 19{,}7\ kN \cdot 33{,}59\ m \approx 1700\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1700 kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{5903\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}048$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}048}{1{,}014 - 0{,}4} = 1{,}57 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 442\ kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{442\ kNm}{1700\ kNm} = 0{,}47$$

$K_\varphi = 1 - 0{,}19 \cdot 0{,}47 = 0{,}91 < 1 \rightarrow K_\varphi = 1$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 33{,}59\ m)^2}{10} = 0{,}89\ m$$

$M_{Ed} = 1700\ kNm + 5903\ kN \cdot 0{,}89\ m = 6954\ kNm$

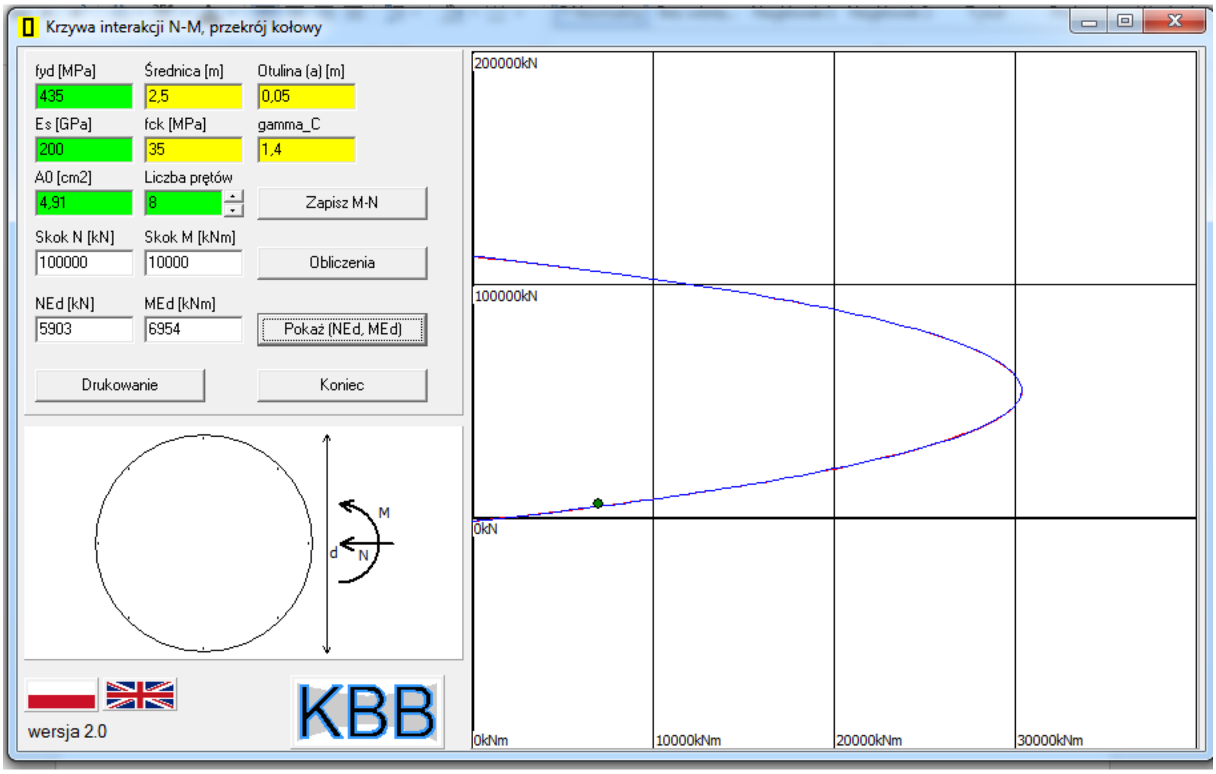


Figure 3.3.15 The curve interaction for bar #40 – second case

The bar #41

First case

$N_{Ed,max} = 10666$ kN

$M_{Ed,cor.} = M_y = 5{,}6$ kNm

Length of the column = 33,59 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{33{,}59}} = 0{,}345 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10666\ kN \cdot \frac{1}{300} = 35{,}5\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 5{,}6\ kNm + 35{,}5\ kN \cdot 33{,}59\ m \approx 1198\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1198\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10666\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}087$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}087}{1{,}014 - 0{,}4} = 1{,}51 > 1{,}0$$

$$K_r = 1{,}0$$

$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$

$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$

$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 33{,}59\ m}{0{,}625\ m} = 107{,}5$

$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{107{,}5}{150} = -0{,}19$

$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$

$M_{0Eqp} \rightarrow SLS\ (QP){:}\ \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal\ 0.$

$\psi_2\ for\ wind\ load\ is\ equal\ 0{,}5.$

$M_{0Eqp} = M_y = 5{,}6\ kNm$

$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$

$\varphi(\infty, t_0) = 1{,}8$

$\varphi_{ef} = 1{,}8 \cdot \frac{5{,}6\ kNm}{1198\ kNm} = 0{,}008$

$K_{\varphi} = 1 - 0{,}19 \cdot 0{,}008 \approx 1$

$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$

$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 33{,}59\ m)^2}{10} = 0{,}89\ m$

$M_{Ed} = 1198\ kNm + 10666\ kN \cdot 0{,}89\ m = 10691\ kNm$

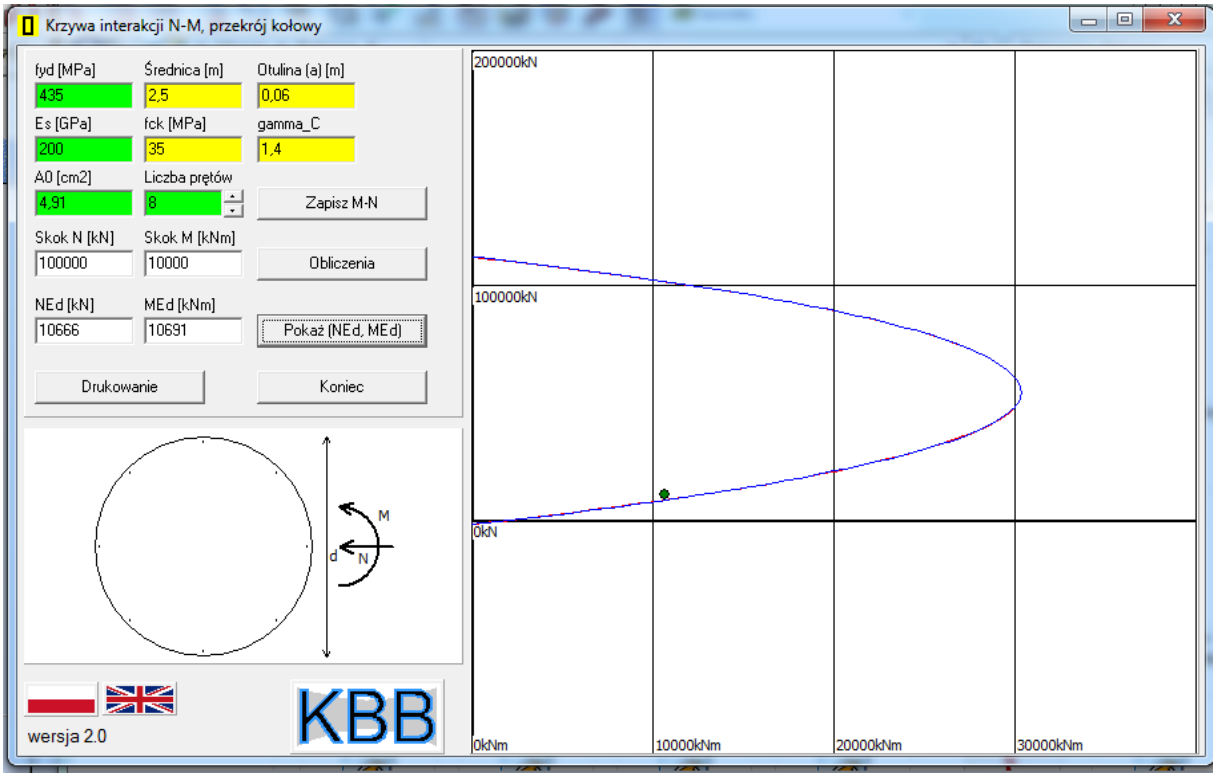


Figure 3.3.16 The curve interaction for bar #41 – first case

Second case

$M_{Ed,max} = M_y = 1000$ kNm

$N_{Ed,cor.} = 5902$ kN

Geometric imperfections:

$$H_i = \theta_i \cdot N = 5902\ kN \cdot \frac{1}{300} = 19{,}7\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1000\ kNm + 19{,}7\ kN \cdot 33{,}59\ m \approx 1662\ kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1662\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{5902\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}048$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}048}{1{,}014 - 0{,}4} = 1{,}57 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$$M_{0Eqp} = M_y = 442\ kNm$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{442\ kNm}{1662\ kNm} = 0{,}48$$

$$K_\varphi = 1 - 0{,}19 \cdot 0{,}48 = 0{,}91 < 1 \rightarrow K_\varphi = 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 33{,}59\ m)^2}{10} = 0{,}89\ m$$

$$M_{Ed} = 1662\ kNm + 5902\ kN \cdot 0{,}89\ m = 6915\ kNm$$

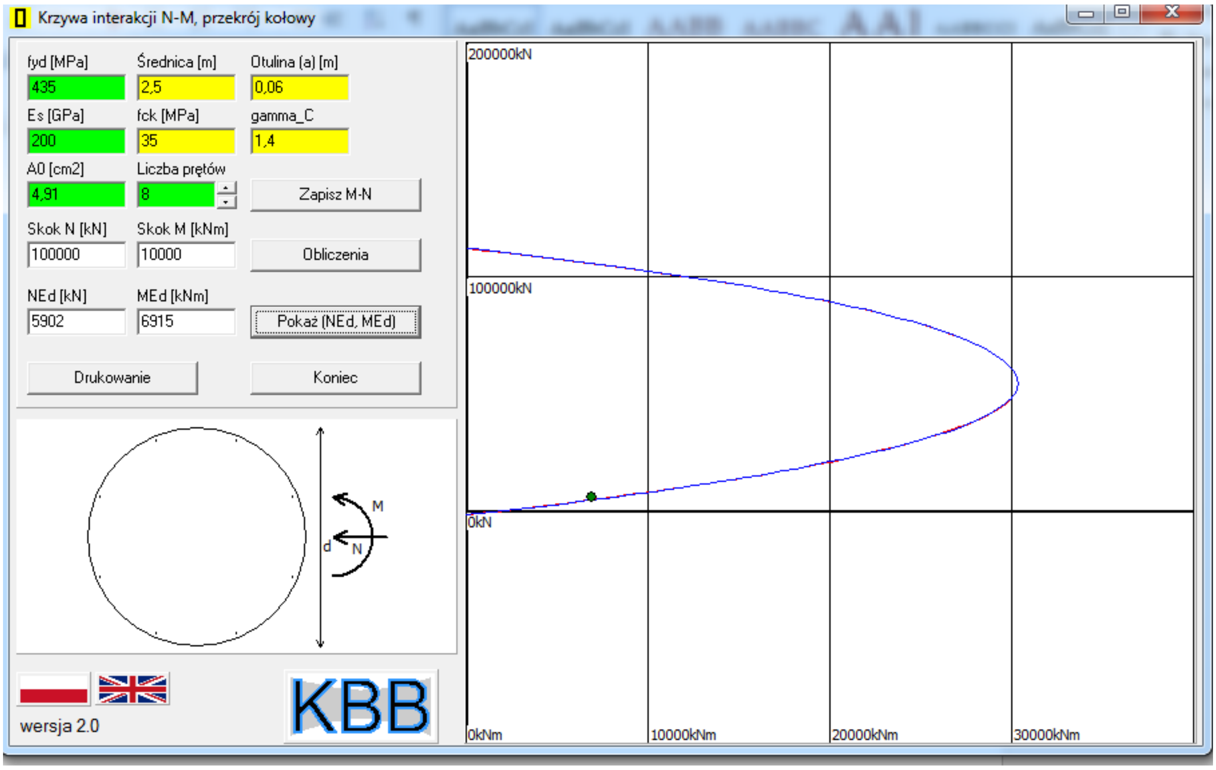


Figure 3.3.17 The curve interaction for bar #41 – second case

The bar #42

First case

$N_{Ed,max} = 11602$ kN

$M_{Ed,cor.} = M_z = 568$ kNm

Length of the column = 39,4 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{39{,}4}} = 0{,}318 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 11602\ kN \cdot \frac{1}{300} = 38{,}7\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 568\ kNm + 38{,}7\ kN \cdot 39{,}4\ m \approx 2093\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 2093\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{11602\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}094$$

$$n_{bal} = 0{,}4$$

$$A_s = 147{,}3\ cm^2 \rightarrow 30\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}01473\ m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}052$$

$$n_u = 1 + \omega = 1{,}052$$

$$K_r = \frac{1{,}052 - 0{,}094}{1{,}052 - 0{,}4} = 1{,}47 > 1{,}0$$

$$K_r = 1{,}0$$

$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$

$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$

$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 39{,}4\ m}{0{,}625\ m} = 126{,}1$

$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{126{,}1}{150} = -0{,}31$

$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_z = 0{,}39\ kNm$

$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$

$\varphi(\infty, t_0) = 1{,}8$

$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}39\ kNm}{2093\ kNm} = 0{,}0003$

$K_{\varphi} = 1 - 0{,}31 \cdot 0{,}0003 \approx 1{,}0$

$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$

$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 39{,}4\ m)^2}{10} = 1{,}23\ m$

$M_{Ed} = 2093\ kNm + 11602\ kN \cdot 1{,}23\ m = 16363\ kNm$

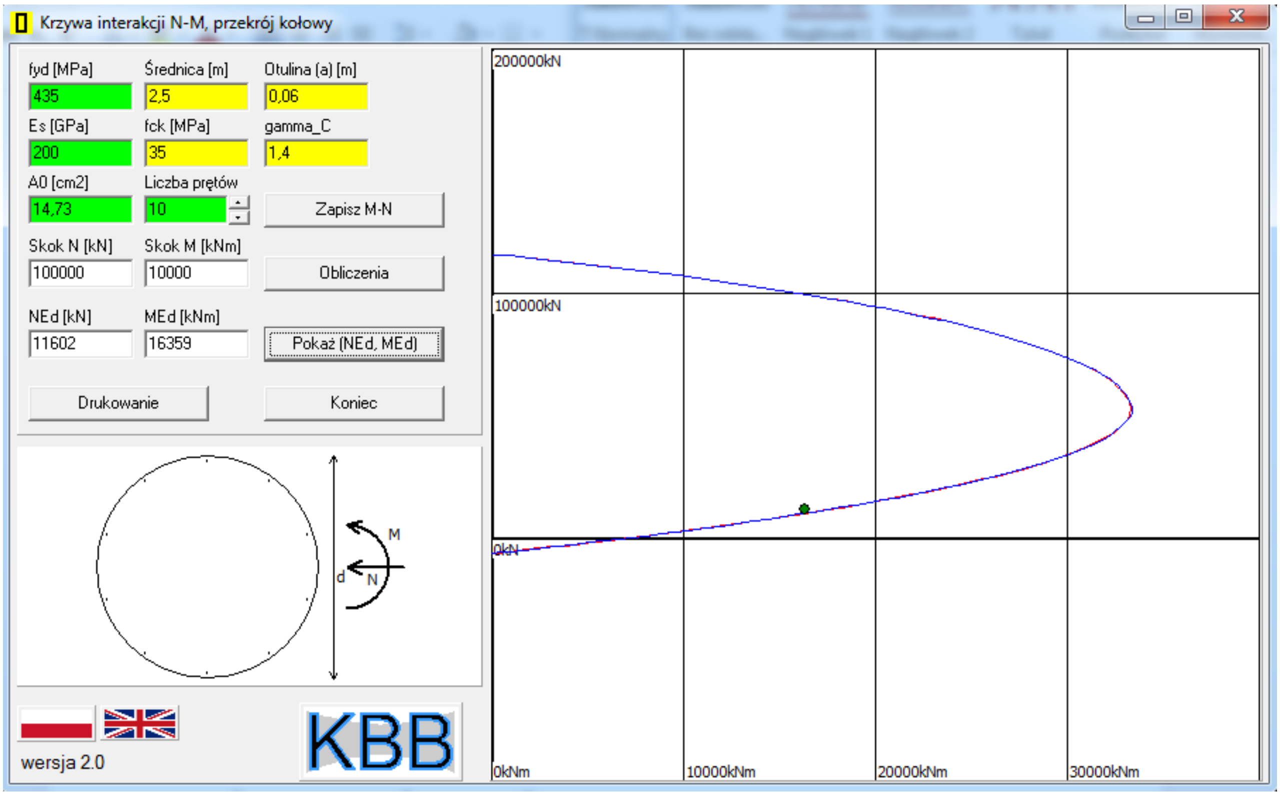


Figure 3.3.18 The curve interaction for bar #42 – first case

Second case

$M_{Ed,max} = M_y = 736$ kNm

$N_{Ed,cor.} = 6603$ kN

Geometric imperfections:

$$H_i = \theta_i \cdot N = 6603\ kN \cdot \frac{1}{300} = 22{,}0\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 736\ kNm + 22{,}0\ kN \cdot 39{,}4\ m \approx 1603\ kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1603\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{6603\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}053$$

$n_{bal} = 0{,}4$

$A_s = 147{,}3\ cm^2 \rightarrow 30\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}01473\ m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}052$$

$n_u = 1 + \omega = 1{,}052$

$$K_r = \frac{1{,}052 - 0{,}053}{1{,}052 - 0{,}4} = 1{,}53 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 39{,}4\ m}{0{,}625\ m} = 126{,}1$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{126{,}1}{150} = -0{,}31$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 325{,}75\ kNm$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$\varphi(\infty, t_0) = 1{,}8$

$$\varphi_{ef} = 1{,}8 \cdot \frac{325{,}75\ kNm}{736\ kNm} = 0{,}80$$

$K_\varphi = 1 - 0{,}31 \cdot 0{,}80 = 0{,}75 < 1{,}0 \rightarrow K_\varphi = 1$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 39{,}4\ m)^2}{10} = 1{,}23\ m$$

$M_{Ed} = 736\ kNm + 6603\ kN \cdot 1{,}23\ m = 8858\ kNm$

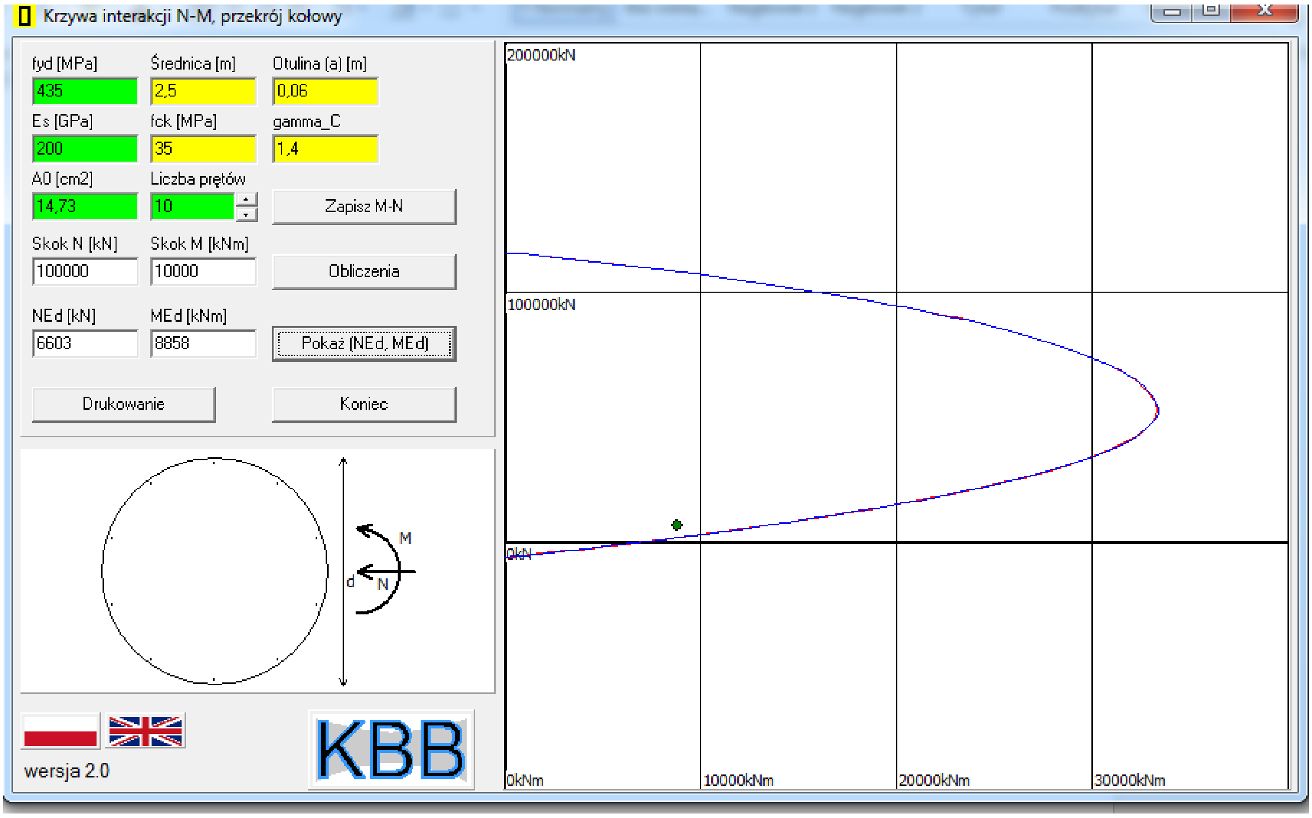


Figure 3.3.19 The curve interaction for bar #42 – second case

The bar #43

First case

$N_{Ed,max} = 11598$ kN

$M_{Ed,cor.} = M_y = 1{,}6$ kNm

Length of the column = 39,4 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{39{,}4}} = 0{,}318 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 11598\ kN \cdot \frac{1}{300} = 38{,}7\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1{,}6\ kNm + 38{,}7\ kN \cdot 39{,}4\ m \approx 1526\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1526\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_{\emptyset} \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{11598\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}094$$

$$n_{bal} = 0{,}4$$

$$A_s = 147{,}3\ cm^2 \rightarrow 30\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}01473\ m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}052$$

$$n_u = 1 + \omega = 1{,}052$$

$$K_r = \frac{1{,}052 - 0{,}094}{1{,}052 - 0{,}4} = 1{,}47 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1,0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1,94\ m^4}{4,91\ m^2}} = 0,625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 39,4\ m}{0,625\ m} = 126,1$$

$$\beta = 0,35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0,35 + \frac{35}{200} - \frac{126,1}{150} = -0,31$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$$M_{0Eqp} = M_y = 326\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1,25\ m$$

$$\varphi(\infty, t_0) = 1,8$$

$$\varphi_{ef} = 1,8 \cdot \frac{326\ kNm}{1526\ kNm} = 0,38$$

$$K_{\varphi} = 1 - 0,31 \cdot 0,38 = 0,88 < 1 \rightarrow K_{\varphi} = 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0,00198\frac{1}{m} = 0,00198\frac{1}{m}$$

$$e_2 = 0,00198\frac{1}{m} \cdot \frac{(2 \cdot 39,4\ m)^2}{10} = 1,23\ m$$

$$M_{Ed} = 1526\ kNm + 11598\ kN \cdot 1,23\ m = 15791\ kNm$$

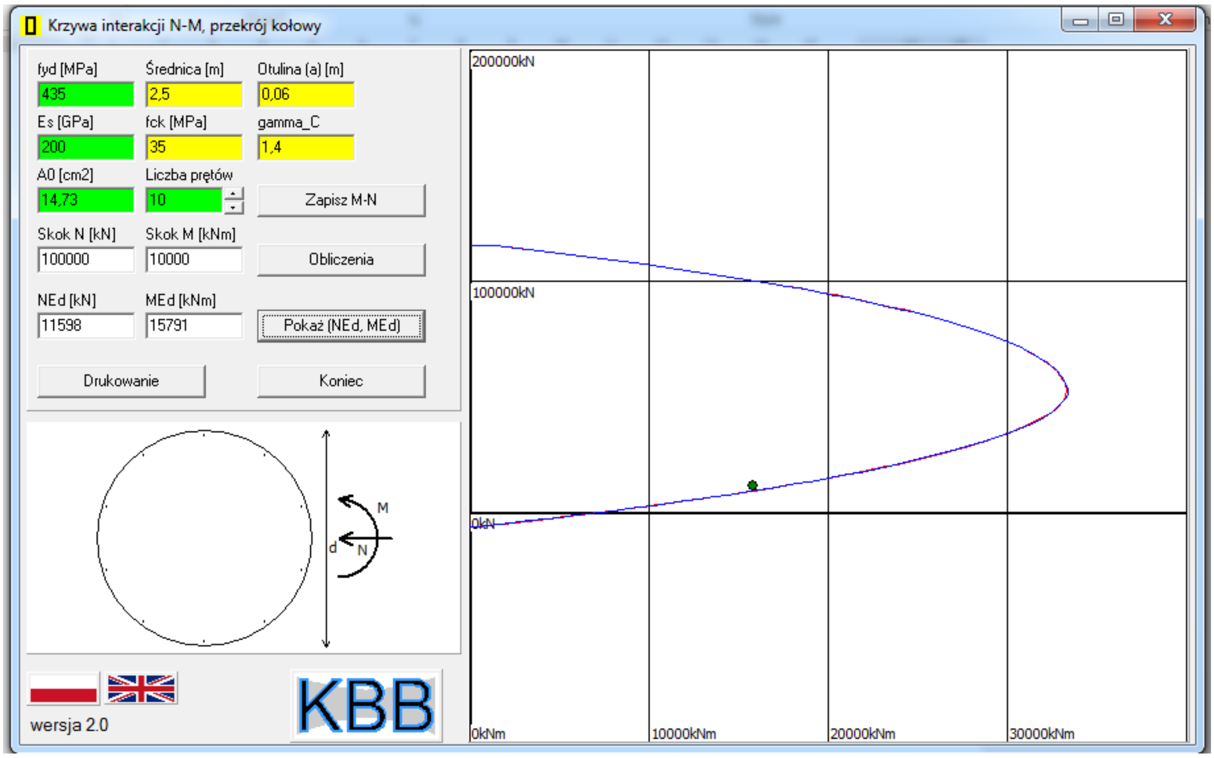


Figure 3.3.20 The curve interaction for bar #43 – first case

Second case

$M_{Ed,max} = M_z = 948$ kNm

$N_{Ed,cor.} = 10254$ kN

<u>Geometric imperfections:</u>

$$H_i = \theta_i \cdot N = 10254\,kN \cdot \frac{1}{300} = 34{,}2\,kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 948\,kNm + 34{,}2\,kN \cdot 39{,}4\,m \approx 2295\,kNm$$

<u>The piers verification – method based on nominal curvature</u>

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 2295\,kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10254\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}083$$

$n_{bal} = 0{,}4$

$A_s = 147{,}3\ cm^2 \rightarrow 30\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}01473\ m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}052$$

$n_u = 1 + \omega = 1{,}052$

$$K_r = \frac{1{,}052 - 0{,}083}{1{,}052 - 0{,}4} = 1{,}48 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta \varphi_{ef} \geq 1{,}0$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 39{,}4\ m}{0{,}625\ m} = 126{,}1$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{126{,}1}{150} = -0{,}31$$

$$\varphi_{ef} = \varphi(\infty, t_0) \frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP): \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal\ 0.$

$\psi_2\ for\ wind\ load\ is\ equal\ 0{,}5.$

$M_{0Eqp} = M_y = 0{,}4\ kNm$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$\varphi(\infty, t_0) = 1{,}8$

$$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}4\ kNm}{2295\ kNm} = 0{,}0003$$

$K_\varphi = 1 - 0{,}31 \cdot 0{,}0003 \approx 1{,}0$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198 \frac{1}{m} = 0{,}00198 \frac{1}{m}$$

$$e_2 = 0{,}00198 \frac{1}{m} \cdot \frac{(2 \cdot 39{,}4\ m)^2}{10} = 1{,}23\ m$$

$$M_{Ed} = 2295kNm + 10254\ kN \cdot 1{,}23\ m = 14907\ kNm$$

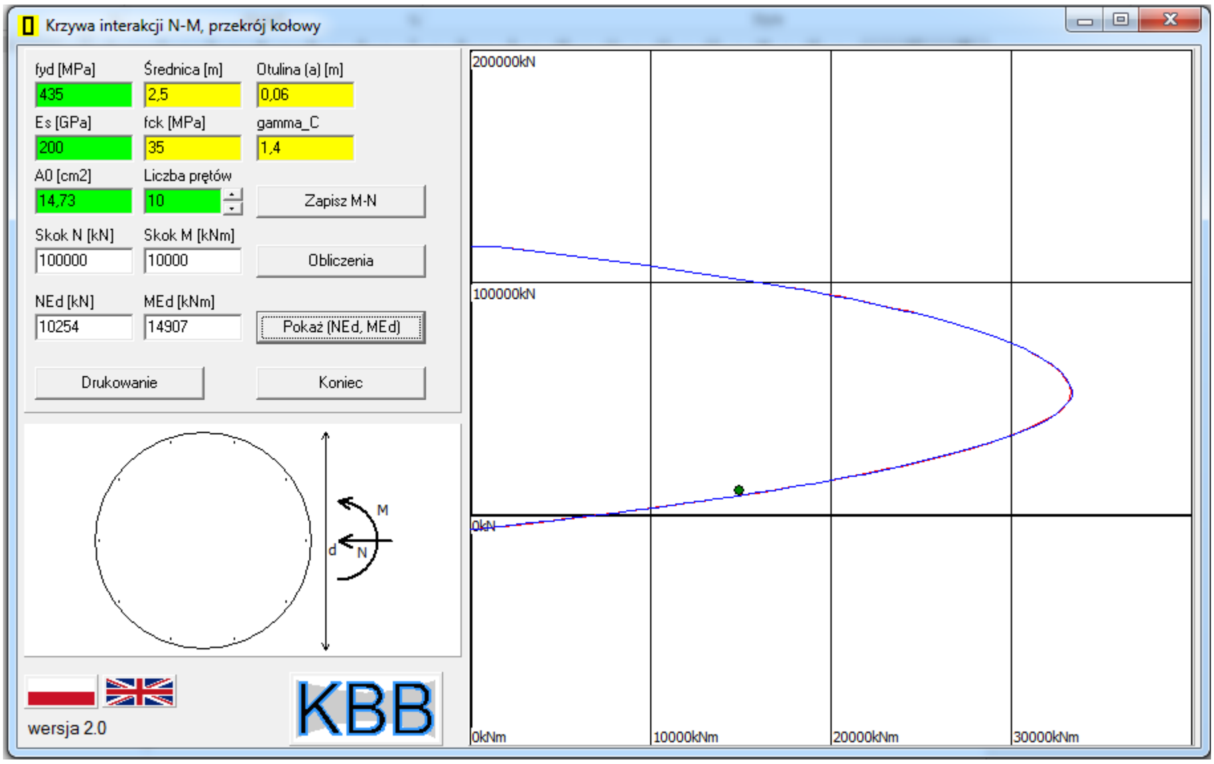


Figure 3.3.21 The curve interaction for bar #43 – second case

The bar #44

First case

$N_{Ed,max} = 10668$ kN

$M_{Ed,cor.} = M_z = 614$ kNm

Length of the column = 39,14 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{39{,}14}} = 0{,}319 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10668\ kN \cdot \frac{1}{300} = 35{,}6\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 614\ kNm + 35{,}6\ kN \cdot 39{,}14\ m \approx 2007\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 2007\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10668\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}087$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}087}{1{,}014 - 0{,}4} = 1{,}51 > 1{,}0$$

$$K_r = 1{,}0$$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$

$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 39{,}14\ m}{0{,}625\ m} = 125{,}2$

$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{125{,}2}{150} = -0{,}31$

$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_z = 0{,}8\ kNm$

$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$

$\varphi(\infty, t_0) = 1{,}8$

$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}8\ kNm}{1810\ kNm} = 0{,}0008$

$K_\varphi = 1 - 0{,}31 \cdot 0{,}0008 \approx 1$

$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$

$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 39{,}14\ m)^2}{10} = 1{,}213\ m$

$M_{Ed} = 2007\ kNm + 10668\ kN \cdot 1{,}213\ m = 14947\ kNm$

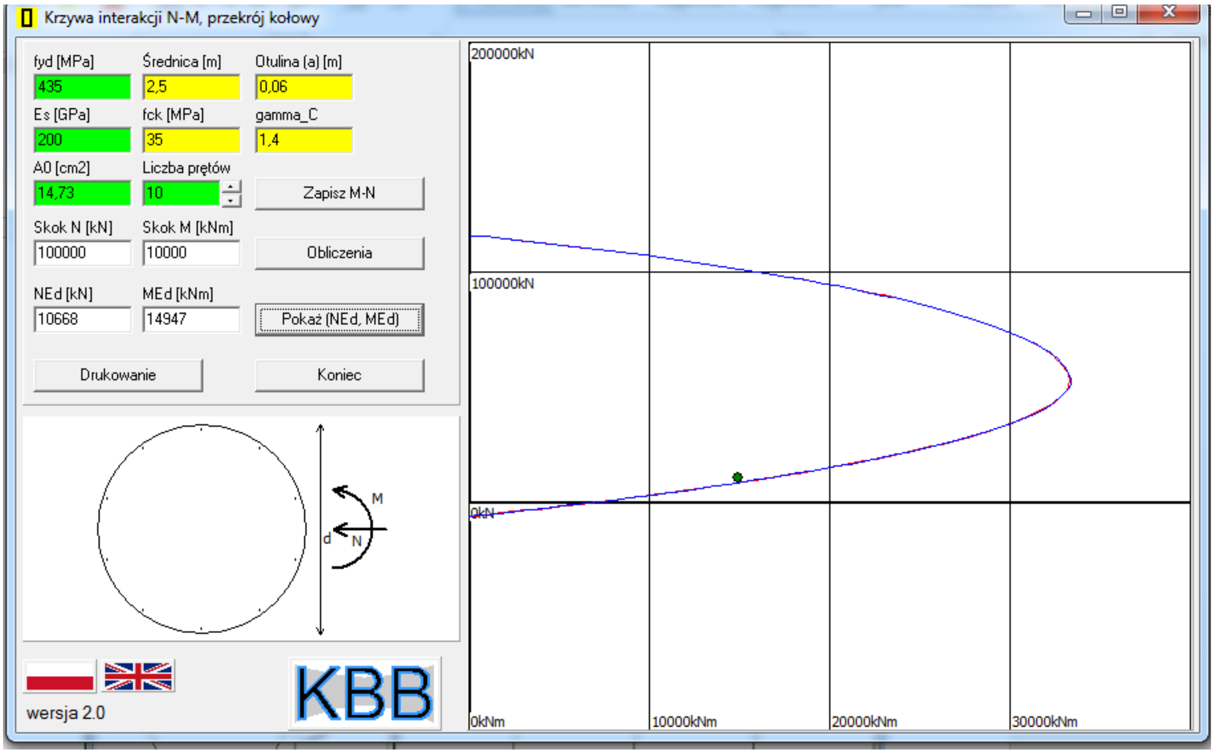


Figure 3.3.22 The curve interaction for bar #44 – first case

Second case

$M_{Ed,max} = M_z = 1025$ kNm

$N_{Ed,cor.} = 5908$ kN

Geometric imperfections:

$$H_i = \theta_i \cdot N = 5908\ kN \cdot \frac{1}{300} = 19{,}7\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1025\ kNm + 19{,}7\ kN \cdot 39{,}14\ m \approx 1796\ kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1796\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{5908\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}048$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}048}{1{,}014 - 0{,}4} = 1{,}57 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP){:}\ \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal$ 0.

$\psi_2\ for\ wind\ load\ is\ equal$ 0,5.

$M_{0Eqp} = M_z = 0{,}8\ kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}8\ kNm}{1687\ kNm} = 0{,}0008$$

$K_\varphi = 1 - 0{,}19 \cdot 0{,}0008 \approx 1$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 39{,}14\ m)^2}{10} = 1{,}213\ m$$

$M_{Ed} = 1796\ kNm + 5908\ kN \cdot 1{,}213\ m \approx 8962\ kNm$

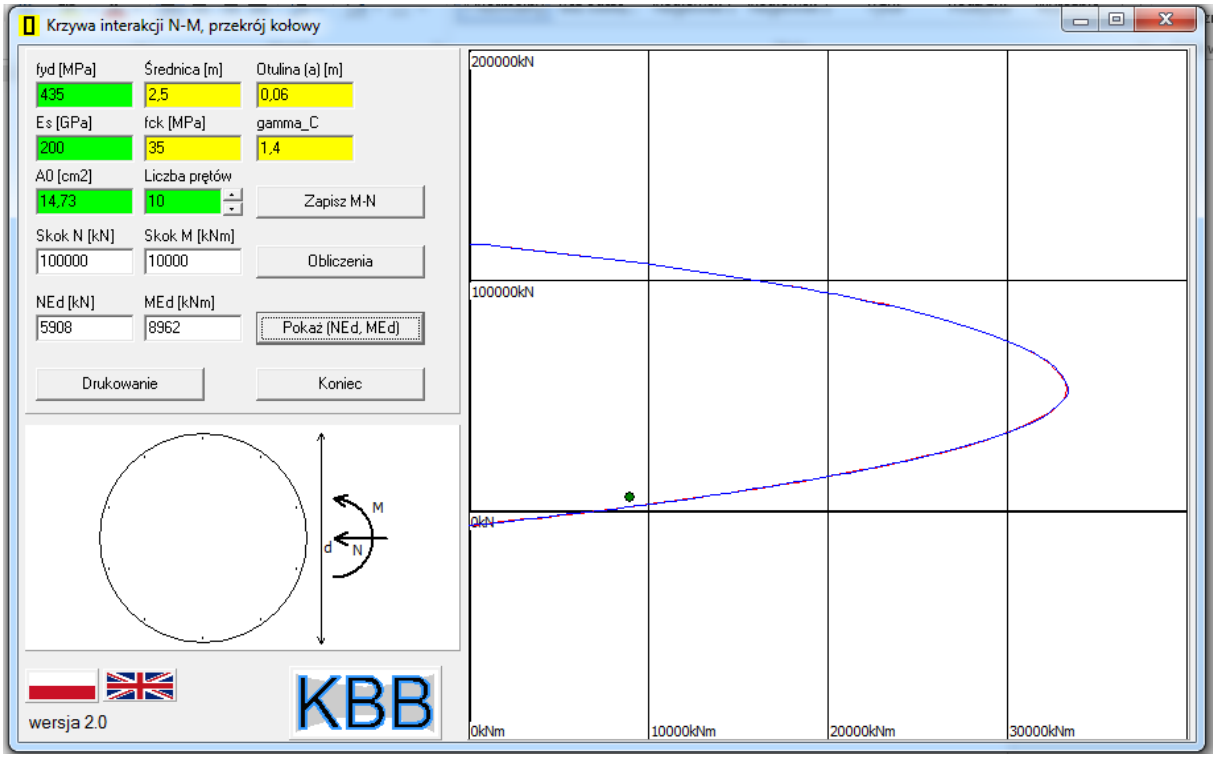


Figure 3.3.23 The curve interaction for bar #44 – second case

The bar #45

First case

$N_{Ed,max} = 10667$ kN

$M_{Ed,cor.} = M_z = 0{,}9$ kNm

Length of the column = 39,14 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{39{,}14}} = 0{,}319 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10667\ kN \cdot \frac{1}{300} = 35{,}6\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 0{,}9\ kNm + 35{,}6\ kN \cdot 39{,}14\ m \approx 1394\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1394\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10667\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}087$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}087}{1{,}014 - 0{,}4} = 1{,}51 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 39{,}14\ m}{0{,}625\ m} = 125{,}2$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{125{,}2}{150} = -0{,}31$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP): \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal$ 0.

