CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Civil Engineering

Department of Concrete and Masonry Structures

STEEL – CONCRETE COMPOSITE FLYOVER

MASTER THESIS

PART C: STRUCTURAL ANALYSIS

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Content

1. Introduction

Static analysis has 2 parts: assessment of ULS and SLS. Dimensions and reinforcement of the superstructure are based on structural analysis, while the other parts are designed only on the basis of experience.

The single span integral bridge serves as a highway overpass above the highway D11. The structure is modeled in SCIA Engineering program. The values of internal forces are subtracted from two cross-sections of the main girder. The first cross-section is in support – 0 m, and the second one is in the mid-span - 23,8 m.

The results of bending moment M_y, shear force V_z and normal force N from the individual load cases are further combined in Microsoft Excel, where other calculations are performed.

Because of limited available time, the design is based on the elastic analysis, long-term deformations were not analysed only a certain stress reserve was left for these effects.

1.1. Used programs

SCIA Engineer 18.1 – student license

AutoCAD 2018 – student license

Microsoft Excel 2010

Microsoft Word 2010

1.2. Characteristic parameters of materials

Concrete reinforcement B500B:

- *Characteristic yield strength*: f_{yk} = 500 MPa
- *Design yield strength*: γ_s = 1,15; $f_{yd} = 500/\gamma_s$ = 434,8 MPa
- *Elastic modulus*: E_s = 200000 MPa
- *Shear modulus:* G_s = 81000 MPs
- *Coefficient of thermal expansion:* α_s = 0,000012
- *Poisson's ratio:* $\nu_s = 0,3$
- *Density:* ρ_s = 7850 kg/m³

Concrete strength class C50/60:

- *Characteristic compressive strength*: f_{ck} = 50 MPa
- *Design compressive strength*: γ_c = 1,5 ; fcd = 50/γ_c = 33,3 MPa
- $f_{ctk,0.95}$ = 5,3 MPa; $f_{ctk,0.05}$ = 2,9 MPa; f_{ctm} = 4,1 MPa
- *Elastic modulus*: E_{cm} = 37000 MPa
- *n – ratio*: $n_0 = E_a/ E_{cm}$ = 210000/37000 = 5,676
- *Poisson's ratio:* v_c = 0,2
- *Coefficient of thermal expansion:* α_s = 0,000012
- *Density:* ρ_c = 2500 kg/m³

Concrete strength class C35/45:

- *Characteristic compressive strength*: f_{ck} = 35 MPa
- *Design compressive strength*: γ_c = 1,5 ; fcd = 35/γ_c = 23,3 MPa
- $f_{ctk,0.95}$ = 4,2 MPa; $f_{ctk,0.05}$ = 2,2 MPa ; f_{ctm} = 3,2 MPa
- *Elastic modulus*: E_{cm} = 34000 MPa
- *n – ratio*: $n_0 = E_a/ E_{cm}$ = 210000/34000 = 6,176
- *Poisson's ratio:* v_c = 0,2
- *Coefficient of thermal expansion:* α_s = 0,000012
- *Density:* ρ_c = 2500 kg/m³

Construction steel S460:

- *Characteristic yield strength:* $f_{y,a,k}$ = 410 MPa for nominal thickness ***63 < t < 80 mm***
- *Design yield strength for* γ_{M0} *= 1,0*: $f_{y,a,d}$ = 410 MPa
- *Design yield strength for* γ_{M0} *= 1,1:* $f_{y,a,d}$ = 372,7 MPa
- *Elastic modulus*: E_a = 210000 MPa
- *Shear modulus:* G_a = 81000 MPs
- *Coefficient of thermal expansion:* α_a = 0,000012
- *Poisson's ratio:* v_a *= 0,3*
- *Density:* ρ_a = 7850 kg/m³

2. Loading analysis

2.1. Permanent load

2.1.1. Self-weight of the structure

	width	depth	lenth	volume	density	weght	n	total weght
	mm	mm	mm	m3	kg/m3	t		t
precast edge	2.9	0.12	46	16.008	2500	40.02	2	80.04
precast middle	3.15	0.12	46	17.388	2500	43.47	2	86.94
upper flange	0.3	0.04	47.6	0.571	7850	4.48	4	17.94
web	0.02	1.4	47.6	1.333	7850	10.46	4	41.85
bottom flange	0.63	0.06	47.6	1.799	7850	14.12	4	56.50
∑	weight of one composite beam in the middle					72.54		283.26

Table 1. The self-weight of the composite precast beam

During calculation of internal forces, the self-weight of the structure is automatically calculated in the program SCIA Engineering.

2.1.2. Road surfacing

Bridge equipment	ρ_k kN/m3	h m	g kN/m2	
Sidewalk ledge	25	0.34	8.5	
Traffic barrier	-	-	1.2	kN/m
Railings	-	-	0.75	kN/m

2.1.3. Layout of the carriageway

Layer	ρ_k kN/m3	h m	g_m kN/m2	k_{sup} -	g_{sup} kN/m2	k_{inf} -	g_{inf} kN/m2
Asphalt mixture SMA-11S	25	0.04	1	1.4	1.4	0.8	0.8
Protective insulation	25	0.055	1.125		1.575		0.9
Waterproofing barrier	23	0.005	0.115		0.161		0.092
Adhesive penetrating coating					0		0
Total			**2.24**		3.136		1.792

2.2. Live load

2.2.1. Vertical live load. Load models.

Division of the carriageway and numbering of notional lanes

*carriageway width **w***	9.45	m
number of notional lanes n_1	3	m
width of notional lane w_1	3	m
width of remaining area	0.45	m

For the evaluation of road traffic effects associated with ULS verifications and with SLS verifications, four different load models, LM1 to LM4, are considered in EN 1991-2:

2.2.1.1. Load model n. 1 (LM1) – TS and UDL systems

Position	*Tandem system (TS) -Axle load* Q_{ik} *[kN]*	*Uniformly distributed load (UDL)* q_{ik} *[kN]*
Notional lane n.1	300	9
Notional lane n.1	200	2.5
Notional lane n.1	100	2.5
Another notional lane	0	2.5
Remaining area	0	2.5

classes	α_{Q1}	α_{Q2}	α_{Q3}	α_{q1}	α_{q2}	$\alpha_{qi(i>2)}$	α_{qr}
1st	1	1	1	1	2.4	1.2	1.2

Position	*Tandem system (TS) -Axle load* $\alpha_{Qi}*Q_{ik}$ *[kN]*	*Uniformly distributed load (UDL)* $\alpha_{qi}*q_{ik}$ *[kN/m2]*
Notional lane n.1	300	9
Notional lane n.1	200	6
Notional lane n.1	100	3
Another notional lane	0	3
Remaining area	0	3

2.2.1.2. Load model n. 2 (LM2) – local load

The Load model n. 2 consists of a single axle $\beta * Q_{ak}$ on specific rectangular tire contact areas, 0,35 x 0,6 m. The single axial load equals to 400 kN.

2.2.1.3. Load model n. 3 (LM3) – special vehicles

The Load model n. 3 is a single vehicle 1800/200 with a specific weight of 1800 kN, which velocity is less or equal to 70 km/hour. The vehicle moves only in one of the lanes (e.g. Lane 1) along the bridge. During the LM3, the LM1 must not be applied (on SCIA program), also vehicles with weight above five tons are not allowed to the bridge. Tire contact area is 1,2*0,15 m.

2.2.1.4. Load model n. 4 (LM4) – crowd loading

Load model n. 4 consists of the uniformly distributed load 5 KN/m2, created by a crowd of people.

2.2.2. Horizontal live load

2.2.2.1. Braking and acceleration forces

Braking force Q_{lk} is acting at the surfacing level of the carriageway.

$$Q_{lk} = 0{,}6\alpha_{Q1}(2Q_{1k}) + 0{,}10\alpha_{q1}q_{1k}w_1L$$
$$180\alpha_{Q1}\,(kN) \le Q_{lk} \le 900\,(kN) \qquad (1.1)$$

From the formula *(1.1)* the braking force equals to *374,3 kN.* The braking force in the uniformly distributed area *(*L*w = 452,2 m²) is equal to ***0,83 kN/m².*** Vertical braking force is 25% of horizontal one, *0.21 kN/m².*

2.2.2.2. Centrifugal force

The centrifugal force will not be considered in this case, because of no inclinations in the bridge.

2.2.2.3. Wind load

Terrain category: **II** (area with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacles.

			without traffic	*with traffic*
depth in z direction	**d_{tot}**	m	**1.6**	**3.6**
width in x direction	**b**	m	**12.6**	**12.6**
	b/d_{tot}	-	7.88	3.5
force coefficient for bridges	**$c_{fx,0}$**	-	1.3	1.4
the basic wind speed	**v_b**	m/s	25.0	25.0
turbulence factor	**k1**		1.0	1.0
roughness length	**z_o**	m	0.05	0.05
roughness length (terrain II)	**$z_{o,II}$**	m	0.05	0.05
reference height of the deck	**z**	m	6.4	7.5
orography coefficient	**$c_o(z)$**	-	1.0	1.0
density of the air	**ρ**	kg/m3	1.25	1.25
turbulence intensity	**$I_{v(z)}$**	-	0.21	0.20
terrain factor	**k_r**	-	0.19	0.19
roughness factor	**$c_r(z)$**	-	0.92	0.95
exposure factor	**c_e (z)**	-	2.08	2.17
the wind load factor	**C**	-	2.70	3.04
wind load	**W**	kN/m2	**1.05**	**1.19**
wind in y direction	**W_y**	kN/m3	0.3	0.3

2.2.3. Thermal actions

Thermal actions should be assessed by the uniform temperature component and the temperature difference components.