$\psi_2\ for\ wind\ load\ is\ equal$ 0,5.

$$M_{0Eqp} = M_z = 0{,}8\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}8\ kNm}{1193\ kNm} = 0{,}001$$

$$K_{\varphi} = 1 - 0{,}31 \cdot 0{,}001 \approx 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 39{,}14\ m)^2}{10} = 1{,}213\ m$$

$$M_{Ed} = 1394\ kNm + 10667\ kN \cdot 1{,}213\ m = 14333\ kNm$$

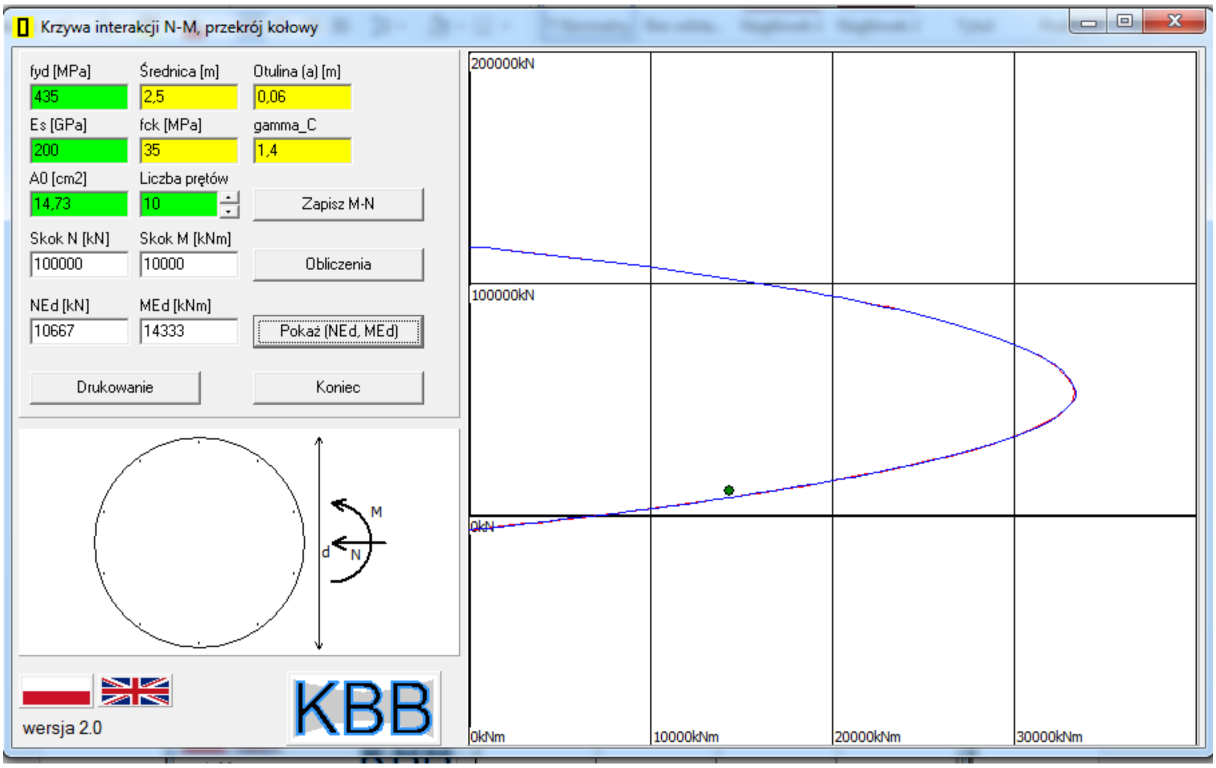


Figure 3.3.24 The curve interaction for bar #45 – first case

Second case

$M_{Ed,max} = M_z = 1026$ kNm

$N_{Ed,cor.} = 9470$ kN

<u>Geometric imperfections:</u>

$$H_i = \theta_i \cdot N = 9470\ kN \cdot \frac{1}{300} = 31{,}6\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1026\ kNm + 31{,}6\ kN \cdot 39{,}14\ m \approx 2263\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 2263\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{9470\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}077$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}07}{1{,}014 - 0{,}4} = 1{,}53 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_z = 0{,}8\ kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}8\ kNm}{2087\ kNm} = 0{,}0007$$

$K_\varphi = 1 - 0{,}19 \cdot 0{,}0007 \approx 1$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198 \frac{1}{m} = 0{,}00198 \frac{1}{m}$$

$$e_2 = 0{,}00198 \frac{1}{m} \cdot \frac{(2 \cdot 39{,}14\ m)^2}{10} = 1{,}213\ m$$

$M_{Ed} = 2263\ kNm + 9470\ kN \cdot 1{,}213\ m = 13750\ kNm$

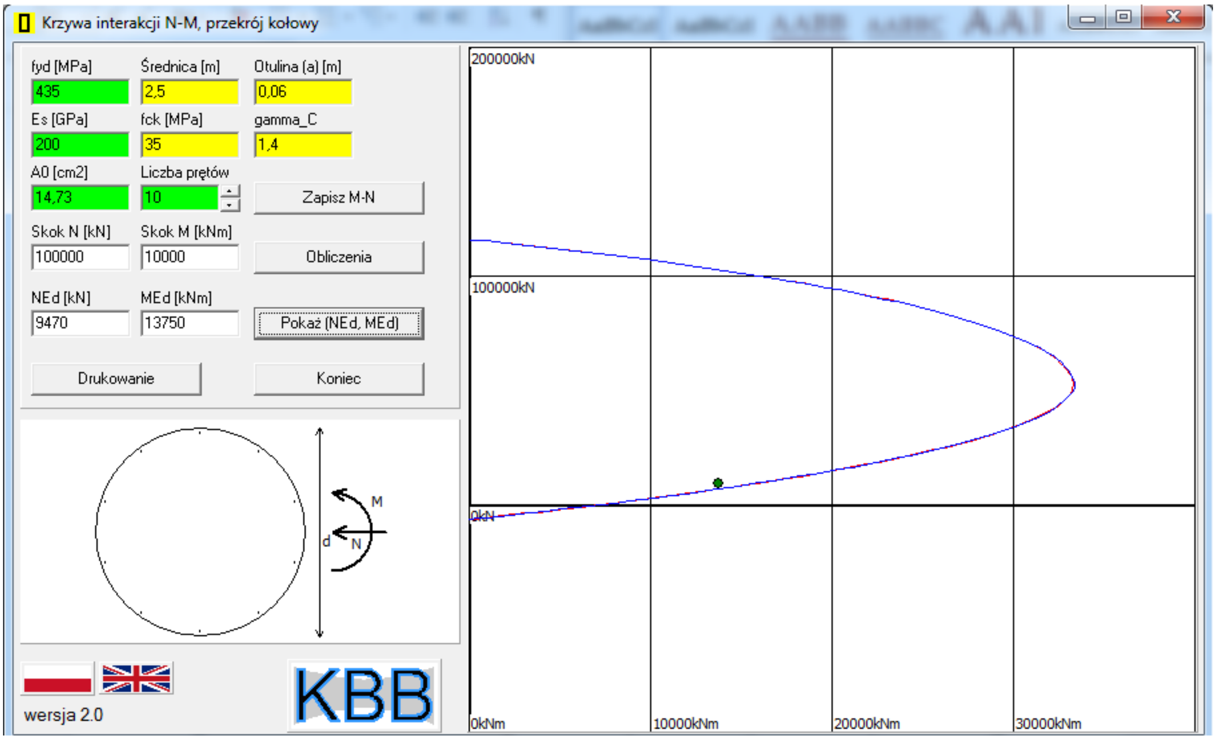


Figure 3.3.25 The curve interaction for bar #45 – second case

The bar #46

First case

$N_{Ed,max} = 10771\text{kN}$

$M_{Ed,cor.} = M_z = 525 \text{ kNm}$

Length of the column = 34,28 m

<u>Geometric imperfections:</u>

$\theta_i = \theta_0 \alpha_h \alpha_m$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{34,28}} = 0,341 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0,5\left(1 + \frac{1}{m}\right)} = 1,0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10771\ kN \cdot \frac{1}{300} = 35,9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 525\ kNm + 35{,}9\ kN \cdot 34{,}28\ m \approx 1756\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1756\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10771\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}088$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}088}{1{,}014 - 0{,}4} = 1{,}51 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_\varphi = 1 + \beta \varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 34{,}28\ m}{0{,}625\ m} = 109{,}7$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{109{,}7}{150} = -0{,}21$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP): \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal\ 0.$

$\psi_2\ for\ wind\ load\ is\ equal\ 0{,}5.$

$$M_{0Eqp} = M_z = 0{,}7\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}7\ kNm}{1756\ kNm} = 0{,}0007$$

$$K_\varphi = 1 - 0{,}21 \cdot 0{,}0007 \approx 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 34{,}28\ m)^2}{10} = 0{,}93\ m$$

$$M_{Ed} = 1756\ kNm + 10771\ kN \cdot 0{,}93\ m = 11773\ kNm$$

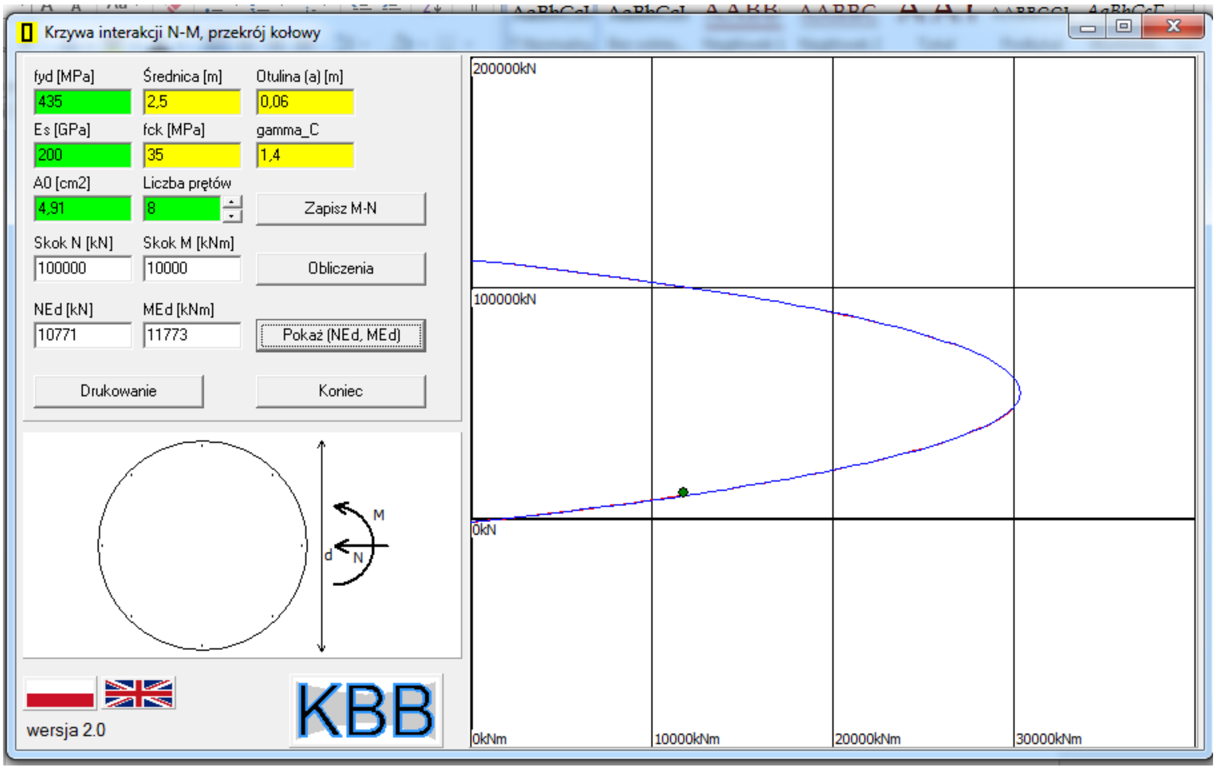


Figure 3.3.26 The curve interaction for bar #46 – first case

Second case

$M_{Ed,max} = M_y = 938\text{kNm}$

$N_{Ed,cor.} = 5986 \text{ kN}$

Geometric imperfections:

$$H_i = \theta_i \cdot N = 5986\, kN \cdot \frac{1}{300} = 20{,}0\, kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 938\, kNm + 20{,}0\, kN \cdot 34{,}28m \approx 1624\, kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1624\, kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{5986\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}049$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}049}{1{,}014 - 0{,}4} = 1{,}57 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_\varphi = 1 + \beta \varphi_{ef} \geq 1{,}0$$

$$\varphi_{ef} = \varphi(\infty, t_0) \frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$$M_{0Eqp} = M_z = 416\ kNm$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{416\ kNm}{1624\ kNm} = 0{,}46$$

$$K_\varphi = 1 - 0{,}21 \cdot 0{,}46 = 0{,}9 < 1 \rightarrow K_\varphi = 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198 \frac{1}{m} = 0{,}00198 \frac{1}{m}$$

$$e_2 = 0{,}00198 \frac{1}{m} \cdot \frac{(2 \cdot 34{,}28\ m)^2}{10} = 0{,}93\ m$$

$$M_{Ed} = 1624\ kNm + 5986\ kN \cdot 0{,}93 m = 7191\ kNm$$

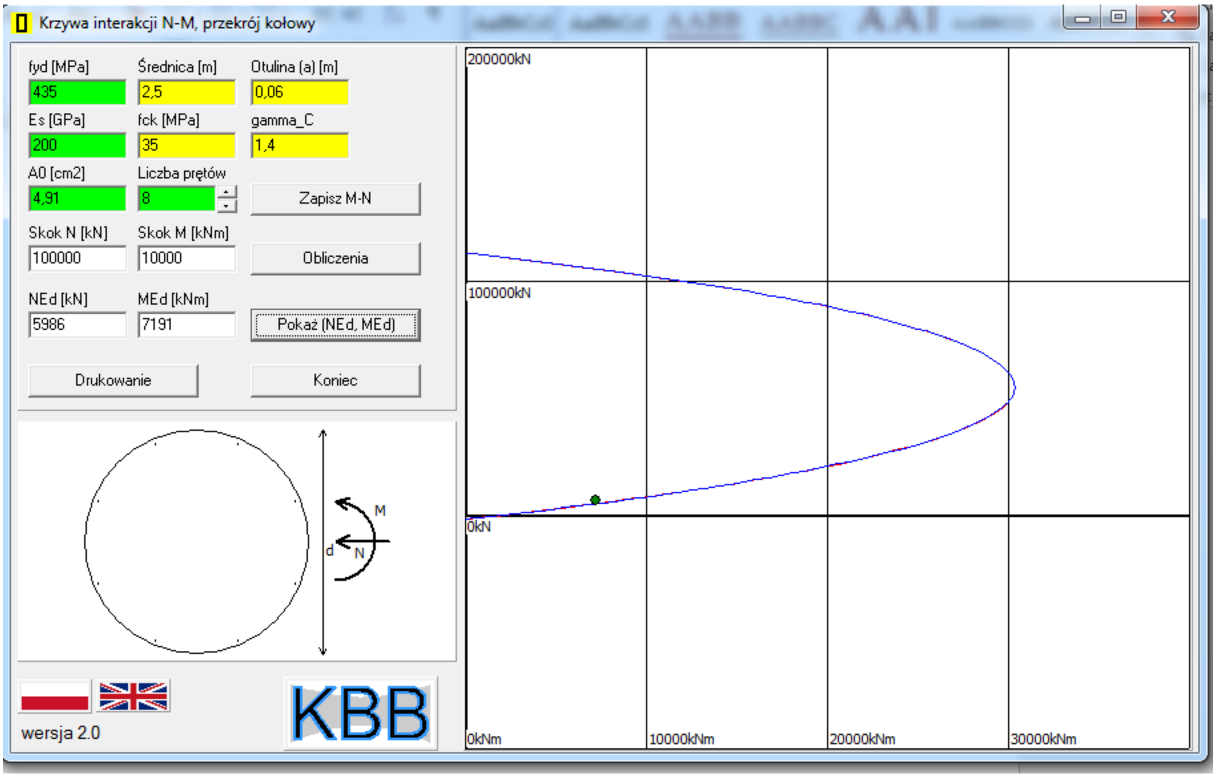


Figure 3.3.27 The curve interaction for bar #46 – second case

The bar #47

First case

$N_{Ed,max} = 10769$ kN

$M_{Ed,cor.} = M_z = 2{,}4$ kNm

Length of the column = 34,28 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{34{,}28}} = 0{,}341 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10769\ kN \cdot \frac{1}{300} = 35{,}9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 2{,}4\ kNm + 35{,}9\ kN \cdot 34{,}28\ m \approx 1233\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1233\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10769\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}088$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}088}{1{,}014 - 0{,}4} = 1{,}51 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 34{,}28\ m}{0{,}625\ m} = 109{,}7$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{109{,}7}{150} = -0{,}21$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP){:}\ \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal\ 0.$

$\psi_2\ for\ wind\ load\ is\ equal\ 0{,}5.$

$$M_{0Eqp} = M_y = 416\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{416\ kNm}{1233\ kNm} = 0{,}61$$

$$K_{\varphi} = 1 - 0{,}21 \cdot 0{,}61 = 0{,}87 < 1 \rightarrow K_{\varphi} = 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 34{,}28\ m)^2}{10} = 0{,}93\ m$$

$$M_{Ed} = 1233\ kNm + 10769\ kN \cdot 0{,}93\ m = 11248\ kNm$$

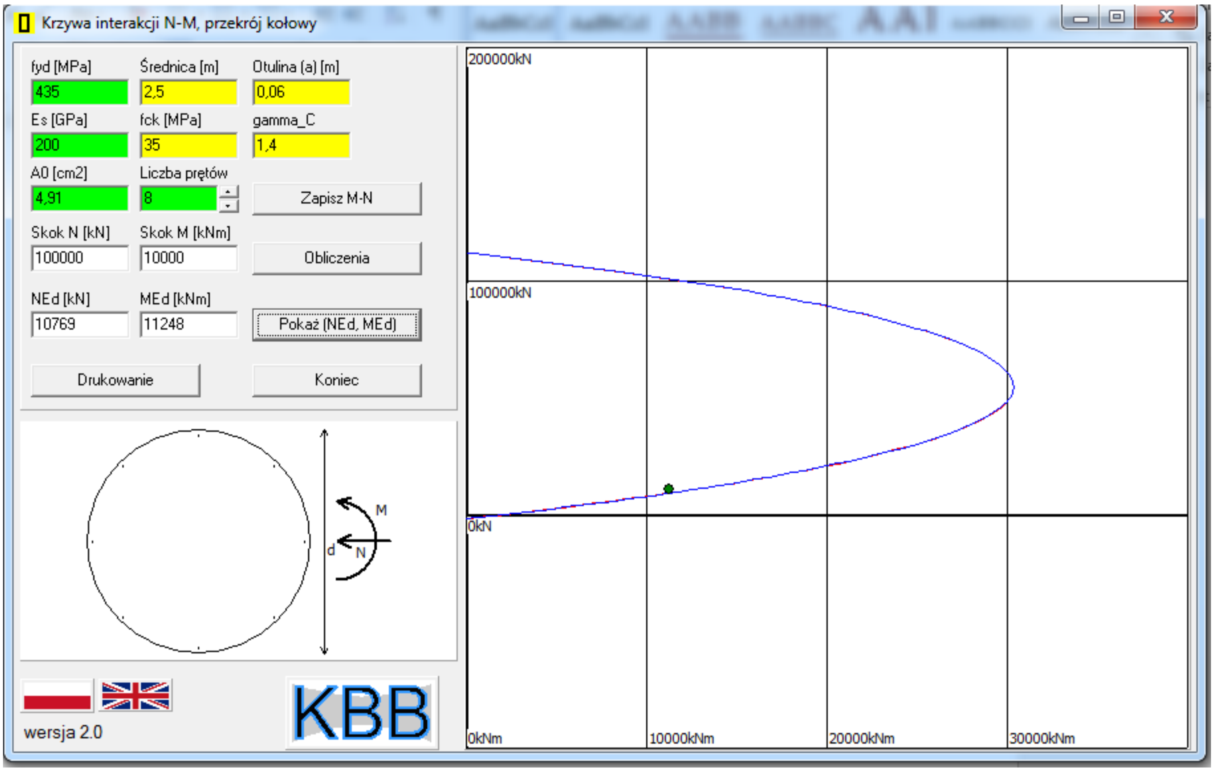


Figure 3.3.28 The curve interaction for bar #47 – first case

Second case

$M_{Ed,max} = M_y = 949\text{kNm}$

$N_{Ed,cor.} = 5984 \text{ kN}$

<u>Geometric imperfections:</u>

$$H_i = \theta_i \cdot N = 5984\ kN \cdot \frac{1}{300} = 19{,}9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 949\ kNm + 19{,}9\ kN \cdot 34{,}28m \approx 1631\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1631\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1,0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{5984\ kN}{4,91\ m^2 \cdot 25000\ kPa} = 0,049$$

$$n_{bal} = 0,4$$

$$A_s = 39,27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0,003927 m^2 \cdot 435\ MPa}{4,91\ m^2 \cdot 25\ MPa} = 0,014$$

$$n_u = 1 + \omega = 1,014$$

$$K_r = \frac{1,014 - 0,049}{1,014 - 0,4} = 1,57 > 1,0$$

$$K_r = 1,0$$

$$K_\varphi = 1 + \beta\varphi_{ef} \geq 1,0$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP): \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal$ 0.

$\psi_2\ for\ wind\ load\ is\ equal$ 0,5.

$$M_{0Eqp} = M_z = 416\ kNm$$

$$\varphi_{ef} = 1,8 \cdot \frac{416\ kNm}{1631\ kNm} = 0,46$$

$$K_\varphi = 1 - 0,21 \cdot 0,46 = 0,9 < 1 \rightarrow K_\varphi = 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0,00198\frac{1}{m} = 0,00198\frac{1}{m}$$

$$e_2 = 0,00198\frac{1}{m} \cdot \frac{(2 \cdot 34,28\ m)^2}{10} = 0,93\ m$$

$$M_{Ed} = 1631\ kNm + 5984\ kN \cdot 0,93m = 7196\ kNm$$

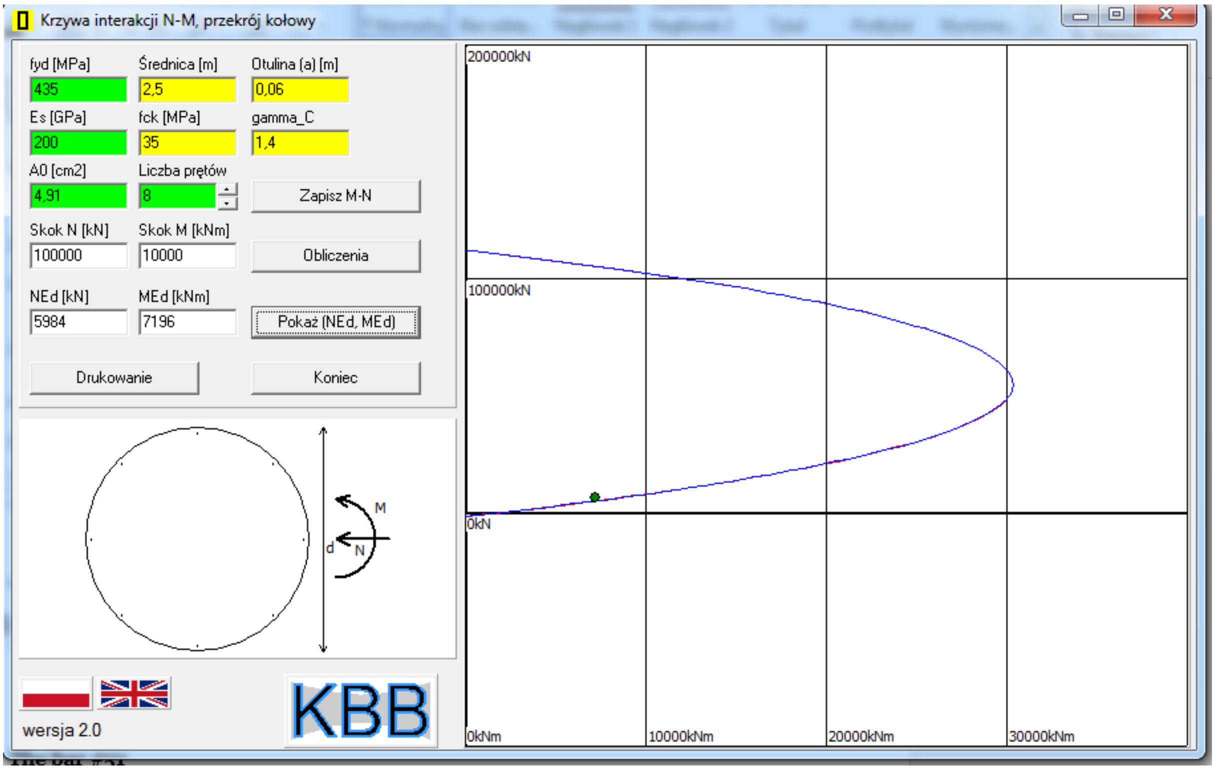


Figure 3.3.29 The curve interaction for bar #47 – second case

The bar #48

First case

$N_{Ed,max} = 10150$ kN

$M_{Ed,cor.} = M_z = 429$ kNm

Length of the column = 30,36 m

<u>Geometric imperfections:</u>

$\theta_i = \theta_0 \alpha_h \alpha_m$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{30,36}} = 0,36 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0,5\left(1 + \frac{1}{m}\right)} = 1,0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10150\ kN \cdot \frac{1}{300} = 33{,}8\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 429\ kNm + 33{,}8\ kN \cdot 30{,}36\ m \approx 1455\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1455\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10150\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}083$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}083}{1{,}014 - 0{,}4} = 1{,}52 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_{\varphi} = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 30{,}36\ m}{0{,}625\ m} = 97{,}1$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{97{,}1}{150} = -0{,}12$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 $for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal$ 0.

ψ_2 $for\ wind\ load\ is\ equal$ 0,5.

$$M_{0Eqp} = M_y = 0{,}7\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{0{,}7\ kNm}{1588\ kNm} = 0{,}0008$$

$$K_{\varphi} = 1 - 0{,}12 \cdot 0{,}0008 \approx 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 30{,}36\ m)^2}{10} = 0{,}73\ m$$

$$M_{Ed} = 1455\ kNm + 10150\ kN \cdot 0{,}73\ m = 8864\ kNm$$

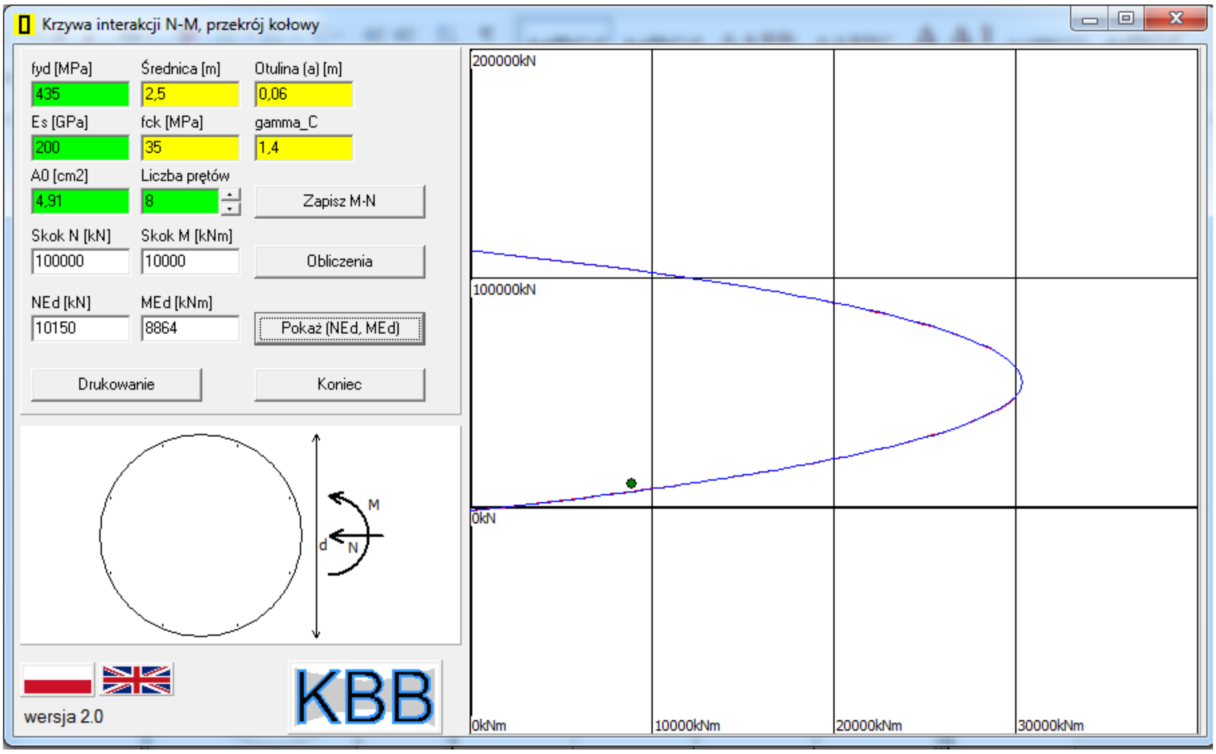


Figure 3.3.30 The curve interaction for bar #48 – first case

Second case

$M_{Ed,max} = M_y = 1180$ kNm

$N_{Ed,cor.} = 9024$ kN

Geometric imperfections:

$$H_i = \theta_i \cdot N = 9024\, kN \cdot \frac{1}{300} = 30{,}1\, kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1180\, kNm + 19{,}9\, kN \cdot 30{,}36\, m \approx 1784\, kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 1784\, kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{9024\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}073$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}073}{1{,}014 - 0{,}4} = 1{,}53 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_z = 523kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{523\ kNm}{1631\ kNm} = 0{,}58$$

$K_\varphi = 1 - 0{,}12 \cdot 0{,}58 = 0{,}93 < 1 \rightarrow K_\varphi = 1$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198 \frac{1}{m} = 0{,}00198 \frac{1}{m}$$

$$e_2 = 0{,}00198 \frac{1}{m} \cdot \frac{(2 \cdot 30{,}36\ m)^2}{10} = 0{,}73\ m$$

$M_{Ed} = 1784\ kNm + 9024\ kN \cdot 0{,}73m = 8371\ kNm$

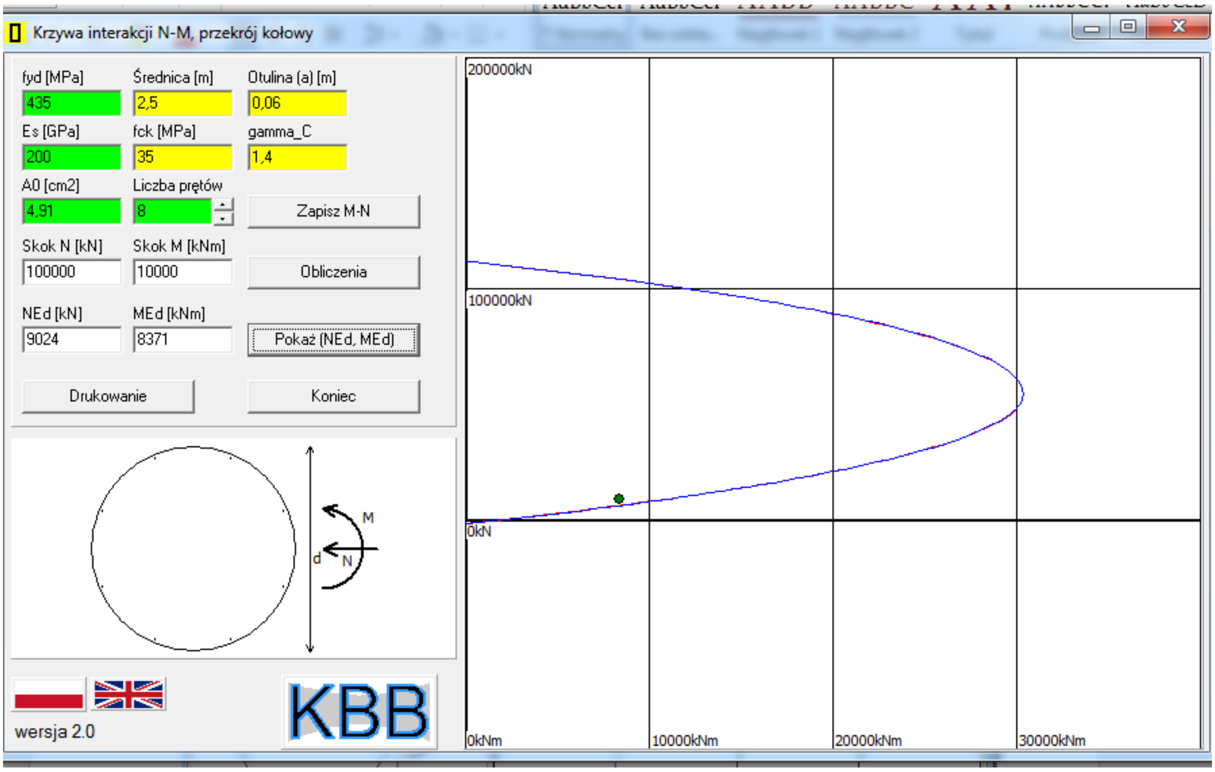


Figure 3.3.31 The curve interaction for bar #48 – second case

The bar #49

First case

$N_{Ed,max} = 10149$ kN

$M_{Ed,cor.} = M_y = 2{,}0$ kNm

Length of the column = 30,36 m

<u>Geometric imperfections:</u>

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{30{,}36}} = 0{,}36 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 10149\ kN \cdot \frac{1}{300} = 33{,}8\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 2{,}0\ kNm + 33{,}8\ kN \cdot 30{,}36\ m \approx 1028\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 1028\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{10149\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}083$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}083}{1{,}014 - 0{,}4} = 1{,}52 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$$

$$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 30{,}36\ m}{0{,}625\ m} = 97{,}1$$

$$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{97{,}1}{150} = -0{,}12$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$$M_{0Eqp} = M_y = 523\ kNm$$

$$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$$

$$\varphi(\infty, t_0) = 1{,}8$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{523\ kNm}{1028\ kNm} = 0{,}91$$

$$K_\varphi = 1 - 0{,}12 \cdot 0{,}91 = 0{,}89 < 1 \rightarrow K_\varphi = 1$$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198\frac{1}{m} = 0{,}00198\frac{1}{m}$$

$$e_2 = 0{,}00198\frac{1}{m} \cdot \frac{(2 \cdot 30{,}36\ m)^2}{10} = 0{,}73\ m$$

$$M_{Ed} = 1028kNm + 10149\ kN \cdot 0{,}73\ m = 8437\ kNm$$

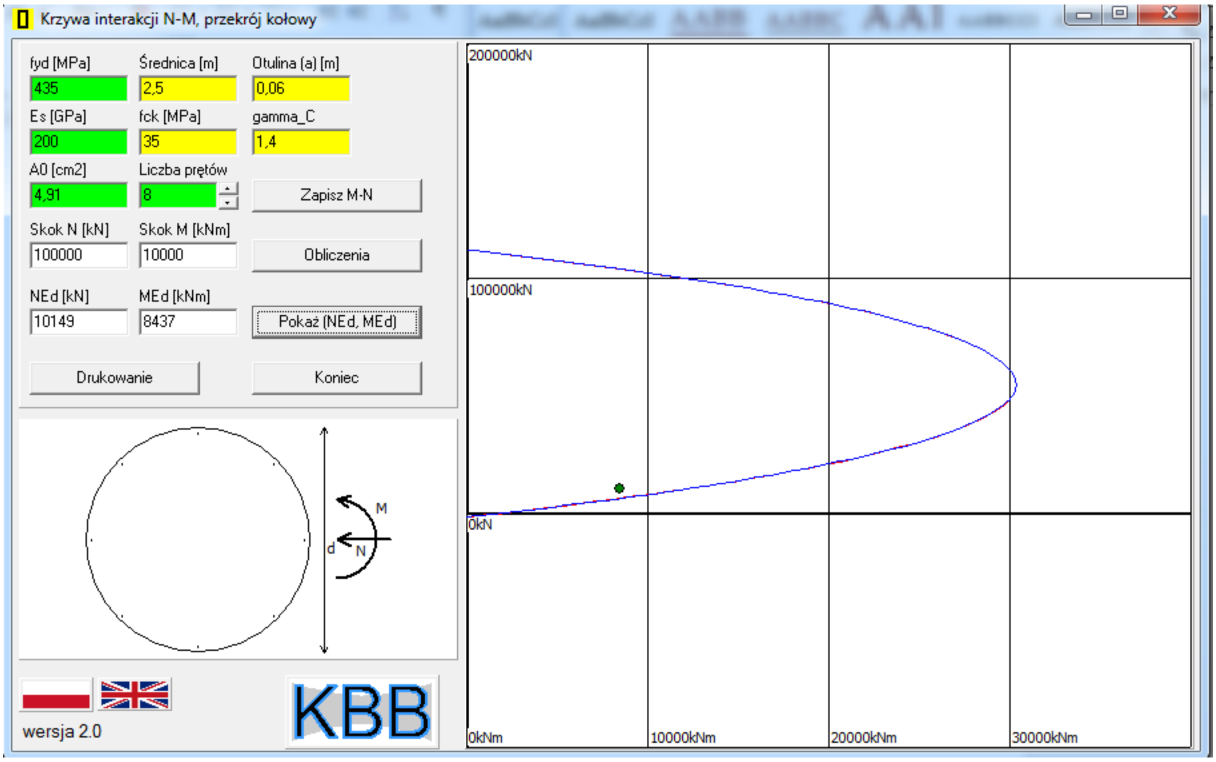


Figure 3.3.32 The curve interaction for bar #49 – first case

Second case

$M_{Ed,max} = M_y = 1198$ kNm

$N_{Ed,cor.} = 9023$ kN

Geometric imperfections:

$$H_i = \theta_i \cdot N = 9023\ kN \cdot \frac{1}{300} = 30,1\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 1198\ kNm + 30,1\ kN \cdot 30,36\ m \approx 2112\ kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 2112\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{9023\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}073$$