Uniform temperature component

Extreme air temperature in the shade from ČSN EN 1991-1-5, NA .2.23:

T_{max} = 40 °C; T_{min} = -32 °C;

Uniform bridge temperature components for Type 2 - Composite deck

$T_{e.max} = T_{max} + 4 = 44,5$ °C

$T_{e.min} = T_{min} + 4 = -27{,}5\ °C$

The initial bridge temperature at the time that the structure is restrained $T_0 = 10\ °C$

The maximum contraction range temperature component $\Delta T_{N,con} = T_0 - T_{e.min} = -37{,}5\ °C$

The maximum expansion range temperature component $\Delta T_{N,exp} = T_{e.max} - T_0 = 34{,}5\ °C$

Temperature difference components

The *Figure 1* represents, that temperature difference during cooling $\Delta T_{con} = -10\ °C$ and during heating $\Delta T_{exp} = 10\ °C$.

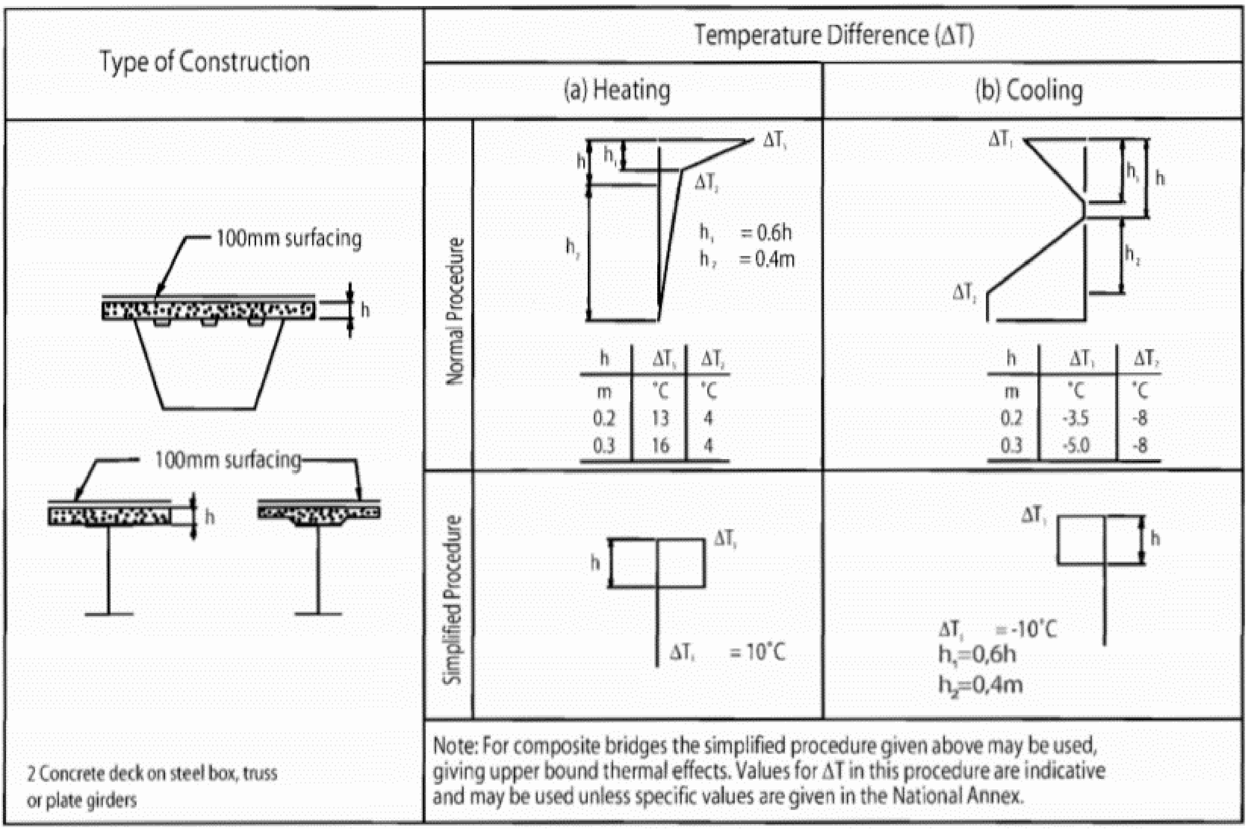


Figure 1. Temperature difference for composite deck

2.2.4. Soil action

Abutments are designed as a rigid structure, therefore, no interaction with backfill is expected, only during expansion of the bridge in hot weather. The modulus of subsoil reaction *kh* is calculated according to Schmitt formula *(1.1)*. The properties of the backfill are taken from the ČSN 736244. The GT3 and GT4 soil properties were taken from the closest area to the highway D11.

$$k_h = 2{,}1\left(\frac{E_{oed}^{4/3}}{(EI)^{1/3}}\right)$$

where:	EI	-	bending stiffness of the structure [MNm^2/m]
	E_{oed}	-	oedometric modulus [MPa]

(1.1) Modulus of Subsoil Reaction According to Schmitt formula.

abutment	h =	8	m
	b =	1	m
	I =	42.6667	m4
C35/45:	Ecm =	33.5	Gpa
	EI =	1429333	MNm2/m

	Eoed	***kh***
soil	[Mpa]	kN/m2
G1	355	46861
G2	161	16328

piles	r =	0.6	m
	I =	0.10174	m4
C35/45:	Ecm =	33.5	Gpa
	EI =	3408.16	MNm2/m

	Eoed	***kh***
soil	[Mpa]	kN/m2
GT3	555	636459
GT4	40	19089

Soil classification *(Figure 2):*

G1 – well graded gravel, medium dense; deformation modulus E_{def} is between 250 – 390 MPa

G2 – poorly graded gravel, medium dense; deformation modulus E_{def} is between 100-190MPa

GT3 – dense soil, rock

GT4 – silty sand, dense soil.