$n_{bal} = 0{,}4$

$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927 m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$n_u = 1 + \omega = 1{,}014$

$$K_r = \frac{1{,}014 - 0{,}073}{1{,}014 - 0{,}4} = 1{,}53 > 1{,}0$$

$K_r = 1{,}0$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 523\ kNm$

$$\varphi_{ef} = 1{,}8 \cdot \frac{523\ kNm}{2112\ kNm} = 0{,}44$$

$K_\varphi = 1 - 0{,}12 \cdot 0{,}44 = 0{,}95 < 1 \rightarrow K_\varphi = 1$

$$\frac{1}{r} = 1 \cdot 1 \cdot 0{,}00198 \frac{1}{m} = 0{,}00198 \frac{1}{m}$$

$$e_2 = 0{,}00198 \frac{1}{m} \cdot \frac{(2 \cdot 30{,}36\ m)^2}{10} = 0{,}73\ m$$

$M_{Ed} = 2112\ kNm + 9023\ kN \cdot 0{,}73m = 8699\ kNm$

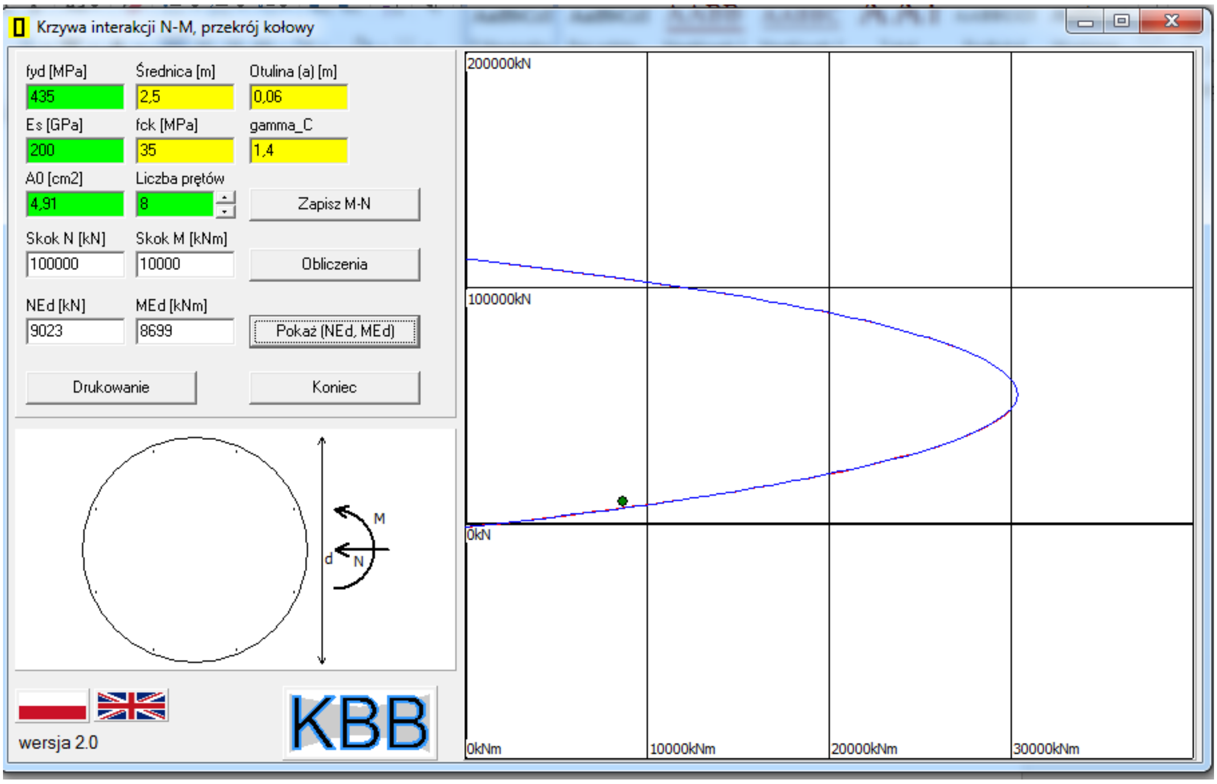


Figure 3.3.33 The curve interaction for bar #49 – second case

The bar #50

First case

$M_{Ed,max}$ = 3748 kNm

$N_{Ed,cor.}$ = 7156 kN

Length of the column = 16,9 m

Geometric imperfections:

$$\theta_i = \theta_0 \alpha_h \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{16,9}} = 0,486 < \frac{2}{3}$$

$$\frac{2}{3} < \alpha_h < 1$$

m = 1

$$\alpha_m = \sqrt{0,5\left(1+\frac{1}{m}\right)} = 1,0$$

$$\theta_0 = \frac{1}{200}$$

$$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$$

$$H_i = \theta_i \cdot N = 7156kN \cdot \frac{1}{300} = 23{,}8\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 3748\ kNm + 23{,}8\ kN \cdot 16{,}9\ m \approx 4150\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 4150\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{7156\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}058$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927\ m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}058}{1{,}014 - 0{,}4} = 1{,}56 > 1{,}0$$

$$K_r = 1{,}0$$

$K_{\varphi} = 1 + \beta \varphi_{ef} \geq 1{,}0$

$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$

$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 16{,}9\ m}{0{,}625\ m} = 54{,}1$

$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{54{,}1}{150} = 0{,}16$

$\varphi_{ef} = \varphi(\infty, t_0) \frac{M_{0Eqp}}{M_{0Ed}}$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$M_{0Eqp} = M_y = 1688\ kNm$

$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$

$\varphi(\infty, t_0) = 1{,}8$

$\varphi_{ef} = 1{,}8 \cdot \frac{1688\ kNm}{4150\ kNm} = 0{,}73$

$K_{\varphi} = 1 + 0{,}16 \cdot 0{,}73 = 1{,}12$

$\frac{1}{r} = 1 \cdot 1{,}12 \cdot 0{,}00198 \frac{1}{m} = 0{,}0022 \frac{1}{m}$

$e_2 = 0{,}0022 \frac{1}{m} \cdot \frac{(2 \cdot 16{,}9\ m)^2}{10} = 0{,}25\ m$

$M_{Ed} = 4150\ kNm + 7156\ kN \cdot 0{,}25\ m = 5939\ kNm$

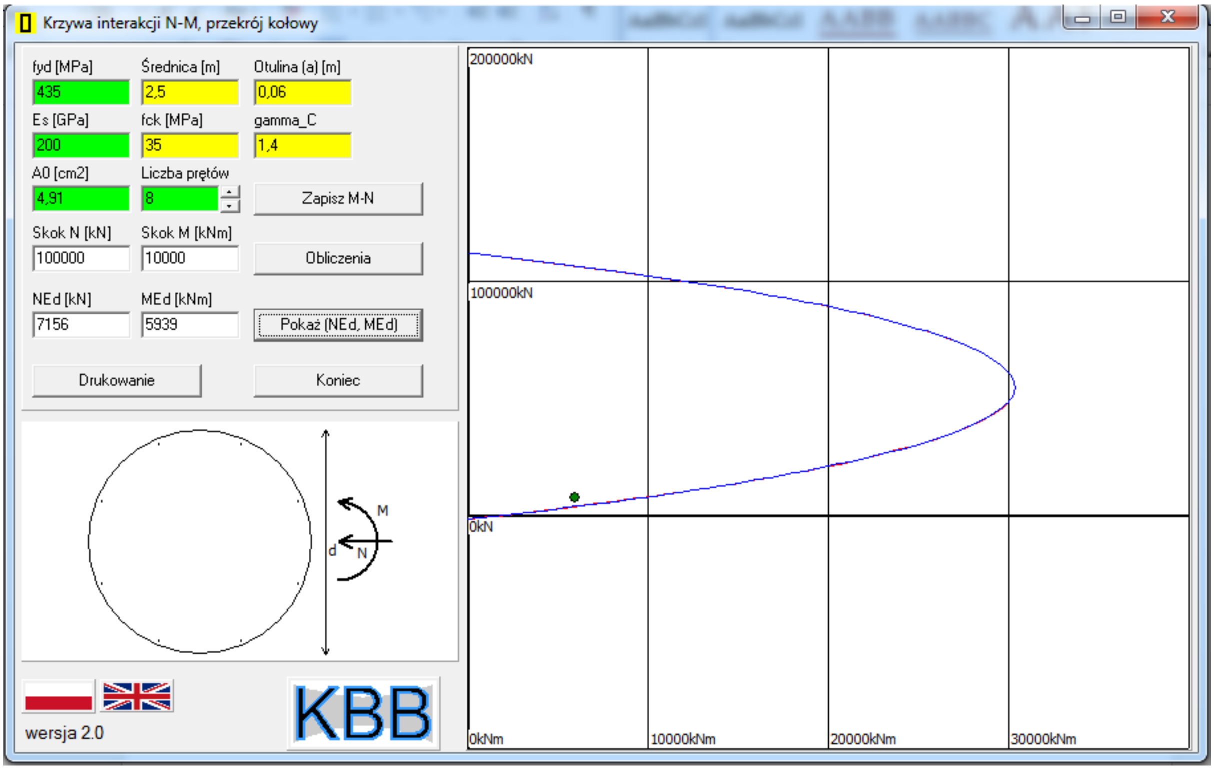


Figure 3.3.34 The curve interaction for bar #50 – first case

Second case

$N_{Ed,max.} = 7944$ kN

$M_{Ed,cor} = M_y = 63$ kNm

Geometric imperfections:

$$H_i = \theta_i \cdot N = 7944\ kN \cdot \frac{1}{300} = 26{,}5\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 63\ kNm + 26{,}5\ kN \cdot 16{,}9\ m \approx 511\ kNm$$

The piers verification – method based on nominal curvature

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 511\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{7944\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}065$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927\ m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}065}{1{,}014 - 0{,}4} = 1{,}54 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$$M_{0Eqp} = M_y = 1688\ kNm$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{1688\ kNm}{511\ kNm} = 5{,}9$$

$$K_\varphi = 1 + 0{,}16 \cdot 5{,}9 = 1{,}9$$

$$\frac{1}{r} = 1 \cdot 1{,}9 \cdot 0{,}00198\frac{1}{m} = 0{,}0038\frac{1}{m}$$

$$e_2 = 0{,}0038\frac{1}{m} \cdot \frac{(2 \cdot 16{,}9\ m)^2}{10} = 0{,}43\ m$$

$$M_{Ed} = 511\ kNm + 7944\ kN \cdot 0{,}43\ m = 3927\ kNm$$

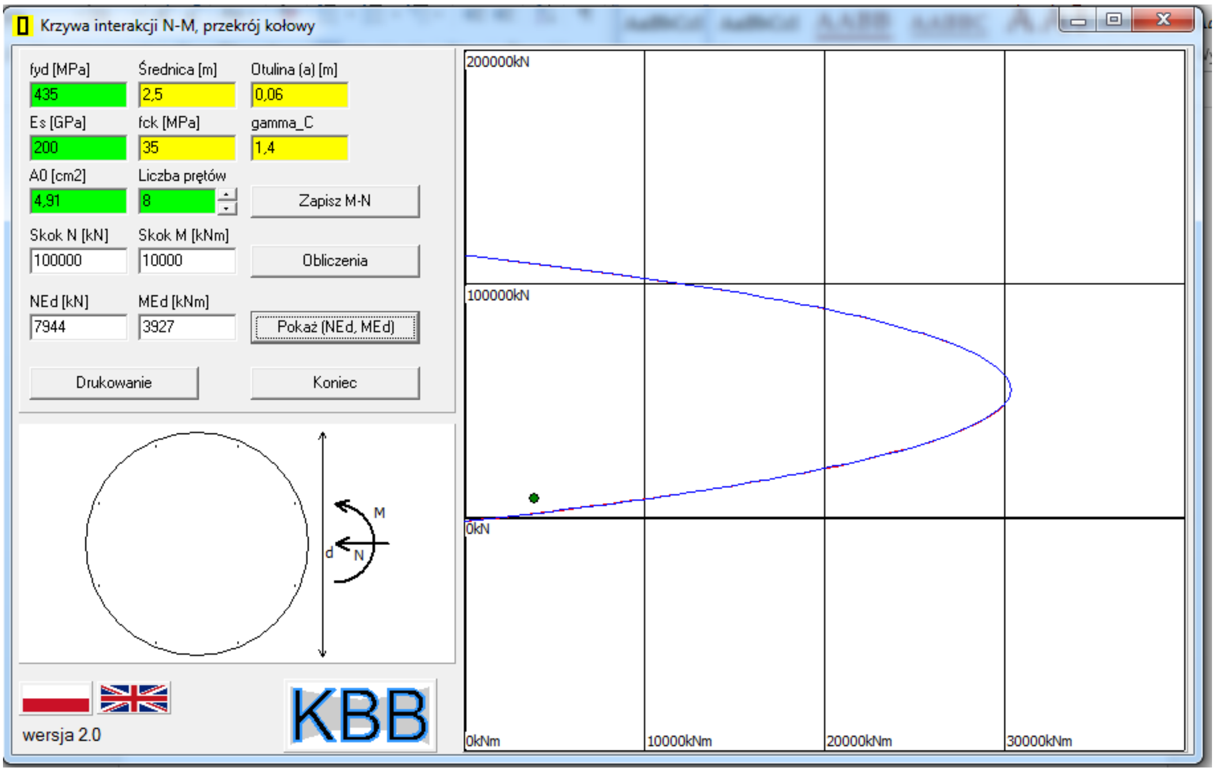


Figure 3.3.35 The curve interaction for bar #50 – second case

The bar #51

First case

$M_{Ed,max} = 3804$ kNm

$N_{Ed,cor.} = 7165$ kN

Length of the column = 16,9 m

<u>Geometric imperfections:</u>

$\theta_i = \theta_0 \alpha_h \alpha_m$

$\alpha_h = \frac{2}{\sqrt{L}} = \frac{2}{\sqrt{16{,}9}} = 0{,}486 < \frac{2}{3}$

$\frac{2}{3} < \alpha_h < 1$

m = 1

$\alpha_m = \sqrt{0{,}5\left(1 + \frac{1}{m}\right)} = 1{,}0$

$\theta_0 = \frac{1}{200}$

$\theta_i = \frac{1}{200} \cdot \frac{2}{3} \cdot 1 = \frac{1}{300}$

$$H_i = \theta_i \cdot N = 7165\ kN \cdot \frac{1}{300} = 23{,}9\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 3804\ kNm + 23{,}9\ kN \cdot 16{,}9\ m \approx 4208\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$$M_{Ed} = M_{0Ed} + M_2$$

$$M_{0Ed} = 4208\ kNm$$

$$M_2 = N_{Ed} \cdot e_2$$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$$c \approx 10$$

$$\frac{1}{r} = K_r K_\emptyset \frac{1}{r_0}$$

$$d = h - c_{nom} - \frac{\emptyset}{2} - \emptyset_{stirrup} = 2{,}5\ m - 0{,}035\ m - \frac{0{,}025}{2} - 0{,}008 = 2{,}44\ m$$

$$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{435\ MPa}{200\ GPa} = 0{,}002175$$

$$\frac{1}{r_0} = \frac{\varepsilon_{yd}}{0{,}45d} = \frac{0{,}002175}{0{,}45 \cdot 2{,}44} = 0{,}00198 \frac{1}{m}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$A_c = \pi r^2 = \pi \cdot (1{,}25\ m)^2 = 4{,}91\ m^2$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{7165\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}058$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927\ m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}058}{1{,}014 - 0{,}4} = 1{,}56 > 1{,}0$$

$$K_r = 1{,}0$$

$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$

$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{1{,}94\ m^4}{4{,}91\ m^2}} = 0{,}625\ m$

$\lambda = \frac{l_0}{i} = \frac{2 \cdot L}{i} = \frac{2 \cdot 16{,}9\ m}{0{,}625\ m} = 54{,}1$

$\beta = 0{,}35 + \frac{f_{ck}}{200} - \frac{\lambda}{150} = 0{,}35 + \frac{35}{200} - \frac{54{,}1}{150} = 0{,}16$

$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$

$M_{0Eqp} \rightarrow SLS\ (QP): \psi_2\ for\ traffic\ load, breaking\ load\ and\ wind\ is\ equal\ 0.$

$\psi_2\ for\ wind\ load\ is\ equal\ 0{,}5.$

$M_{0Eqp} = M_y = 1687{,}7\ kNm$

$h_0 = \frac{2A_c}{u} = \frac{2\pi r^2}{2\pi r} = r = 1{,}25\ m$

$\varphi(\infty, t_0) = 1{,}8$

$\varphi_{ef} = 1{,}8 \cdot \frac{1687{,}7\ kNm}{4208\ kNm} = 0{,}72$

$K_\varphi = 1 + 0{,}16 \cdot 0{,}72 = 1{,}11$

$\frac{1}{r} = 1 \cdot 1{,}11 \cdot 0{,}00198\frac{1}{m} = 0{,}0022\frac{1}{m}$

$e_2 = 0{,}0022\frac{1}{m} \cdot \frac{(2 \cdot 16{,}9\ m)^2}{10} = 0{,}25\ m$

$M_{Ed} = 4208\ kNm + 7165\ kN \cdot 0{,}25\ m = 5999\ kNm$

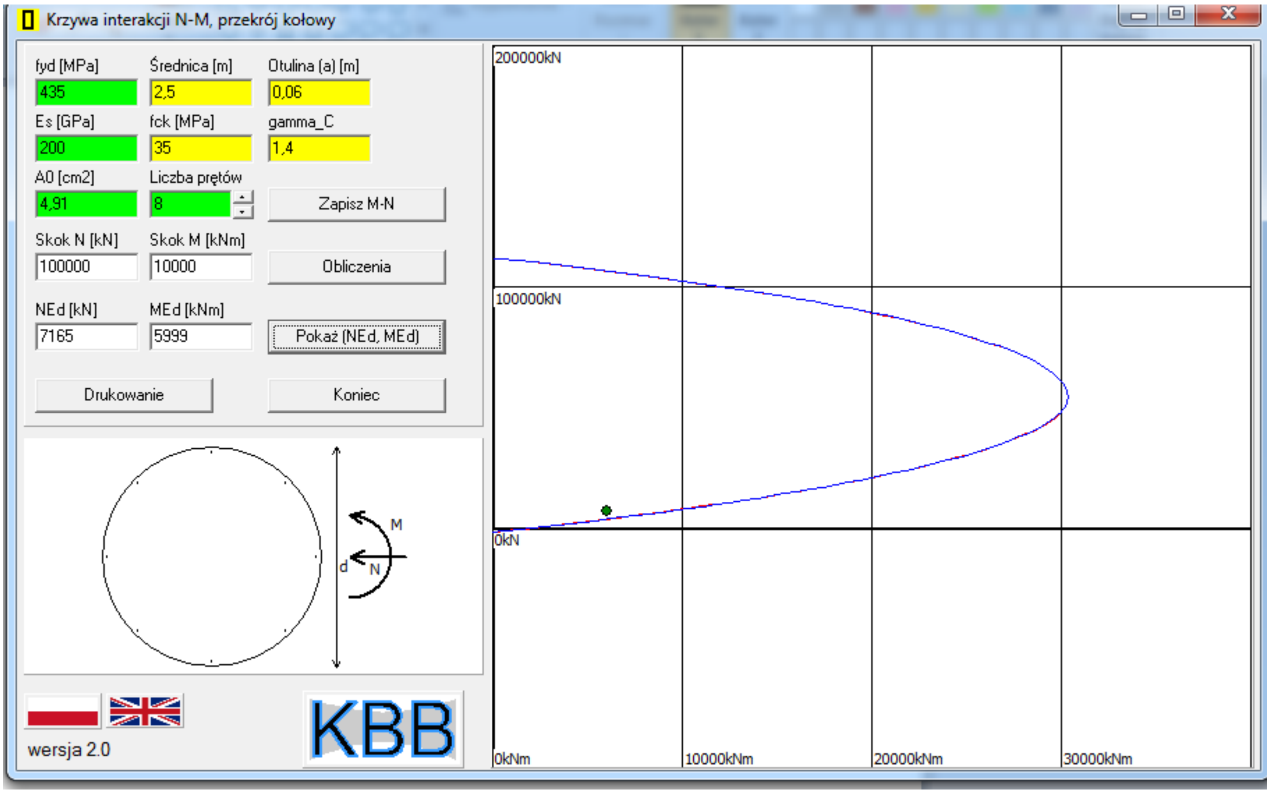


Figure 3.3.36 The curve interaction for bar #51 – first case

Second case

$N_{Ed,max.} = 7953$ kN

$M_{Ed,cor} = M_y = 118$ kNm

<u>Geometric imperfections:</u>

$$H_i = \theta_i \cdot N = 7953\ kN \cdot \frac{1}{300} = 26{,}5\ kN$$

$$M_{0Ed} = M_{max} + H_i \cdot L = 118\ kNm + 26{,}5\ kN \cdot 16{,}9\ m \approx 566\ kNm$$

<u>The piers verification – method based on nominal curvature</u>

$M_{Ed} = M_{0Ed} + M_2$

$M_{0Ed} = 566\ kNm$

$M_2 = N_{Ed} \cdot e_2$

$$e_2 = \frac{1}{r} \cdot \frac{l_0^2}{c}$$

$c \approx 10$

$$\frac{1}{r} = K_r K_\phi \frac{1}{r_0}$$

$$K_r = \frac{n_u - n}{n_u - n_{bal}} \leq 1{,}0$$

$$n = \frac{N_{Ed}}{A_c f_{cd}} = \frac{7953\ kN}{4{,}91\ m^2 \cdot 25000\ kPa} = 0{,}065$$

$$n_{bal} = 0{,}4$$

$$A_s = 39{,}27\ cm^2 \rightarrow 8\#25$$

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} = \frac{0{,}003927\ m^2 \cdot 435\ MPa}{4{,}91\ m^2 \cdot 25\ MPa} = 0{,}014$$

$$n_u = 1 + \omega = 1{,}014$$

$$K_r = \frac{1{,}014 - 0{,}065}{1{,}014 - 0{,}4} = 1{,}54 > 1{,}0$$

$$K_r = 1{,}0$$

$$K_\varphi = 1 + \beta\varphi_{ef} \geq 1{,}0$$

$$\varphi_{ef} = \varphi(\infty, t_0)\frac{M_{0Eqp}}{M_{0Ed}}$$

$M_{0Eqp} \rightarrow SLS\ (QP)$: ψ_2 *for traffic load, breaking load and wind is equal* 0.

ψ_2 *for wind load is equal* 0,5.

$$M_{0Eqp} = M_y = 1687{,}7\ kNm$$

$$\varphi_{ef} = 1{,}8 \cdot \frac{1687{,}7\ kNm}{566\ kNm} = 5{,}4$$

$$K_\varphi = 1 + 0{,}16 \cdot 5{,}36 = 1{,}86$$

$$\frac{1}{r} = 1 \cdot 1{,}11 \cdot 0{,}00198\frac{1}{m} = 0{,}0037\frac{1}{m}$$

$$e_2 = 0{,}0037\frac{1}{m} \cdot \frac{(2 \cdot 16{,}9\ m)^2}{10} = 0{,}42\ m$$

$$M_{Ed} = 566\ kNm + 7953kN \cdot 0{,}42\ m = 3906\ kNm$$

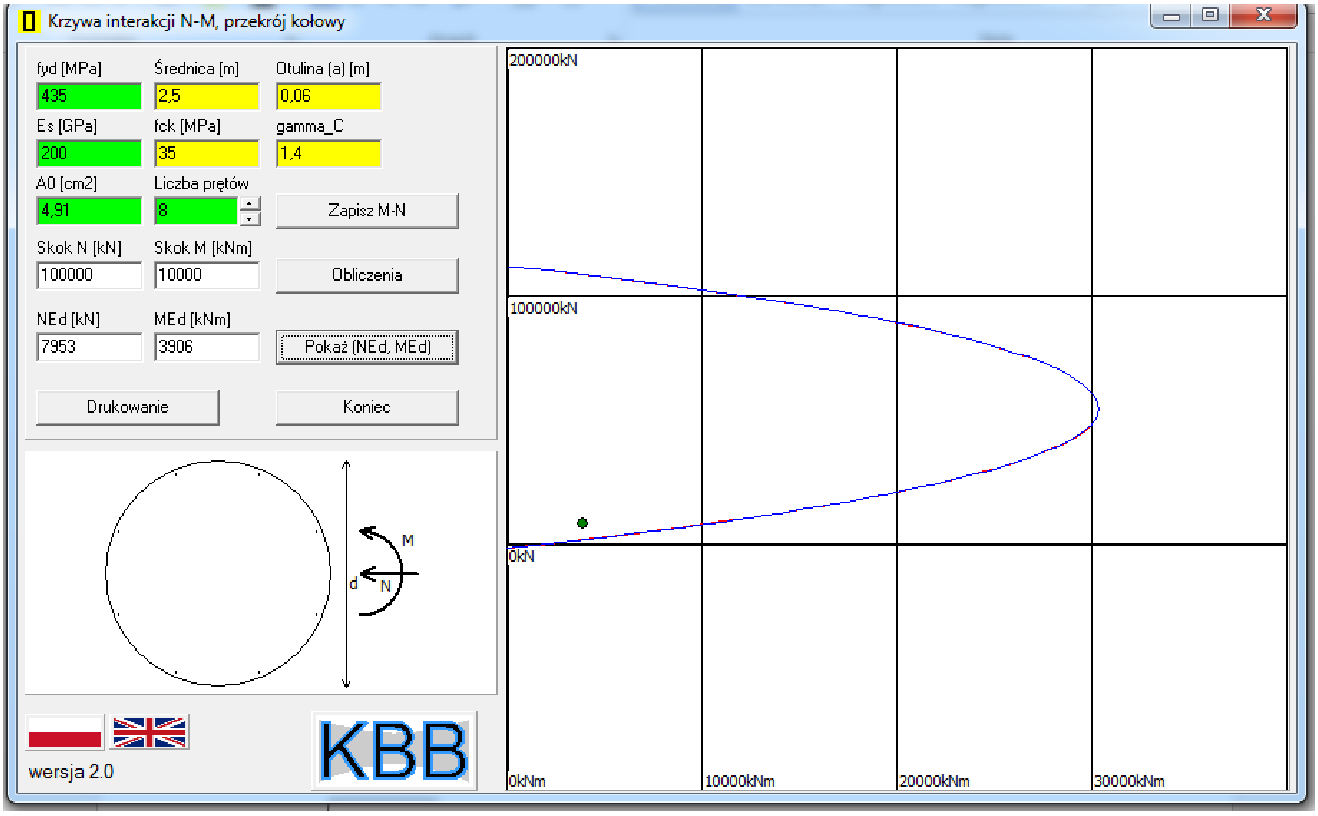


Figure 3.3.37 The curve interaction for bar #51 – second case

Because of the fact that the computer program didn't allow to put more than 12 steel reinforcement bars all the columns were checked for 8#25 instead of the pier #42 and #43 which were checked for 10#(3x#25) = 30#25. Taking into consideration the minimum area of reinforcement it is necessary to use 20#25 in each column besides the longest piers - #42 and #43 in which it should be used 30#25.

3.4. Foundations

3.4.1. Spread foundations and pile caps

$$f_{ck} = 30\ MPa\ (C30/37)$$

$$f_{cd} = \frac{30\ MPa}{1,4} = 21,43\ MPa$$

x – longitudinal direction of the viaduct

y – transversal direction of the viaduct

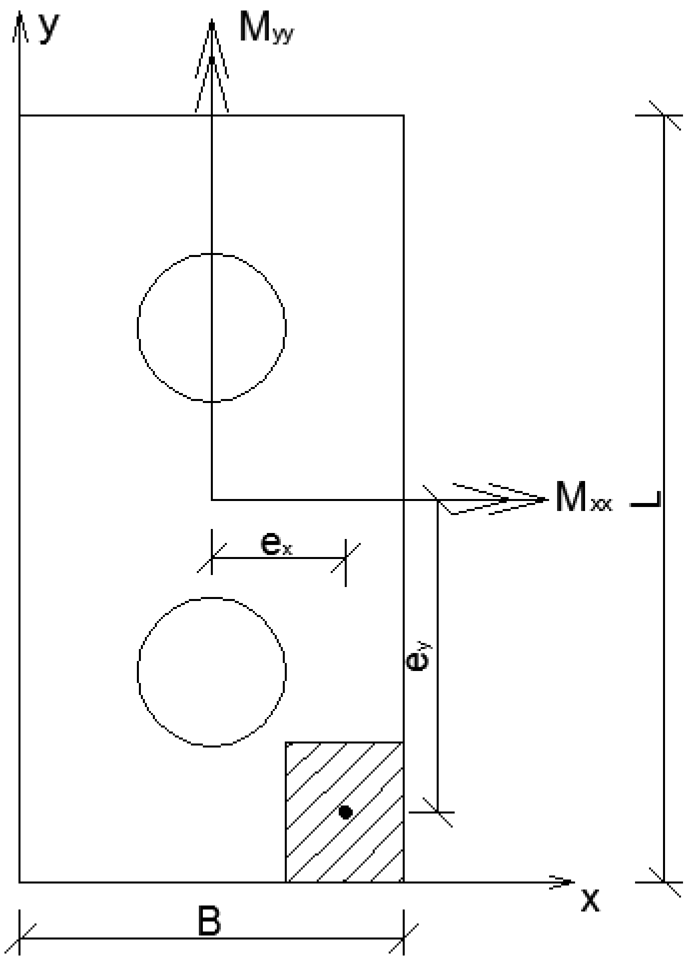


Figure 3.4.1 Effective area of the foundation

In order to get the reinforcement of the foundations, the sectional forces of two columns were summed. In addition two cases should be considered for each spread footing in the calculations - the sum of the maximum bending moments and the sum of the corresponding axial forces to it and the sum of the maximum axial forces and the sum of the corresponding bending moments to it.

The nominal concrete cover:

$C_{nom} = C_{min} + \Delta\ C_{dev}$

$\Delta\ C_{dev} = 10$ mm

$C_{min} = \max\{\ C_{min,b};\ C_{min,dur} + \Delta\ C_{dur,y} - \Delta\ C_{dur,st} - \Delta\ C_{dur,add};\ 10 \text{ mm}\ \}$

$C_{min,b} =\ 20$ mm

$C_{min,dur} = 25$ mm

$\Delta\ C_{dur,y} = \Delta\ C_{dur,st} = \Delta\ C_{dur,add} = 0$

$C_{nom} = 25$ mm + 10 mm = 35 mm

Foundation P2

ULTIMATE LIMIT STATE

First case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #36:

$$M_{Ed,max} = M_{yy,36} = 2592\ kNm$$
$$M_{Ed,cor.xx} = M_{xx,36} = -258\ kNm$$
$$N_{Ed,cor.} = N_{Ed,36} = -4184\ kN$$

The sectional forces in the column #37:

$$M_{Ed,max} = M_{yy,37} = 2559\ kNm$$
$$M_{Ed,cor.xx} = M_{xx,37} = 2\ kNm$$
$$N_{Ed,cor.} = N_{Ed,37} = -4187\ kN$$

The sum of the sectional forces:

$$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 6{,}35\ m \cdot 12{,}7\ m \cdot 1{,}5\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 4083\ kN$$
$$M_{yy} = M_{yy,36} + M_{yy,37} = 5151\ kNm$$
$$M_{xx} = M_{xx,36} + M_{xx,37} = -256\ kNm$$
$$N' = N_{Ed,36} + N_{Ed,37} + G_f = 12454\ kN$$

The eccentricity of the actions:

$$e_x = \frac{M_{yy}}{N'} = \frac{5151\ kNm}{12454\ kN} = 0{,}41\ m$$

$$e_y = \frac{M_{xx}}{N'} = \frac{-256\ kNm}{12454\ kN} = -\ 0{,}020\ m$$

Effective dimensions of the foundation:

$$B' = 2 \cdot \left(\frac{B}{2} - e_x\right) = B - 2e_x = 6{,}35\ m - 2 \cdot 0{,}41\ m = 5{,}53\ m$$
$$L' = 2 \cdot \left(\frac{L}{2} - |e_y|\right) = L - 2e_y = 12{,}7\ m - 2 \cdot 0{,}020\ m = 12{,}66\ m \approx 12{,}70\ m$$

Effective area of the foundation:

$$A' = B' \cdot L' = 5{,}53\ m \cdot 12{,}7\ m = 70{,}2\ m^2$$

The design value of the bearing pressure:

$$\sigma = \frac{N'}{A'} = \frac{12454\ kN}{70{,}2\ m^2} = 177{,}4 \approx 177\frac{kN}{m}/m$$

<u>The simplified static model of the spread foundation in the x-direction:</u>

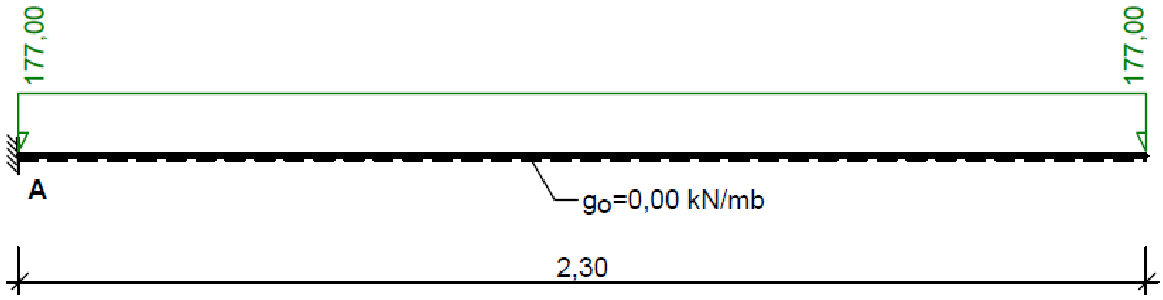


Figure 3.4.2 The static model for the foundation P2 in the x-direction – first case

$$L = 0{,}15a + l'$$

$$a = 2{,}5\ m$$

$$l' = \frac{B-a}{2} = \frac{6{,}35\ m - 2{,}5\ m}{2} = 1{,}925$$

$$L = 0{,}15 \cdot 2{,}5\ m + 1{,}925\ m = 2{,}3\ m$$

The bending moment is given by computer program Belka by SPECBUD [kNm]:

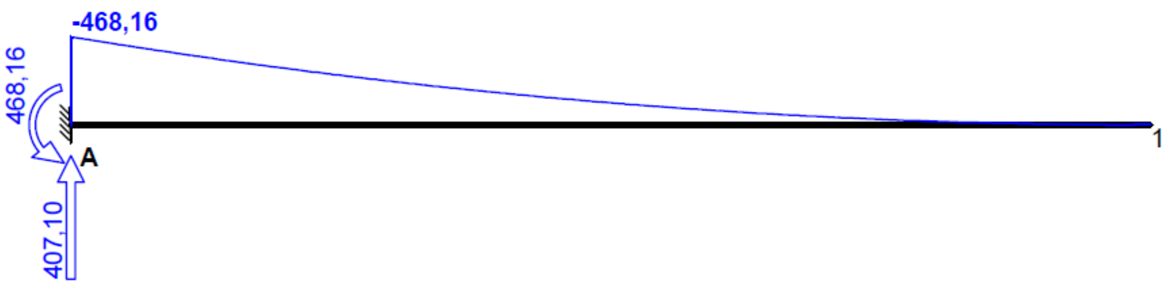


Figure 3.4.3 The bending moment for the foundation P2 in the x-direction – first case

$$M_{Ed,x} \approx 468\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \emptyset - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - 0{,}02 - \frac{0{,}020}{2} m = 1{,}435\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{468\ kNm}{1{,}0\ m \cdot (1{,}435\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}011$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}011} = 0{,}011$$

$$A_{s,min} = 0{,}011 \cdot 1{,}0\ m \cdot 1{,}435\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 7{,}78\ cm^2$$

That gives us #20/0,30 m with total area equal $A_s = 10{,}47\ cm^2$

<u>The simplified static model of the spread foundation in the y-direction:</u>

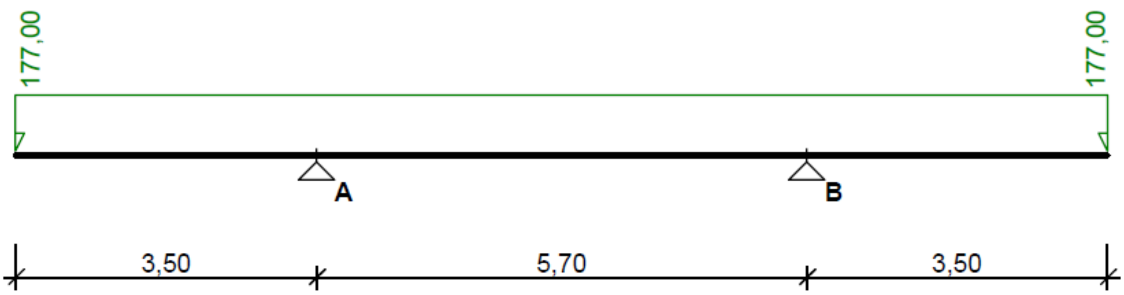


Figure 3.4.4 The static model for the foundation P2 in the y-direction – first case

The bending moment is given by computer freeware program Belka by SPECBUD [kNm]:

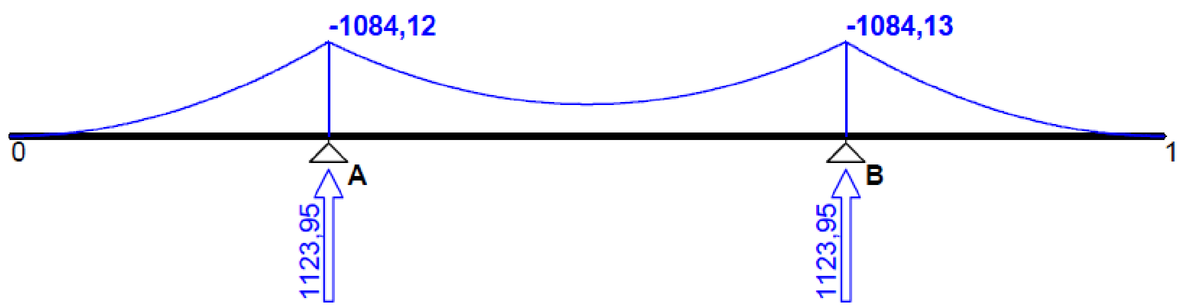


Figure 3.4.5 The bending moment for the foundation P2 in the y-direction – first case

$$M_{Ed,y} \approx 1084\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - \frac{0{,}020}{2} m = 1{,}455\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{1084\ kNm}{1{,}0\ m \cdot (1{,}455\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}024$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}024} = 0{,}024$$

$$A_{s,min} = 0{,}024 \cdot 1{,}0\ m \cdot 1{,}455\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 17{,}2\ cm^2$$

That gives us #20/0,175 m with total area equal $A_s = 17{,}94\ cm^2$

Second case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #36:

$$N_{Ed,max} = N_{Ed,36} = -8340\ kNm$$

$$M_{Ed,cor.yy.} = M_{yy,36} = -55\ kNm$$

$$M_{Ed,cor,xx} = M_{xx,36} = -3\ kN$$

The sectional forces in the column #37:

$$N_{Ed,max} = N_{Ed,37} = -8343\ kNm$$

$$M_{Ed,cor.yy.} = M_{yy,37} = -88\ kNm$$

$$M_{Ed,cor,xx} = M_{xx,37} = -253\ kN$$

The sum of the sectional forces:

$$M_{yy} = M_{yy,36} + M_{yy,37} = -143\ kNm$$

$$M_{xx} = M_{xx,36} + M_{xx,37} = -256\ kNm$$

$$N' = N_{Ed,36} + N_{Ed,37} + G_f = 20766\ kN$$

The eccentricity of the actions:

$$e_x = \frac{M_{yy}}{N'} = \frac{-143\ kNm}{20766\ kN} = -0{,}007\ m$$

$$e_y = \frac{M_{xx}}{N'} = \frac{-256\ kNm}{20766\ kN} = -\ 0{,}012\ m$$

Effective dimensions of the foundation:

$$B' = 2 \cdot \left(\frac{B}{2} - e_x\right) = B - 2e_x = 6{,}35\ m - 2 \cdot 0{,}007\ m = 6{,}336\ m \approx 6{,}35\ m$$

$$L' = 2 \cdot \left(\frac{L}{2} - |e_y|\right) = L - 2e_y = 12{,}7\ m - 2 \cdot 0{,}012\ m = 12{,}67\ m \approx 12{,}70\ m$$

Effective area of the foundation:

$$A' = A = 80{,}6\ m^2$$

The design value of the bearing pressure:

$$\sigma = \frac{N'}{A'} = \frac{20766\ kN}{80{,}6\ m^2} = 257{,}64 \approx 258\frac{kN}{m}/m$$

<u>The simplified static model of the spread foundation in the x-direction:</u>

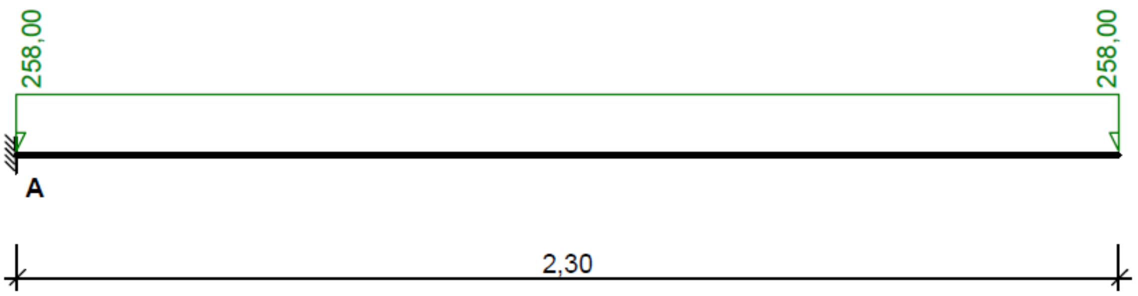


Figure 3.4.6 The static model for the foundation P2 in the x-direction – second case

The bending moment is given by computer program Belka by SPECBUD [kNm]:

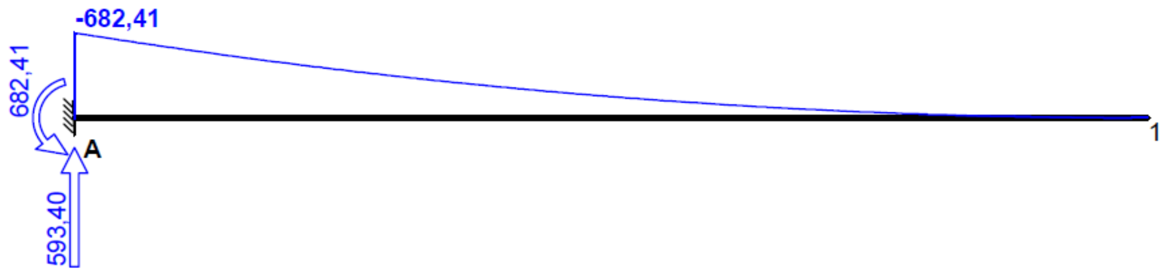


Figure 3.4.7 The bending moment for the foundation P2 in the x-direction – second case

$$M_{Ed,x} \approx 682\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \emptyset - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - 0{,}02 - \frac{0{,}020}{2} m = 1{,}435\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{682\ kNm}{1{,}0\ m \cdot (1{,}435\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}015$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}015} = 0{,}015$$

$$A_{s,min} = 0{,}015 \cdot 1{,}0\ m \cdot 1{,}435\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 10{,}60\ cm^2$$

That gives us #20/0,275 m with total area equal $A_s = 11{,}42\ cm^2$

The simplified static model of the spread foundation in the y-direction:

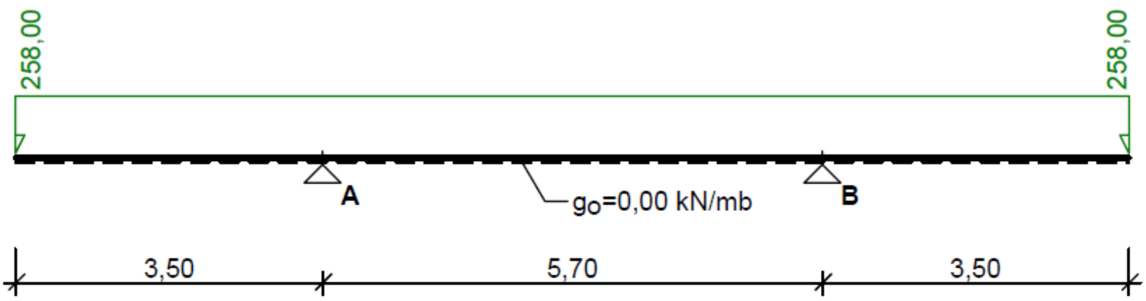


Figure 3.4.8 The static model for the foundation P2 in the y-direction – second case

The bending moment is given by computer freeware program Belka by SPECBUD [kNm]:

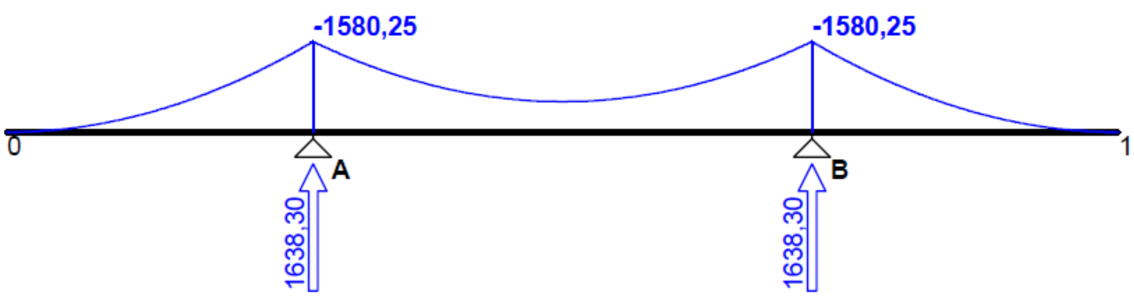


Figure 3.4.9 The bending moment for the foundation P2 in the y-direction – second case

$$M_{Ed,y} \approx 1580\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - \frac{0{,}020}{2} m = 1{,}455\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{1580\ kNm}{1{,}0\ m \cdot (1{,}455\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}035$$

$$\omega = 1 - \sqrt{1-2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}035} = 0{,}036$$

$$A_{s,min} = 0{,}036 \cdot 1{,}0\ m \cdot 1{,}455\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 25{,}80\ cm^2$$

That gives us #20/0,10 m with total area equal $A_s = 31{,}40\ cm^2$

Taking into account the above two cases of the calculations, the reinforcement which was adopted is #20/0,275 m in x-direction and #20/0,10 m in y-direction.

GEO LIMIT STATE

First case

The sum of the sectional forces:

$M_{yy} = M_{yy,36} + M_{yy,37} = 5151\ kNm$

$N' = N_{Ed,36} + N_{Ed,37} + G_f = 12454\ kN$

$H'_x = H_{Ed,36} + H_{Ed,37} = 148\ kN + 146 kN = 294\ kN$

<u>The Bearing resistance of spread foundation</u>

$\gamma_k = 18\ kN/m^3$

$\varphi = 30°$

Depth of foundation

D = 9,4 m

The total vertical stress at the founding level:

$$q = \gamma \cdot D = 18 \frac{kN}{m^3} \cdot 9{,}4\ m = 169{,}2\ kPa$$

The effective dimensions of the foundation:

$B' = 5{,}53\ m$

$L' = 12{,}7\ m$

The capacity factors:

$$N_q = e^{\pi \cdot tan\varphi} \cdot \left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right)^2 = 18{,}401$$

$$N_\gamma = 2 \cdot \left(N_q - 1\right) \cdot tan\varphi = 20{,}093$$

$$N_c = \left(N_q - 1\right) \cdot cot\varphi = 30{,}14$$

The shape factors:

$$s_q = 1 + \frac{B'}{L'} \cdot sin\varphi = 1{,}218$$

$$s_\gamma = 1 - 0{,}3 \cdot \frac{B'}{L'} = 0{,}869$$

$$s_c = \frac{s_q \cdot N_q - 1}{N_q - 1} = 1{,}23$$

Load's inclination factors:

c' = 0 for Fx || B'

$$m = \frac{2 + \frac{B'}{L'}}{1 + \frac{B'}{L'}} = 1{,}697$$

$$i_q = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^m = 0{,}96$$

$$i_\gamma = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^{m+1} = 0{,}94$$

$$i_c = i_q - \frac{1 - i_q}{N_c \cdot tan\varphi} = 0{,}96$$

Foundation base's inclination factors

Because the base of the foundation is horizontal:

$$b_q = 1$$

$$b_\gamma = 1$$

$$b_c = 1$$

The value of the design drained bearing resistance

$$\frac{R_k}{A'} = q \cdot N_q \cdot b_q \cdot s_q \cdot i_q + 0{,}5 \cdot \gamma_k \cdot B' \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma + c' \cdot N_c \cdot b_c \cdot s_c \cdot i_c = 4371\ kPa$$

$$R_k = 4371\ \ kPa \cdot 5{,}53\ m \cdot 12{,}7\ m = 306{,}9\ MN$$

$\gamma_R = 1{,}4$

$$R_d = \frac{R_k}{\gamma_R} = \frac{306{,}9\ MN}{1{,}4} = 219{,}2\ MN$$

$V_d = 12454\ kN < R_d = 219200\ kN$

Second case

The sum of the sectional forces:

$M_{yy} = M_{yy,36} + M_{yy,37} = -143\ kNm$

$N' = N_{Ed,36} + N_{Ed,37} + G_f = 18660\ kN$

$H'_x = H_{Ed,36} + H_{Ed,37} = -3\ kN - 5\ kN = -8\ kN$

The Bearing resistance of spread foundation

$\gamma_k = 18\ kN/m^3$

$\varphi = 30°$

Depth of foundation

D = 9,4 m

The total vertical stress at the founding level:

$$q = \gamma \cdot D = 18 \frac{kN}{m^3} \cdot 9{,}4\ m = 169{,}2\ kPa$$

The effective dimensions of the foundation:

$B' = 6{,}35\ m$

$L' = 12{,}7\ m$

The capacity factors:

$$N_q = e^{\pi \cdot tan\varphi} \cdot \left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right)^2 = 18{,}401$$

$$N_\gamma = 2 \cdot (N_q - 1) \cdot tan\varphi = 20{,}093$$

$$N_c = (N_q - 1) \cdot cot\varphi = 30{,}14$$

The shape factors:

$$s_q = 1 + \frac{B'}{L'} \cdot sin\varphi = 1{,}25$$

$$s_\gamma = 1 - 0{,}3 \cdot \frac{B'}{L'} = 0{,}85$$

$$s_c = \frac{s_q \cdot N_q - 1}{N_q - 1} = 1{,}264$$

Load's inclination factors:
c' = 0 for Fx || B'

$$m = \frac{2 + \frac{B'}{L'}}{1 + \frac{B'}{L'}} = 1{,}667$$

$$i_q = (1 - \frac{F_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^m = 0{,}999$$

$$i_\gamma = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^{m+1} = 1$$

$$i_c = i_q - \frac{1 - i_q}{N_c \cdot tan\varphi} = 1$$

Foundation base's inclination factors
Because the base of the foundation is horizontal:

$$b_q = 1$$

$$b_\gamma = 1$$

$$b_c = 1$$

The value of the design drained bearing resistance

$$\frac{R_k}{A'} = q \cdot N_q \cdot b_q \cdot s_q \cdot i_q + 0{,}5 \cdot \gamma_k \cdot B' \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma + c' \cdot N_c \cdot b_c \cdot s_c \cdot i_c = 4772\ kPa$$

$$R_k = 4772\ kPa \cdot 6{,}35\ m \cdot 12{,}7\ m = 384{,}8\ MN$$

$$\gamma_R = 1{,}4$$

$$R_d = \frac{R_k}{\gamma_R} = \frac{384{,}8\ MN}{1{,}4} = 274{,}8\ MN$$

$$V_d = 20766\ kN < R_d = 274800\ kN$$

Foundation P3

ULTIMATE LIMIT STATE

First case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #34:

$M_{Ed,max} = M_{yy,34} = 1438\ kNm$

$M_{Ed,cor.xx} = M_{xx,34} = -372\ kNm$

$N_{Ed,cor.} = N_{Ed,34} = -5096\ kN$

The sectional forces in the column #35:

$M_{Ed,max} = M_{yy,35} = 1419\ kNm$

$M_{Ed,cor.xx} = M_{xx,35} = -0{,}5\ kNm$

$N_{Ed,cor.} = N_{Ed,35} = -5097\ kN$

The sum of the sectional forces:

$$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 6{,}35\ m \cdot 12{,}7\ m \cdot 1{,}5\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 4083\ kN$$

$M_{yy} = M_{yy,34} + M_{yy,35} = 2857\ kNm$

$M_{xx} = M_{xx,34} + M_{xx,35} = -372\ kNm$

$N' = N_{Ed,34} + N_{Ed,35} + G_f = 14276\ kN$

The eccentricity of the actions:

$$e_x = \frac{M_{yy}}{N'} = \frac{2857\ kNm}{14276\ kN} = 0{,}20\ m$$

$$e_y = \frac{M_{xx}}{N'} = \frac{-372\ kNm}{14276\ kN} = -\ 0{,}026\ m$$

Effective dimensions of the foundation:

$$B' = 2 \cdot \left(\frac{B}{2} - e_x\right) = B - 2e_x = 6{,}35\ m - 2 \cdot 0{,}20m = 5{,}95\ m$$

$$L' = 2 \cdot \left(\frac{L}{2} - |e_y|\right) = L - 2e_y = 12{,}7\ m - 2 \cdot 0{,}026\ m = 12{,}65\ m \approx 12{,}7\ m$$

Effective area of the foundation:

$A' = B' \cdot L' = 5{,}95\ m \cdot 12{,}7\ m = 75{,}6\ m^2$

The design value of the bearing pressure:

$$\sigma = \frac{N'}{A'} = \frac{14276\ kN}{75{,}6\ m^2} = 188{,}8 \approx 189\frac{kN}{m}/m$$

The simplified static model of the spread foundation in the x-direction:

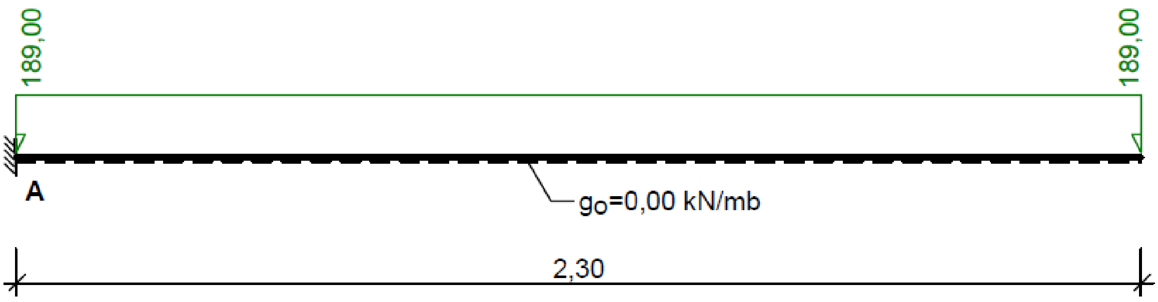


Figure 3.4.10 The static model for the foundation P3 in the x-direction – first case

$$L = 0{,}15a + l'$$

$$a = 2{,}5\ m$$

$$l' = \frac{B-a}{2} = \frac{6{,}35\ m - 2{,}5\ m}{2} = 1{,}925$$

$$L = 0{,}15 \cdot 2{,}5\ m + 1{,}925\ m = 2{,}3\ m$$

The bending moment is given by computer program Belka by SPECBUD [kNm]:

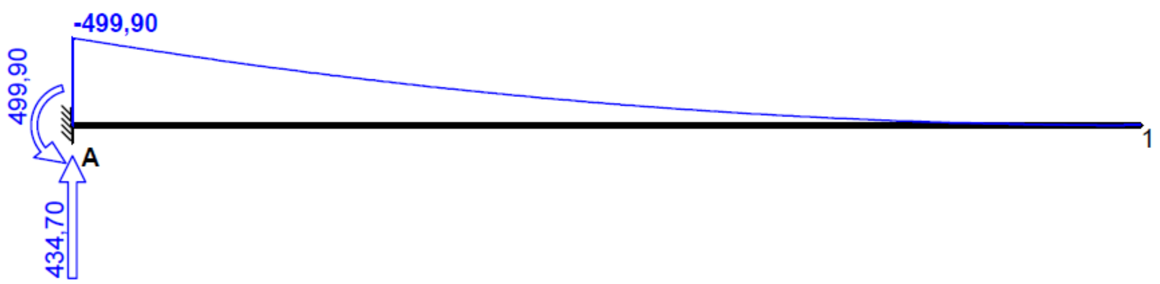


Figure 3.4.11 The bending moment for the foundation P3 in the x-direction – first case

$$M_{Ed,x} \approx 500\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \emptyset - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - 0{,}02 - \frac{0{,}020}{2} m = 1{,}435\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{500\ kNm}{1{,}0\ m \cdot (1{,}435\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}011$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}011} = 0{,}011$$

$$A_{s,min} = 0{,}011 \cdot 1{,}0\ m \cdot 1{,}435\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 7{,}78\ cm^2$$

That gives us #20/0,30 m with total area equal $A_s = 10{,}47\ cm^2$

The simplified static model of the spread foundation in the y-direction:

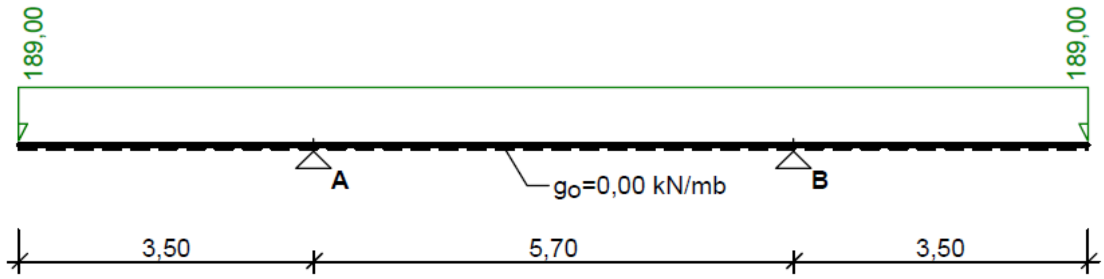


Figure 3.4.12 The static model for the foundation P3 in the y-direction – first case

The bending moment is given by computer freeware program Belka by SPECBUD [kNm]:

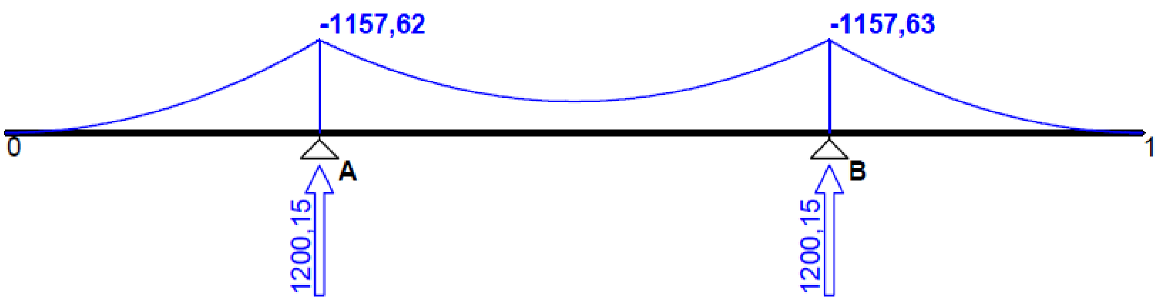


Figure 3.4.13 The bending moment for the foundation P3 in the y-direction – first case

$$M_{Ed,y} \approx 1158\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - \frac{0{,}020}{2} m = 1{,}455\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{1158\ kNm}{1{,}0\ m \cdot (1{,}455\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}025$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}025} = 0{,}025$$

$$A_{s,min} = 0{,}025 \cdot 1{,}0\ m \cdot 1{,}455\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 17{,}92\ cm^2$$

That gives us #20/0,175 m with total area equal $A_s = 17{,}94\ cm^2$

Second case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #34:

$$N_{Ed,max} = N_{Ed,34} = -9572\ kNm$$

$$M_{Ed,cor.yy.} = M_{yy,34} = -1\ kNm$$

$$M_{Ed,cor,xx} = M_{xx,34} = 1\ kN$$

The sectional forces in the column #35:

$$N_{Ed,max} = N_{Ed,35} = -9574\ kNm$$

$$M_{Ed,cor.yy.} = M_{yy,35} = -20\ kNm$$

$$M_{Ed,cor,xx} = M_{xx,35} = -374\ kN$$

The sum of the sectional forces:

$$M_{yy} = M_{yy,34} + M_{yy,35} = -21\ kNm$$

$$M_{xx} = M_{xx,34} + M_{xx,35} = -373\ kNm$$

$$N' = N_{Ed,34} + N_{Ed,35} + G_f = 23229\ kN$$

The eccentricity of the actions:

$$e_x = \frac{M_{yy}}{N'} = \frac{-21\ kNm}{23229\ kN} = -0{,}0009\ m$$

$$e_y = \frac{M_{xx}}{N'} = \frac{-373\ kNm}{23229\ kN} = -\ 0{,}016\ m$$

Effective dimensions of the foundation:

$$B' = 2 \cdot \left(\frac{B}{2} - |e_x|\right) = B - 2e_x = 6{,}35\ m - 2 \cdot 0{,}0009\ m = 6{,}348\ m \approx 6{,}35\ m$$

$$L' = 2 \cdot \left(\frac{L}{2} - |e_y|\right) = L - 2e_y = 12{,}7\ m - 2 \cdot 0{,}016\ m = 12{,}668\ m \approx 12{,}7\ m$$

Effective area of the foundation:

$$A' = A = 80{,}6\ m^2$$

The design value of the bearing pressure:

$$\sigma = \frac{N'}{A'} = \frac{23229\ kN}{80{,}6\ m^2} = 288{,}2 \approx 288\frac{kN}{m}/m$$

<u>The simplified static model of the spread foundation in the x-direction:</u>

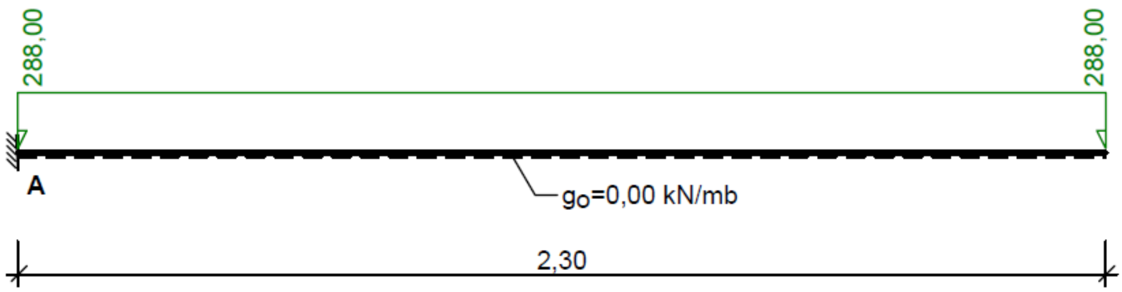


Figure 3.4.14 The static model for the foundation P3 in the x-direction – second case

The bending moment is given by computer program Belka by SPECBUD [kNm]:

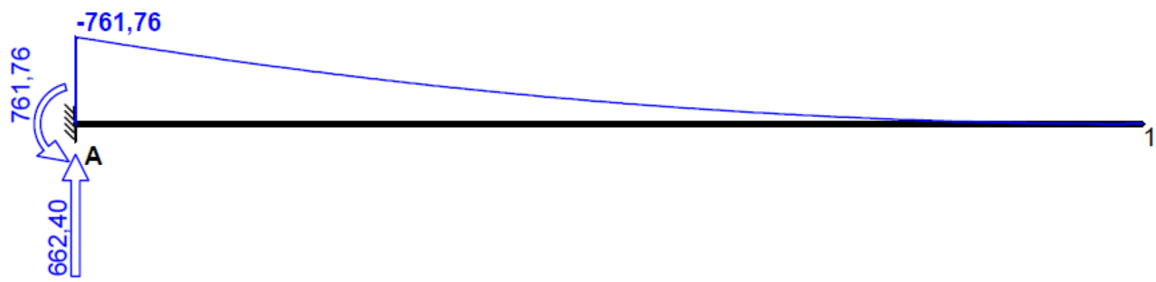


Figure 3.4.15 The bending moment for the foundation P3 in the x-direction – second case

$$M_{Ed,x} \approx 762\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \emptyset - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - 0{,}02 - \frac{0{,}020}{2}m = 1{,}435\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{762\ kNm}{1,0\ m \cdot (1,435\ m)^2 \cdot 21,43\ kPa \cdot 10^3} = 0,017$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0,017} = 0,017$$

$$A_{s,min} = 0,017 \cdot 1,0\ m \cdot 1,435\ m \cdot \frac{21,43\ MPa}{435\ MPa} = 12,02\ cm^2$$

That gives us #20/0,25 m with total area equal $A_s = 12,56\ cm^2$

The simplified static model of the spread foundation in the y-direction:

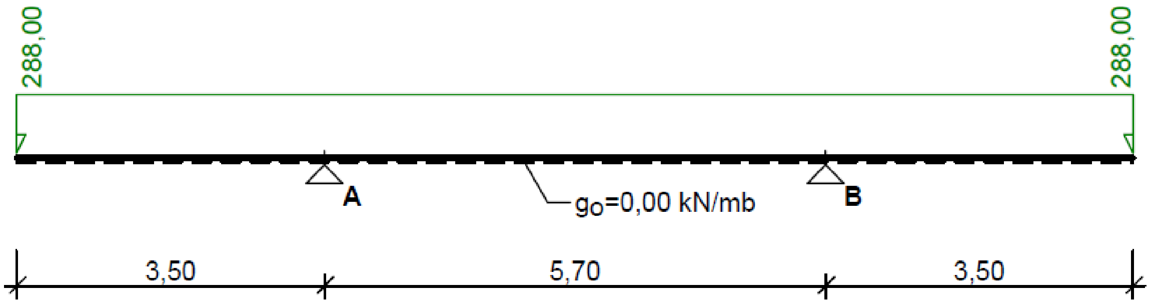


Figure 3.4.16 The static model for the foundation P3 in the y-direction – second case

The bending moment is given by computer freeware program Belka by SPECBUD [kNm]:

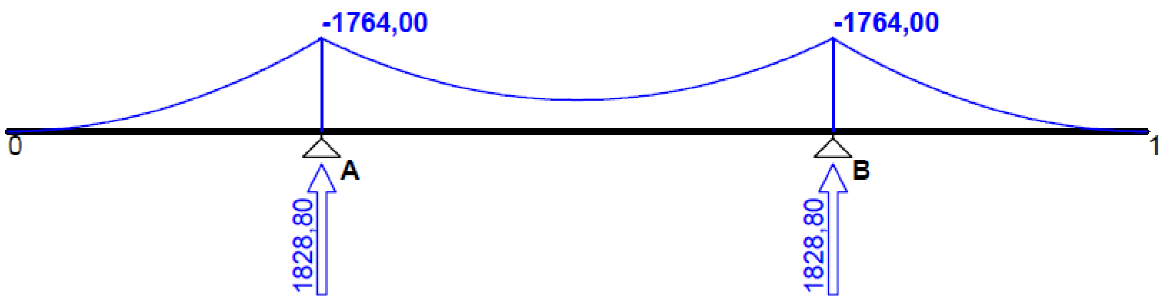


Figure 3.4.17 The bending moment for the foundation P3 in the y-direction – second case

$M_{Ed,y} \approx 1764\ kNm/m$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\varnothing}{2} = 1,5\ m - 0,035\ m - \frac{0,020}{2} m = 1,455\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{1764\ kNm}{1{,}0\ m \cdot (1{,}455\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}039$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}039} = 0{,}040$$

$$A_{s,min} = 0{,}040 \cdot 1{,}0\ m \cdot 1{,}755\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 34{,}58\ cm^2$$

That gives us #25/0,125 m with total area equal $A_s = 39{,}28\ cm^2$

Taking into account the above two cases of the calculations, the reinforcement which was adopted is #20/0,25 m in x-direction and #25/0,125 m in y-direction.

GEO LIMIT STATE

First case

The sum of the sectional forces:

$$M_{yy} = M_{yy,34} + M_{yy,35} = 2857\ kNm$$

$$N' = N_{Ed,34} + N_{Ed,35} + G_f = 14276\ kN$$

$$H'_x = H_{Ed,34} + H_{Ed,35} = 57\ kN + 58\ kN = 115\ kN$$

<u>The Bearing resistance of spread foundation</u>

$$\gamma_k = 18\ kN/m^3$$

$$\varphi = 30°$$

Depth of foundation

D = 8,1 m

The total vertical stress at the founding level:

$$q = \gamma \cdot D = 18 \frac{kN}{m^3} \cdot 8{,}1\ m = 145{,}8\ kPa$$

The effective dimensions of the foundation:

$$B' = 5{,}95\ m$$

$$L' = 12{,}7\ m$$

The capacity factors:

$$N_q = e^{\pi \cdot tan\varphi} \cdot \left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right)^2 = 18{,}401$$

$$N_\gamma = 2 \cdot (N_q - 1) \cdot tan\varphi = 20{,}093$$

$$N_c = (N_q - 1) \cdot cot\varphi = 30{,}14$$

The shape factors:

$$s_q = 1 + \frac{B'}{L'} \cdot sin\varphi = 1{,}234$$

$$s_\gamma = 1 - 0{,}3 \cdot \frac{B'}{L'} = 0{,}859$$

$$s_c = \frac{s_q \cdot N_q - 1}{N_q - 1} = 1{,}248$$

Load's inclination factors:

c' = 0 for Fx || B'

$$m = \frac{2 + \frac{B'}{L'}}{1 + \frac{B'}{L'}} = 1{,}681$$

$$i_q = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^m = 0{,}986$$

$$i_\gamma = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^{m+1} = 0{,}98$$

$$i_c = i_q - \frac{1 - i_q}{N_c \cdot tan\varphi} = 0{,}99$$

Foundation base's inclination factors

Because the base of the foundation is horizontal:

$$b_q = 1$$

$$b_\gamma = 1$$

$$b_c = 1$$

The value of the design drained bearing resistance

$$\frac{R_k}{A'} = q \cdot N_q \cdot b_q \cdot s_q \cdot i_q + 0{,}5 \cdot \gamma_k \cdot B' \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma + c' \cdot N_c \cdot b_c \cdot s_c \cdot i_c = 4092\ kPa$$

$$R_k = 4092\ \ kPa \cdot 5{,}95\ m \cdot 12{,}7\ m = 309\ MN$$

$$\gamma_R = 1{,}4$$

$$R_d = \frac{R_k}{\gamma_R} = \frac{309\ MN}{1{,}4} = 220{,}7\ MN$$

$$V_d = 14276\ kN < R_d = 220700\ kN$$

Second case

The sum of the sectional forces:

$M_{yy} = M_{yy,34} + M_{yy,35} = -21\ kNm$

$N' = N_{Ed,34} + N_{Ed,35} + G_f = 23229\ kN$

$H'_x = H_{Ed,34} + H_{Ed,35} = -1\ kN + 0\ kN = -1\ kN$

<u>The Bearing resistance of spread foundation</u>

$\gamma_k = 18\ kN/m^3$

$\varphi = 30°$

Depth of foundation

D = 8,1 m

The total vertical stress at the founding level:

$$q = \gamma \cdot D = 18\frac{kN}{m^3} \cdot 8{,}1m = 145{,}8\ kPa$$

The effective dimensions of the foundation:

$B' = 8{,}75\ m$

$L' = 14\ m$

The capacity factors:

$$N_q = e^{\pi \cdot tan\varphi} \cdot \left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right)^2 = 18{,}401$$

$$N_\gamma = 2 \cdot (N_q - 1) \cdot tan\varphi = 20{,}093$$

$$N_c = (N_q - 1) \cdot cot\varphi = 30{,}14$$

The shape factors:

$$s_q = 1 + \frac{B'}{L'} \cdot sin\varphi = 1{,}25$$

$$s_\gamma = 1 - 0{,}3 \cdot \frac{B'}{L'} = 0{,}85$$

$$s_c = \frac{s_q \cdot N_q - 1}{N_q - 1} = 1{,}264$$

Load's inclination factors:

c' = 0 for Fx || B'

$$m = \frac{2 + \frac{B'}{L'}}{1 + \frac{B'}{L'}} = 1,667$$

$$i_q = (1 - \frac{F_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^m = 1$$

$$i_\gamma = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^{m+1} = 1$$

$$i_c = i_q - \frac{1 - i_q}{N_c \cdot tan\varphi} = 1$$

Foundation base's inclination factors

Because the base of the foundation is horizontal:

$b_q = 1$

$b_\gamma = 1$

$b_c = 1$

The value of the design drained bearing resistance

$$\frac{R_k}{A'} = q \cdot N_q \cdot b_q \cdot s_q \cdot i_q + 0,5 \cdot \gamma_k \cdot B' \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma + c' \cdot N_c \cdot b_c \cdot s_c \cdot i_c = 4247\ kPa$$

$R_k = 4247\ kPa \cdot 6,35\ m \cdot 12,7\ m = 342,5\ MN$

$\gamma_R = 1,4$

$$R_d = \frac{R_k}{\gamma_R} = \frac{342,5\ MN}{1,4} = 244,6\ MN$$

$V_d = 23229\ kN < R_d = 244600\ kN$

The visual drawing of a pile cap for the foundations P4-P8

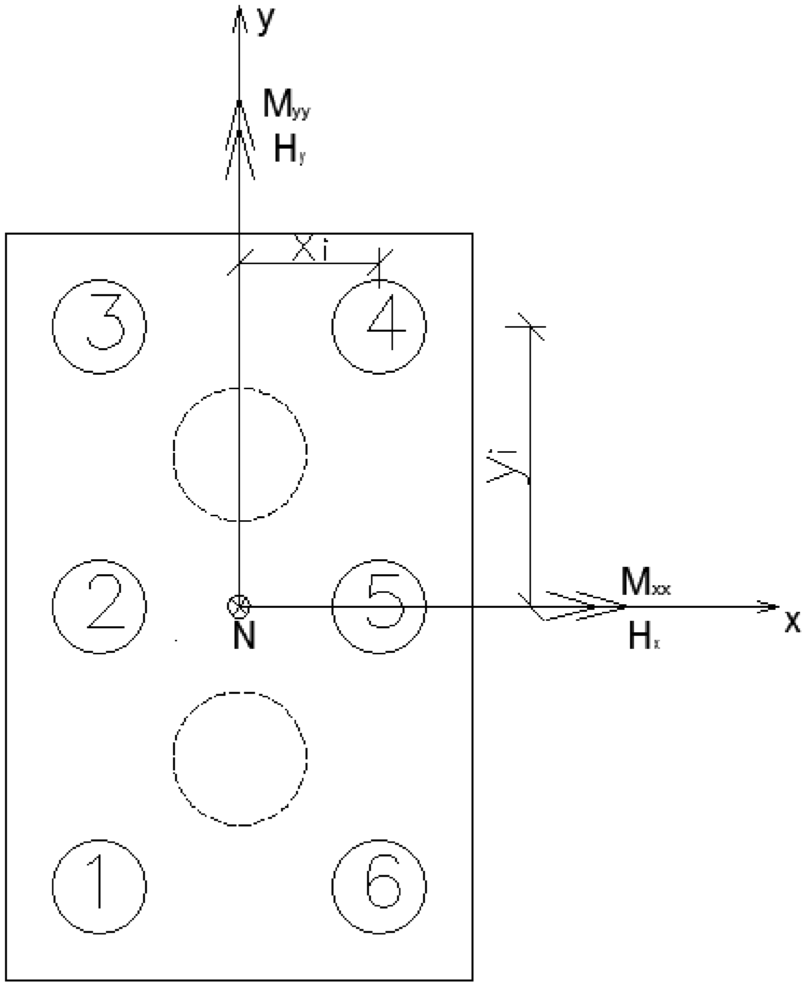


Figure 3.4.18 The sketch of the pile cap

The figure below shows the simplified way how to calculate the steel force Fs for piles 1, 3, 4, 6