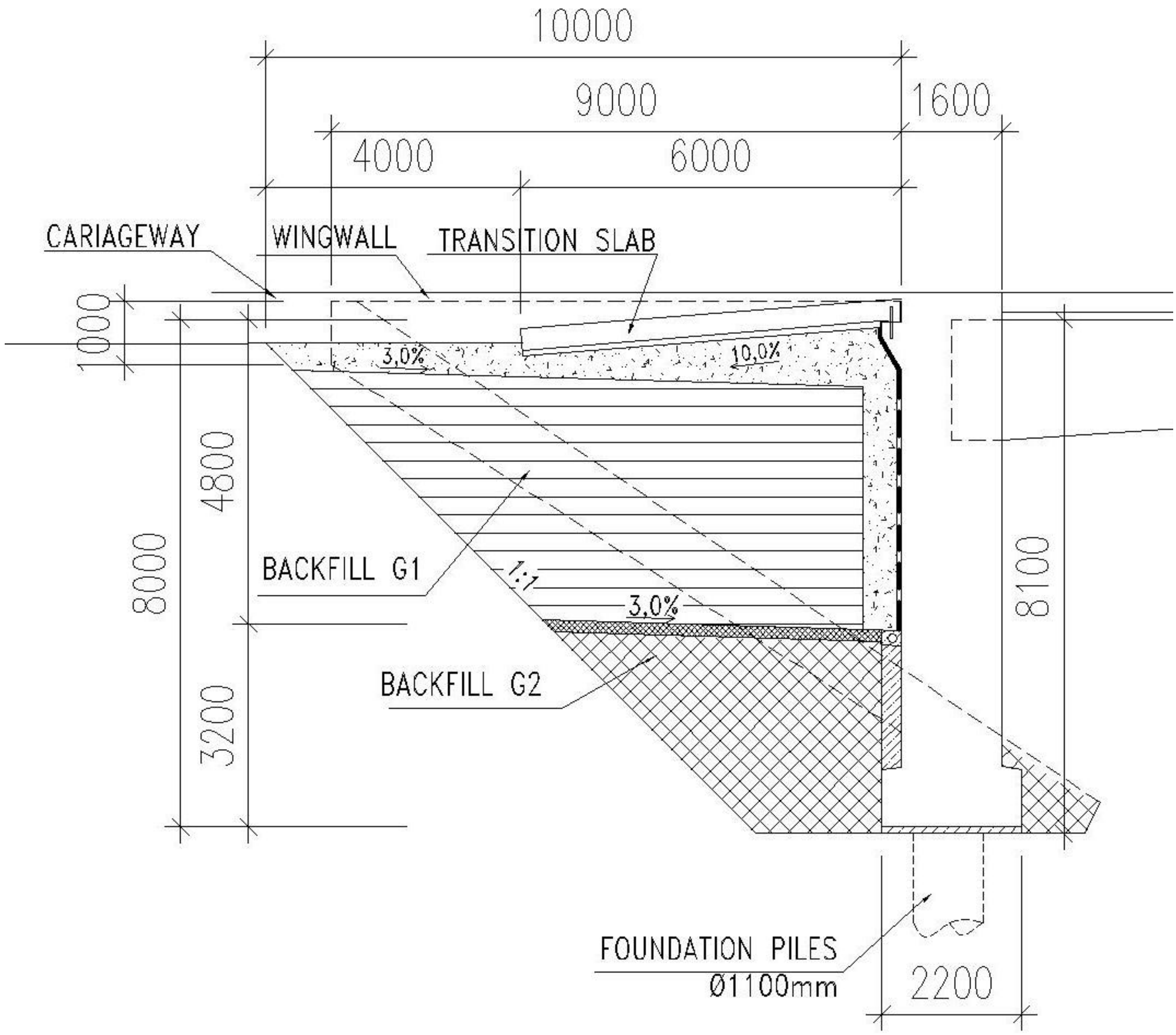


Figure 2. The Backfill

3. Calculation of internal forces

3.1. Scheme of the structure

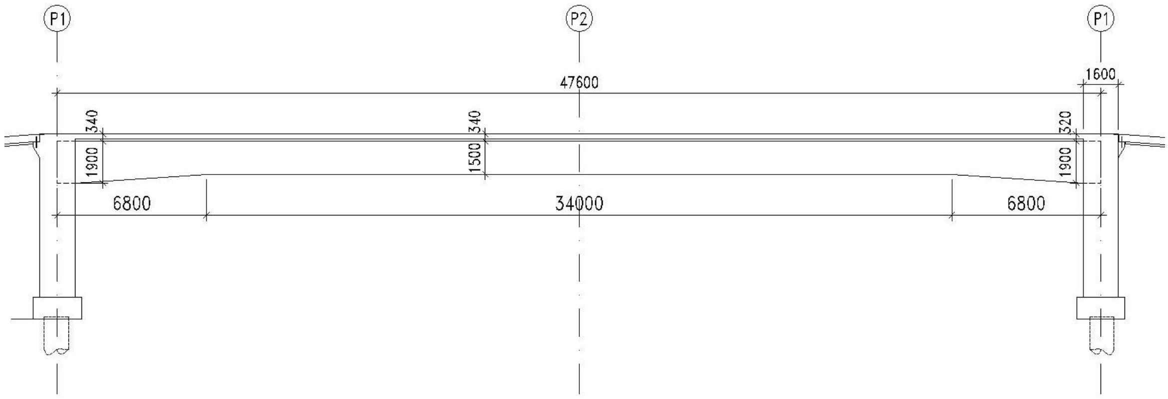


Figure 3. Scheme of the structure

3.2. Overview of steel cross section

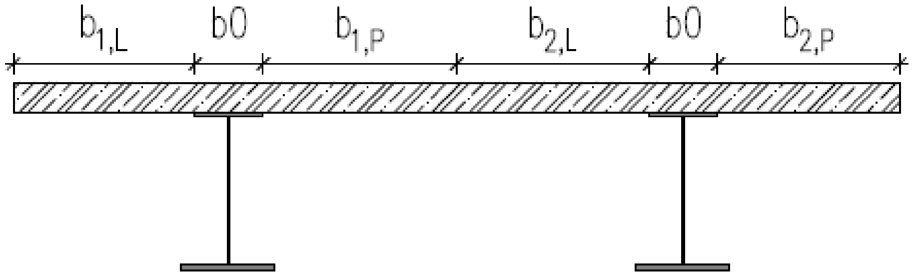
position	***c/s***	***bottom flange***			***web***			***upper flange***		
		width	thickness	material	width	thickness	material	width	thickness	material
		mm	mm		mm	mm		mm	mm	
support	P1	630	60	S460	1800	20	S460	300	40	S460
mid span	P2	630	60	S460	1400	20	S460	300	40	S460

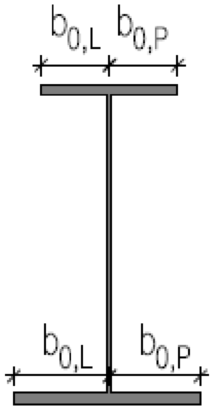
Table 2. Cross-section details of steel beam

position	***c/s***	***RC in cast-in-situ slab***			***RC in precast slab***		
		profile	***spacing***	***material***	***profile***	***spacing***	***material***
		mm	mm		mm	mm	
support	P1	28	200	B500B	20	150	B500B
mid span	P2	20	200	B500B	20	150	B500B

Table 3. Cross-section details of reinforcement

3.3. Effective width





3.3.1. Steel part

			support	***mid-span***	
			P1	**P2**	
Total length		L		47600	mm
factor			0,30	0,60	-
Effective length		***Le***	***28560***	***28560***	***mm***
Upper flange					
Flange thickness		t	**40**	**40**	mm
Left part of the flange	*Flange width in the left part*	$b_{0,L}$	150	150	mm
	Area of all longitudinal RC	$A_{sl,L}$	0	0	mm^2
	Ortotropy factor	$\alpha_{0,L}$	1	1	-
	Coefficient	κ	0,0053	0,0053	-
	Effective width factor	β	1,000	1,000	-
	Effective flange width on the left	$b_{eff,L}$	150,0	150	mm

Right part of the flange	*Flange width in the right part*	$b_{0,R}$	150	150	mm
	Area of all longitudinal RC	$A_{sl,R}$	0	0	mm^2
	Ortotropy factor	$\alpha_{0,R}$	1	1	-
	Coefficient	κ	0,0053	0,0053	-
	Effective width factor	β	1,000	1,000	-
	Effective flange width on the right	$b_{eff,R}$	150,0	150	mm
Effective width of upper flange		b_{eff}	**300**	**300**	mm

Bottom flange					
Flange thickness		t	**60**	**60**	mm
Left part of the flange	*Flange width in the left part*	$b_{0,L}$	315	315	mm
	Area of all longitudinal RC	$A_{sl,L}$	0	0	mm^2
	Ortotropy factor	$\alpha_{0,L}$	1	1	-
	Coefficient	κ	0,0110	0,01102941	-
	Effective width factor	β	1,000	1,000	-
	Effective flange width on the left	$b_{eff,L}$	315	315	mm
Right part of the flange	*Flange width in the right part*	$b_{0,R}$	315	315	mm
	Area of all longitudinal RC	$A_{sl,R}$	0	0	mm^2
	Ortotropy factor	$\alpha_{0,R}$	1,000	1,000	-
	Coefficient	κ	0,0110294	0,01102941	-
	Effective width factor	β	1,000	1	-
	Effective flange width on the right	$b_{eff,R}$	315	315	mm
Effective width of upper flange			**630**	**630**	mm

Table 4. The Effective width of steel flange

3.3.2. Concrete part

Effective width of concrete slab for the girder on the edge				
Total length L = 47,6 m		**support**	**mid span**	
		P1	**P2**	
	Le/8	3570	3570	mm
Width of steel flange	b_0	300	300	mm
Width of left flange	$b_{1,L}$	1175	1175	mm
Width of the right flange	$b_{1,R}$	1425	1425	mm
Effective width value	$b_{e,1,L}$	1175	1175	mm
	$b_{e,1,R}$	1425	1425	mm
Reduction factor	$\beta_{e,1,L}$	1,000	1,000	mm
	$\beta_{e,1,R}$	1,000	1,000	mm
Reduced effective width	$b_{eff,1,L}$	1175	1175	mm
	$b_{eff,1,R}$	1425	1425	mm
Effective width of concrete slab for the girder on the edge	$b_{eff,1}$	**2900**	**2900**	mm

Table 5. The Effective width of precast concrete slab

For the central beam effective width remains the same as the real width of concrete slab, 3,15 m**.**

3.4. SCIA model

The foundation piles were modeled as a 1D member – column, which has flexible node support in the Z-axis. The soil action to piles is created as line support with stiffness:

- k_h=19 MN/m^2 – GT4 soil type, acts in the distance of 5,5 m from the bottom of the pile
- k_h= 636 MN/m^2 – GT4 soil type, acts in the distance of 0,5 m from the top of the pile

The abutment was modeled as a 2D member – wall, which is supported by foundation piles in a rigid node. The soil action to abutment is designed as surface support with stiffness:

- k_h=16 MN/m^2 – G2 soil type, acts in the distance of 3,2m from the bottom of abutment
- k_h=47 MN/m^2 – G1 soil type, acts in the distance of 4,8 m from the top of the abutment

The static scheme of soil action to the structure is shown in the *Figure 4.*

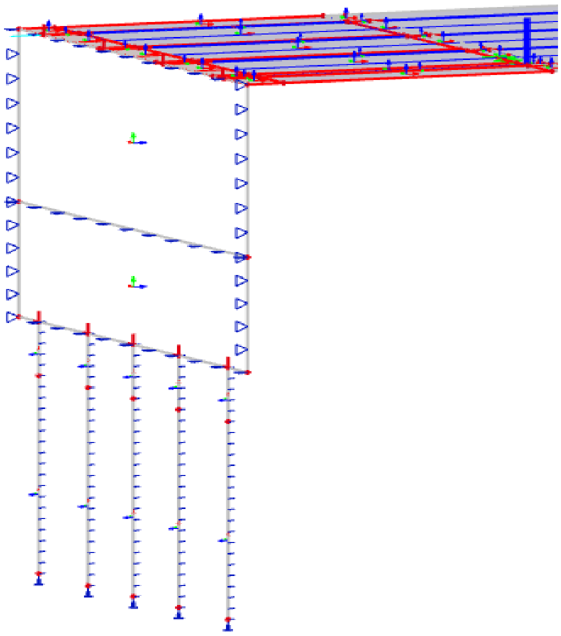


Figure 4. The static scheme of soil action to the structure

The steel girders were designed as a 1D member - plate ribs, which were rigidly supported on abutment.