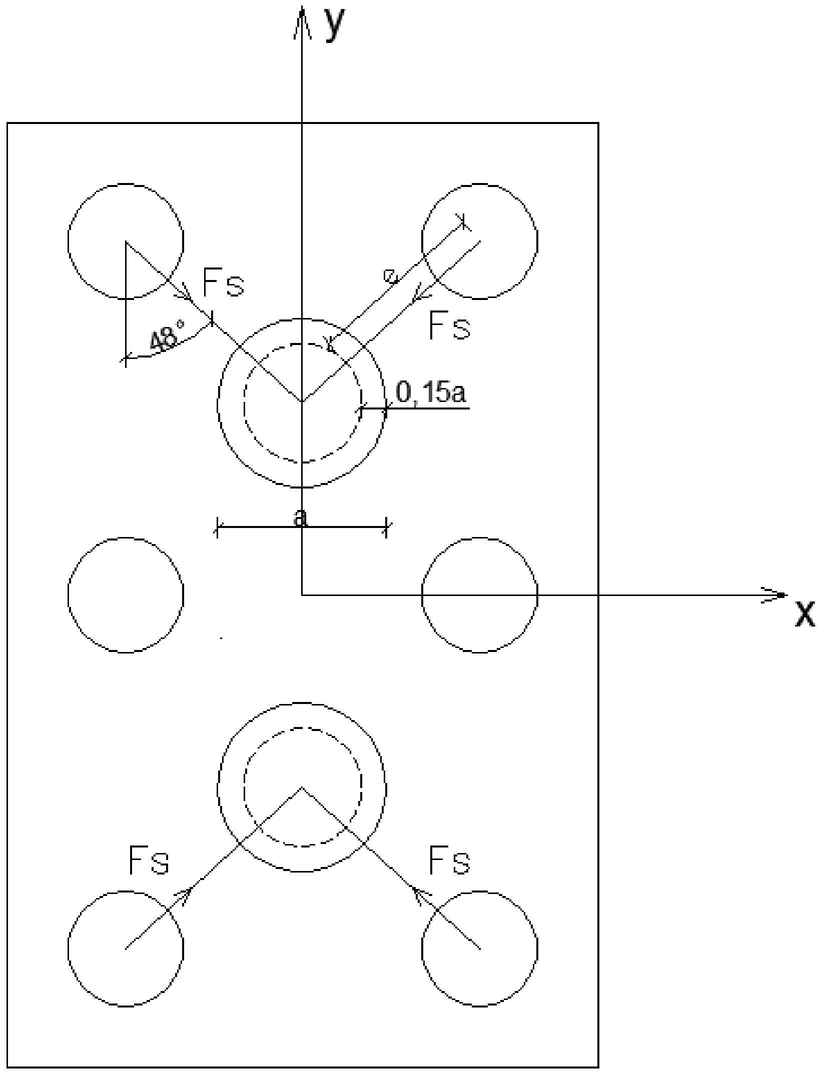


Figure 3.4.19 The relationship between the forces for piles #1,3,4,6

$a = 2{,}5\ m$ ---> $0{,}15a = 0{,}375\ m$

$e_1 = e_3 = e_4 = e_6 = 2{,}68\ m$

$d = h_f - c_{nom} - \frac{\emptyset}{2} = 3\ m - 0{,}035\ m - \frac{25}{2} = 2{,}95\ m$

$tan\theta = \frac{d}{e} = \frac{2{,}95m}{2{,}68m} = 1{,}1$

The figure below shows the simplified way how to calculate the steel force Fs for piles 2 & 5

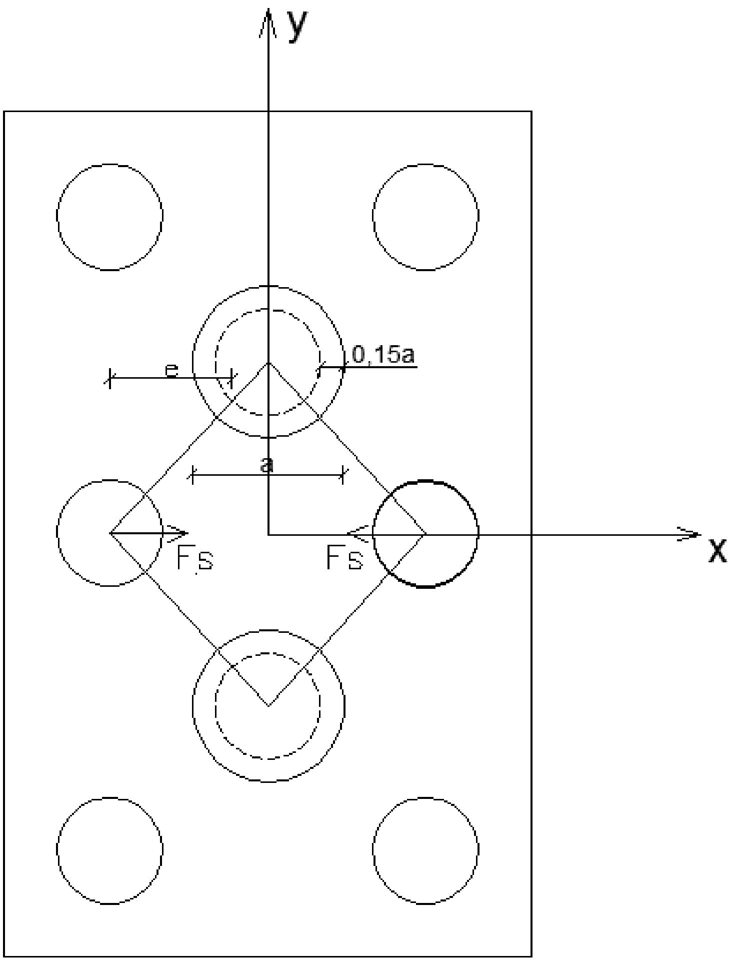


Figure 3.4.20 The relationship between the forces for piles #2,5

$a = 2{,}5\ m$ ---> $0{,}15a = 0{,}375\ m$

$e_2 = e_5 = 2{,}03\ m$

$$d = h_f - c_{nom} - \frac{\emptyset}{2} = 3\ m - 0{,}035\ m - \frac{25}{2} = 2{,}95\ m$$

$$tan\theta = \frac{d}{e} = \frac{2{,}95m}{2{,}03m} = 1{,}45$$

The figure below shows the simplified way how to calculate the steel force Fs for every piles

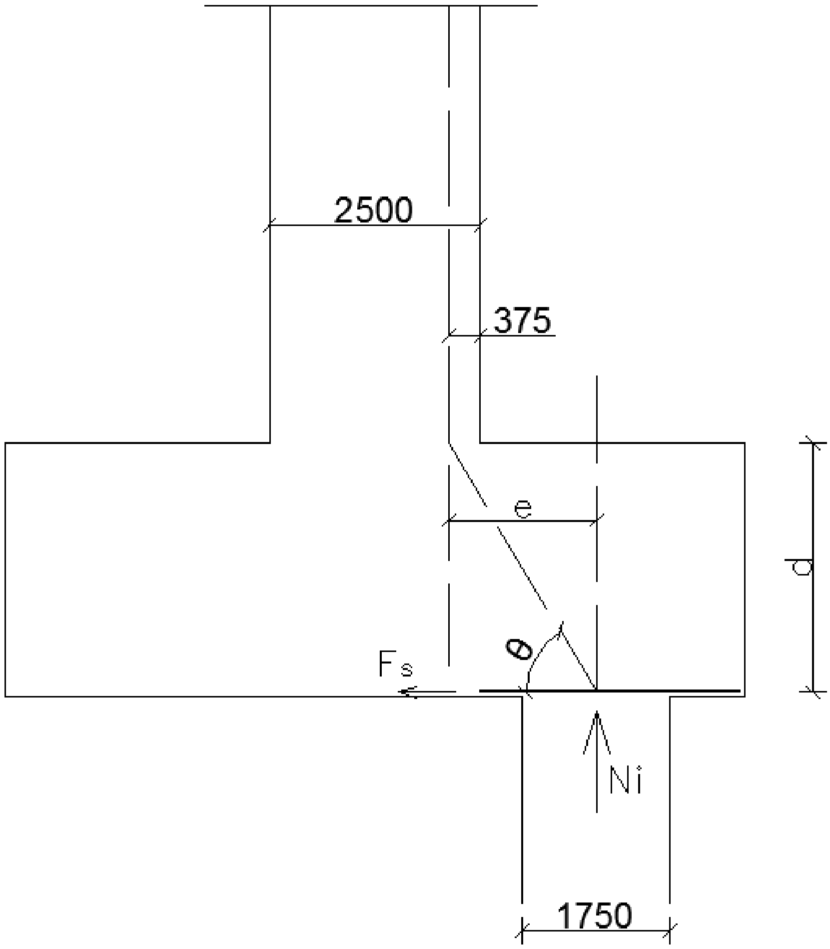


Figure 3.4.21 The relationship between the forces for piles – side view

$F_s = F_c cos\theta$

$N_i = F_c sin\theta$

$$\frac{F_s}{N_i} = \frac{1}{tan\theta}$$

$$F_s = \frac{N_i}{tan\theta}$$

Foundation P4

ULTIMATE LIMIT STATE

First case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #38:

$M_{Ed,max} = M_{yy,38} = 1125\ kNm$

$M_{Ed,cor.xx} = M_{xx,38} = -468\ kNm$

$N_{Ed,cor.} = N_{Ed,38} = -5540\ kN$

$H_{Ed,cor.y} = F_{Ed,38,y} = 34\ kN$

$H_{Ed,cor.x} = F_{Ed,38,x} = 39\ kN$

The sectional forces in the column #39:

$M_{Ed,max} = M_{yy,39} = 1111\ kNm$

$M_{Ed,cor.xx} = M_{xx,39} = -0{,}5\ kNm$

$N_{Ed,cor.} = N_{Ed,39} = -5540\ kN$

$H_{Ed,cor.y} = F_{Ed,39,y} = 0\ kN$

$H_{Ed,cor.x} = F_{Ed,39,x} = 39\ kN$

The sum of the sectional forces for the pile cap:

$$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8{,}75\ m \cdot 14{,}0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 12403\ kN$$

$$H_x{}' = F_{Ed,38,x} + F_{Ed,39,x} = 39\ kN + 39\ kN = 78\ kN$$

$$H_y{}' = F_{Ed,38,y} + F_{Ed,39,y} = 34\ kN + 0\ kN = 34\ kN$$

$$M'_{yy} = M_{yy,38} + M_{yy,39} + H_x{}' \cdot h_f = 1125\ kNm + 1111\ kNm + 78\ kN \cdot 3m = 2470\ kNm$$

$$M'_{xx} = M_{xx,38} + M_{xx,39} + H_y{}' \cdot h_f = -468\ kNm - 0{,}5\ kNm - 34\ kN \cdot 3\ m = -570\ kNm$$

$$N' = N_{Ed,38} + N_{Ed,39} + G_f = 23483\ kN$$

<u>The sectional forces for each pile:</u>

n = 6 (the number of piles)

$\emptyset = 1{,}75\ m$

$E_c = 32\ GPa$

$E_s = 5\ MPa$

$$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$$

$$H_x = \frac{H_x{}'}{n} = \frac{78\ kN}{6} = 13\ kN$$

$$H_y = \frac{H_y{}'}{n} = \frac{34\ kN}{6} = 5{,}7\ kN \approx 6\ kN$$

$$M_x = H_y \cdot t = 6\ kN \cdot 5{,}2\ m = 31{,}2\ kNm \approx 31\ kNm$$

$$M_y = H_x \cdot t = 13\ kN \cdot 5{,}2\ m = 67{,}6\ kNm \approx 68\ kNm$$

$$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{31^2 + 68^2} = 74{,}7\ kNm \approx 75\ kNm$$

$$N_1 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{23483\ kN}{6} + (2470\ kNm + 68\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (570\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 3914\ kN + 161\ kN + 29\ kN = 4104\ kN$$

$$N_2 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{23483\ kN}{6} + (2470\ kNm + 68\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (570\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 3914\ kN + 161\ kN = 4075\ kN$$

$$N_3 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{23483\ kN}{6} + (2470\ kNm + 68\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (570\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 3914\ kN + 161\ kN - 29\ kN = 4046\ kN$$

$$N_4 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{23483\ kN}{6} - (2470\ kNm + 68\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (570\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 3914\ kN - 161\ kN - 29\ kN = 3724\ kN$$

$$N_5 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_5|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_5|}{\sum_{i=1}^{6} y_i^2} = \frac{23483\ kN}{6} - (2470\ kNm + 68\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (570\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 3914\ kN - 161\ kN = 3753\ kN$$

$$N_6 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{23483\ kN}{6} - (2470\ kNm + 68\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (570\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 3914\ kN - 161\ kN + 29\ kN = 3782\ kN$$

<u>The cap reinforcement:</u>

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1{,}1} = \frac{4104\ kN}{1{,}1} = 3731\ kN$$

$$F_{s1,y} = cos48° \cdot F_s = 0{,}669 \cdot 3731\ kN = 2496\ kN$$

$$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0{,}743 \cdot 3731\ kN = 2772\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s1,x} = \frac{2772\ kN}{435\ MPa} = 63{,}72\ cm^2$$

That gives us 8#32 with total area equal $A_s = 64{,}32\ cm^2$

$$A_{s1,y} = \frac{2496\ kN}{435\ MPa} = 57{,}38\ cm^2$$

That gives us 8#32 with total area equal $A_s = 64{,}32\ cm^2$

$$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1{,}45} = \frac{4075\ kN}{1{,}45} = 2810\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s2,x} = \frac{2810\ kN}{435\ MPa} = 64{,}6\ cm^2$$

That gives us 9#32 with total area equal $A_s = 72{,}36\ cm^2$

Second case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #38:

$$N_{Ed,max.} = N_{Ed,38} = -10167\ kN$$

$$M_{Ed,cor.yy} = M_{yy,38} = -5\ kNm$$

$$M_{Ed,cor.xx} = M_{xx,38} = 1\ kNm$$

$$H_{Ed,cor.y} = F_{Ed,38,y} = 0\ kN$$

$$H_{Ed,cor.x} = F_{Ed,38,x} = 0\ kN$$

The sectional forces in the column #39:

$$N_{Ed,max} = N_{Ed,39} = -10167\ kN$$

$$M_{Ed,cor.yy} = M_{yy,39} = -18\ kNm$$

$$M_{Ed,cor.xx} = M_{xx,39} = -469\ kNm$$

$$H_{Ed,cor.y} = F_{Ed,39,y} = 34\ kN$$

$$H_{Ed,cor.x} = F_{Ed,39,x} = 0\ kN$$

The sum of the sectional forces for the pile cap:

$$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8{,}75\ m \cdot 14{,}0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 12403\ kN$$

$$H_x{}' = F_{Ed,38,x} + F_{Ed,39,x} = 0\ kN$$

$$H_y{}' = F_{Ed,38,y} + F_{Ed,39,y} = 34\ kN + 0\ kN = 34\ kN$$

$$M'_{yy} = M_{yy,38} + M_{yy,39} + H_x{}' \cdot h_f = -18\ kNm - 5\ kNm + 0\ kN \cdot 3m = -23\ kNm$$

$$M'_{xx} = M_{xx,38} + M_{xx,39} + H_y{}' \cdot h_f = -469\ kNm + 1\ kNm - 34\ kN \cdot 3\ m = -570\ kNm$$

$$N' = N_{Ed,38} + N_{Ed,39} + G_f = 32737\ kN$$

<u>The sectional forces for each pile:</u>

n = 6 (the number of piles)

$\emptyset = 1{,}75\ m$

$E_c = 32\ GPa$

$E_s = 5\ MPa$

$$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$$

$$H_x = \frac{H_x{}'}{n} = \frac{0\ kN}{6} = 0\ kN$$

$$H_y = \frac{H_y{}'}{n} = \frac{34\ kN}{6} = 5{,}7\ kN \approx 6\ kN$$

$$M_x = H_y \cdot t = 6\ kN \cdot 5{,}2\ m = 31{,}2\ kNm \approx 31\ kNm$$

$$M_y = H_x \cdot t = 0kN \cdot 5{,}2\ m = 0\ kNm$$

$$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{31^2 + 0^2} = 31\ kNm$$

$$N_1 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{32737\ kN}{6} - (23\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (570\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5456\ kN - 1\ kN + 29\ kN = 5484\ kN$$

$$N_2 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{32737\ kN}{6} - (23\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (570\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 5456\ kN - 1\ kN = 5455\ kN$$

$$N_3 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{32737\ kN}{6} - (23\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (570\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5456\ kN - 1\ kN - 29\ kN = 5426\ kN$$

$$N_4 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{32737\ kN}{6} + (23\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (570\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5456\ kN + 1\ kN - 29\ kN = 5428\ kN$$

$$N_5 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{32737\ kN}{6} + (23\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (570\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 5456\ kN + 1\ kN = 5457\ kN$$

$$N_6 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{32737\ kN}{6} + (23\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (570\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5456\ kN + 1\ kN + 29\ kN = 5486\ kN$$

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1{,}1} = \frac{5486\ kN}{1{,}1} = 4987\ kN$$

$$F_{s1,y} = cos48° \cdot F_s = 0{,}669 \cdot 4987\ kN = 3336\ kN$$

$$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0{,}743 \cdot 4984\ kN = 3705\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s1,x} = \frac{3705\ kN}{435\ MPa} = 85{,}17\ cm^2$$

That gives us 11#32 with total area equal $A_s = 88{,}44\ cm^2$

$$A_{s1,y} = \frac{3336\ kN}{435\ MPa} = 76{,}69\ cm^2$$

That gives us 10#32 with total area equal $A_s = 80{,}40\ cm^2$

$$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1{,}45} = \frac{5457\ kN}{1{,}45} = 3763\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s2,x} = \frac{3763\ kN}{435\ MPa} = 86{,}5\ cm^2$$

That gives us 11#32 with total area equal $A_s = 88{,}44\ cm^2$

Taking into account the above two cases of the calculations, the reinforcement which was adopted is:

$A_{s2,x}$ -> 11#32

$A_{s1,y}$ -> 10#32

$A_{s1,x}$ -> 11#32

Foundation P5

ULTIMATE LIMIT STATE

First case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #40:

$M_{Ed,max} = M_{yy,40} = 952\ kNm$

$M_{Ed,cor.xx} = M_{xx,40} = -522\ kNm$

$N_{Ed,cor.} = N_{Ed,40} = -5903\ kN$

$H_{Ed,cor.y} = F_{Ed,40,y} = 30\ kN$

$H_{Ed,cor.x} = F_{Ed,40,x} = 36\ kN$

The sectional forces in the column #41:

$M_{Ed,max} = M_{yy,41} = 944\ kNm$

$M_{Ed,cor.xx} = M_{xx,41} = -0{,}2\ kNm$

$N_{Ed,cor.} = N_{Ed,41} = -5902\ kN$

$H_{Ed,cor.y} = F_{Ed,41,y} = 0\ kN$

$H_{Ed,cor.x} = F_{Ed,41,x} = 30\ kN$

The sum of the sectional forces for the pile cap:

$$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8{,}75\ m \cdot 14{,}0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 12403\ kN$$

$H_x{}' = F_{Ed,40,x} + F_{Ed,41,x} = 30kN + 36\ kN = 66\ kN$

$H_y{}' = F_{Ed,40,y} + F_{Ed,41,y} = 30\ kN + 0\ kN = 30\ kN$

$M'_{yy} = M_{yy,40} + M_{yy,41} + H_x{}' \cdot h_f = 952\ kNm + 944\ kNm + 66\ kN \cdot 3m = 2094\ kNm$

$M'_{xx} = M_{xx,40} + M_{xx,41} + H_y{}' \cdot h_f = -522\ kNm - 0{,}2\ kNm - 30\ kN \cdot 3\ m = -612\ kNm$

$N' = N_{Ed,38} + N_{Ed,39} + G_f = 24208\ kN$

<u>The sectional forces for each pile:</u>

n = 6 (the number of piles)

$\emptyset = 1{,}75\ m$

$E_c = 32\ GPa$

$E_s = 5\ MPa$

$$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$$

$$H_x = \frac{H_x{}'}{n} = \frac{66\ kN}{6} = 11\ kN$$

$$H_y = \frac{H_y{}'}{n} = \frac{30\ kN}{6} = 5\ kN$$

$M_x = H_y \cdot t = 5\ kN \cdot 5{,}2\ m = 26\ kNm$

$M_y = H_x \cdot t = 11\ kN \cdot 5{,}2\ m = 57{,}2\ kNm \approx 57\ kNm$

$$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{26^2 + 57^2} = 62{,}65\ kNm \approx 63\ kNm$$

$$N_1 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{24208\ kN}{6} + (2094\ kNm + 57\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (612\ kNm + 26\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4035\ kN + 136\ kN + 30\ kN = 4201\ kN$$

$$N_2 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{24208\ kN}{6} + (2094\ kNm + 57\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (612\ kNm + 26\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 4035\ kN + 136\ kN = 4171\ kN$$

$$N_3 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{24208\ kN}{6} + (2094\ kNm + 57\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (612\ kNm + 26\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4035\ kN + 136\ kN - 30\ kN = 4141\ kN$$

$$N_4 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{24208\ kN}{6} - (2094\ kNm + 57\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (612\ kNm + 26\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4035\ kN - 136\ kN - 30\ kN = 3869\ kN$$

$$N_5 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_5|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_5|}{\sum_{i=1}^{6} y_i^2} = \frac{24208\ kN}{6} - (2094\ kNm + 57\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (612\ kNm + 26\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 4035\ kN - 136\ kN = 3899\ kN$$

$$N_6 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{24208\ kN}{6} - (2094\ kNm + 57\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (612\ kNm + 26\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4035\ kN - 136\ kN + 30\ kN = 3930\ kN$$

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1{,}1} = \frac{4201\ kN}{1{,}1} = 3819\ kN$$

$$F_{s1,y} = cos48° \cdot F_s = 0{,}669 \cdot 3819\ kN = 2555\ kN$$

$$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0{,}743 \cdot 3819\ kN = 2837\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s1,x} = \frac{2837\ kN}{435\ MPa} = 65{,}22\ cm^2$$

That gives us 9#32 with total area equal $A_s = 72{,}36\ cm^2$

$$A_{s1,y} = \frac{2555kN}{435\ MPa} = 58{,}73\ cm^2$$

That gives us 8#32 with total area equal $A_s = 64{,}32\ cm^2$

$$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1{,}45} = \frac{4171\ kN}{1{,}45} = 2876\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s2,x} = \frac{2872\ kN}{435\ MPa} = 66{,}02\ cm^2$$

That gives us 9#32 with total area equal $A_s = 72{,}36\ cm^2$

Second case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #40:

$$N_{Ed,max.} = N_{Ed,40} = -10667\ kN$$

$$M_{Ed,cor.yy} = M_{yy,40} = 2\ kNm$$

$$M_{Ed,cor.xx} = M_{xx,40} = -522\ kNm$$

$$H_{Ed,cor.y} = F_{Ed,40,y} = 36\ kN$$

$$H_{Ed,cor.x} = F_{Ed,40,x} = 0\ kN$$

The sectional forces in the column #41:

$$N_{Ed,max} = N_{Ed,41} = -10666\ kN$$

$$M_{Ed,cor.yy} = M_{yy,41} = -5\ kNm$$

$$M_{Ed,cor.xx} = M_{xx,41} = -1\ kNm$$

$$H_{Ed,cor.y} = F_{Ed,41,y} = 0\ kN$$

$$H_{Ed,cor.x} = F_{Ed,41,x} = 0\ kN$$

The sum of the sectional forces for the pile cap:

$$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8{,}75\ m \cdot 14{,}0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 12403\ kN$$

$$H_x{}' = F_{Ed,40,x} + F_{Ed,41,x} = 0\ kN$$

$$H_y{}' = F_{Ed,40,y} + F_{Ed,41,y} = 36\ kN + 0\ kN = 36\ kN$$

$$M'_{yy} = M_{yy,40} + M_{yy,41} + H_x{}' \cdot h_f = 2\ kNm - 5\ kNm + 0\ kN \cdot 3m = -3\ kNm$$

$$M'_{xx} = M_{xx,40} + M_{xx,41} + H_y{}' \cdot h_f = -522\ kNm - 1\ kNm - 36\ kN \cdot 3\ m = -631\ kNm$$

$$N' = N_{Ed,38} + N_{Ed,39} + G_f = 33736\ kN$$

<u>The sectional forces for each pile:</u>

n = 6 (the number of piles)

$\emptyset = 1{,}75\ m$

$E_c = 32\ GPa$

$E_s = 5\ MPa$

$$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$$

$$H_x = \frac{H_x{}'}{n} = \frac{0\ kN}{6} = 0\ kN$$

$$H_y = \frac{H_y{}'}{n} = \frac{36\ kN}{6} = 6\ kN$$

$$M_x = H_y \cdot t = 6\ kN \cdot 5{,}2\ m = 31{,}2\ kNm \approx 31\ kNm$$

$$M_y = H_x \cdot t = 0kN \cdot 5{,}2\ m = 0\ kNm$$

$$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{31^2 + 0^2} = 31\ kNm$$

$$N_1 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{33736\ kN}{6} - (3\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (631\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5623\ kN - 0{,}2\ kN + 31\ kN = 5654\ kN$$

$$N_2 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{33736\ kN}{6} - (3\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (631\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 5623\ kN - 0{,}2\ kN = 5623\ kN$$

$$N_3 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{33736\ kN}{6} - (3\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (631\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5623\ kN - 0{,}2\ kN - 31\ kN = 5592\ kN$$

$$N_4 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{33736\ kN}{6} + (3\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (631\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5623\ kN + 0{,}2\ kN - 31\ kN = 5592\ kN$$

$$N_5 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_5|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_5|}{\sum_{i=1}^{6} y_i^2} = \frac{33736\ kN}{6} + (3\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (631\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 5623\ kN + 0{,}2\ kN = 5623\ kN$$

$$N_6 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{33736\ kN}{6} + (3\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (631\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5623\ kN + 0{,}2\ kN + 31\ kN = 5654\ kN$$

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1{,}1} = \frac{5654\ kN}{1{,}1} = 5140\ kN$$

$$F_{s1,y} = cos48° \cdot F_s = 0{,}669 \cdot 5140\ kN = 3439\ kN$$

$$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0{,}743 \cdot 4984\ kN = 3819\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s1,x} = \frac{3819\ kN}{435\ MPa} = 87{,}79\ cm^2$$

That gives us 11#32 with total area equal $A_s = 88{,}44 cm^2$

$$A_{s1,y} = \frac{3439\ kN}{435\ MPa} = 79{,}06\ cm^2$$

That gives us 10#32 with total area equal $A_s = 80{,}40\ cm^2$

$$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1{,}45} = \frac{5623\ kN}{1{,}45} = 3878\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s2,x} = \frac{3878\ kN}{435\ MPa} = 89{,}15\ cm^2$$

That gives us 12#32 with total area equal $A_s = 96{,}48\ cm^2$

Taking into account the above two cases of the calculations, the reinforcement which was adopted is:

$A_{s2,x}$ -> 12#32

$A_{s1,y}$ -> 10#32

$A_{s1,x}$ -> 11#32

Foundation P6

ULTIMATE LIMIT STATE

First case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #42:

$M_{Ed,max} = M_{xx,42} = -835\ kNm$

$M_{Ed,cor.yy} = M_{yy,42} = 1\ kNm$

$N_{Ed,cor.} = N_{Ed,42} = -6606\ kN$

$H_{Ed,cor.y} = F_{Ed,42,y} = 59\ kN$

$H_{Ed,cor.x} = F_{Ed,40,x} = 0\ kN$

The sectional forces in the column #43:

$M_{Ed,max} = M_{xx,43} = -836\ kNm$

$M_{Ed,cor.yy} = M_{yy,43} = -3\ kNm$

$N_{Ed,cor.} = N_{Ed,43} = -10254\ kN$

$H_{Ed,cor.y} = F_{Ed,43,y} = 60\ kN$

$H_{Ed,cor.x} = F_{Ed,43,x} = 0\ kN$

The sum of the sectional forces for the pile cap:

$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8{,}75\ m \cdot 14{,}0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 12403\ kN$

$H_x{}' = F_{Ed,42,x} + F_{Ed,43,x} = 0\ kN$

$H_y{}' = F_{Ed,42,y} + F_{Ed,43,y} = 59\ kN + 60\ kN = 119\ kN$

$M'_{yy} = M_{yy,42} + M_{yy,43} + H_x{}' \cdot h_f = 1kNm - 3\ kNm + 0\ kN \cdot 3m = -2\ kNm$

$M'_{xx} = M_{xx,42} + M_{xx,43} + H_y{}' \cdot h_f = -835\ kNm - 836\ kNm - 119\ kN \cdot 3\ m = -2028\ kNm$

$N' = N_{Ed,42} + N_{Ed,43} + G_f = 29263\ kN$

<u>The sectional forces for each pile:</u>

n = 6 (the number of piles)

$\emptyset = 1{,}75\ m$

$E_c = 32\ GPa$

$E_s = 5\ MPa$

$$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$$

$$H_x = \frac{H_x{}'}{n} = \frac{0\ kN}{6} = 0\ kN$$

$$H_y = \frac{H_y{}'}{n} = \frac{119\ kN}{6} = 19{,}8\ kN \approx 20\ kN$$

$M_x = H_y \cdot t = 20\ kN \cdot 5{,}2\ m = 104\ kNm$

$M_y = H_x \cdot t = 0\ kN \cdot 5{,}2\ m = 0\ kNm$

$$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{104^2 + 0^2} = 104\ kNm$$

$$N_1 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{29263\ kN}{6} - (2\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (2028\ kNm + 104\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4877\ kN - 0{,}1\ kN + 101kN = 4978\ kN$$

$$N_2 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{29263\ kN}{6} - (2\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (2028\ kNm + 104\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 4877\ kN - 0{,}1\ kN = 4877\ kN$$

$$N_3 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{29263\ kN}{6} - (2\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (2028\ kNm + 104\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4877\ kN - 0{,}1\ kN - 101\ kN = 4776\ kN$$

$$N_4 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{29263\ kN}{6} + (2\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (2028\ kNm + 104\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4877\ kN + 0{,}1\ kN - 101kN = 4776\ kN$$

$$N_5 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_5|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_5|}{\sum_{i=1}^{6} y_i^2} = \frac{29263\ kN}{6} + (2\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (2028\ kNm + 104\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 4877\ kN + 0{,}1\ kN = 4877\ kN$$

$$N_6 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{29263\ kN}{6} + (2\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (2028\ kNm + 104\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4877\ kN + 0{,}1\ kN + 101kN = 4978\ kN$$

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1{,}1} = \frac{4978\ kN}{1{,}1} = 4525\ kN$$

$$F_{s1,y} = cos48° \cdot F_s = 0{,}669 \cdot 4525\ kN = 3027\ kN$$

$$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0{,}743 \cdot 4525\ kN = 3362\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s1,x} = \frac{3362\ kN}{435\ MPa} = 77{,}29\ cm^2$$

That gives us 10#32 with total area equal $A_s = 80{,}40\ cm^2$

$$A_{s1,y} = \frac{3027\ kN}{435\ MPa} = 69{,}59\ cm^2$$

That gives us 9#32 with total area equal $A_s = 72{,}36\ cm^2$

$$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1{,}45} = \frac{4877\ kN}{1{,}45} = 3363\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s2,x} = \frac{3363\ kN}{435\ MPa} = 77{,}31\ cm^2$$

That gives us 10#32 with total area equal $A_s = 80{,}40\ cm^2$

Second case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #42:

$N_{Ed,max.} = N_{Ed,42} = -11602\ kN$

$M_{Ed,cor.yy} = M_{yy,42} = 1\ kNm$

$M_{Ed,cor.xx} = M_{xx,42} = -501\ kNm$

$H_{Ed,cor.y} = F_{Ed,42,y} = 36\ kN$

$H_{Ed,cor.x} = F_{Ed,42,x} = 0\ kN$

The sectional forces in the column #43:

$N_{Ed,max} = N_{Ed,43} = -11598\ kN$

$M_{Ed,cor.yy} = M_{yy,43} = -2\ kNm$

$M_{Ed,cor.xx} = M_{xx,43} = -1\ kNm$

$H_{Ed,cor.y} = F_{Ed,43,y} = 0\ kN$

$H_{Ed,cor.x} = F_{Ed,43,x} = 0\ kN$

The sum of the sectional forces for the pile cap:

$$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8{,}75\ m \cdot 14{,}0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 12403\ kN$$

$H_x{}' = F_{Ed,42,x} + F_{Ed,43,x} = 0\ kN$

$H_y{}' = F_{Ed,42,y} + F_{Ed,43,y} = 36\ kN + 0\ kN = 36\ kN$

$M'_{yy} = M_{yy,40} + M_{yy,41} + H_x{}' \cdot h_f = 1\ kNm - 2\ kNm + 0\ kN \cdot 3m = -1\ kNm$

$M'_{xx} = M_{xx,40} + M_{xx,41} + H_y{}' \cdot h_f = -501\ kNm - 1\ kNm - 36\ kN \cdot 3\ m = -610\ kNm$

$N' = N_{Ed,38} + N_{Ed,39} + G_f = 35603\ kN$

<u>The sectional forces for each pile:</u>

n = 6 (the number of piles)

$$\emptyset = 1{,}75\ m$$

$$E_c = 32\ GPa$$

$$E_s = 5\ MPa$$

$$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$$

$$H_x = \frac{H_x{}'}{n} = \frac{0\ kN}{6} = 0\ kN$$

$$H_y = \frac{H_y{}'}{n} = \frac{36\ kN}{6} = 6\ kN$$

$$M_x = H_y \cdot t = 6\ kN \cdot 5{,}2\ m = 31{,}2\ kNm \approx 31\ kNm$$

$$M_y = H_x \cdot t = 0kN \cdot 5{,}2\ m = 0\ kNm$$

$$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{31^2 + 0^2} = 31\ kNm$$

$$N_1 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{35603\ kN}{6} - (1\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} + (610\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4\cdot(5{,}25^2)} = 5934\ kN - 0{,}1\ kN + 31\ kN = 5965\ kN$$

$$N_2 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{35603\ kN}{6} - (1\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} + (610\ kNm + 31\ kNm) \cdot \frac{0\ m}{4\cdot(5{,}25^2)} = 5934\ kN - 0{,}1\ kN = 5934\ kN$$

$$N_3 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{35603\ kN}{6} - (1\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} - (610\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4\cdot(5{,}25^2)} = 5934\ kN - 0{,}1\ kN - 31\ kN = 5903\ kN$$

$$N_4 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{35603\ kN}{6} + (1\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} - (610\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4\cdot(5{,}25^2)} = 5934\ kN + 0{,}1\ kN - 31\ kN = 5903\ kN$$

$$N_5 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{35603\ kN}{6} + (1\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} + (610\ kNm + 31\ kNm) \cdot \frac{0\ m}{4\cdot(5{,}25^2)} = 5934\ kN + 0{,}1\ kN = 5934\ kN$$

$$N_6 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{35603\ kN}{6} + (1\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} + (610\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4\cdot(5{,}25^2)} = 5934\ kN + 0{,}1\ kN + 31\ kN = 5965\ kN$$

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1{,}1} = \frac{5965\ kN}{1{,}1} = 5423\ kN$$

$F_{s1,y} = cos48° \cdot F_s = 0{,}669 \cdot 5423\ kN = 3628\ kN$

$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0{,}743 \cdot 5423\ kN = 4029\ kN$

$A_s = \frac{F_s}{f_{yd}}$

$A_{s1,x} = \frac{4029\ kN}{435\ MPa} = 92{,}62\ cm^2$

That gives us 12#32 with total area equal $A_s = 96{,}48\ cm^2$

$A_{s1,y} = \frac{3628\ kN}{435\ MPa} = 83{,}4\ cm^2$

That gives us 11#32 with total area equal $A_s = 88{,}44\ cm^2$

$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1{,}45} = \frac{5934\ kN}{1{,}45} = 4092\ kN$

$A_s = \frac{F_s}{f_{yd}}$

$A_{s2,x} = \frac{4092\ kN}{435\ MPa} = 94{,}07\ cm^2$

That gives us 12#32 with total area equal $A_s = 96{,}48\ cm^2$

Taking into account the above two cases of the calculations, the reinforcement which was adopted is:

$A_{s2,x}$ -> 12#32

$A_{s1,y}$ -> 11#32

$A_{s1,x}$ -> 12#32

Foundation P7

ULTIMATE LIMIT STATE

First case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #44:

$M_{Ed,max} = M_{yy,44} = 944\ kNm$

$M_{Ed,cor.xx} = M_{xx,44} = 1\ kNm$

$N_{Ed,cor.} = N_{Ed,44} = -9476\ kN$

$H_{Ed,cor.y} = F_{Ed,44,y} = 0\ kN$

$H_{Ed,cor.x} = F_{Ed,44,x} = 30\ kN$

The sectional forces in the column #45:

$M_{Ed,max} = M_{yy,45} = 950\ kNm$

$M_{Ed,cor.xx} = M_{xx,45} = -548\ kNm$

$N_{Ed,cor.} = N_{Ed,45} = -9476\ kN$

$H_{Ed,cor.y} = F_{Ed,45,y} = 36\ kN$

$H_{Ed,cor.x} = F_{Ed,45,x} = 30\ kN$

The sum of the sectional forces for the pile cap:

$$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8{,}75\ m \cdot 14{,}0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 12403\ kN$$

$$H_x{'} = F_{Ed,44,x} + F_{Ed,45,x} = 30\ kN + 30\ kN = 60\ kN$$

$$H_y{'} = F_{Ed,44,y} + F_{Ed,45,y} = 0\ kN + 36\ kN = 36\ kN$$

$$M'_{yy} = M_{yy,44} + M_{yy,45} + H_x{'} \cdot h_f = 944\ kNm + 950\ kNm + 60\ kN \cdot 3m = 2074\ kNm$$

$$M'_{xx} = M_{xx,44} + M_{xx,45} + H_y{'} \cdot h_f = \ 1\ kNm - 548\ kNm - 36\ kN \cdot 3\ m = -655\ kNm$$

$$N' = N_{Ed,44} + N_{Ed,45} + \ G_f = 31355\ kN$$

<u>The sectional forces for each pile:</u>

n = 6 (the number of piles)

$\emptyset = 1{,}75\ m$

$E_c = 32\ GPa$

$E_s = 5\ MPa$

$$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$$

$$H_x = \frac{H_x{'}}{n} = \frac{60\ kN}{6} = 10\ kN$$

$$H_y = \frac{H_y{'}}{n} = \frac{36\ kN}{6} = 6\ kN$$

$$M_x = H_y \cdot t = 6\ kN \cdot 5{,}2\ m = 31{,}2\ kNm \approx 31\ kNm$$

$$M_y = H_x \cdot t = 10\ kN \cdot 5{,}2\ m = 52\ kNm$$

$$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{31^2 + 52^2} = 60{,}2\ kNm \approx 60\ kNm$$

$N_1 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{31355\ kN}{6} + (2074\ kNm + 52\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} + (655\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4\cdot(5{,}25^2)} = 5226\ kN + 135\ kN + 33\ kN = 5394\ kN$

$N_2 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{31355\ kN}{6} + (2074\ kNm + 52\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} + (655\ kNm + 31\ kNm) \cdot \frac{0\ m}{4\cdot(5{,}25^2)} = 5226\ kN + 135\ kN = 5361\ kN$

$N_3 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{31355\ kN}{6} + (2074\ kNm + 52\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} - (655\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4\cdot(5{,}25^2)} = 5226\ kN + 135\ kN - 33\ kN = 5328\ kN$

$N_4 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{31355\ kN}{6} - (2074\ kNm + 52\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} - (655\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4\cdot(5{,}25^2)} = 5226\ kN - 135\ kN - 33\ kN = 5058\ kN$

$N_5 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_5|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_5|}{\sum_{i=1}^{6} y_i^2} = \frac{31355\ kN}{6} - (2074\ kNm + 52\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} + (655\ kNm + 31\ kNm) \cdot \frac{0\ m}{4\cdot(5{,}25^2)} = 5226\ kN - 135\ kN = 5091\ kN$

$N_6 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{31355\ kN}{6} - (2074\ kNm + 52\ kNm) \cdot \frac{2{,}625\ m}{6\cdot(2{,}625^2)} + (655\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4\cdot(5{,}25^2)} = 5226\ kN - 135\ kN + 33\ kN = 5124\ kN$

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1{,}1} = \frac{5394\ kN}{1{,}1} = 4904\ kN$$

$$F_{s1,y} = cos48° \cdot F_s = 0{,}669 \cdot 4904\ kN = 3281\ kN$$

$$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0{,}743 \cdot 4904\ kN = 3644\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s1,x} = \frac{3644\ kN}{435\ MPa} = 83{,}77\ cm^2$$

That gives us 11#32 with total area equal $A_s = 88{,}44\ cm^2$

$$A_{s1,y} = \frac{3281\ kN}{435\ MPa} = 75{,}42\ cm^2$$

That gives us 10#32 with total area equal $A_s = 80{,}40\ cm^2$

$$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1,45} = \frac{5361\ kN}{1,45} = 3697\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s2,x} = \frac{3697\ kN}{435\ MPa} = 84,99\ cm^2$$

That gives us 11#32 with total area equal $A_s = 88,44\ cm^2$

Second case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #44:

$N_{Ed,max.} = N_{Ed,44} = -10668\ kN$

$M_{Ed,cor.yy} = M_{yy,44} = -6\ kNm$

$M_{Ed,cor.xx} = M_{xx,44} = -546\ kNm$

$H_{Ed,cor.y} = F_{Ed,44,y} = 36\ kN$

$H_{Ed,cor.x} = F_{Ed,44,x} = 0\ kN$

The sectional forces in the column #45:

$N_{Ed,max} = N_{Ed,45} = -10667\ kN$

$M_{Ed,cor.yy} = M_{yy,45} = -1\ kNm$

$M_{Ed,cor.xx} = M_{xx,45} = -1\ kNm$

$H_{Ed,cor.y} = F_{Ed,45,y} = 0\ kN$

$H_{Ed,cor.x} = F_{Ed,45,x} = 0\ kN$

The sum of the sectional forces for the pile cap:

$$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8,75\ m \cdot 14,0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1,35 = (-)\ 12403\ kN$$

$H_x{}' = F_{Ed,44,x} + F_{Ed,45,x} = 0\ kN$

$H_y{}' = F_{Ed,44,y} + F_{Ed,45,y} = 36\ kN + 0\ kN = 36\ kN$

$M'_{yy} = M_{yy,44} + M_{yy,45} + H_x{}' \cdot h_f = -6\ kNm - 1\ kNm + 0\ kN \cdot 3m = -7\ kNm$

$M'_{xx} = M_{xx,44} + M_{xx,45} + H_y{}' \cdot h_f = -546\ kNm - 1\ kNm - 36\ kN \cdot 3\ m = -655\ kNm$

$N' = N_{Ed,44} + N_{Ed,45} + G_f = 33738\ kN$

The sectional forces for each pile:

n = 6 (the number of piles)

$$\emptyset = 1{,}75\ m$$

$$E_c = 32\ GPa$$

$$E_s = 5\ MPa$$

$$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$$

$$H_x = \frac{H_x{}'}{n} = \frac{0\ kN}{6} = 0\ kN$$

$$H_y = \frac{H_y{}'}{n} = \frac{36\ kN}{6} = 6\ kN$$

$$M_x = H_y \cdot t = 6\ kN \cdot 5{,}2\ m = 31{,}2\ kNm \approx 31\ kNm$$

$$M_y = H_x \cdot t = 0kN \cdot 5{,}2\ m = 0\ kNm$$

$$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{31^2 + 0^2} = 31\ kNm$$

$$N_1 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{33738\ kN}{6} - (7\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (655\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5623\ kN - 0{,}4\ kN + 33\ kN = 5656\ kN$$

$$N_2 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{33738\ kN}{6} - (7\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (655\ kNm + 31\ kNm) \cdot \frac{0m}{4 \cdot (5{,}25^2)} = 5623\ kN - 0{,}4\ kN = 5623\ kN$$

$$N_3 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{33738\ kN}{6} - (7\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (655\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5623\ kN - 0{,}4\ kN - 33\ kN = 5590\ kN$$

$$N_4 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{33738\ kN}{6} + (7\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (655\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5623\ kN + 0{,}4\ kN - 33\ kN = 5590\ kN$$

$$N_5 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_5|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_5|}{\sum_{i=1}^{6} y_i^2} = \frac{33738\ kN}{6} + (7\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (655\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 5623\ kN + 0{,}4\ kN = 5623\ kN$$

$$N_6 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{33738\ kN}{6} + (7\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (655\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5623\ kN + 0{,}4\ kN + 33\ kN = 5656\ kN$$

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1{,}1} = \frac{5656\ kN}{1{,}1} = 5142\ kN$$

$F_{s1,y} = cos48° \cdot F_s = 0,669 \cdot 5142\ kN = 3440\ kN$

$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0,743 \cdot 5142\ kN = 3820\ kN$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s1,x} = \frac{3820\ kN}{435\ MPa} = 87,82\ cm^2$$

That gives us 11#32 with total area equal $A_s = 88,44\ cm^2$

$$A_{s1,y} = \frac{3440\ kN}{435\ MPa} = 79,08\ cm^2$$

That gives us 10#32 with total area equal $A_s = 80,40\ cm^2$

$$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1,45} = \frac{5623\ kN}{1,45} = 3878\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s2,x} = \frac{3878\ kN}{435\ MPa} = 89,1\ cm^2$$

That gives us 12#32 with total area equal $A_s = 96,48\ cm^2$

Taking into account the above two cases of the calculations, the reinforcement which was adopted is:

$A_{s2,x}$ -> 12#32

$A_{s1,y}$ -> 10#32

$A_{s1,x}$ -> 11#32

Foundation P8

ULTIMATE LIMIT STATE

First case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #46:

$M_{Ed,max} = M_{yy,46} = 886\ kNm$

$M_{Ed,cor.xx} = M_{xx,46} = 1\ kNm$

$N_{Ed,cor.} = N_{Ed,46} = -5986\ kN$

$H_{Ed,cor.y} = F_{Ed,46,y} = 0\ kN$

$H_{Ed,cor.x} = F_{Ed,46,x} = 27\ kN$

The sectional forces in the column #47:

$M_{Ed,max} = M_{yy,47} = 897kNm$

$M_{Ed,cor.xx} = M_{xx,47} = -463\ kNm$

$N_{Ed,cor.} = N_{Ed,47} = -5984\ kN$

$H_{Ed,cor.y} = F_{Ed,47,y} = 34\ kN$

$H_{Ed,cor.x} = F_{Ed,47,x} = 28\ kN$

The sum of the sectional forces for the pile cap:

$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8{,}75\ m \cdot 14{,}0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 12403\ kN$

$H_x{}' = F_{Ed,46,x} + F_{Ed,47,x} = 27\ kN + 28\ kN = 55\ kN$

$H_y{}' = F_{Ed,46,y} + F_{Ed,47,y} = 0\ kN + 34\ kN = 34\ kN$

$M'_{yy} = M_{yy,46} + M_{yy,47} + H_x{}' \cdot h_f = 886\ kNm + 897\ kNm + 55\ kN \cdot 3m = 1948\ kNm$

$M'_{xx} = M_{xx,46} + M_{xx,47} + H_y{}' \cdot h_f = \ 1\ kNm - 463\ kNm - 34\ kN \cdot 3\ m = -564\ kNm$

$N' = N_{Ed,44} + N_{Ed,45} + \ G_f = 24373\ kN$

<u>The sectional forces for each pile:</u>

n = 6 (the number of piles)

$\emptyset = 1{,}75\ m$

$E_c = 32\ GPa$

$E_s = 5\ MPa$

$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$

$H_x = \frac{H_x{}'}{n} = \frac{55\ kN}{6} = 9{,}17\ kN \approx 9\ kN$

$H_y = \frac{H_y{}'}{n} = \frac{34\ kN}{6} = 5{,}67\ kN\ \ \approx 6\ kN$

$M_x = H_y \cdot t = 6\ kN \cdot 5{,}2\ m = 31{,}2\ kNm \approx 31\ kNm$

$M_y = H_x \cdot t = 9\ kN \cdot 5{,}2\ m = 46{,}8\ kNm \approx 47\ kNm$

$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{31^2 + 47^2} = 56{,}3\ kNm \approx 56\ kNm$

$N_1 = \frac{N\prime}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{24373\ kN}{6} + (1948\ kNm + 47\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (564\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4062\ kN + 127\ kN + 28\ kN = 4217\ kN$

$N_2 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{24373\ kN}{6} + (1948\ kNm + 47\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (564\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 4062\ kN + 127\ kN = 4189\ kN$

$N_3 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{24373\ kN}{6} + (1948\ kNm + 47\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (564\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4062\ kN + 127\ kN - 28\ kN = 4161\ kN$

$N_4 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{24373\ kN}{6} - (1948\ kNm + 47\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (564\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4062\ kN - 127\ kN - 28\ kN = 3907\ kN$

$N_5 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_5|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_5|}{\sum_{i=1}^{6} y_i^2} = \frac{24373\ kN}{6} - (1948\ kNm + 47\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (564\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 4062\ kN - 127\ kN = 3935\ kN$

$N_6 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp (M'_{xx} - M_x) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{24373\ kN}{6} - (1948\ kNm + 47\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (564\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 4062\ kN - 127\ kN + 28\ kN = 3963\ kN$

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1{,}1} = \frac{4217\ kN}{1{,}1} = 3834\ kN$$

$$F_{s1,y} = cos48° \cdot F_s = 0{,}669 \cdot 3834\ kN = 2565\ kN$$

$$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0{,}743 \cdot 3834 kN = 2849\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s1,x} = \frac{2849\ kN}{435\ MPa} = 65{,}49\ cm^2$$

That gives us 9#32 with total area equal $A_s = 72{,}36\ cm^2$

$$A_{s1,y} = \frac{2565\ kN}{435\ MPa} = 58{,}86\ cm^2$$

That gives us 8#32 with total area equal $A_s = 64{,}32\ cm^2$

$$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1{,}45} = \frac{4189\ kN}{1{,}45} = 2889\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s2,x} = \frac{2889\ kN}{435\ MPa} = 66{,}41\ cm^2$$

That gives us 9#32 with total area equal $A_s = 72{,}36\ cm^2$

Second case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #46:

$N_{Ed,max.} = N_{Ed,46} = -10771\ kN$

$M_{Ed,cor.yy} = M_{yy,46} = -13\ kNm$

$M_{Ed,cor.xx} = M_{xx,46} = -461\ kNm$

$H_{Ed,cor.y} = F_{Ed,46,y} = 34\ kN$

$H_{Ed,cor.x} = F_{Ed,46,x} = 0\ kN$

The sectional forces in the column #47:

$N_{Ed,max} = N_{Ed,47} = -10769\ kN$

$M_{Ed,cor.yy} = M_{yy,47} = -2\ kNm$

$M_{Ed,cor.xx} = M_{xx,47} = -1\ kNm$

$H_{Ed,cor.y} = F_{Ed,47,y} = 0\ kN$

$H_{Ed,cor.x} = F_{Ed,47,x} = 0\ kN$

The sum of the sectional forces for the pile cap:

$G_f = A_f \cdot h_f \cdot 25\frac{kN}{m^3} = 8{,}75\ m \cdot 14{,}0\ m \cdot 3\ m \cdot 25\frac{kN}{m^3} \cdot 1{,}35 = (-)\ 12403\ kN$

$H_x{}' = F_{Ed,46,x} + F_{Ed,47,x} = 0\ kN$

$H_y{}' = F_{Ed,46,y} + F_{Ed,47,y} = 34\ kN + 0\ kN = 34\ kN$

$M'_{yy} = M_{yy,46} + M_{yy,47} + H_x{}' \cdot h_f = -13\ kNm - 2\ kNm + 0\ kN \cdot 3m = -15\ kNm$

$M'_{xx} = M_{xx,46} + M_{xx,47} + H_y{}' \cdot h_f = -461\ kNm - 1\ kNm - 34\ kN \cdot 3\ m = -564\ kNm$

$N' = N_{Ed,44} + N_{Ed,45} + G_f = 33943\ kN$

The sectional forces for each pile:

n = 6 (the number of piles)

$\emptyset = 1{,}75\ m$

$E_c = 32\ GPa$

$E_s = 5\ MPa$

$$t = \frac{\emptyset}{3}\sqrt[4]{\frac{E_c}{E_s}} = \frac{1{,}75\ m}{3}\sqrt[4]{\frac{32000\ MPa}{5\ MPa}} = 5{,}2\ m$$

$$H_x = \frac{H_x{}'}{n} = \frac{0\ kN}{6} = 0\ kN$$

$$H_y = \frac{H_y{}'}{n} = \frac{34\ kN}{6} = 5{,}7\ kN \approx 6\ kN$$

$$M_x = H_y \cdot t = 6\ kN \cdot 5{,}2\ m = 31{,}2\ kNm \approx 31\ kNm$$

$$M_y = H_x \cdot t = 0kN \cdot 5{,}2\ m = 0\ kNm$$

$$M = \sqrt{M_x^2 + M_y^2} = \sqrt[2]{31^2 + 0^2} = 31\ kNm$$

$$N_1 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_1|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_1|}{\sum_{i=1}^{6} y_i^2} = \frac{33943\ kN}{6} - (15\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (564\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5657\ kN - 1\ kN + 28\ kN = 5684\ kN$$

$$N_2 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_2|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_2|}{\sum_{i=1}^{6} y_i^2} = \frac{33943\ kN}{6} - (15\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (564\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 5657\ kN - 1\ kN = 5656\ kN$$

$$N_3 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_3|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_3|}{\sum_{i=1}^{6} y_i^2} = \frac{33943\ kN}{6} - (15\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} - (564\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5657\ kN - 1\ kN - 28\ kN = 5628\ kN$$

$$N_4 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_4|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_4|}{\sum_{i=1}^{6} y_i^2} = \frac{33943\ kN}{6} + (15\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (564\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5657\ kN + 1\ kN + 28\ kN = 5630\ kN$$

$$N_5 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_5|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_5|}{\sum_{i=1}^{6} y_i^2} = \frac{33943\ kN}{6} + (15\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (564\ kNm + 31\ kNm) \cdot \frac{0\ m}{4 \cdot (5{,}25^2)} = 5657\ kN + 1\ kN = 5658\ kN$$

$$N_6 = \frac{N'}{n} \mp \left(M'_{yy} - M_y\right) \cdot \frac{|x_6|}{\sum_{i=1}^{6} x_i^2} \mp \left(M'_{xx} - M_x\right) \cdot \frac{|y_6|}{\sum_{i=1}^{6} y_i^2} = \frac{33943\ kN}{6} + (15\ kNm) \cdot \frac{2{,}625\ m}{6 \cdot (2{,}625^2)} + (564\ kNm + 31\ kNm) \cdot \frac{5{,}25\ m}{4 \cdot (5{,}25^2)} = 5657\ kN + 1\ kN + 28\ kN = 5686\ kN$$

$$F_{s1} = \frac{N_i}{tan\theta} = \frac{\max(N_1, N_3, N_4, N_6)}{1,1} = \frac{5686\ kN}{1,1} = 5169\ kN$$

$$F_{s1,y} = cos48° \cdot F_s = 0,669 \cdot 5169\ kN = 3458\ kN$$

$$F_{s1,x} = \cos(90° - 48°) \cdot F_s = 0,743 \cdot 5169\ kN = 3840\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s1,x} = \frac{3840\ kN}{435\ MPa} = 88,27\ cm^2$$

That gives us 11#32 with total area equal $A_s = 88,44\ cm^2$

$$A_{s1,y} = \frac{3458\ kN}{435\ MPa} = 79,49\ cm^2$$

That gives us 10#32 with total area equal $A_s = 80,40\ cm^2$

$$F_{s2} = \frac{N_i}{tan\theta} = \frac{\max(N_2, N_5)}{1,45} = \frac{5658\ kN}{1,45} = 3902\ kN$$

$$A_s = \frac{F_s}{f_{yd}}$$

$$A_{s2,x} = \frac{3902\ kN}{435\ MPa} = 89,70\ cm^2$$

That gives us 12#32 with total area equal $A_s = 96,48\ cm^2$

Taking into account the above two cases of the calculations, the reinforcement which was adopted is:

$A_{s2,x}$ -> 12#32

$A_{s1,y}$ -> 10#32

$A_{s1,x}$ -> 11#32

Foundation P9

ULTIMATE LIMIT STATE

First case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #48:

$M_{Ed,max} = M_{yy,48} = 1107\ kNm$

$M_{Ed,cor.xx} = M_{xx,48} = 1\ kNm$

$N_{Ed,cor.} = N_{Ed,48} = -9024\ kN$

The sectional forces in the column #49:

$M_{Ed,max} = M_{yy,49} = 1124\ kNm$

$M_{Ed,cor.xx} = M_{xx,49} = -374\ kNm$

$N_{Ed,cor.} = N_{Ed,49} = -9023\ kN$

The sum of the sectional forces:

$G_f = A_f \cdot h_f \cdot 25 \frac{kN}{m^3} = 6{,}35\ m \cdot 12{,}7\ m \cdot 1{,}5\ m \cdot 25 \frac{kN}{m^3} \cdot 1{,}35 = (-)\ 4083\ kN$

$M_{yy} = M_{yy,48} + M_{yy,49} = 2231\ kNm$

$M_{xx} = M_{xx,48} + M_{xx,49} = -373\ kNm$

$N' = N_{Ed,48} + N_{Ed,49} + G_f = 22130\ kN$

The eccentricity of the actions:

$$e_x = \frac{M_{yy}}{N'} = \frac{2231\ kNm}{22130\ kN} = 0{,}10\ m$$

$$e_y = \frac{M_{xx}}{N'} = \frac{-373\ kNm}{22130\ kN} = -\ 0{,}017\ m$$

Effective dimensions of the foundation:

$$B' = 2 \cdot \left(\frac{B}{2} - e_x\right) = B - 2e_x = 6{,}35\ m - 2 \cdot 0{,}10\ m \approx 6{,}15\ m$$

$$L' = 2 \cdot \left(\frac{L}{2} - |e_y|\right) = L - 2e_y = 12{,}7\ m - 2 \cdot 0{,}017\ m = 12{,}66\ m \approx 12{,}70\ m$$

Effective area of the foundation:

$A' = B' \cdot L' = 6{,}15\ m \cdot 12{,}7\ m = 78{,}1\ m^2$

The design value of the bearing pressure:

$$\sigma = \frac{N'}{A'} = \frac{22130\ kN}{78{,}1\ m^2} = 283{,}3 \approx 283 \frac{kN}{m}/m$$

The simplified static model of the spread foundation in the x-direction:

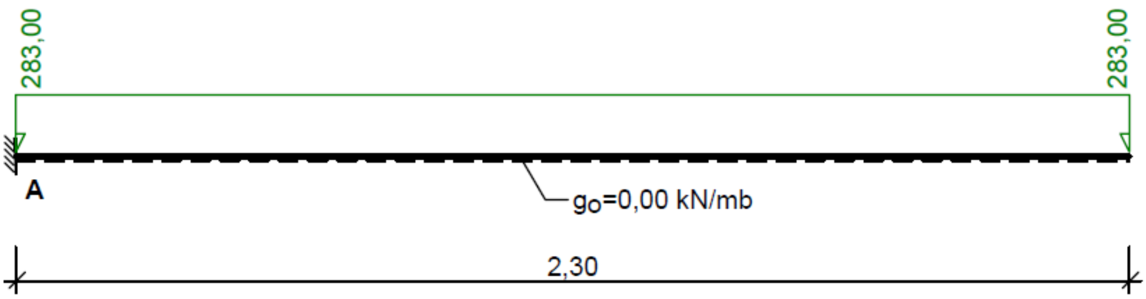


Figure 3.4.22 The static model for the foundation P9 in the x-direction – first case

$L = 0{,}15a + l'$

$a = 2{,}5\ m$

$l' = \frac{B-a}{2} = \frac{6{,}35\ m - 2{,}5\ m}{2} = 1{,}925$

$L = 0{,}15 \cdot 2{,}5\ m + 1{,}925\ m = 2{,}3\ m$

The bending moment is given by computer program Belka by SPECBUD [kNm]:

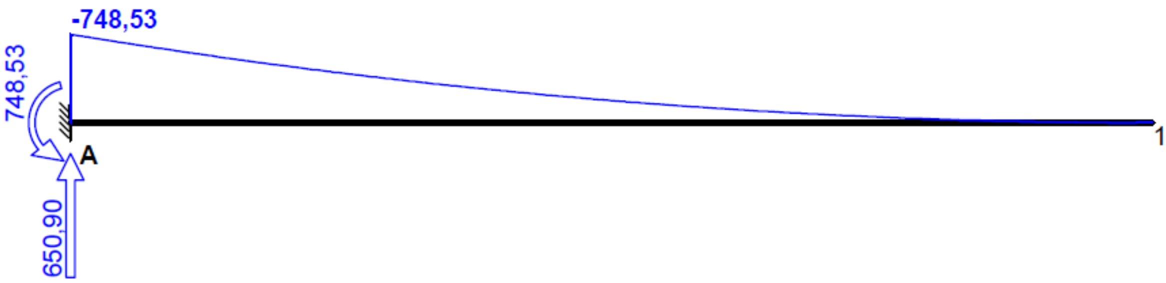


Figure 3.4.23 The bending moment for the foundation P9 in the x-direction – first case

$M_{Ed,x} \approx 749\ kNm/m$

Minimum area of reinforcement:

$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$

Assuming bars #20:

$d = h - c_{nom} - \emptyset - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - 0{,}02 - \frac{0{,}020}{2} m = 1{,}435\ m$

Calculated minimum area of reinforcement:

$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{749\ kNm}{1{,}0\ m \cdot (1{,}435\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}017$

$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}017} = 0{,}017$

$$A_{s,min} = 0{,}017 \cdot 1{,}0\ m \cdot 1{,}435\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 12{,}02\ cm^2$$

That gives us #20/0,25 m with total area equal $A_s = 12{,}56\ cm^2$

<u>The simplified static model of the spread foundation in the y-direction:</u>

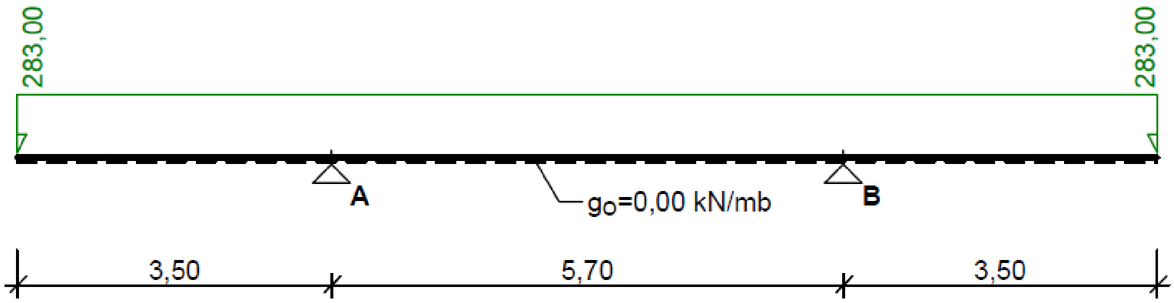


Figure 3.4.24 The static model for the foundation P9 in the y-direction – first case

The bending moment is given by computer program Belka by SPECBUD [kNm]:

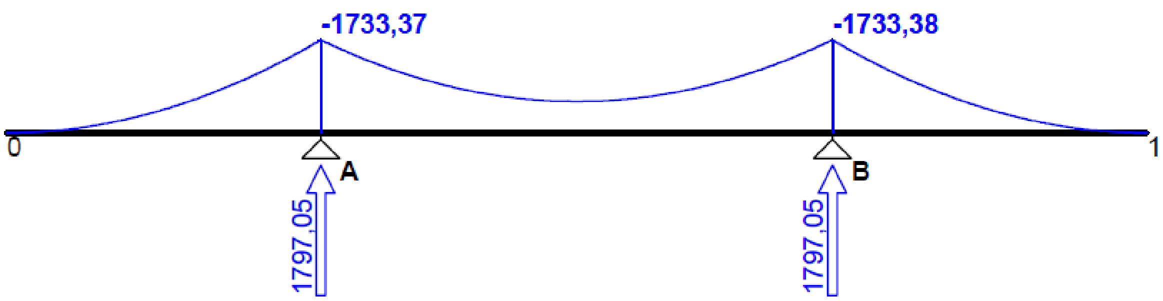


Figure 3.4.25 The bending moment for the foundation P9 in the y-direction – first case

$$M_{Ed,y} \approx 1733\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - \frac{0{,}020}{2} m = 1{,}455\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{1733\ kNm}{1{,}0\ m \cdot (1{,}455\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}038$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}038} = 0{,}038$$

$$A_{s,min} = 0{,}038 \cdot 1{,}0\ m \cdot 1{,}455\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 27{,}2\ \ cm^2$$

That gives us #25/0,175 m with total area equal $A_s = 28{,}06\ cm^2$

Second case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #48:

$N_{Ed,max} = N_{Ed,48} = -10150\ kNm$

$M_{Ed,cor.yy.} = \ M_{yy,48} = -19\ kNm$

$M_{Ed,cor,xx} = M_{xx,48} = -372\ kN$

The sectional forces in the column #49:

$N_{Ed,max} = N_{Ed,49} = -10149\ kNm$

$M_{Ed,cor.yy.} = \ M_{yy,49} = -2\ kNm$

$M_{Ed,cor,xx} = M_{xx,47} = -1\ kN$

The sum of the sectional forces:

$M_{yy} = M_{yy,44} + M_{yy,45} = -21\ kNm$

$M_{xx} = M_{xx,44} + M_{xx,45} = -373\ kNm$

$N' = N_{Ed,44} + N_{Ed,45} + \ G_f = 24382\ kN$

The eccentricity of the actions:

$$e_x = \frac{M_{yy}}{N'} = \frac{-21\ kNm}{24382\ kN} = -0{,}0009\ m$$

$$e_y = \frac{M_{xx}}{N'} = \frac{-373\ kNm}{24382\ kN} = -\ 0{,}015\ m$$

$$B' = 2 \cdot \left(\frac{B}{2} - |e_x|\right) = B - 2e_x = 6{,}35\ m - 2 \cdot 0{,}0009\ m \approx 6{,}35\ m$$

$$L' = 2 \cdot \left(\frac{L}{2} - |e_{y|}\right) = L - 2e_y = 12{,}7\ m - 2 \cdot 0{,}015\ m \approx 12{,}70\ m$$

Effective area of the foundation:

$A' = A = 80{,}6\ m^2$

The design value of the bearing pressure:

$$\sigma = \frac{N'}{A'} = \frac{24382kN}{80,6\ m} = 302,5 \approx 303\frac{kN}{m}/m$$

<u>The simplified static model of the spread foundation in the x-direction:</u>

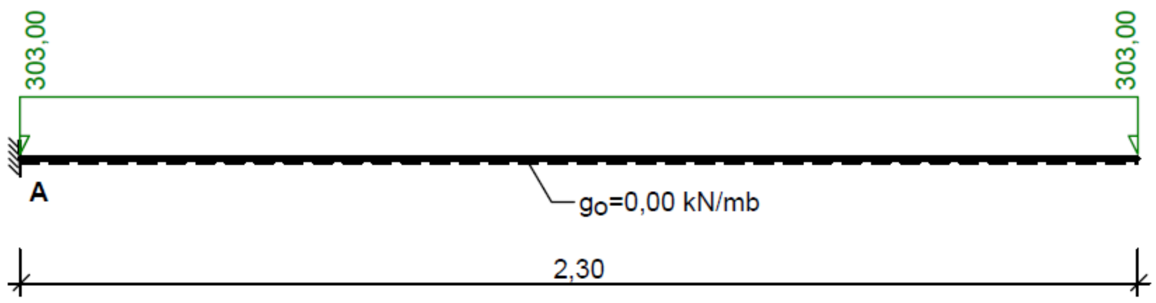


Figure 3.4.26 The static model for the foundation P9 in the x-direction – second case

The bending moment is given by computer program Belka by SPECBUD [kNm]:

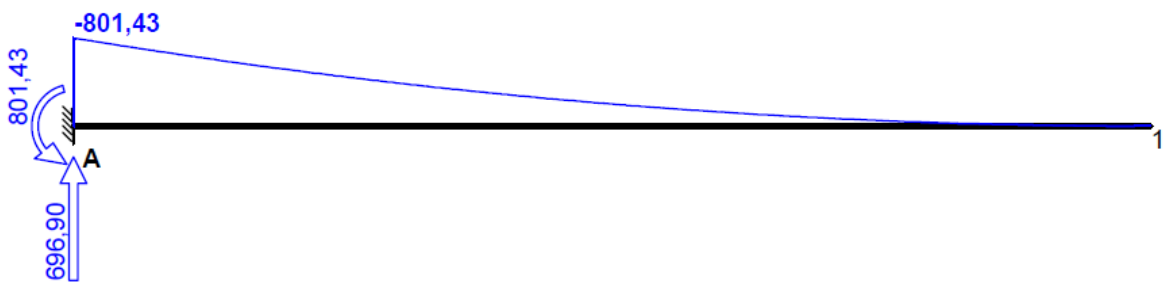


Figure 3.4.27 The bending moment for the foundation P9 in the x-direction – second case

$M_{Ed,x} \approx 801\ kNm/m$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \emptyset - \frac{\emptyset}{2} = 1,5\ m - 0,035\ m - 0,02 - \frac{0,020}{2}m = 1,435\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{801\ kNm}{1,0\ m \cdot (1,435\ m)^2 \cdot 21,43\ kPa \cdot 10^3} = 0,018$$

$$\omega = 1 - \sqrt{1-2\mu} = 1 - \sqrt{1 - 2 \cdot 0,018} = 0,018$$

$$A_{s,min} = 0,018 \cdot 1,0\ m \cdot 1,435\ m \cdot \frac{21,43\ MPa}{435\ MPa} = 12,72\ cm^2$$

That gives us #20/0,225 m with total area equal $A_s = 13{,}96\ cm^2$

<u>The simplified static model of the spread foundation in the y-direction:</u>

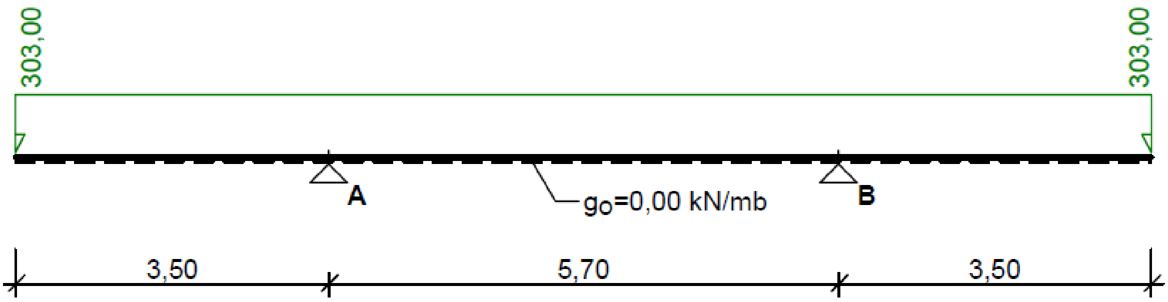


Figure 3.4.28 The static model for the foundation P9 in the y-direction – second case

The bending moment is given by computer program Belka by SPECBUD [kNm]:

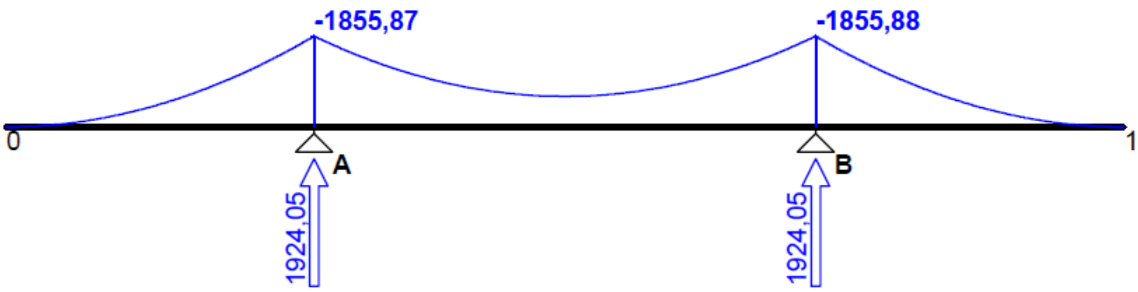


Figure 3.4.29 The bending moment for the foundation P9 in the y-direction – second case

$M_{Ed,y} \approx 1856\ kNm/\mathrm{m}$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - \frac{0{,}020}{2} m = 1{,}455\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{1856\ kNm}{1{,}0\ m \cdot (1{,}455\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}041$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}041} = 0{,}042$$

$$A_{s,min} = 0{,}042 \cdot 1{,}0\ m \cdot 1{,}455\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 30{,}10\ cm^2$$

That gives us #25/0,15 m with total area equal $A_s = 32{,}73\ cm^2$

Taking into account the above two cases of the calculations, the reinforcement which was adopted is #20/0,225 m in x-direction and #25/0,15 m in y-direction.