The concrete deck was designed as a 2D member – plate. In the area of negative moment, the concrete slab is modeled as orthotropic *(Fig. 5. red color slab)* and in the mid-span as isotropic (Fig. 5. grey color slab). Because in longitudinal direction, close to support concrete slab does not carry any load, only reinforcement.

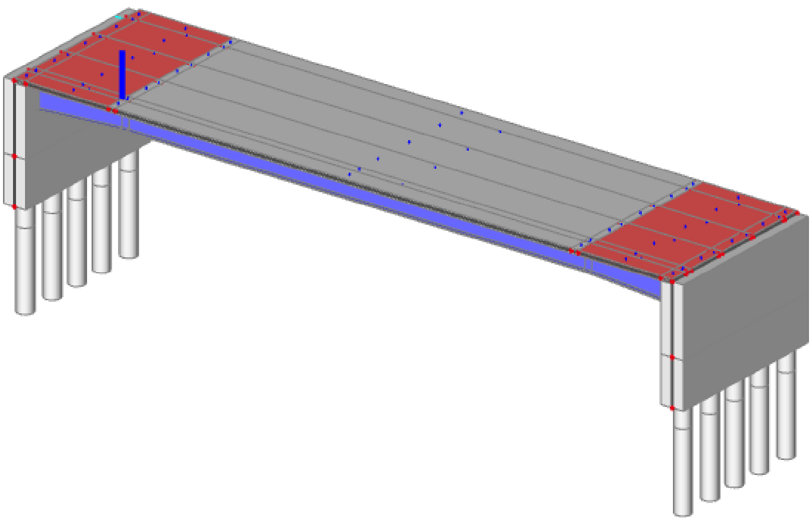


Figure 5. 3D Model of Integral Bridge on SCIA Engineering

3.5. Inputs. List of loads

ZS1	*permanent load*	*$G_{m1\ s.w}$ - self weight of the structure (simple support)*
ZS2	*permanent load*	*G_{m2} - load from fresh concrete (simple support)*
ZS3	*permanent load*	*G_c -carriageway (rigid support)*
ZS4	*permanent load*	*$G_{b.e.}$ - bridge equipment*
ZS5	*live load*	*LM1_TS_My*
ZS6	*temporary load*	*LM1_TS_Vz*
ZS7	*temporary load*	*LM1_UDL*
ZS8	*temporary load*	*LM2*
ZS9	*temporary load*	*LM3_1800/200_My*
ZS10	*temporary load*	*LM3_1800/200_Vz*
ZS11	*temporary load*	*LM4*
ZS12	*temporary load*	*LM4 _only in sidewalk*
ZS13	*temporary load*	*B - braking force*
ZS14	*temporary load*	*Tr + expansion rage temperature*
ZS15	*temporary load*	*Tr - construction rage temperature*
ZS16	*temporary load*	*Tn + heating temperature difference*
ZS17	*temporary load*	*Tn - cooling temperature difference*