GEO LIMIT STATE

First case

The sum of the sectional forces:

$M_{yy} = M_{yy,48} + M_{yy,49} = 2231\ kNm$

$N' = N_{Ed,48} + N_{Ed,49} + G_f = 22130\ kN$

$H'_x = H_{Ed,48} + H_{Ed,49} = 39\ kN + 39\ kN = 78\ kN$

<u>The Bearing resistance of spread foundation</u>

$\gamma_k = 18\ kN/m^3$

$\varphi = 30°$

Depth of foundation

D = 10,2 m

The total vertical stress at the founding level:

$$q = \gamma \cdot D = 18 \frac{kN}{m^3} \cdot 10{,}2\ m = 183{,}6\ kPa$$

The effective dimensions of the foundation:

$B' = 6{,}15\ m$

$L' = 12{,}7\ m$

The capacity factors:

$$N_q = e^{\pi \cdot tan\varphi} \cdot \left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right)^2 = 18{,}401$$

$$N_\gamma = 2 \cdot (N_q - 1) \cdot tan\varphi = 20{,}093$$

$$N_c = (N_q - 1) \cdot cot\varphi = 30{,}14$$

The shape factors:

$$s_q = 1 + \frac{B'}{L'} \cdot sin\varphi = 1{,}242$$

$$s_\gamma = 1 - 0{,}3 \cdot \frac{B'}{L'} = 0{,}855$$

$$s_c = \frac{s_q \cdot N_q - 1}{N_q - 1} = 1{,}256$$

Load's inclination factors:

c' = 0 for Fx || B'

$$m = \frac{2 + \frac{B'}{L'}}{1 + \frac{B'}{L'}} = 1{,}674$$

$$i_q = (1 - \frac{F_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^m = 0{,}994$$

$$i_\gamma = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^{m+1} = 0{,}99$$

$$i_c = i_q - \frac{1 - i_q}{N_c \cdot tan\varphi} = 0{,}99$$

Foundation base's inclination factors

Because the base of the foundation is horizontal:

$$b_q = 1$$

$$b_\gamma = 1$$

$$b_c = 1$$

The value of the design drained bearing resistance

$$\frac{R_k}{A'} = q \cdot N_q \cdot b_q \cdot s_q \cdot i_q + 0{,}5 \cdot \gamma_k \cdot B' \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma + c' \cdot N_c \cdot b_c \cdot s_c \cdot i_c = 5113\ kPa$$

$$R_k = 5113\ kPa \cdot 6{,}15\ m \cdot 12{,}7\ m = 399{,}3\ MN$$

$$\gamma_R = 1{,}4$$

$$R_d = \frac{R_k}{\gamma_R} = \frac{399{,}3\ MN}{1{,}4} = 285{,}2\ MN$$

$$V_d = 22130\ kN < R_d = 285200\ kN$$

Second case

The sum of the sectional forces:

$M_{yy} = M_{yy,48} + M_{yy,49} = 21\ kNm$

$N' = N_{Ed,48} + N_{Ed,49} + G_f = 24382\ kN$

$H'_x = H_{Ed,48} + H_{Ed,49} = -1\ kN$

<u>The Bearing resistance of spread foundation</u>

$\gamma_k = 18\ kN/m^3$

$\varphi = 30°$

Depth of foundation

D = 10,2 m

The total vertical stress at the founding level:

$$q = \gamma \cdot D = 18 \frac{kN}{m^3} \cdot 10{,}2\ m = 183{,}6\ kPa$$

The effective dimensions of the foundation:

$B' = 8{,}55\ m$

$L' = 14\ m$

The capacity factors:

$$N_q = e^{\pi \cdot tan\varphi} \cdot \left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right)^2 = 18{,}401$$

$$N_\gamma = 2 \cdot (N_q - 1) \cdot tan\varphi = 20{,}093$$

$$N_c = (N_q - 1) \cdot cot\varphi = 30{,}14$$

The shape factors:

$$s_q = 1 + \frac{B'}{L'} \cdot sin\varphi = 1{,}25$$

$$s_\gamma = 1 - 0{,}3 \cdot \frac{B'}{L'} = 0{,}85$$

$$s_c = \frac{s_q \cdot N_q - 1}{N_q - 1} = 1{,}264$$

Load's inclination factors:

c' = 0 for Fx || B'

$$m = \frac{2 + \frac{B'}{L'}}{1 + \frac{B'}{L'}} = 1{,}667$$

$$i_q = (1 - \frac{F_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^m = 1$$

$$i_\gamma = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^{m+1} = 1$$

$$i_c = i_q - \frac{1 - i_q}{N_c \cdot tan\varphi} = 1$$

Foundation base's inclination factors

Because the base of the foundation is horizontal:

$b_q = 1$

$b_\gamma = 1$

$b_c = 1$

The value of the design drained bearing resistance

$$\frac{R_k}{A'} = q \cdot N_q \cdot b_q \cdot s_q \cdot i_q + 0{,}5 \cdot \gamma_k \cdot B' \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma + c' \cdot N_c \cdot b_c \cdot s_c \cdot i_c = 5199\ kPa$$

$R_k = 5199\ kPa \cdot 6{,}35\ m \cdot 12{,}7m = 419{,}3\ MN$

$\gamma_R = 1{,}4$

$$R_d = \frac{R_k}{\gamma_R} = \frac{419{,}3\ MN}{1{,}4} = 299{,}5\ MN$$

$V_d = 24382\ kN < R_d = 299500\ kN$

Foundation P10

ULTIMATE LIMIT STATE

First case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #50:

$M_{Ed,max} = M_{yy,50} = 3331\ kNm$

$M_{Ed,cor.xx} = M_{xx,50} = -2\ kNm$

$N_{Ed,cor.} = N_{Ed,50} = -7156\ kN$

The sectional forces in the column #51:

$M_{Ed,max} = M_{yy,51} = 3381\ kNm$

$M_{Ed,cor.xx} = M_{xx,51} = -319\ kNm$

$N_{Ed,cor.} = N_{Ed,51} = -7165\ kN$

The sum of the sectional forces:

$G_f = A_f \cdot h_f \cdot 25 \frac{kN}{m^3} = 6{,}35\ m \cdot 12{,}7\ m \cdot 1{,}5\ m \cdot 25 \frac{kN}{m^3} \cdot 1{,}35 = (-)\ 4083\ kN$

$M_{yy} = M_{yy,50} + M_{yy,51} = 6712\ kNm$

$M_{xx} = M_{xx,50} + M_{xx,51} = -321\ kNm$

$N' = N_{Ed,50} + N_{Ed,51} + G_f = 18404\ kN$

The eccentricity of the actions:

$e_x = \frac{M_{yy}}{N'} = \frac{6712\ kNm}{18404\ kN} = 0{,}36\ m$

$e_y = \frac{M_{xx}}{N'} = \frac{-321\ kNm}{18404\ kN} = -\ 0{,}017\ m$

Effective dimensions of the foundation:

$B' = 2 \cdot \left(\frac{B}{2} - e_x\right) = B - 2e_x = 6{,}35\ m - 2 \cdot 0{,}36\ m = 5{,}63\ m$

$L' = 2 \cdot \left(\frac{L}{2} - |e_y|\right) = L - 2e_y = 12{,}7\ m - 2 \cdot 0{,}019\ m = 12{,}66\ m \approx 12{,}70\ m$

Effective area of the foundation:

$A' = B' \cdot L' = 5{,}63\ m \cdot 12{,}7\ m = 71{,}5\ m^2$

The design value of the bearing pressure:

$\sigma = \frac{N'}{A'} = \frac{18404\ kN}{71{,}5\ m} = 257 \frac{kN}{m} /m$

The simplified static model of the spread foundation in the x-direction:

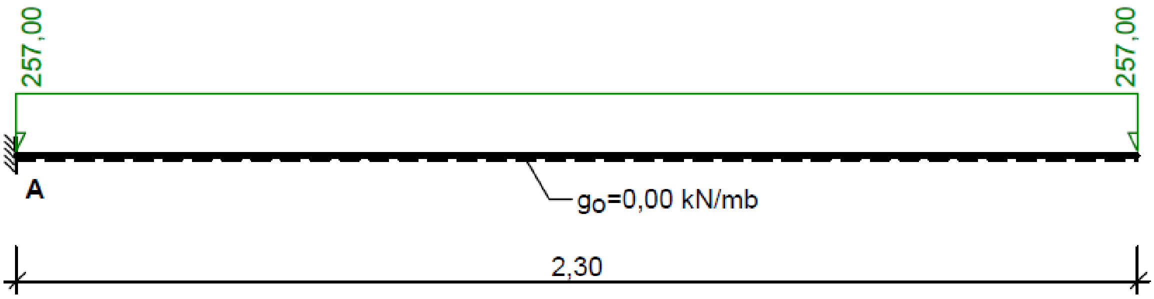


Figure 3.4.30 The static model for the foundation P10 in the x-direction – first case

$L = 0{,}15a + l'$

$a = 2{,}5\ m$

$l' = \frac{B - a}{2} = \frac{6{,}35\ m - 2{,}5\ m}{2} = 1{,}925$

$L = 0{,}15 \cdot 2{,}5\ m + 1{,}925\ m = 2{,}3\ m$

The bending moment is given by computer program Belka by SPECBUD [kNm]:

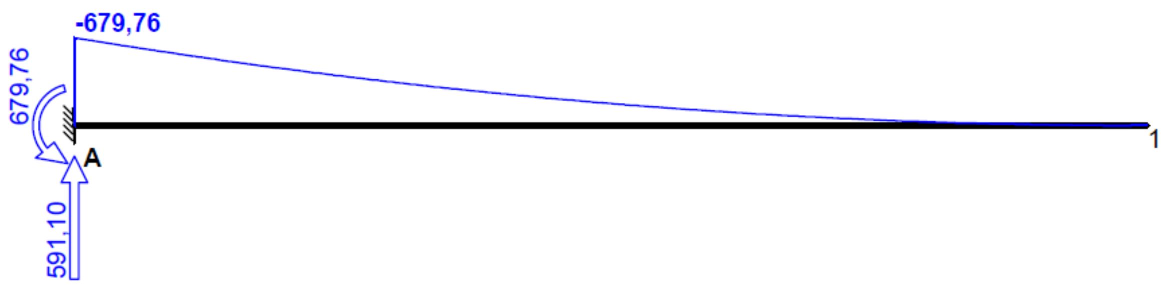


Figure 3.4.31 The bending moment for the foundation P10 in the x-direction – first case

$M_{Ed,x} \approx 680\ kNm/m$

Minimum area of reinforcement:

$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$

Assuming bars #20:

$d = h - c_{nom} - \emptyset - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - 0{,}02 - \frac{0{,}020}{2} m = 1{,}435\ m$

Calculated minimum area of reinforcement:

$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{680\ kNm}{1{,}0\ m \cdot (1{,}435\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}015$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}015} = 0{,}015$$

$$A_{s,min} = 0{,}015 \cdot 1{,}0\ m \cdot 1{,}435\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 10{,}60\ cm^2$$

That gives us #20/0,275 m with total area equal $A_s = 11{,}42\ cm^2$

The simplified static model of the spread foundation in the y-direction:

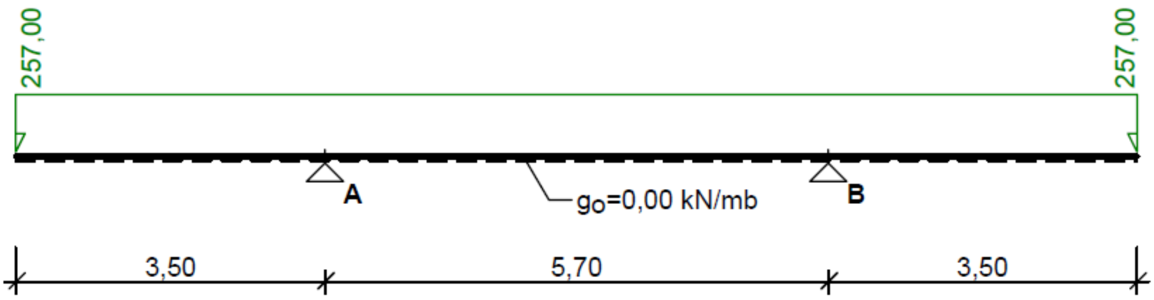


Figure 3.4.32 The static model for the foundation P10 in the y-direction – first case

The bending moment is given by computer program Belka by SPECBUD [kNm]:

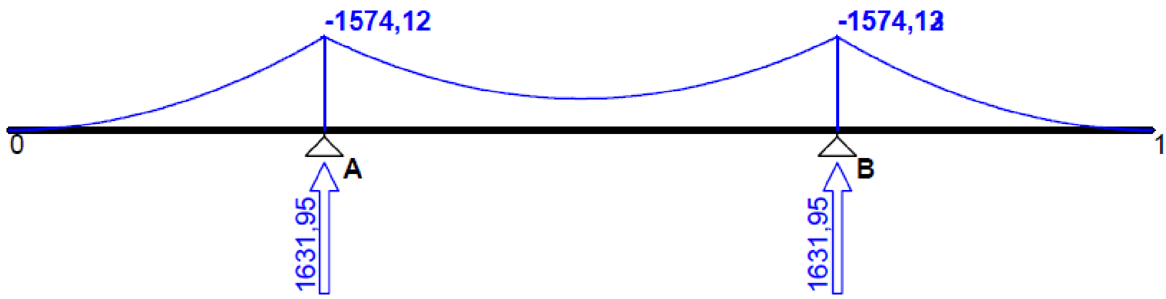


Figure 3.4.33 The bending moment for the foundation P10 in the y-direction – first case

$$M_{Ed,y} \approx 1574\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - \frac{0{,}020}{2} m = 1{,}455\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{1574\ kNm}{1,0\ m \cdot (1,455\ m)^2 \cdot 21,43\ kPa \cdot 10^3} = 0,035$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0,035} = 0,035$$

$$A_{s,min} = 0,035 \cdot 1,0\ m \cdot 1,455\ m \cdot \frac{21,43\ MPa}{435\ MPa} = 25,08\ cm^2$$

That gives us #20/0,125 m with total area equal $A_s = 25,12\ cm^2$

Second case

The sectional forces are given by computer program Autodesk robot structural analysis professional 2014:

The sectional forces in the column #50:

$$N_{Ed,max} = N_{Ed,50} = -7944\ kNm$$

$$M_{Ed,cor.yy.} = M_{yy,50} = 56\ kNm$$

$$M_{Ed,cor,xx} = M_{xx,50} = -3\ kN$$

The sectional forces in the column #51:

$$N_{Ed,max} = N_{Ed,51} = -7953\ kNm$$

$$M_{Ed,cor.yy.} = M_{yy,51} = 105\ kNm$$

$$M_{Ed,cor,xx} = M_{xx,51} = -319\ kN$$

The sum of the sectional forces:

$$M_{yy} = M_{yy,50} + M_{yy,51} = 161\ kNm$$

$$M_{xx} = M_{xx,50} + M_{xx,51} = -322\ kNm$$

$$N' = N_{Ed,50} + N_{Ed,51} + G_f = 19980\ kN$$

The eccentricity of the actions:

$$e_x = \frac{M_{yy}}{N'} = \frac{161\ kNm}{19980\ kN} = 0,008\ m$$

$$e_y = \frac{M_{xx}}{N'} = \frac{-322\ kNm}{18074\ kN} = -\ 0,016\ m$$

Effective dimensions of the foundation:

$$B' = 2 \cdot \left(\frac{B}{2} - e_x\right) = B - 2e_x = 6{,}35\ m - 2 \cdot 0{,}008\ m = 6{,}33\ m \approx 6{,}35\ m$$

$$L' = 2 \cdot \left(\frac{L}{2} - |e_y|\right) = L - 2e_y = 12{,}7\ m - 2 \cdot 0{,}016\ m = 12{,}66\ m \approx 12{,}70\ m$$

Effective area of the foundation:

$$A' = A = 80{,}6\ m^2$$

The design value of the bearing pressure:

$$\sigma = \frac{N'}{A'} = \frac{19980\ kN}{80{,}6\ m^2} = 247{,}89 \approx 248\frac{kN}{m}/m$$

<u>The simplified static model of the spread foundation in the x-direction:</u>

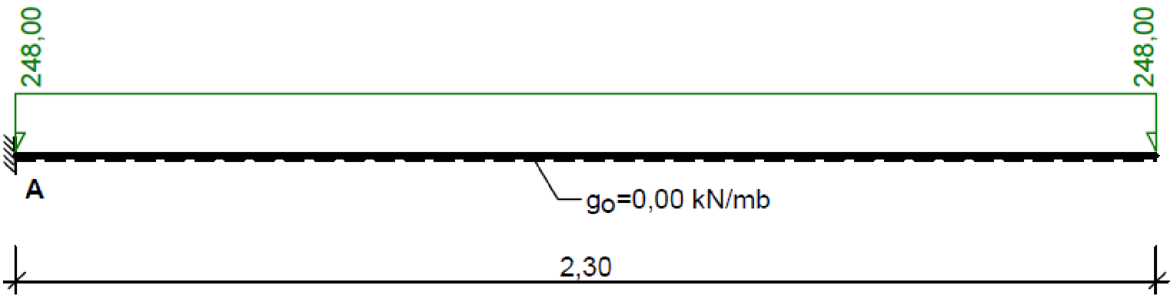


Figure 3.4.34 The static model for the foundation P10 in the x-direction – second case

The bending moment is given by computer program Belka by SPECBUD [kNm]:

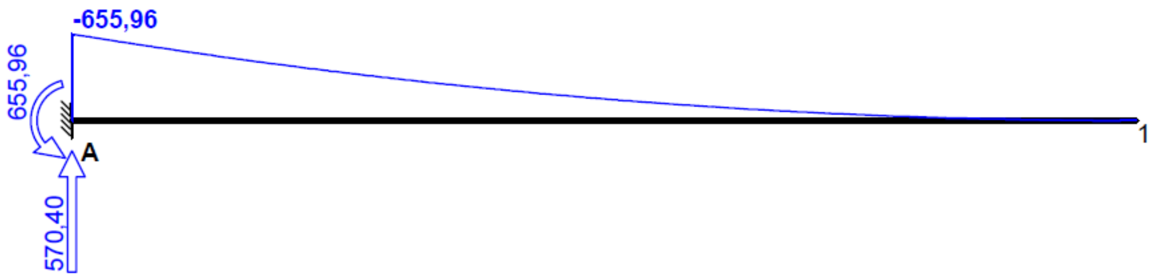


Figure 3.4.35 The bending moment for the foundation P10 in the x-direction – second case

$$M_{Ed,x} \approx 656\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - \frac{0{,}020}{2}m = 1{,}435\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{656\ kNm}{1{,}0\ m \cdot (1{,}435\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}015$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}015} = 0{,}015$$

$$A_{s,min} = 0{,}015 \cdot 1{,}0\ m \cdot 1{,}435\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 10{,}60\ cm^2$$

That gives us #20/0,275 m with total area equal $A_s = 11{,}42\ cm^2$

The simplified static model of the spread foundation in the y-direction:

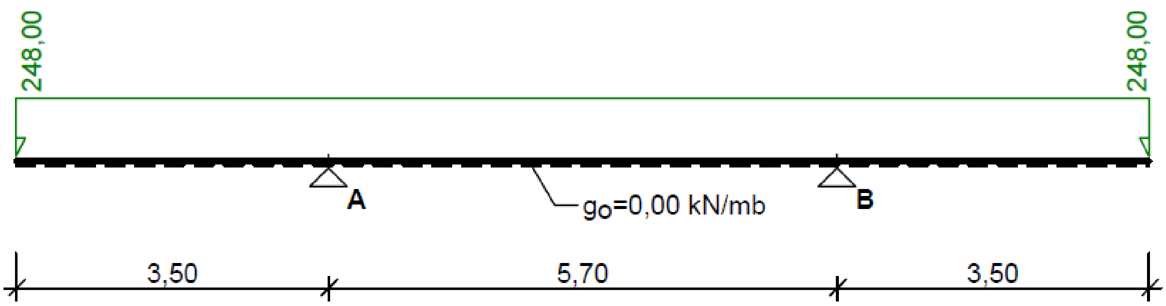


Figure 3.4.36 The static model for the foundation P10 in the y-direction – second case

The bending moment is given by computer program Belka by SPECBUD [kNm]:

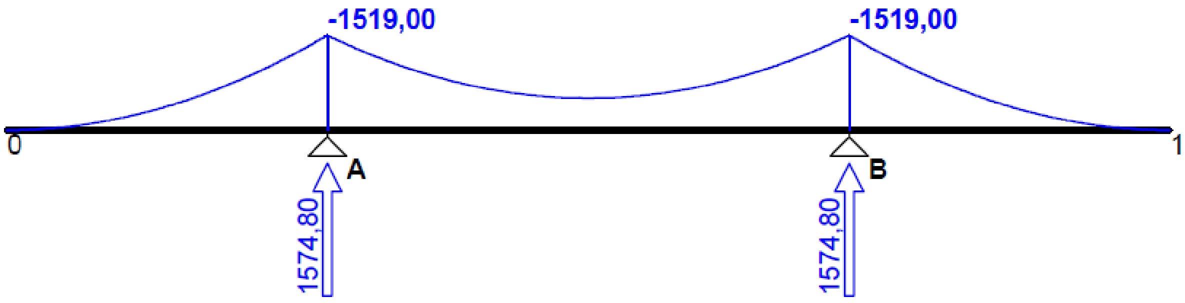


Figure 3.4.37 The bending moment for the foundation P10 in the y-direction – second case

$$M_{Ed,y} \approx 1519\ kNm/m$$

Minimum area of reinforcement:

$$A_{s,min} = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}}$$

Assuming bars #20:

$$d = h - c_{nom} - \emptyset - \frac{\emptyset}{2} = 1{,}5\ m - 0{,}035\ m - -\frac{0{,}020}{2} m = 1{,}455\ m$$

Calculated minimum area of reinforcement:

$$\mu = \frac{M_{Ed}}{b \cdot d^2 \cdot f_{cd}} = \frac{1519\ kNm}{1{,}0\ m \cdot (1{,}455\ m)^2 \cdot 21{,}43\ kPa \cdot 10^3} = 0{,}033$$

$$\omega = 1 - \sqrt{1 - 2\mu} = 1 - \sqrt{1 - 2 \cdot 0{,}033} = 0{,}033$$

$$A_{s,min} = 0{,}033 \cdot 1{,}0\ m \cdot 1{,}455\ m \cdot \frac{21{,}43\ MPa}{435\ MPa} = 23{,}65\ cm^2$$

That gives us #20/0,125 m with total area equal $A_s = 25{,}12\ cm^2$

Taking into account the above two cases of the calculations, the reinforcement which was adopted is #20/0,275 m in x-direction and #20/0,125 m in y-direction.

GEO LIMIT STATE

First case

The sum of the sectional forces:

$M_{yy} = M_{yy,50} + M_{yy,51} = 6712\ kNm$

$N' = N_{Ed,50} + N_{Ed,51} + G_f = 18404\ kN$

$H'_x = H_{Ed,50} + H_{Ed,51} = 222\ kN + 225\ kN = 447\ kN$

<u>The Bearing resistance of spread foundation</u>

$\gamma_k = 18\ kN/m^3$

$\varphi = 30°$

Depth of foundation

D = 6,6 m

The total vertical stress at the founding level:

$$q = \gamma \cdot D = 18 \frac{kN}{m^3} \cdot 6{,}6\ m = 118{,}8\ kPa$$

The effective dimensions of the foundation:

$B' = 5{,}63\ m$

$L' = 12{,}70\ m$

The capacity factors:

$$N_q = e^{\pi \cdot tan\varphi} \cdot \left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right)^2 = 18{,}401$$

$$N_\gamma = 2 \cdot (N_q - 1) \cdot tan\varphi = 20{,}093$$

$$N_c = (N_q - 1) \cdot cot\varphi = 30{,}14$$

The shape factors:

$$s_q = 1 + \frac{B'}{L'} \cdot sin\varphi = 1{,}222$$

$$s_\gamma = 1 - 0{,}3 \cdot \frac{B'}{L'} = 0{,}867$$

$$s_c = \frac{s_q \cdot N_q - 1}{N_q - 1} = 1{,}234$$

Load's inclination factors:

c' = 0 for Fx || B'

$$m = \frac{2 + \frac{B'}{L'}}{1 + \frac{B'}{L'}} = 1{,}693$$

$$i_q = (1 - \frac{F_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^m = 0{,}959$$

$$i_\gamma = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^{m+1} = 0{,}94$$

$$i_c = i_q - \frac{1 - i_q}{N_c \cdot tan\varphi} = 0{,}96$$

Foundation base's inclination factors

Because the base of the foundation is horizontal:

$$b_q = 1$$

$$b_\gamma = 1$$

$$b_c = 1$$

The value of the design drained bearing resistance

$$\frac{R_k}{A'} = q \cdot N_q \cdot b_q \cdot s_q \cdot i_q + 0{,}5 \cdot \gamma_k \cdot B' \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma + c' \cdot N_c \cdot b_c \cdot s_c \cdot i_c = 3388\ kPa$$

$$R_k = 3388\ kPa \cdot 5{,}63\ m \cdot 12{,}7\ m = 242{,}2\ MN$$

$\gamma_R = 1{,}4$

$$R_d = \frac{R_k}{\gamma_R} = \frac{242{,}2\ MPa}{1{,}4} = 173\ MN$$

$V_d = 18404\ kN < R_d = 173000\ kN$

Second case

The sum of the sectional forces:

$M_{yy} = M_{yy,50} + M_{yy,51} = 161\ kNm$

$N' = N_{Ed,50} + N_{Ed,51} + G_f = 19980\ kN$

$H'_x = H_{Ed,50} + H_{Ed,51} = 4\ kN + 7\ kN = 11\ kN$

<u>The Bearing resistance of spread foundation</u>

$\gamma_k = 18\ kN/m^3$

$\varphi = 30°$

Depth of foundation

D = 6,6 m

The total vertical stress at the founding level:

$$q = \gamma \cdot D = 18\frac{kN}{m^3} \cdot 6{,}6\ m = 118{,}8\ kPa$$

The effective dimensions of the foundation:

$B' = 6{,}35\ m$

$L' = 12{,}70\ m$

The capacity factors:

$$N_q = e^{\pi \cdot tan\varphi} \cdot \left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right)^2 = 18{,}401$$

$$N_\gamma = 2 \cdot (N_q - 1) \cdot tan\varphi = 20{,}093$$

$$N_c = (N_q - 1) \cdot cot\varphi = 30{,}14$$

The shape factors:

$$s_q = 1 + \frac{B'}{L'} \cdot sin\varphi = 1{,}25$$

$$s_\gamma = 1 - 0{,}3 \cdot \frac{B'}{L'} = 0{,}85$$

$$s_c = \frac{s_q \cdot N_q - 1}{N_q - 1} = 1{,}264$$

Load's inclination factors:

c' = 0 for Fx || B'

$$m = \frac{2 + \frac{B'}{L'}}{1 + \frac{B'}{L'}} = 1{,}667$$

$$i_q = (1 - \frac{F_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^m = 0{,}987$$

$$i_\gamma = (1 - \frac{H_{Ed}}{V_{Ed} + B' \cdot L' \cdot c' \cdot cot\varphi})^{m+1} = 0{,}98$$

$$i_c = i_q - \frac{1 - i_q}{N_c \cdot tan\varphi} = 0{,}99$$

Foundation base's inclination factors

Because the base of the foundation is horizontal:

$b_q = 1$

$b_\gamma = 1$

$b_c = 1$

The value of the design drained bearing resistance

$$\frac{R_k}{A'} = q \cdot N_q \cdot b_q \cdot s_q \cdot i_q + 0{,}5 \cdot \gamma_k \cdot B' \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma + c' \cdot N_c \cdot b_c \cdot s_c \cdot i_c = 3651\ kPa$$

$R_k = 3651\ kPa \cdot 6{,}35\ m \cdot 12{,}7\ m = 294{,}4\ MN$

$\gamma_R = 1{,}4$

$$R_d = \frac{R_k}{\gamma_R} = \frac{294{,}4\ MN}{1{,}4} = 210{,}3\ MN$$

$V_d = 19980\ kN < R_d = 210300\ kN$

3.4.2. Piles

Minimum area of reinforcement:

$A_{s,bpmin} \geq 0{,}0025 \cdot A_c = 0{,}0025 \cdot \pi \cdot (0{,}875\ m)^2 = 60{,}13\ cm^2$

That gives us 8#32 with total area equal $A_s = 64{,}34\ cm^2$

The nominal concrete cover:

$C_{nom} = C_{min} + \Delta C_{dev}$

$\Delta C_{dev} = 10$ mm

$C_{min} = \max \{ C_{min,b}; C_{min,dur} + \Delta C_{dur,y} - \Delta C_{dur,st} - \Delta C_{dur,add}; 10 \text{ mm} \}$

$C_{min,b} = 32$ mm

$C_{min,dur} = 25$ mm

$\Delta C_{dur,y} = \Delta C_{dur,st} = \Delta C_{dur,add} = 0$

$C_{nom} = 32 \text{ mm} + 10 \text{ mm} = 42 \text{ mm}$

<u>The verification for the most loaded pile:</u>

Two cases should be considered for pile in the calculations - the maximum bending moment and the corresponding axial force to it and the maximum axial force and the corresponding bending moment to it.

According to the calculations the most loaded pile is #6 (the maximum bending moment) and #1 (the maximum axial force) in foundation P6.

ULTIMATE LIMIT STATE

First case

$M_{Ed,max} = 104\ kNm$

$N_{Ed,cor} = 4978\ kN$

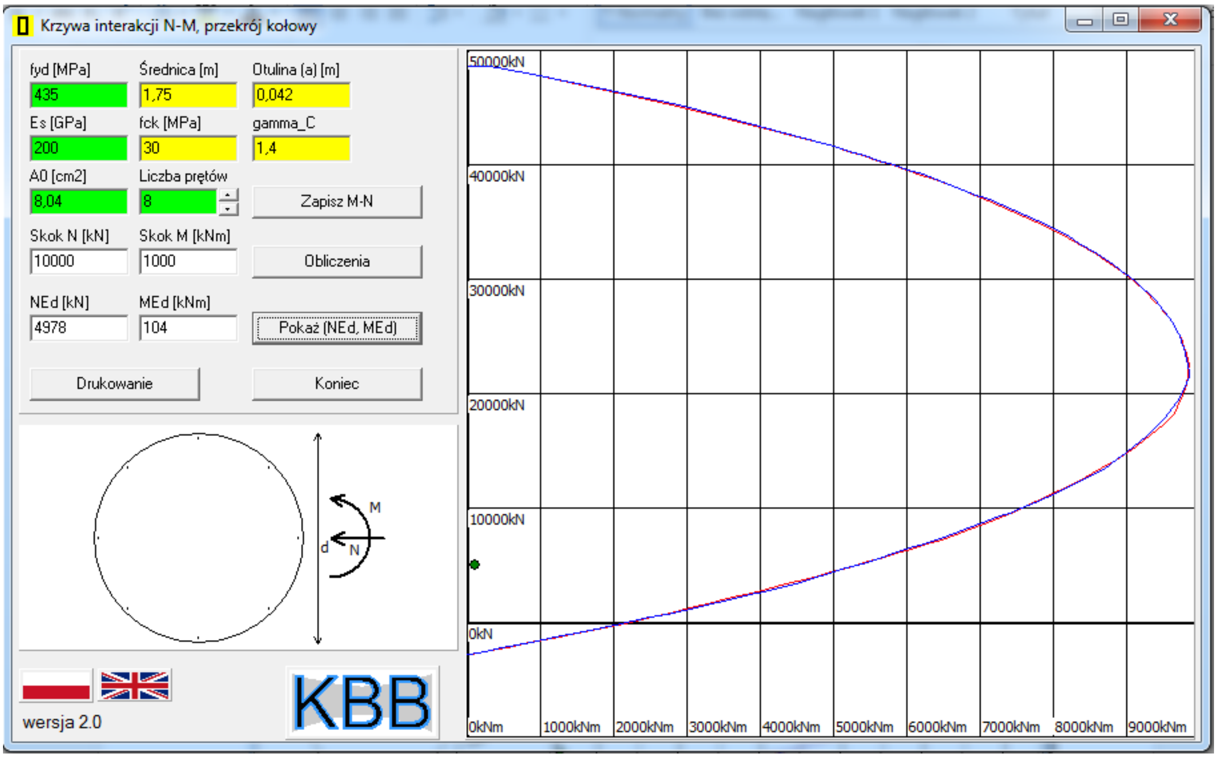


Figure 3.4.38 The curve interaction for the most loaded pile – first case

Second case

$N_{Ed,max} = 5965\ kN$

$M_{Ed,cor} = 31\ kNm$

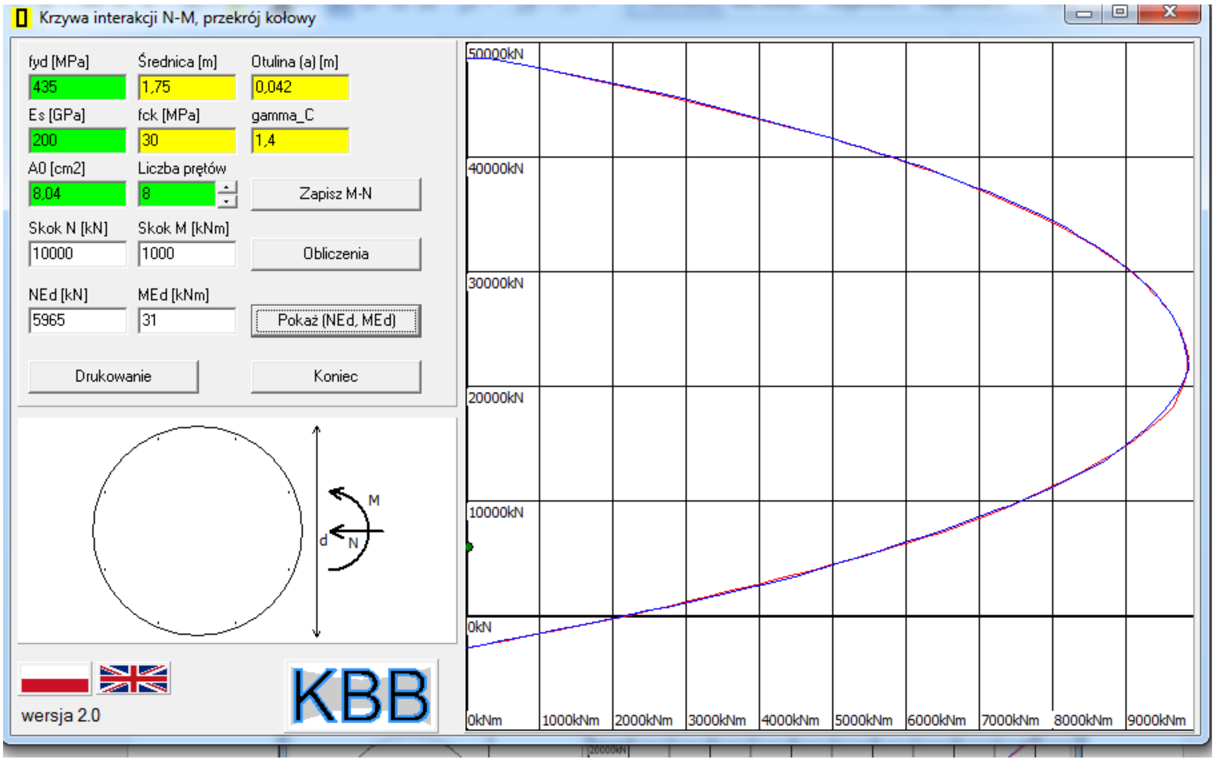


Figure 3.4.39 The curve interaction for the most loaded pile – second case

GEO LIMIT STATE

Characteristics of the soil:

$\gamma_k = 18\ kN/m^3$

$\varphi = 30°$

$F_{c,d} \leq R_{c,d}$

$R_{c,k} = R_{b,k} + R_{s,k}$

$$R_{d,k} = \frac{R_{b,k}}{\gamma_b} + \frac{R_{s,k}}{\gamma_s}$$

$\gamma_b = 1{,}25$

$\gamma_s = 1{,}0$

The weight of the pile is ignored as it is assumed that the pressure at the toe due to the pile weight is similar to the overburden pressure at that depth.

$F_{c,d} = 5965\ kN$

Bearing capacity factor:

$$N_q = e^{\pi \cdot tan\varphi} \cdot \left(\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right)^2 = 18{,}401$$

When $\delta = \varphi$ and there is a single layer of soil:

$$R_{s,k} = A_s \cdot q_{sk} = A_s \cdot \sum \sigma'_h tan\delta = A_s \cdot \sum K_0 \sigma'_v tan\delta = A_s \cdot 0{,}5 \cdot (1 - sin\varphi) \cdot \sigma'_{v0} tan\varphi$$

$$\sigma'_{v0} = \gamma_k \cdot L = 18 \frac{kN}{m^3} \cdot L = 18L\ \frac{kN}{m^3}$$

$$R_{b,k} = A_b \cdot q_b = A_b \cdot \sigma'_{v0} \cdot N_q$$

$$A_s = \pi \cdot D \cdot L = \pi \cdot 1{,}75\ m \cdot L = 5{,}49 \cdot L\ m$$

$$R_{b,k} = 18{,}401 \cdot 18L \cdot \pi \cdot \frac{1{,}75^2}{4} = 797L\ [\frac{kN}{m}]$$

$$R_{s,k} = 5{,}49 \cdot L\ m \cdot 0{,}5 \cdot (1 - sin30°) \cdot 18L\ \frac{kN}{m^3} \cdot tan30° = 14{,}26\ \cdot L^2\ [\frac{kN}{m^2}]$$

$$R_{d,k} = \frac{797L}{1{,}25} + \frac{14{,}26\ \cdot L^2}{1{,}0}$$

The piles verification was calculated for the shortest pile despite the maximum axial force comes from the longest pile.

For L= 9,0 m (Foundation P4):

$$R_{d,k} = \frac{797 \cdot 9}{1{,}25} + \frac{14{,}26\ \cdot 9^2}{1{,}0} = 6893\ kN$$

$$F_{c,d} = 5965\ kN < \ R_{d,k} = 6893\ kN$$

3.5. Bearings

The designed displacements are given by the computer program Autodesk robot structural analysis professional 2014 (third calculative model). In order to get the displacement of creep and shrinkage the additional temperature load ($\Delta T = -60°C$) was applied on the structure. It was assumed that mentioned load is sufficient approximation to the real displacement due to rheology of concrete.

Bearings in the viaduct were splited in 2 cases as follows:

- Abutments (P1, P11)

- Other bearings (P2, P3, P4, P5, P6, P7, P8, P9, P10)

Abutments (P_1, P_{11}):

Displacements:

Creep + shrinkage:
$\delta_{c+s} = 56\ mm$

Temperature variation (for $15°C$):
$\delta_{\Delta T_U} = +12\ mm / -14\ mm$

Temperature variation (for $8°C$):
$\delta_{\Delta T_U} = +7\ mm / -6\ mm$

Breaking load:
$\delta_{BL} = \mp 4\ mm$

Max displacement:
$\delta_{max}{}^{+} = \delta_{c+s} + \delta_{BL} + \Psi_1 \delta_{\Delta T_U}$
$\delta_{max}{}^{+} = 56 + 4 + 0{,}5 \cdot 7 = 64\ mm$
$\delta_{max}{}^{-} = \delta_{BL} + \Psi_1 \delta_{\Delta T_U}$
$\delta_{max}{}^{-} = -4 - 0{,}5 \cdot 14 = -\ 11\ mm$

$H_T = \max(P_1, P_{11}) = 24\ kN$
$N = \max(P_1, P_{11}) = 750\ kN$

Other bearings:

$N = \max(P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9, P_{10}) = 11602\ kN$
$H_T = \max(P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9, P_{10}) = 62\ kN$
$H_L = \max(P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9, P_{10}) = 225\ kN$

3.6. Expansion joints

In this construction neoprene expansion joints would be use. The designed displacements are given by the computer program Autodesk robot structural analysis professional 2014. (third calculative model).

$\delta_{max}{}^{+} = \delta_{c+s} + 1 \cdot \delta_{BL} + \Psi_1 \delta_{\Delta T_U}$

$\delta_{max}{}^{+} = 56 + 1 \cdot 4 + 0{,}5 \cdot 7 = 64\ mm$

$\delta_{max}{}^{-} = 1 \cdot \delta_{BL} + \Psi_1 \delta_{\Delta T_U}$

$\delta_{max}{}^{-} = -1 \cdot 4 - 0{,}5 \cdot 14 = -\ 11\ mm$

4. Conclusions

The project allowed to design the crossing through the valley which was the main objective of this work. According to the calculations the structure is safe and meets the requirements of the eurocodes and national annexes (Polish). The preliminary design can be used to create the final project of this viaduct. This work allowed me to use all the knowledge from 5 years of my studies. I have not done anything similar to it before so it is very important experience for me. The thesis is the result of connecting a few subjects like designing of foundations, concrete structures, prestressed stuctures.

Bibliography

Standards and eurocodes:

- PN-EN 1990:2004
- PN-EN 1991-1-1:2004
- PN-EN 1991-1-4:2004
- PN-EN 1991-2:2007
- PN-EN 1992-1-1:2008
- PN-EN 1992-2:2010
- PN-EN 1997-1:2008

Articles/guidebooks:

- Eurocode 7: Geotechnical design worked examples, Andrew J. Bond, Bernd Schuppener, Giuseppe Scarpelli and Trevor L.L. Orr. European Union, 2013.
- Evaluation of Eurocode 7: Geotechnical design, Trevor L.L. Orr. Dublin,2005
- Designers' guide to Eurocode 2: design of concrete structures, A.W. Beeby and R.S. Narayanan. London, 2005.

ANNEX A1

Calculation of the breaking and acceleration force (breaking load)

$Q_{ik} = 0,6 \cdot \alpha_{Q1}(2Q_{ik}) + 0,1\alpha_{q1}q_{1k}w_I L$

$180\alpha_{Q1} \leq Q_{1k} \leq 900\ kN$

$\alpha_{Q1} = 1,0$

$L = 288\ m$

$w_I = 3,0\ m$

$Q_{ik} = 300\ kN$

$q_{1k} = 9,0\ kN$

$$Q_{ik} = 0,6 \cdot 1,0 \cdot (2 \cdot 300\ kN) + 0,1 \cdot 1,0 \cdot 9,0 \frac{kN}{m^2} \cdot 3,0\ m \cdot 288\ m = 1137,6\ kN$$

$Q_{ik} > 900\ kN$

Because the value of Q_{ik} is higher than 900 kN it was assumed that $Q_{ik} = 900\ kN$

ANNEX A2

Calculation of wind load (wind action)

Because of 9 different lengths of the columns, there are only calculations for the most dangerous pier (the longest). The value of this action was applied in each column.

1. The basics values from the national annex.

The viaduct is located in third wind area in Poland (A = 500 m.a.s.l.)