3.6. Example of results from SCIA engineering

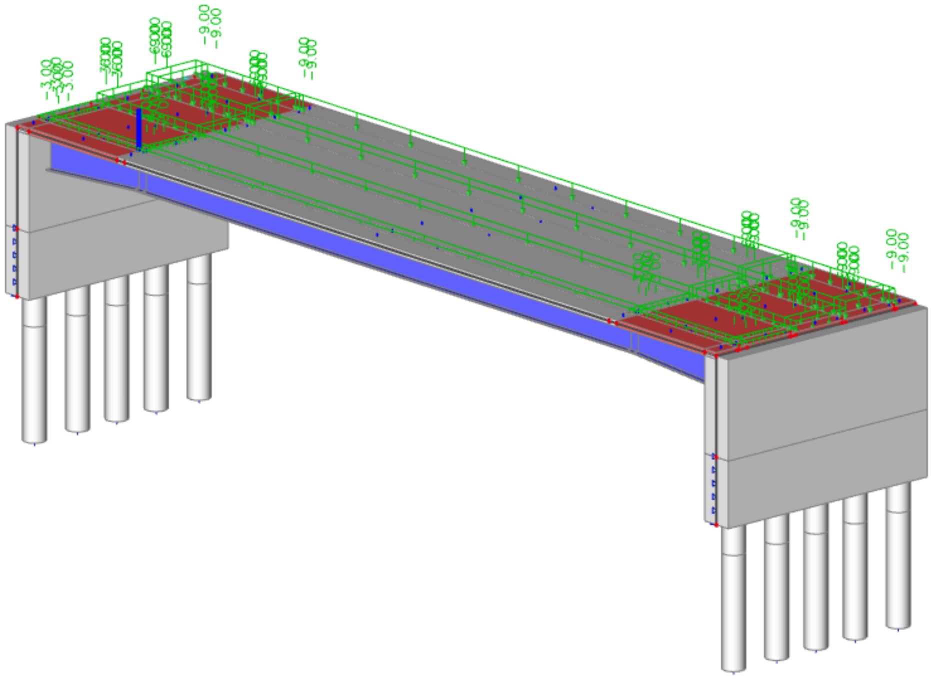


Figure 6. Application of LM1_UDL to the structure

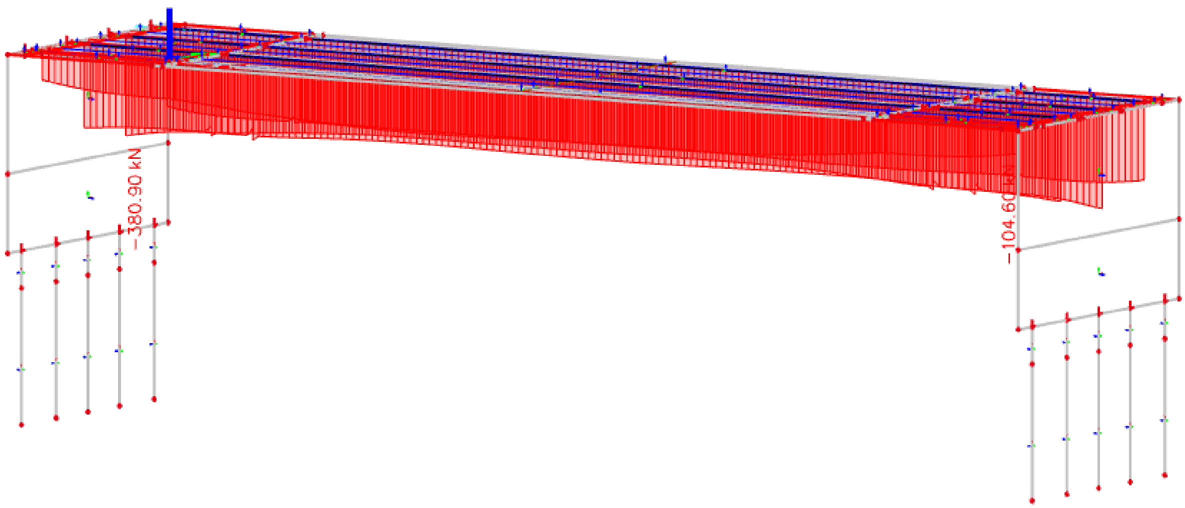


Figure 7. Normal force results from LM1_UDL application

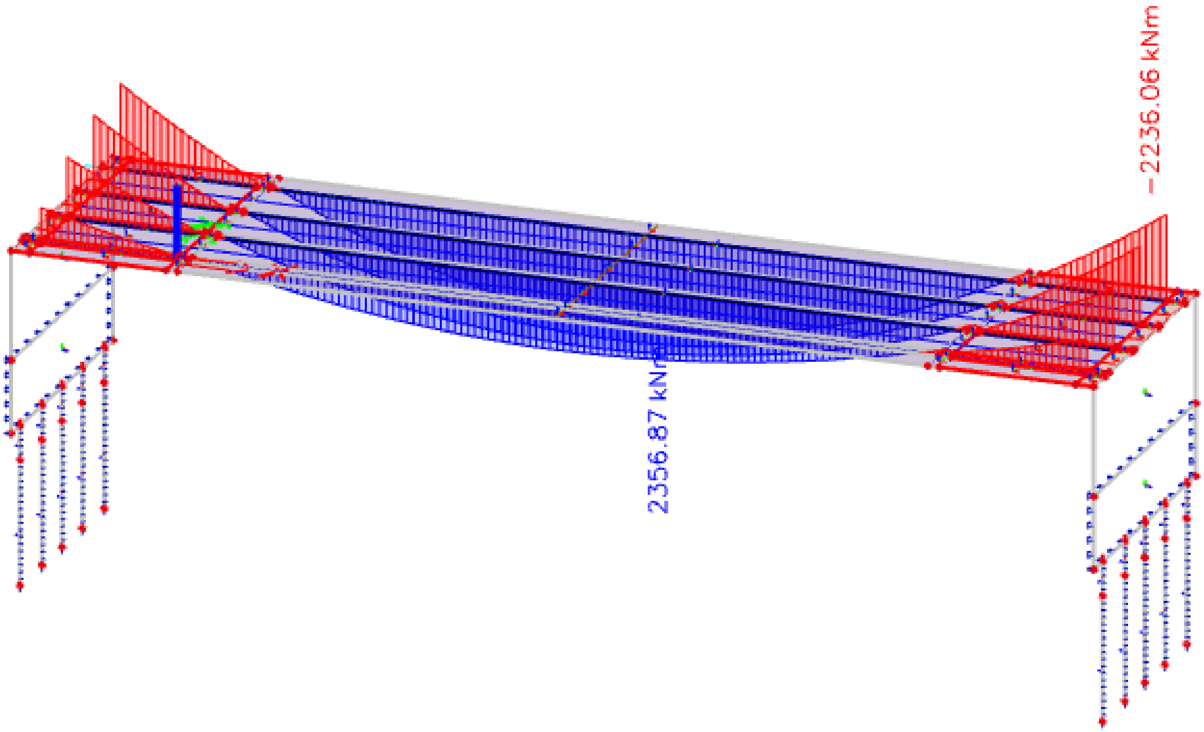


Figure 8. Bending moment results from LM1_UDL application

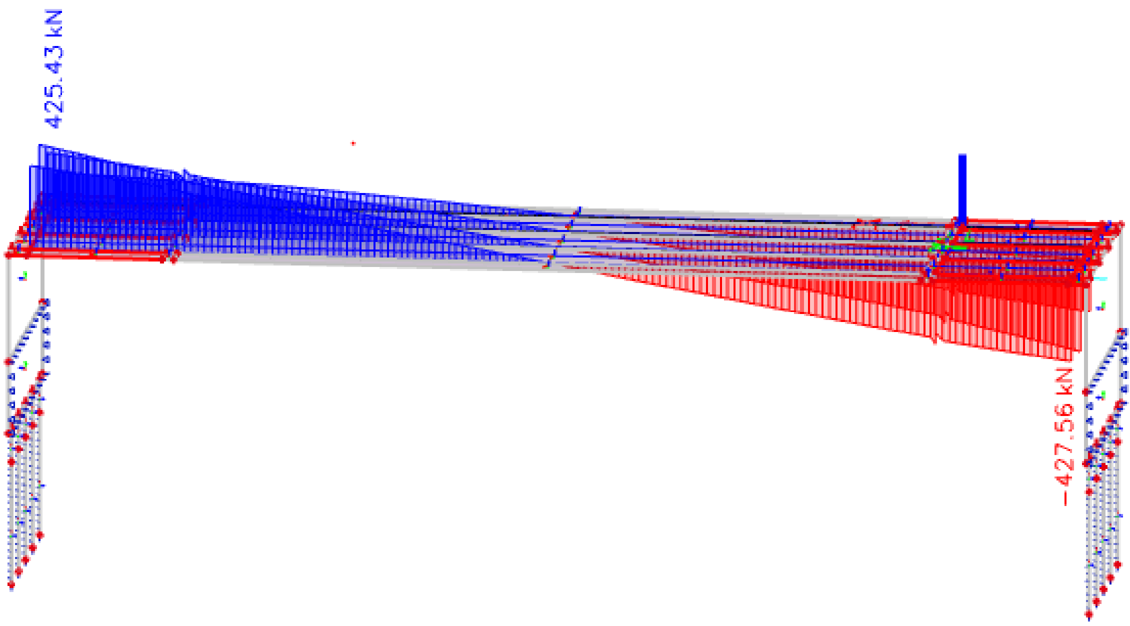


Figure 9. Shear force results from LM1_UDL application

3.7. Outputs. Results of internal forces.

Results of internal forces such as normal force *N*, bending moment *My* and shear force *Vz* are taken from the support and mid-span of the composite beam in characteristic values. (*Table 1 – 3*)

Load cases				$G_{m1\ s.w}$	G_{m2}	G_c	$G_{b.e.}$
Composite beam	*support*	N_x	*kN*	0.0	0.0	-140.0	-195.0
		M_y	*kNm*	0.0	0.0	-705.0	-1026.0
		V_z	*kN*	-377.0	-356.6	-143.8	-233.0
	mid span	N_x	*kN*	0.0	0.0	-110.0	-243.0
		M_y	*kNm*	4032.6	4244.0	711.2	948.4
		V_z	*kN*	0.0	0.0	0.0	0.0

Table 6. Internal forces from permanent loads $G_{m1\ s.w}$, G_{m2}, G_c, $G_{b.e}$

Load cases				**LM1_TS**	**LM1_UDL**	**LM3-1800/200**	**LM4**	**LM4 sidewalk**
Composite beam	*support*	N_x	*kN*	-242.0	-378.0	-535.0	-313.0	-88.0
		M_y	*kNm*	-1671.1	-2236.0	-4218.0	-1574.0	-470.0
		V_z	*kN*	-428.4	-425.0	-859.0	-321.0	-107.0
	mid span	N_x	*kN*	-276.7	-316.0	-513.0	-252.4	-111.6
		M_y	*kNm*	2741.3	2356.9	5678.8	1587.5	431.5
		V_z	*kN*	-223.0	0.0	0.0	0.0	0.0

Table 7. Internal forces from Load Models LM1-LM4

Load cases				**B**	**W**	T_{r+}	T_{r-}	T_{n+}	T_{n-}
Composite beam	support	N_x	kN	-62.0	-16.0	-532.0	790.0	-170.0	-51.0
		M_y	kNm	-207.0	-183.0	2606.0	-2668.0	785.0	-658.0
		V_z	kN	-22.0	-22.0	-6.0	-6.3	-5.0	-4.5
	mid span	N_x	kN	-4.7	-353.0	-665.0	724.0	-200.0	-82.0
		M_y	kNm	66.7	157.0	2291.0	-2664.0	666.0	-692.0
		V_z	kN	-6.0	0.0	0.0	0.0	0.0	0.0

Table 8. Internal forces from Braking force, wind load, thermal actions.

3.8. Combinations for ULS and SLS

Combination for ULS by ČSN EN 1990:

Equations 6.10a and 6.10b

$$\sum_{j\geq 1} \gamma_G G_{k,j} \text{ "+" } \gamma_P P \text{ "+" } \gamma_{Q,1} \Psi_{0,1} Q_{k,1} \text{ "+" } \sum_{i>1} \gamma_{Q,i} \Psi_{0,i} Q_{k,i}$$

$$\sum_{j\geq 1} \xi_j \gamma_G G_{k,j} \text{ "+" } \gamma_P P \text{ "+" } \gamma_{Q,1} Q_{k,1} \text{ "+" } \sum_{i>1} \gamma_{Q,i} \Psi_{0,i} Q_{k,i}$$

Characteristic combination for SLS by ČSN EN 1990:

$$\sum_{j\geq 1} G_{k,j} \text{ "+" } P \text{ "+" } Q_{k,1} \text{ "+" } \sum_{i>1} \Psi_{0,i} Q_{k,i}$$

Coefficients:

- *Permanent load case factor*: γ_{Gsup} = 1,35 γ_{Ginf} =1,00
- *Traffic load case factor*: γ_Q = 1,35
- *Other temporary load case factor:* γ_Q = 1,5
- *Reduction coefficient for permanent loads: ξ = 0,85*
- *Additional dynamic factor for LM3: ϕ = 1,25*

Load cases	***type***		ψ_0	ψ_1	ψ_2
traffic load	LM1	TS	0,75	0,75	0
		UDL	0,4	0,4	0
	LM3		0	-	0
	LM4		0	-	0
thermal actions	Tk		0,6	0,6	0,5

Table 9. Combination factors

effect	Permanent				Temporary									
condition	Gm1 s.w	Gm2	Gc	Gb.e.	LM1 TS	LM1 UDL	LM3-1800/200	LM4	LM4 sidewalk	B	W	T_r	T_n	description
1	1.350	1.350	1.350	1.620	1.013	0.540			0.324		0.900			6.10a
2	1.350	1.350	1.350	1.620	1.013	0.540			0.324			0.900	0.675	6.10a
3	1.350	1.350	1.350	1.620	1.013	0.540			0.324			0.315	0.900	6.10a
4	1.148	1.148	1.148	1.377	1.350	1.350			0.810		0.900			6.10b
5	1.148	1.148	1.148	1.377	1.350	1.350			0.810			0.900	0.675	6.10b
6	1.148	1.148	1.148	1.377	1.350	1.350			0.810			0.315	0.900	6.10b
7	1.148	1.148	1.148	1.377			1.350				0.900			6.10b
8	1.148	1.148	1.148	1.377			1.350					0.900	0.675	6.10b
9	1.148	1.148	1.148	1.377			1.350					0.315	0.900	6.10b
10	1.148	1.148	1.148	1.377				1.350	1.350		0.900			6.10b
11	1.148	1.148	1.148	1.377				1.350	1.350			0.900	0.675	6.10b
12	1.148	1.148	1.148	1.377				1.350	1.350			0.315	0.900	6.10b
13	1.148	1.148	1.148	1.377	1.013	0.540			0.324		1.500			6.10b
14	1.148	1.148	1.148	1.377	1.013	0.540			0.324			1.500	1.125	6.10b
15	1.148	1.148	1.148	1.377	1.013	0.540			0.324			0.525	1.500	6.10b
16	1.148	1.148	1.148	1.377	1.013	0.540			0.324	1.350	0.900			6.10b
17	1.148	1.148	1.148	1.377	1.013	0.540			0.324	1.350		0.900	0.675	6.10b
18	1.148	1.148	1.148	1.377	1.013	0.540			0.324	1.350		0.315	0.900	6.10b

*Table 10. Evaluated combination factors for **ULS***

effect	Permanent				Temporary									
condition	Gm1 s.w	Gm2	Gc	Gb.e.	LM1 TS	LM1 UDL	LM3-1800/200	LM4	LM4 sidewalk	B	W	Tr	Tn	description
1	1.000	1.000	1.000	1.000	1.00	1.00			0.600		0.600			char
2	1.000	1.000	1.000	1.000	1.00	1.00			0.600			0.600	0.450	char
3	1.000	1.000	1.000	1.000	1.00	1.00			0.600			0.210	0.600	char
4	1.000	1.000	1.000	1.000					0.600		0.600			char
5	1.000	1.000	1.000	1.000					0.600			0.600	0.450	char
6	1.000	1.000	1.000	1.000					0.600			0.210	0.600	char
7	1.000	1.000	1.000	1.000			1.000				0.600			char
8	1.000	1.000	1.000	1.000			1.000					0.600	0.450	char
9	1.000	1.000	1.000	1.000			1.000					0.210	0.600	char
10	1.000	1.000	1.000	1.000	0.75	0.40		1.000	1.000		0.600			char
11	1.000	1.000	1.000	1.000	0.75	0.40		1.000	1.000			0.600	0.450	char
12	1.000	1.000	1.000	1.000	0.75	0.40		1.000	1.000			0.210	0.600	char
13	1.000	1.000	1.000	1.000	0.75	0.40			0.240		1.000			char
14	1.000	1.000	1.000	1.000	0.75	0.40			0.240			1.000	0.750	char
15	1.000	1.000	1.000	1.000	0.75	0.40			0.240			0.350	1.000	char
16	1.000	1.000	1.000	1.000	0.75	0.40			0.240	1.000	0.600			char
17	1.000	1.000	1.000	1.000	0.75	0.40			0.240	1.000		0.600	0.450	char
18	1.000	1.000	1.000	1.000	0.75	0.40			0.240	1.000		0.210	0.600	char

*Table 11. Evaluated characteristic combination factors for **SLS***

3.8.1. Extreme values from ULS combinations

Results of internal forces			Permanent action		Live action
			prefab c/s	composite str	
6.10a	N_x	[kN]	0.0	-490.1	-1071.2
	M_y	[kNm]	0.0	-2527.2	-5897.1
	V_z	[kN]	-990.4	-547.5	-717.7
6.10b	N_x	[kN]	0.0	-416.5	-1501.8
	M_y	[kNm]	0.0	-2148.1	-8539.7
	V_z	[kN]	-990.4	-465.4	-1258.5

Table 12. ULS Combination results from the cross section above support

Results of internal forces			Permanent action		Temporary action
			prefab c/s	composite str	
6.10a	N_x	[kN]	0.0	-506.3	-1220.5
	M_y	[kNm]	11173.5	2432.4	6699.5
	V_z	[kN]	0.0	0.0	-225.8
6.10b	N_x	[kN]	0.0	-430.3	-1709.5
	M_y	[kNm]	9497.5	2067.5	9743.4
	V_z	[kN]	0.0	0.0	-301.1

Table 13. ULS Combination results from the cross section in the mid-span

3.8.2. Results of characteristic combination for SLS

Results of internal forces			Permanent action		Temporary action
			prefab c/s	composite str	
characteristic	N_x	[kN]	0.0	-335.0	-1068.5
	M_y	[kNm]	0.0	-1731.0	-6086.0
	V_z	[kN]	-733.6	-376.8	-930.8

Table 14. SLS Combination results from the cross section above support

Results of internal forces			Permanent action		Temporary action
			prefab c/s	composite str	
characteristic	N_x	[kN]	0.0	-353.0	-1148.7
	M_y	[kNm]	8280.0	1659.6	7031.3
	V_z	[kN]	0.0	0.0	-223.0

Table 15. SLS Combination results from the cross section in the mid-span

4. Design of reinforcement

4.1. Design of concrete cover

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

where:

c_{nom} – nominal concrete cover

c_{min} – minimum concrete cover

Δc_{dev} = 10 mm, deviation

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

$c_{min,b}$ =20 mm (rebar diameter)

$c_{min,dur}$ determined as a function of the structural class and the exposure class

C35/45: exposure class XC2 + XD1 + XF2

structural class S4 + 2 - 1 = S5

$c_{min,dur} = 30\ mm$

$\Delta c_{dur,\gamma} = 0\ mm$

$\Delta c_{dur,\ st} = 0\ mm$

$\Delta c_{dur,\ add} = 0\ mm$

c_{min} = max {20; 30; 10} = 30 mm

$c_{nom} = c_{min} + \Delta c_{dev}$ = 30 + 10mm = 40 mm

4.2. Design of reinforcement in longitudinal direction

Upper RC in-situ concrete slab			Bottom RC in-situ concrete slab			RC precast concrete slab		
cover	40	mm	**cover**	40	mm	**cover**	40	mm
diameter	**28**	mm	**diameter**	**20**	mm	**diameter**	**20**	mm
A_1	615.8	mm^2	**A_1**	314.2	mm^2	**A_1**	314.2	mm^2
along	200	mm	**along**	200	mm	**along**	150	mm
b	2900	mm	**b**	2900	mm	**b**	2900	mm
number	15		**number**	15		**number**	19	
rows	2		**rows**	2		**rows**	1	
A	17856.813	mm2	**A**	9110.619	mm2	**A**	6073.7458	mm2

Table 16. Steel reinforcement above support

Upper RC in-situ concrete slab			Bottom RC in-situ concrete slab			RC precast concrete slab		
cover	40	mm	**cover**	40	mm	**cover**	40	mm
diameter	**20**	mm	**diameter**	**20**	mm	**diameter**	**20**	mm
A_1	314.2	mm^2	**A_1**	314.2	mm^2	**A_1**	314.2	mm^2
along	200	mm	**along**	200	mm	**along**	150	mm
b	2900	mm	**b**	2900	mm	**b**	2900	mm
number	15	ks	**number**	15	ks	**number**	19	ks
rows	1		**rows**	1		**rows**	1	
A	4555.3093	mm2	**A**	4555.309	mm2	**A**	6073.7458	mm2

Table 17. Steel reinforcement in the mid-span

4.3. Design of reinforcement in transverse direction

Design of RC of prefabricated concrete slab

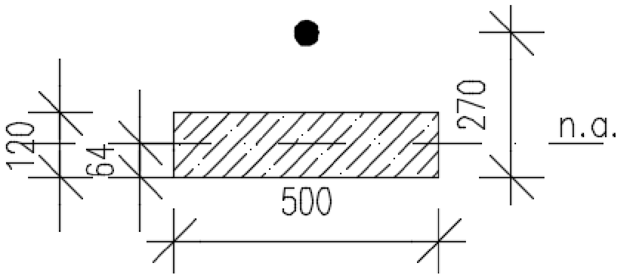


Figure 10. Rebar above precast slab

dead load	char		design	
G_c = ρ*0.22m	5.72	kN/m2	7.722	kN/m2
$G_{s.w}$ = ρ2*0.12m	3.00	kN/m2	4.05	kN/m2
total load d.l.	8.72	kN/m2	11.772	kN/m2
	load for each 0.5 m		**5.886**	kN/m
live load (one-person weight)	2kN/m2 *1.575m*1.5 =		**4.725**	kN/m
Total load f			**10.611**	kN/m
Med = 0.5*f*L^2	**13.16**	**kNm/m**		

	z mm	**stress** MPa	**design stress** MPa	**usage** %	
casted concrete slab					
reinf in casted concrete	**146**	**17.6**	434.8	**4%**	OK
prefab concrete slab	**120**	**2.5**	33.3	**8%**	OK
reinf in prefab concrete					
	zd	**Iy**			
	64	**1E+08**			

cover	40	mm
diameter	20	mm
A_1	314.16	mm2
along	500	mm
number	1.0	
rows	1	
A	314.16	mm2