Basic wind velocity:

$$V_{b,0} = 22[1 + 0{,}0006(A - 300)] = 22[1 + 0{,}0006(500 - 300)] = 24{,}64\ m/s$$

Reference mean (basic) velocity pressure:

$$q_{b,0} = 0{,}30[1 + 0{,}0006(A - 300)]^2 \cdot \left[\frac{20000 - A}{20000 + A}\right] = 0{,}358\frac{kN}{m^2} \approx 0{,}36\ kN/m^2$$

2. The main calculations.

The wind action:

$$F_w = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref}$$

$$c_s c_d = 1{,}0$$

It was assumed that the columns are circular cylinders.

$$h = 39{,}4\ m$$

$$q_p(h) = C_e(h) \cdot q_b$$

$$v_b = c_{dir} \cdot c_{season} \cdot v_{b,0} = 1 \cdot 1 \cdot 24{,}64\frac{m}{s} = 24{,}64\ m/s$$

$$q_b = 0{,}5 \cdot \rho \cdot v_b^2 = 0{,}5 \cdot 1{,}25\frac{kg}{m^3} \cdot \left(24{,}64\frac{m}{s}\right)^2 = 379\ Pa \approx 0{,}38\ kPa$$

$$C_e(h) = 1{,}9 \cdot (\frac{h}{10})^{0{,}26} = 1{,}9 \cdot \left(\frac{37{,}65}{10}\right)^{0{,}26} = 2{,}68$$

$$q_p(h) = 2{,}68 \cdot 0{,}38\ kPa = 1{,}02\ kPa$$

$$c_f = c_{f,0} \cdot \psi_\lambda$$

Equivalent roughness k/b:

$$\frac{k}{b} = \frac{0{,}2\ mm}{2500\ mm} = 8 \cdot 10^{-5}$$

The Reynolds number:

$\upsilon = 15 \cdot 10^{-6} m^2/s$

$$V(z_e) = \sqrt{\frac{2q_p}{\rho}} = \sqrt{\frac{2 \cdot 1020\ Pa}{1{,}25\ kg/m^3}} = 40{,}4\ m/s$$

$$Re = \frac{b \cdot V(z_e)}{\upsilon} = \frac{2{,}5\ m \cdot 40{,}4\ m/s}{15 \cdot 10^{-6} m^2/s} = 6{,}73 \cdot 10^6$$

According to Figure 7.28 in EN 1991-1-4:2005 and the values of Re and k/b:

$c_{f,0} = 0{,}66$

End-effect factor ψ_λ:

Effective slenderness (for circular cylinders)

$L \geq 50\ m \rightarrow \lambda = \min\left(0{,}7 \cdot \frac{L}{b}; 70\right) = \min(11; 70) = 11$

$L < 15\ m \rightarrow \lambda = \min\left(\frac{L}{b}; 70\right) = \min(15{,}76; 70) = 15{,}76$

35 m – 4,76

24,4 m – x

x = 3,32

$\lambda = 15{,}76 - 3{,}32 = 12{,}44$

The solidity ratio φ:

$$\varphi = \frac{A}{A_c} = 1$$

According to Figure 7.36 in EN 1991-1-4:2005 and the values of φ and λ:

$\psi_\lambda = 0{,}71$

$c_f = 0{,}66 \cdot 0{,}71 = 0{,}47$

The wind force:

$F_w = 1 \cdot 0{,}47 \cdot 1{,}02\ kPa \cdot 2{,}5\ m = 1{,}2\ kPa$

ANNEX A3

Calculation of axial forces in model #1 (reactions)

Because of the fact that in 3-dimensions model (column model) there weren't included additional loads like: prestressing loads, additional permanent loads and traffic loads, one extra combination was created in 2-dimenions model in order to get the values of reactions. The results was applied in third calculative model. The reactions were divided by two because of one-beam simplified model.

Combinations	Name	Analysis type	Combi nation	Case nature	Definition
11 (C)	Decompression limit state	Linear Combination	S:QPR		(1+2+3)*1.00+10*0.50
13 (C)	Ultimate limit state of bending	Linear Combination	ULS		(1+3+4+5+9)*1.35+2*1.00
17 (C)	Ultimate limit state of bending - Ved (1,2)	Linear Combination	ULS		(1+3+4+5+9)*1.35+2*1.20
32 (C)	SLS:QPR/1=3*1.00 + 2*1.00	Linear Combination	S:QPR	dead	(3+2)*1.00
33 (C)	SLS:QPR/2=3*1.00 + 2*1.00 + 10*0.50	Linear Combination	S:QPR	dead	(3+2)*1.00+10*0.50
34 (C)	SLS:QPR/3=3*1.00 + 2*1.00 + 12*0.50	Linear Combination	S:QPR	dead	(3+2)*1.00+12*0.50
39 (C)	ULS (Reactions) withous self weight	Linear Combination	ULS		2*1.00+(3+4+5+9)*1.35
43 (C)	ULS (Reactions) without self weight P=1,2	Linear Combination	ULS		2*1.20+(3+4+5+9)*1.35

Figure 3.4.40 The combination table (reactions)

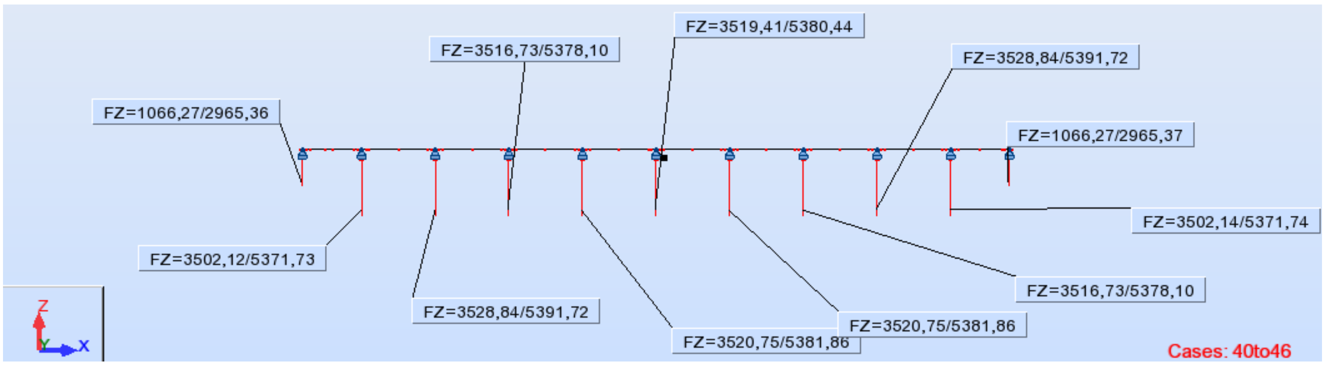


Figure 3.4.41 The reactions (ULS)

ANNEX A4
Calculation of prestressing loads

All the dimensions have been taken from the drawing #6 - "Prestressing Layout".

$$P_0 = \sigma_{P0} \cdot A_p = 1120\ MPa \cdot 4 \cdot 19 \cdot 1{,}4\ cm^2 = 11917\ kN$$

$$P_\infty = \sigma_{P\infty} \cdot A_p = 1000\ MPa \cdot 4 \cdot 19 \cdot 1{,}4\ cm^2 = 10640\ kN$$

The prestressing force used in calculative model:

$P = 1000\ kN$

$$tan\alpha = \frac{2f_1}{L} = \frac{2 \cdot (1{,}286\ m - 0{,}275)}{9\ m} = 0{,}224$$

$$q_1 = \frac{2f_1 \cdot P}{L^2} = \frac{2 \cdot (1{,}286\ m - 0{,}275\ m) \cdot 1000\ kN}{(9\ m)^2} = 24{,}32\ kN/m$$

$$V_1 = q_1 \cdot L = 24{,}321 \frac{kN}{m} \cdot 9m = 218{,}89\ kN$$

$$q_2 = \frac{2f_2 \cdot P}{L^2} = \frac{2 \cdot (1{,}4294\ m - 0{,}275\ m) \cdot 1000\ kN}{(12\ m)^2} = 16{,}033\ kN/m$$

$$q_3 = \frac{2f_3 \cdot P}{L^2} = \frac{2 \cdot (1{,}718\ m - 1{,}4294\ m) \cdot 1000\ kN}{(3\ m)^2} = 64{,}133\ kN/m$$

$e_1 = 0{,}084\ m$

$M_1 = Pe_1 = 1000\ kN \cdot 0{,}084\ m = 84\ kNm$

$e_2 = 1{,}37\ m - 0{,}275\ m - 0{,}649\ m = 0{,}446\ m$

$M_2 = Pe_2 = 1000\ kN \cdot 0{,}446\ m = 446\ kNm$

$1{,}4294\ m - 0{,}275\ m = ax^2$

$1{,}1544 = 144a$

$a = 0{,}00802$

$$V_2 = P \cdot tan\beta = P \cdot 2 \cdot a \cdot x = 1000\ kN \cdot 2 \cdot 0{,}00802 \cdot 9\ m = 144{,}36\ kN$$

ANNEX A5

The results of decompression limit state

x [m]	Mg,1	Mg,2	Mg,3	Mg,4	Mg,5	Mg,6	Mg,7	Mg,8	Mg,9	Mg,10	Mg,e	Mg(x,t=0)	Mg(x,t=10000 days)
0	-65,64	-3,66	0	-0,84	0	0	0	0	0	0	-76,73	-70,14	-74,753
3	3601,7	-812,55	233,11	-66,48	18,71	-5,54	1,58	-0,45	0,12	-0,02	2630,2	2970,18	2732,215
6	6096,3	-1636,2	464,11	-134,54	38,3	-10,9	3,13	-0,88	0,26	-0,04	4271,3	4819,6	4435,811
9	7487,5	-2445,1	697,27	-200,17	57,22	-16,46	4,69	-1,34	0,38	-0,06	4742,4	5584,01	4994,848
12	7798,8	-3254	930,62	-265,8	76,14	-21,82	6,24	-1,77	0,51	-0,09	4090,5	5268,86	4444,008
15	6934,5	-4048,1	1163,97	-333,87	96,06	-27,18	7,8	-2,23	0,64	-0,11	2354,1	3791,48	2785,3
18	4988,1	-4857	1397,33	-399,5	114,65	-32,74	9,35	-2,69	0,77	-0,13	-597,06	1218,09	-52,515
21	1940,5	-5680,6	1630,68	-467,56	133,57	-38,1	10,91	-3,12	0,89	-0,15	-4372,6	-2473,03	-3802,736
24	-2295,5	-6500,7	1859,94	-533,19	152,49	-43,61	12,46	-3,55	1,02	-0,17	-9567,9	-7350,8	-8902,798
27	-552,91	-2523,9	1049,37	-304,61	86,71	-24,83	7,12	-2,05	0,57	-0,1	-4560,2	-2264,63	-3871,515
30	0	1454,45	231,69	-66,12	18,05	-5,35	1,45	-0,44	0,14	-0,03	-718,94	1633,84	-13,106
33		4875,27	-586	163,86	-48,24	13,44	-4	1,17	-0,32	0,05	2037,4	4415,23	2750,77
36		7188,66	-1403,68	402,36	-114,5	32,92	-9,22	2,68	-0,76	0,13	3751,9	6098,55	4455,888
39		8394,6	-2221,36	632,34	-180,8	51,71	-14,9	4,29	-1,22	0,21	4297,4	6664,84	5007,646
42		8585,87	-3039,04	870,83	-249,5	71,19	-20,35	5,79	-1,66	0,28	3758,4	6223,42	4497,892
45		7470,77	-3856,72	1100,8	-315,8	89,98	-25,8	7,4	-2,12	0,35	2050,7	4468,88	2776,14
48		5344,93	-4660,06	1339,3	-382,1	108,76	-31,24	8,9	-2,56	0,43	-699,2	1726,39	28,477
51		2111,35	-5477,74	1569,3	-448,4	128,24	-36,69	10,52	-3	0,51	-4533,8	-2145,89	-3817,448
54		-2302,7	-6302,8	1799,3	-514,7	146,93	-42,14	10,02	-3,44	0,58	-9688,9	-7208,93	-8944,923
57		-553,31	-2306,69	991,5	-282,1	81,89	-23,57	6,68	-1,93	0,32	-4614	-2087,22	-3855,938
60		0	1586,16	195,35	-52,6	14,45	-4,7	1,1	-0,41	0,06	-765,99	1739,41	-14,37
63			5000,15	-630,34	176,9	-50,59	14,94	-4,1	1,18	-0,2	1997,1	4507,94	2750,373
66			7302,44	-1426,5	406,41	-118	33,8	-9,68	2,77	-0,47	3718,6	6190,72	4460,229
69			8503,97	-2252,2	644,11	-183,1	52,67	-14,9	4,29	-0,72	4270,9	6754,19	5015,894
72			8571,66	-3048,4	873,62	-250,5	71,53	-20,5	5,88	-0,98	3696,4	6202,38	4448,222
75			7538,98	-3844,5	1103,1	-315,6	90,39	-26	7,4	-1,25	2037,9	4552,52	2792,265
78			5394,39	-4670,2	1332,6	-380,6	109,25	-31,2	8,91	-1,51	-705,27	1761,64	34,803
81			2137,79	-5466,4	1570,3	-448	128,11	-36,8	10,5	-1,76	-4702,3	-2106,24	-3923,482
84			-2302,67	-6286,6	1791,6	-513,1	146,97	-42	12	-2,02	-9524,2	-7195,71	-8825,667
87			-550,98	-2366,2	990,98	-283,3	81,8	-22,8	6,53	-1,12	-4584,5	-2145,14	-3852,678
90			0	1671,6	189,27	-47,74	15,92	-4,65	1,24	-0,18	-741,95	1825,41	28,258
93				5015,4	-641,1	179,45	-52,71	14,83	-4,33	0,72	2015,8	4512,25	2764,7
96				7284,8	-1443	406,63	-115,9	33,02	-9,62	1,61	3688,9	6157,83	4429,572
99				8503,6	-2244	642,23	-184,5	52,5	-14,9	2,55	4278,4	6756,94	5021,99
102				8584,6	-3075	869,41	-250,4	71,98	-20,5	3,46	3740,7	6183,72	4473,62
105				7533,7	-3877	1105	-316,3	90,16	-25,8	4,35	2034,4	4514,67	2778,467
108				5426,2	-4678	1332,2	-382,1	109,6	-31,4	5,25	-714,18	1781,56	34,542
111				2105,5	-5451	1567,8	-448	127,8	-36,6	6,19	-4547,5	-2128,67	-3821,858
114				-2273,2	-6285	1795	-513,9	146,4	-41,3	7,09	-9544,5	-7165,2	-8830,703
117				-538,41	-2379	984,25	-285,1	82,84	-23,1	3,96	-4578,9	-2154,64	-3851,629
120				0	1684,6	190,07	-54,79	14,74	-3,65	0,73	-738,26	1831,68	32,722
123					5046,6	-633,5	175,53	-53,4	14,8	-2,46	2017,6	4547,64	2776,591

126	7378,5	-1428	405,85	-117	33,3	-5,75	3688,8	6267,34	4462,39
129	8497,5	-2251	636,18	-185	52,8	-8,88	4276,5	6741,33	5015,914
132	8569,4	-3045	866,5	-249	71,3	-12	3736,9	6201,17	4476,153
135	7528,3	-3869	1106,4	-317	90,8	-15,1	2112,7	4524,61	2836,287
138	5396,1	-4663	1336,7	-380	109	-18,4	-721,84	1780,21	28,775
141	2172,7	-5487	1567,1	-448	129	-21,6	-4557,1	-2088,27	-3816,416
144	-2255	-6285	1797,4	-512	147	-24,5	-9556,4	-7132,47	-8829,221
147	-581,9	-2274	994,05	-284	81,9	-13,6	-4566,2	-2078,04	-3819,745
150	0	1612,9	188,05	-62,2	13,9	-2,63	-728,7	1749,94	14,892
153		4968,4	-649,9	175,9	-50,8	8,87	2024	4452,41	2752,516
156		7317,2	-1422	413,9	-115	19,82	3692,1	6213,89	4448,644
159		8514,4	-2227	636,1	-184	30,76	4276,5	6770,96	5024,803
162		8578,2	-3032	874,2	-252	41,71	3733,7	6210,53	4476,763
165		7513,4	-3871	1113	-316	53,21	2022,2	4492,55	2763,291
168		5395,9	-4676	1334	-381	64,16	-731,39	1737,7	9,337
171		2068,7	-5481	1573	-449	75,66	-4569,8	-2213,28	-3862,816
174		-2297	-6285	1795	-514	86,61	-9572,8	-7214,35	-8865,244
177		-531,5	-2338	976,3	-290	48,43	-4556,6	-2135,18	-3830,202
180		0	1602,8	199,5	-52,3	8,23	-721,04	1758,22	22,738
183			5000,2	-633	174	-30	2029,8	4511,08	2774,17
186			7296,8	-1410	412	-68,3	3738,5	6230,6	4486,102
189			8492,8	-2242	638	-108	4278,4	6780,89	5029,175
192			8568	-3074	876	-148	3733,8	6221,51	4480,141
195			7516,6	-3851	1102	-186	2104,7	4581,15	2847,621
198			5476	-4683	1340	-224	-735,07	1908,02	57,857
201			2111,2	-5460	1566	-265	-4575,3	-2047,8	-3817,071
204			-2291	-6285	1792	-303	-9580,7	-7086,63	-8832,486
207			-553,7	-2447	987	-169	-4542,3	-2183,25	-3834,571
210			0	1626	196	-28,3	-712,12	1794,24	39,788
213				5112	-636	105,6	2033,3	4581,92	2797,872
216				7304	-1426	246,1	3736,3	6124,46	4452,769
219				8516	-2258	379,9	4270,9	6638,46	4981,154
222				8587	-3048	513,7	3720,9	6052,22	4420,275
225				7525	-3839	654,2	2086,3	4340,83	2762,652
228				5473	-4670	788,1	-759,1	1590,87	-54,109
231				2138	-5502	921,9	-4604,8	-2442,78	-3956,194
234				-2227	-6285	1056	-9688,9	-7456,33	-9019,143
237				-563	-2380	578,3	-4712,5	-2365,23	-4008,284
240				0	1691	110,4	-706,07	1801,78	46,285
243					5012	-381	2046,1	4630,79	2821,486
246					7271	-849	3713,7	6422,79	4526,392
249					8505	-1316	4297,4	7188,14	5164,622
252					8563	-1808	3754,2	6755,14	4654,447
255					7530	-2276	2042,1	5254,31	3005,728

258	5436	-2744	-712,07	2692,89	309,418
261	2087	-3235	-4551	-1147,67	-3530,029
264	-2265	-3701	-9614,7	-5966,84	-8520,314
267	-588	-788	-4381,9	-1375,98	-3480,124
270	0	2265	-473,91	2265,02	347,769
273		4618	2349,3	4618,39	3030,048
276		5936	4088	5936,34	4642,509
279		6112	4745,6	6111,65	5155,429
282		5182	4273,5	5182,13	4546,054
285		3198	2716,5	3198,49	2861,111
288		-80	-77,73	-80	-78,411

Table 1 Self weight

x [m]	Mp,1	Mp,2	Mp,3	Mp,4	Mp,5	Mp,6	Mp,7	Mp,8	Mp,9	Mp,10	Mp,e	Mp (x,t=0)	Mp (x,t=10000 days)
0	0	0	0	0	0	0	0	0	0	0	0	0	0,00
3	-627,93	58,71	-16,94	4,9	-1,37	0,4	-0,12	0,03	-0	0	-553,7	-6939,6	-5982,53
6	-965,56	119,21	-34,48	9,9	-2,8	0,8	-0,23	0,07	-0	0	-802,4	-10405	-8763,39
9	-1078,7	179,59	-51,18	14,71	-4,24	1,2	-0,34	0,1	-0	0,01	-833,1	-11188	-9201,78
12	-1011,2	240,09	-68,72	19,54	-5,58	1,6	-0,46	0,13	-0	0,01	-683	-9826,5	-7718,97
15	-800,48	298,64	-85,42	24,36	-7,01	2	-0,57	0,16	-0,1	0,01	-385,8	-6773,1	-4687,42
18	-432,37	359,14	-103	29,55	-8,4	2,41	-0,69	0,2	-0,1	0,01	39,45	-1825,3	-195,10
21	50,4	417,68	-119,7	34,19	-9,79	2,81	-0,8	0,23	-0,1	0,01	649,8	4468,88	6036,86
24	347,96	477,7	-136,7	39,02	-11,2	3,2	-0,92	0,26	-0,1	0,02	1006	8571,3	9790,99
27	56,89	431,13	-78,18	22,4	-6,34	1,81	-0,52	0,15	-0	0,01	707,1	5092,25	6630,16
30	-446	382,87	-16,73	4,87	-1,48	0,39	-0,11	0,03	-0	0	201	-907,72	1253,99
33		-470,33	44,72	-12,7	3,55	-1	0,29	-0,1	0,02	-0,01	-180,2	-5190	-2731,91
36		-733,58	103,25	-29,6	8,41	-2,4	0,69	-0,2	0,06	-0,01	-414,2	-7786	-5170,75
39		-855,46	164,7	-47,1	13,3	-3,8	1,08	-0,3	0,09	-0,02	-501,2	-8670,5	-6055,64
42		-828,59	223,23	-63,4	18,3	-5,2	1,49	-0,4	0,12	-0,03	-441,2	-7800	-5375,09
45		-664,44	281,75	-81,6	23,2	-6,6	1,9	-0,5	0,15	-0,03	-244,3	-5317,6	-3244,03
48		-353,54	343,21	-97,8	28,2	-8	2,29	-0,7	0,19	-0,04	108,4	-1027,2	532,51
51		102,73	404,66	-115	33,1	-9,4	2,7	-0,8	0,22	-0,05	600,3	4978,33	5804,57
54		347,94	463,18	-132	37,9	-11	3,1	-0,9	0,25	-0,06	875,5	8441,05	8781,46
57		65,09	416,36	-72,9	20,5	-5,9	1,71	-0,5	0,14	-0,03	579,5	5058,41	5671,10
60		-446	371,46	-14,4	3,68	-1,2	0,31	-0,1	0,03	-0,01	93,05	-1027,5	417,82
63			-488	46,32	-13,2	3,82	-1,09	0,31	-0,1	0,02	-267,8	-5384,3	-3436,63
66			-743,2	104,9	-30,6	8,52	-2,46	0,7	-0,2	0,05	-481,5	-7892,9	-5700,49
69			-863,7	163,4	-47,4	13,4	-3,86	1,11	-0,3	0,07	-548,3	-8786,4	-6437,50
72			-838	224,1	-63,6	18,4	-5,26	1,5	-0,4	0,1	-473,4	-7904,7	-5643,02
75			-663,5	284,8	-81,1	23,2	-6,63	1,91	-0,5	0,12	-262,2	-5264,5	-3362,81
78			-356,8	345,5	-98,5	28,1	-8,06	2,3	-0,7	0,15	117,8	-1048,5	596,39
81			112,63	401,9	-115	32,9	-9,43	2,7	-0,8	0,17	633,8	5062,1	6076,44
84			348,51	460,4	-132	37,8	-10,8	3,09	-0,9	0,2	913,2	8415,67	9055,82

87	52,85	417,1	-72,7	21,1	-5,89	1,65	-0,5	0,11	621,2	4930,42	5947,10
90	-446	370,6	-11,9	3,87	-1,09	0,29	-0,1	0,02	111,6	-1004,2	561,83
93		-482	46,9	-13	3,73	-1,1	0,31	-0,07	-240,2	-5299,1	-3208,32
96		-746	104	-30	8,62	-2,4	0,7	-0,16	-461,1	-7927,7	-5557,72
99		-864	167	-47	13,5	-3,9	1,11	-0,24	-534,9	-8744,2	-6326,32
102		-839	225	-64	18,3	-5,2	1,5	-0,33	-467	-7903,1	-5595,24
105		-674	284	-81	23,3	-6,6	1,91	-0,42	-252,2	-5394,9	-3323,06
108		-345	345	-98	28,1	-8	2,3	-0,51	109,8	-912,37	573,49
111		108	404	-115	33	-9,4	2,69	-0,5	618,8	5034,81	5957,56
114		348,5	462	-132	37,6	-11	3,09	-0,68	902,1	8429,25	8976,71
117		63,14	416	-73	20,9	-5,9	1,72	-0,37	599	5033,38	5809,41
120		-446	371	-13	3,77	-1,2	0,33	-0,07	110,2	-1021,2	546,95
123			-475	46,3	-13,3	3,79	-1,1	0,24	-242,3	-5228,2	-3204,82
126			-745	105	-30,4	8,55	-2,5	0,55	-463,9	-7912,1	-5574,39
129			-863	165	-47,2	13,3	-3,8	0,88	-538,5	-8755,8	-6355,71
132			-840	224	-63,9	18,5	-5,2	1,17	-465,9	-7928,6	-5594,02
135			-667	283	-81	23,3	-6,7	1,48	-257,1	-5330	-3342,46
138			-356	344	-98,4	28,2	-8,1	1,78	104,1	-1056,9	492,54
141			113	403	-115	32,6	-9,4	2,1	612,5	5081,41	5922,60
144			348	462	-132	37,7	-11	2,41	906,2	8426,39	9006,26
147			63	417	-72,8	20,7	-5,9	1,3	611	5042,44	5901,06
150			-446	370	-13	4,02	-1,2	0,22	119,2	-1020,9	614,42
153				-474	45,5	-13	3,75	-0,85	-257,8	-5234,9	-3322,50
156				-747	106	-31	8,61	-1,93	-466,3	-7922,4	-5595,12
159				-864	165	-47	13,5	-3,01	-538,5	-8764,7	-6358,10
162				-837	225	-65	18,5	-4,08	-468,9	-7889,8	-5605,81
165				-667	283	-81	23,2	-5,16	-252,4	-5330,7	-3307,42
168				-348	344	-98	28,2	-6,27	111,3	-961,34	571,31
171				107	402	-115	32,9	-7,35	600,5	5000,97	5811,75
174				348	462	-132	37,7	-8,36	902,2	8433,42	8978,20
177				57,3	416	-71	21	-4,7	617,3	4989,05	5934,20
180				-446	371	-13	4,07	-0,94	108,7	-1011,9	538,49
183					-482	45,6	-13	2,93	-242,2	-5321,2	-3228,90
186					-746	104	-30	6,8	-462	-7930,2	-5565,24
189					-866	167	-47	10,6	-534,9	-8764,5	-6331,75
192					-836	223	-64	14,2	-465,9	-7907,6	-5588,11
195					-672	286	-81	18	-239,2	-5360,7	-3217,38
198					-351	342	-98	21,8	122,6	-1023	638,75
201					101	402	-115	25,6	626,9	4927,32	5988,80
204					348	461	-132	29,2	913,3	8410,66	9054,70
207					58,2	416	-73	15,8	624,4	4974,51	5983,04
210					-446	371	-14	3,37	117,4	-1011,9	603,06
213						-482	45,8	-10,5	-247,1	-5320,9	-3265,48
216						-749	105	-23,7	-476,6	-7952,1	-5680,00
219						-864	167	-36,5	-548,1	-8741,1	-6423,80
222						-840	224	-49,7	-484,7	-7932	-5734,94

225	-668	285	-63,2	-263,9	-5310,5	-3388,24
228	-345	343	-76,3	92,18	-941,32	434,42
231	84,3	402	-89,5	590,9	4727,59	5667,40
234	348	461	-102	875,5	8421,98	8776,28
237	58,4	415	-56,2	606,5	4974,51	5849,28
240	-446	371	-10,2	115,6	-1016,3	588,40
243		-477	35,8	-232,8	-5255,6	-3141,56
246		-748	81,8	-439,7	-7942,6	-5402,62
249		-864	129	-501,3	-8761,1	-6080,00
252		-836	175	-417,8	-7880,1	-5222,19
255		-665	221	-191,9	-5283,9	-2844,57
258		-349	268	175,4	-954,55	1050,92
261		111	313	700,3	5053,28	6569,15
264		348	358	1007	8411,97	9755,39
267		55	324	656,9	4521,43	6103,37
270		-446	-160	46,08	-7224,4	-1591,88
273			-553	-378,1	-6587,8	-4580,96
276			-803	-680,3	-9563,8	-7628,48
279			-912	-845,7	-10872	-9210,96
282			-834	-800	-9944,6	-8621,79
285			-542	-551,4	-6464	-5838,46
288			0	0	0	0,00

Table 2 Prestressing load

x [m]	M,apl
0	-17,36
3	795,12
6	1263,86
9	1409,13
12	1219,77
15	707,63
18	-160,33
21	-1329,86
24	-2818,53
27	-1350,76
30	-206,48
33	635,42
36	1122,31
39	1285,72
42	1115,1
45	599,78
48	-228,12
51	-1379,51
54	-2842,54

57	-1371,97
60	-224,88
63	598,73
66	1109,61
69	1275,8
72	1118,55
75	616,9
78	-197,77
81	-1378,02
84	-2850,08
87	-1362,21
90	-550,97
93	605,05
96	1114,15
99	1278,64
102	1109,14
105	616,23
108	-200,16
111	-1424,67
114	-2855,97
117	-1361,35
120	-216,37
123	626,23
126	1113,81
129	1277,81
132	1107,99
135	614,69
138	-233,83
141	-1384,54
144	-2858,72
147	-1357,82
150	-213,72
153	606,9
156	1114,69
159	1277,91
162	1107,09
165	612,92
168	-236,5
171	-1388,08
174	-2822,66
177	-1355,48
180	-211,77
183	608,45
186	1115,83
189	1278,52
192	1117,99

195	612,85
198	-205,2
201	-1388,95
204	-2816,81
207	-1351,35
210	-209,36
213	609,14
216	1114,75
219	1275,85
222	1113,47
225	627,62
228	-213,22
231	-1398,74
234	-2873,81
237	-1352,79
240	-239,88
243	634,42
246	1121,81
249	1285,72
252	1115,61
255	622,12
258	-226,59
261	-1377,48
264	-2842,52
267	-1302,77
270	-139,83
273	699,62
276	1215,59
279	1408,91
282	1267,48
285	782,19
288	-16,63

Table 3 Additional permanent loads

	t = 15	t = -8
x [m]	M,t1	M,t2
0	0	0
3	665,58	-358,13
6	1331,82	-706,96
9	1966,34	-1055,8
12	2632,59	-1404,63
15	3267,11	-1753,46
18	3933,35	-2102,3
21	4599,6	-2461,39
24	5248,35	-2800,78

27	5111,04	-2723,55
30	4966,86	-2647,76
33	4822,68	-2572,27
36	4685,37	-2496,78
39	4541,2	-2423,51
42	4397,02	-2345,8
45	4252,84	-2270,32
48	4115,53	-2194,83
51	3971,36	-2119,34
54	3832,01	-2043,6
57	3871,35	-2065,23
60	3912,67	-2086,87
63	3953,98	-2108,5
66	3993,33	-2130,13
69	4034,64	-2151,76
72	4075,95	-2173,39
75	4115,3	-2195,02
78	4156,61	-2217,29
81	4197,92	-2238,92
84	4237,61	-2260,17
87	4226,11	-2253,85
90	4214,04	-2247,53
93	4201,97	-2241,21
96	4190,48	-2234,89
99	4178,41	-2228,57
102	4166,34	-2222,25
105	4154,84	-2215,74
108	4142,77	-2209,61
111	4131,27	-2203,1
114	4119,2	-2196,84
117	4123,33	-2199,11
120	4127,67	-2201,38
123	4131,8	-2203,72
126	4136,14	-2205,93
129	4140,48	-2208,13
132	4144,82	-2210,54
135	4148,95	-2212,81
138	4153,29	-2215,08
141	4157,63	-2217,35
144	4161,76	-2219,6
147	4157,49	-2217,32
150	4153,36	-2215,05
153	4149,02	-2212,77
156	4144,68	-2210,5
159	4140,35	-2208,22
162	4136,21	-2205,95

165	4131,88	-2203,68
168	4127,54	-2201,39
171	4123,2	-2199,12
174	4119,07	-2196,84
177	4131,07	-2203,11
180	4142,57	-2209,44
183	4154,64	-2215,77
186	4166,71	-2222,1
189	4178,21	-2228,44
192	4190,28	-2234,77
195	4202,35	-2241,1
198	4214,42	-2247,76
201	4225,91	-2254,09
204	4237,95	-2260,09
207	4196,64	-2238,01
210	4155,33	-2216,34
213	4115,98	-2194,67
216	4074,67	-2173
219	4033,36	-2151,33
222	3994,01	-2129,66
225	3952,7	-2107,99
228	3911,38	-2086,33
231	3872,04	-2064,66
234	3831,66	-2043,78
237	3975,83	-2119,4
240	4113,14	-2195,02
243	4257,32	-2270,64
246	4401,5	-2346,26
249	4545,67	-2421,88
252	4682,98	-2497,5
255	4827,16	-2573,12
258	4971,34	-2648,74
261	5108,65	-2724,36
264	5245,16	-2799,98
267	4610,64	-2455,01
270	3944,39	-2105,57
273	3278,15	-1756,12
276	2611,9	-1406,68
279	1977,38	-1057,23
282	1311,14	-707,79
285	676,62	-339,95
288	0	0

Table 4 Temperature load

	for T=15		for T=-8	
x [m]	M (t=0)	M (t=10000)	M (t=0)	M (t=10000)
0	-87,5	-92,113	-87,5	-92,113
3	-2841,54	-2122,40652	-3353,39	-2634,2615
6	-3655,48	-2397,81028	-4674,87	-3417,2003
9	-3211,85	-1814,63256	-4722,92	-3325,7026
12	-2021,59	-738,89588	-4040,2	-2757,5059
15	-640,481	439,06492	-3150,77	-2071,2201
18	1199,108	1558,73496	-1818,72	-1459,09
21	2965,785	3204,06336	-564,71	-326,43164
24	1026,147	693,83884	-2998,42	-3330,7262
27	4032,383	3963,4014	115,0883	46,1064
30	3003,072	3517,83184	-804,238	-289,47816
33	2272,017	3065,62488	-1425,46	-631,85012
36	1777,573	2750,13028	-1813,5	-840,94472
39	1550,708	2508,32704	-1931,65	-974,02796
42	1736,996	2436,40808	-1634,41	-935,00192
45	1877,476	2258,3104	-1384,1	-1003,2696
48	2528,79	2390,63272	-626,39	-764,54728
51	3438,607	2593,28888	393,2568	-452,06112
54	305,5844	-1090	-2632,22	-4027,805
57	3534,894	2378,86572	566,604	-589,42428
60	2443,381	2134,90716	-556,389	-864,86284
63	1699,321	1889,45812	-1331,92	-1141,7819
66	1404,128	1866,0176	-1657,6	-1195,7124
69	1260,906	1871,51608	-1832,29	-1221,6839
72	1454,24	1961,72724	-1670,43	-1162,9428
75	1962,616	2104,00044	-1192,54	-1051,1596
78	2593,717	2511,73128	-593,233	-675,21872
81	3676,803	2873,89816	458,3833	-344,52184
84	488,6812	-501,12096	-2760,21	-3750,011
87	3536,125	2845,26732	296,1454	-394,71268
90	2377,214	2146,14256	-853,571	-1084,6424
93	1919,153	2262,41324	-1302,44	-959,17676
96	1439,555	2081,24312	-1773,13	-1131,4419
99	1380,567	2063,51444	-1822,92	-1139,9756
102	1472,914	2070,69448	-1721,38	-1123,6005
105	1813,375	2149,05348	-1371,92	-1036,2365
108	2740,419	2479,25236	-435,771	-696,93764
111	3547,108	2776,66644	379,9233	-390,51856
114	467,6816	-650,36036	-2690,34	-3808,3804
117	3579,058	2658,09408	417,8383	-503,12592
120	2657,977	2427,1362	-506,548	-737,3888

123	2011,544	2263,8998	-1156,22	-903,8602
126	1537,166	2069,87824	-1633,87	-1101,1568
129	1333,603	2008,25576	-1840,7	-1166,0492
132	1452,952	2062,53044	-1724,73	-1115,1496
135	1883,778	2182,99176	-1297,1	-997,88824
138	2566,106	2364,12624	-618,079	-820,05876
141	3687,414	2800,4554	499,9238	-387,0346
144	516,0815	-600,80108	-2674,6	-3791,4811
147	3685,325	2802,24104	497,9202	-385,16396
150	2591,971	2492,26944	-592,234	-691,93556
153	1898,92	2111,4264	-1281,97	-1069,4686
156	1478,498	2040,55552	-1699,09	-1137,0345
159	1354,33	2014,78576	-1819,96	-1159,4992
162	1495,956	2046,14632	-1675,12	-1124,9337
165	1840,698	2134,72828	-1327,08	-1033,0507
168	2603,626	2407,9218	-560,839	-756,5432
171	3461,209	2622,45288	300,0491	-538,70712
174	455,9476	-650,16676	-2702,01	-3808,1218
177	3563,927	2814,05764	396,837	-353,03236
180	2605,863	2420,7434	-570,142	-755,2616
183	1875,671	2231,04048	-1309,53	-954,16452
186	1499,617	2120,04564	-1694,79	-1074,3594
189	1384,038	2065,05304	-1819,29	-1138,272
192	1526,995	2105,16428	-1685,53	-1107,3607
195	1934,432	2344,2696	-1287,29	-877,4554
198	2787,075	2598,61812	-444,015	-632,47188
201	3603,527	2895,73248	363,527	-344,26752
204	626,1961	-475,61716	-2622,82	-3724,6372
207	3538,233	2895,44124	320,9083	-321,88376
210	2650,673	2511,15756	-535,162	-674,67744
213	1928,11	2199,52216	-1227,22	-955,80284
216	1324,45	1924,8496	-1799,38	-1198,9854
219	1189,871	1849,87976	-1902,47	-1242,4652
222	1230,74	1795,81128	-1831,1	-1266,0237
225	1634,346	1978,37784	-1396	-1051,9672
228	2392,016	2122,78156	-606,839	-876,07344
231	2822,093	2248,482	-146,257	-719,868
234	7,67224	-1200,84668	-2930,05	-4138,5667
237	3244,408	2476,11716	196,7933	-571,49784
240	2602,188	2451,37764	-551,892	-702,70236
243	2138,235	2443,01024	-1125,75	-820,96976
246	1802,789	2446,3324	-1571,09	-927,5476
249	1985,555	2643,17	-1498,22	-840,60256
252	2332,124	2889,36052	-1258,12	-700,87948
255	3006,131	3196,85592	-694,009	-503,28408

258	3997,418	3619,42144	187,3783	-190,61856
261	5082,46	4215,96264	1165,955	299,45764
264	2225,192	1015,1364	-1797,38	-3007,4336
267	4147,999	3625,796	615,174	92,971
270	-3127,06	588,25168	-6152,04	-2436,7283
273	369,2482	787,78676	-2147,89	-1729,3482
276	-1105,87	-464,42668	-3115,16	-2473,7167
279	-2363,11	-1657,93388	-3880,41	-3175,2389
282	-2839,44	-2152,69016	-3848,9	-3162,1552
285	-2145,03	-1856,84428	-2653,31	-2365,1293
288	-96,63	-95,041	-96,63	-95,041

Table 5 The bending moments (DLS)