Design of reinforcement in cast-in-situ slab

Internal forces from the Load Model 2 have been used

Upper reinforcement design:

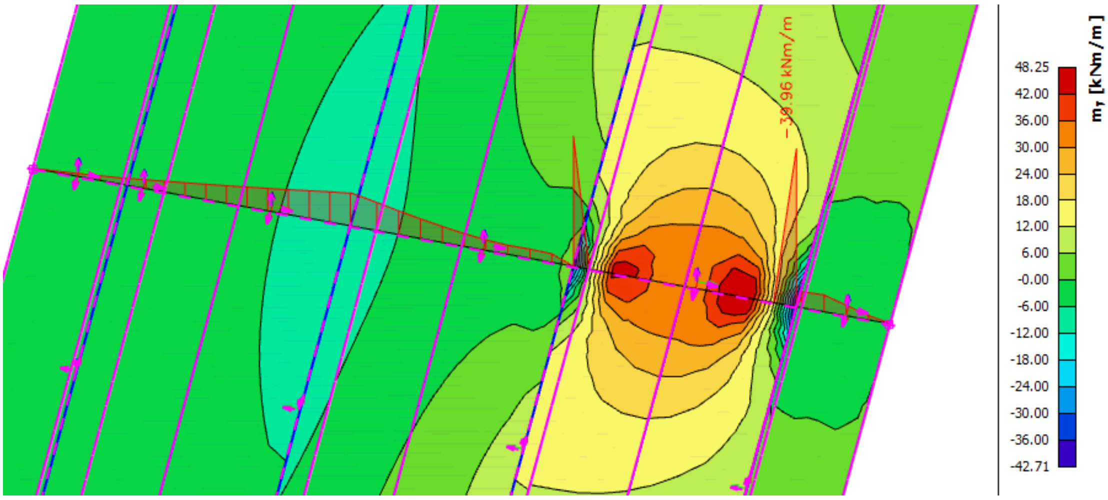


Figure 11. Bending moment results from LM2 application for max negative value

Negative bending moment from LM2

Med = 42.71 kNm

Dimensions of the concrete slab for 1m

h = 220 mm b = 1000 mm

RC design

preliminary design of RC Ø = 16 mm d = 174 mm

$A_{s,req}$ = 589.976 mm^2

$A_{s,\ prov}$ = 1005.5 mm^2/m

along 200 mm

number 5

Check:

x = 23.420 mm

$\xi_{bal,1}$ = 0.617

ξ = *0.121118* < *0.617* *OK*

Mrd = *71.1* > *42.71* *kNm*

OK

60%

Bottom reinforcement design:

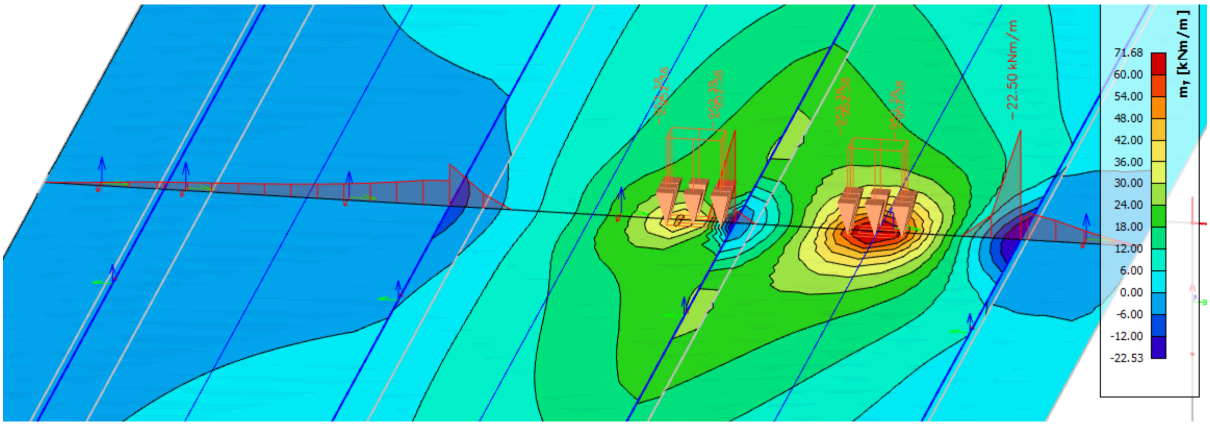


Figure 12. Bending moment results from LM2 application for max positive value

Positive bending moment from LM2

Med = 71.68 kNm

Dimensions of the concrete slab for 1m

h = 220 mm b = 1000 mm

RC design

preliminary design of RC Ø = 16 mm d = 172 mm

$A_{s,req}$ = 1014.232 mm^2

$A_{s,\ prov}$ = 1608.8 mm^2/m

along 125 mm

number **8.00**

***Check*:**

x = 37.472 mm

$\xi_{bal,1}$ = 0.617

ξ = *0.217861* **<** *0.617* ***OK***

Mrd = *109.8* **>** *71.68* *kNm*

OK

65%

4.4. Composite cross-section resistance. Shear resistance. Headed stud connectors design

Design resistance of headed stud when the failure is due to the shear of the steel shank toe of the stud: $P_{rd} = 0.8(\frac{fu}{\gamma v})*(\frac{\pi d2}{4})$

f_u	360	Mpa
d	***19***	mm
γ_v	1,25	
$\boldsymbol{P_{Rd}}$	**65291,9**	N
h_{sc}	80	mm
beff	2900	mm
hc	**120**	mm
Ac	348000	
fck	**50**	MPa
fcd	33,3	MPa
Ncf	11600	MN
L	47600	
L/2	23800	m
spacing	**200**	**mm**
n	119	

Nrd = ***15539,5*** ***>*** ***11600 MN***

OK

5. Stress calculation

5.1. ULS

Results of internal forces			Permanent load		Live load
			prefab c/s	composite str	
6.10a	N_x	[kN]	0,0	-490,1	-1071,2
	M_y	[kNm]	0,0	-2527,2	-5897,1
	V_z	[kN]	-990,4	-547,5	-717,7
6.10b	N_x	[kN]	0,0	-416,5	-1501,8
	M_y	[kNm]	0,0	-2148,1	-8539,7
	V_z	[kN]	-990,4	-465,4	-1258,5
Cross-section properties			prefab c/s	composite c/s	
				Longterm load	Short-term load
	$I_{y,eff}$	[mm⁴]	5,51E+10	9,73E+10	9,73E+10
	A_{eff}	[mm²]	9,19E+04	1,19E+05	1,19E+05
	n	[-]			
	z_d	[mm]	764	1086	1086
	$z_{s,H}$	[mm]	0	-1100	-1100
	$z_{s,D}$	[mm]	-1196	-874	-984
	z_{aH}	[mm]	-1136	-814	-814
	z_{aD}	[mm]	764	1086	1086
6.10a Stress results	reinf in cast concrete	[MPa]	0,0	24,4	57,6
	reinf in prefab concrete	[MPa]	0,0	18,6	50,6
	upper flange	[MPa]	0,0	17,0	40,3
	bottom flange	[MPa]	0,0	-32,3	-74,9
6.10b Stress results	reinf in cast concrete	[MPa]	0,0	20,8	83,9
	reinf in prefab concrete	[MPa]	0,0	15,8	73,7
	upper flange	[MPa]	0,0	14,5	58,8
	bottom flange	[MPa]	0,0	-27,5	-108,0

Table 18. Stress results of cross-section above support

Results of internal forces			Permanent load		Live load
			prefab c/s	composite str	
6.10a	N_x	[kN]	0,0	-506,3	-1220,5
	M_y	[kNm]	11173,5	2432,4	6699,5
	V_z	[kN]	0,0	0,0	-225,8
6.10b	N_x	[kN]	0,0	-430,3	-1709,5
	M_y	[kNm]	9497,5	2067,5	9743,4
	V_z	[kN]	0,0	0,0	-301,1
Cross-section properties			prefab c/s	composite c/s	
				Longterm load	Short-term load
	$I_{y,eff}$	[mm⁴]	6,57E+10	1,00E+11	1,00E+11
	A_{eff}	[mm²]	1,45E+05	2,58E+05	2,58E+05
	n_{beton}	[-]	6,18	6,18	6,18
	n_{pref}	[-]	5,68	5,68	5,68
	z_d	[mm]	1001	1321	1321
	$z_{c,H}$	[mm]	0	-519	-519
	$z_{c,D}$	[mm]	-619	-299	-299
	$z_{s,H}$	[mm]	0	-469	-469
	$z_{s,D}$	[mm]	-559	-239	-239
	$z_{a,H}$	[mm]	-499	-179	-179
	$z_{a,D}$	[mm]	1001	1321	1321
6.10a Stress results	casted concrete slab	[MPa]	0,0	-4,0	-6,4
	prefab concrete slab	[MPa]	-18,5	-3,2	-8,3
	reinf in casted concrete	[MPa]	0,0	-13,3	-36,0
	reinf in prefab concrete	[MPa]	-95,1	-7,8	-7,8
	upper flange	[MPa]	-84,9	-6,3	-6,3
	bottom flange	[MPa]	170,1	30,1	30,1
6.10b Stress results	cast concrete slab	[MPa]	0,0	-3,4	-14,8
	prefab concrete slab	[MPa]	-15,8	-2,8	-11,8
	reinf in cast concrete	[MPa]	0,0	-11,3	-52,2
	reinf in prefab concrete	[MPa]	-80,8	-6,6	-29,8
	upper flange	[MPa]	-72,1	-5,4	-24,0
	bottom flange	[MPa]	144,6	25,6	121,7

Table 19. Stress results of cross-section in the mid-span

materials	type	strength	ULS coef	Design value	
RC	*B500B*	500	1,15	**434,8**	Mpa
prefab concr	*C50/60*	50	1,5	**33,3**	Mpa
concrete	*C35/45*	35	1,5	**23,3**	Mpa
steel	*S460N for 63-80cm*	410	1	**410,0**	Mpa

Table 20. Design strength of materials for ULS check

position	stress	6.10a	6.10b	max stress [Mpa]	design stress	usage [%]
support	reinf in cast concrete	82,1	104,7	**104,7**	434,8	**24,1%**
	reinf in prefab concrete	69,2	89,5	**89,5**	434,8	**20,6%**
	upper flange	57,3	73,2	**73,2**	410	**17,9%**
	bottom flange	-107,2	-135,5	**-135,5**	410	**33,0%**
mid span	cast concrete slab	-10,4	-18,2	**-18,2**	23,3	**78,0%**
	prefab concrete slab	-30,0	-30,3	**-30,3**	33,3	**90,8%**
	reinf in cast concrete	-49,4	-63,5	**-63,5**	434,8	**14,6%**
	reinf in prefab concrete	-110,6	-117,2	**-117,2**	434,8	**27,0%**
	upper flange	-97,5	-101,5	**-101,5**	410	**24,8%**
	bottom flange	230,2	291,8	**291,8**	410	**71,2%**

Table 21. Usage of materials in ULS

5.2. SLS

Results of internal forces			Permanent load		Live load
			prefab c/s	composite str	
6.10a	N_x	[kN]	0,0	-335,0	-1068,5
	M_y	[kNm]	0,0	-1731,0	-6086,0
	V_z	[kN]	-733,6	-376,8	-930,8
6.10b	N_x	[kN]	0,0	-335,0	-1013,3
	M_y	[kNm]	0,0	-1731,0	-5941,9
	V_z	[kN]	-733,6	-376,8	-872,2
Cross-section properties			**prefab c/s**	**composite c/s**	
				Longterm load	**Longterm load**
	$I_{y,eff}$	[mm^4]	5,51E+10	1,10E+11	1,10E+11
	A_{eff}	[mm^2]	9,19E+04	1,19E+05	1,19E+05
	n	[-]			
	z_d	[mm]	764	1086	1086
	$z_{s,H}$	[mm]	0	-1100	-1100
	$z_{s,D}$	[mm]	-1196	-874	-984
	z_{aH}	[mm]	-1136	-814	-814
	z_{aD}	[mm]	764	1086	1086
6.10a Stress results	reinf in casted concrete	[MPa]	0,0	14,5	52,0
	reinf in prefab concrete	[MPa]	0,0	11,0	45,6
	upper flange	[MPa]	0,0	10,0	36,2
	bottom flange	[MPa]	0,0	-20,0	-69,3
6.10b Stress results	reinf in cast concrete	[MPa]	0,0	14,5	51,0
	reinf in prefab concrete	[MPa]	0,0	11,0	44,8
	upper flange	[MPa]	0,0	10,0	35,6
	bottom flange	[MPa]	0,0	-20,0	-67,4

Table 22. Stress results of cross-section above support

Results of internal forces			Permanent load		Temporary load
			prefab c/s	composite str	
6.10a	N_x	[kN]	0,0	-353,0	-1148,7
	M_y	[kNm]	8280,0	1659,6	7031,3
	V_z	[kN]	0,0	0,0	-223,0
6.10b	N_x	[kN]	0,0	-353,0	-1175,7
	M_y	[kNm]	8280,0	1659,6	5892,8
	V_z	[kN]	0,0	0,0	-167,3
Cross-section properties			**prefab c/s**	**composite c/s**	
				Longterm load	**Longterm load**
	$I_{y,eff}$	[mm^4]	6,57E+10	1,27E+11	1,27E+11
	A_{eff}	[mm^2]	1,45E+05	2,58E+05	2,58E+05
	n_{beton}	[-]	6,18	6,18	6,18
	n_{pref}	[-]	5,68	5,68	5,68
	z_d	[mm]	1001	1321	1321
	$z_{c,H}$	[mm]	0	-519	-519
	$z_{c,D}$	[mm]	-619	-299	-299
	$z_{s,H}$	[mm]	0	-469	-469
	$z_{s,D}$	[mm]	-559	-239	-239
	$z_{a,H}$	[mm]	-499	-179	-179
	$z_{a,D}$	[mm]	1001	1321	1321
6.10a Stress results	cast concrete slab	[MPa]	0,0	-2,5	-5,4
	prefab concrete slab	[MPa]	-13,7	-2,1	-7,4
	reinf in cast concrete	[MPa]	0,0	-7,5	-30,5
	reinf in prefab concrete	[MPa]	-70,4	-4,5	-4,5
	upper flange	[MPa]	-62,9	-3,7	-3,7
	bottom flange	[MPa]	126,1	15,9	15,9
6.10b Stress results	Cast concrete slab	[MPa]	0,0	-2,5	-8,5
	prefab concrete slab	[MPa]	-13,7	-2,1	-7,0
	reinf in cast concrete	[MPa]	0,0	-7,5	-26,4
	reinf in prefab concrete	[MPa]	-70,4	-4,5	-15,7
	upper flange	[MPa]	-62,9	-3,7	-12,9
	bottom flange	[MPa]	126,1	15,9	56,9

Table 23. Stress results of cross-section in the mid-span

materials	type	strength	long term coef		short term coef		
steel	*B500B*	500	0,8	**400**	0,8	**400**	MPa
prefab concr	*C50/60*	50	0,45	**22,5**	0,6	**30**	MPa
concrete	*C35/45*	35	0,45	**15,75**	0,6	**21**	MPa
steel	*S460N for 63-80cm*	410	1	**410**	1	**410**	MPa

Table 24. Strength of materials for ULS check

SLS long-term

position	stress	6.10a	usage [%]
support	reinf in cast concrete	14,5	**3,6%**
	reinf in prefab concrete	11,0	**2,7%**
	upper flange	10,0	**2,4%**
	bottom flange	-20,0	**4,9%**
mid span	cast concrete slab	-2,5	**15,7%**
	prefab concrete slab	-15,8	**70,2%**
	reinf in cast concrete	-7,5	**1,9%**
	reinf in prefab concrete	-74,9	**18,7%**
	upper flange	-66,6	**16,2%**
	bottom flange	142,0	**34,6%**

Table 25. usage of materials in SLS long-term load

SLS short-term

position	stress	6.10a	usage [%]
support	reinf in cast concrete	52,0	**13,0%**
	reinf in prefab concrete	45,6	**11,4%**
	upper flange	36,2	**8,8%**
	bottom flange	-69,3	**16,9%**
`mid span	cast concrete slab	-5,4	**40,3%**
	prefab concrete slab	-21,1	**70,4%**
	reinf in cast concrete	-30,5	**7,6%**
	reinf in prefab concrete	-74,9	**21,5%**
	upper flange	-66,6	**18,5%**
	bottom flange	142,0	**44,6%**

Table 26. Usage of materials in SLS short-term load

6. Conclusion

position	stress	6.10a	6.10b	max stress [Mpa]	design stress	usage [%]
support	reinf in cast concrete	82,1	104,7	**104,7**	434,8	**24,1%**
	reinf in prefab concrete	69,2	89,5	**89,5**	434,8	**20,6%**
	upper flange	57,3	73,2	**73,2**	410	**17,9%**
	bottom flange	-107,2	-135,5	**-135,5**	410	**33,0%**
mid span	cast concrete slab	-10,4	-18,2	**-18,2**	23,3	**78,0%**
	prefab concrete slab	-30,0	-30,3	**-30,3**	33,3	**90,8%**
	reinf in cast concrete	-49,4	-63,5	**-63,5**	434,8	**14,6%**
	reinf in prefab concrete	-110,6	-117,2	**-117,2**	434,8	**27,0%**
	upper flange	-97,5	-101,5	**-101,5**	410	**24,8%**
	bottom flange	230,2	291,8	**291,8**	410	**71,2%**

Table 27. Usage of materials in ULS

In the range of this static calculation, the main supporting structure (superstructure) of the bridge has complied with all the above-mentioned estimates of the serviceability limit state and the ultimate limit state. But because of neglecting the long-term deformations in elastic analysis, in the end I had to get results with 20-30% reserve. Only the results of the serviceability limit state have complied this case. In the mid-span cross-section, the usage of the stress in prefabricated concrete slab (Table.27) exceeds the reserve by 10 – 20 %.

The solution of this problem is to increase the strength of the precast concrete or increase the depth of the slab till 130 - 140 mm.