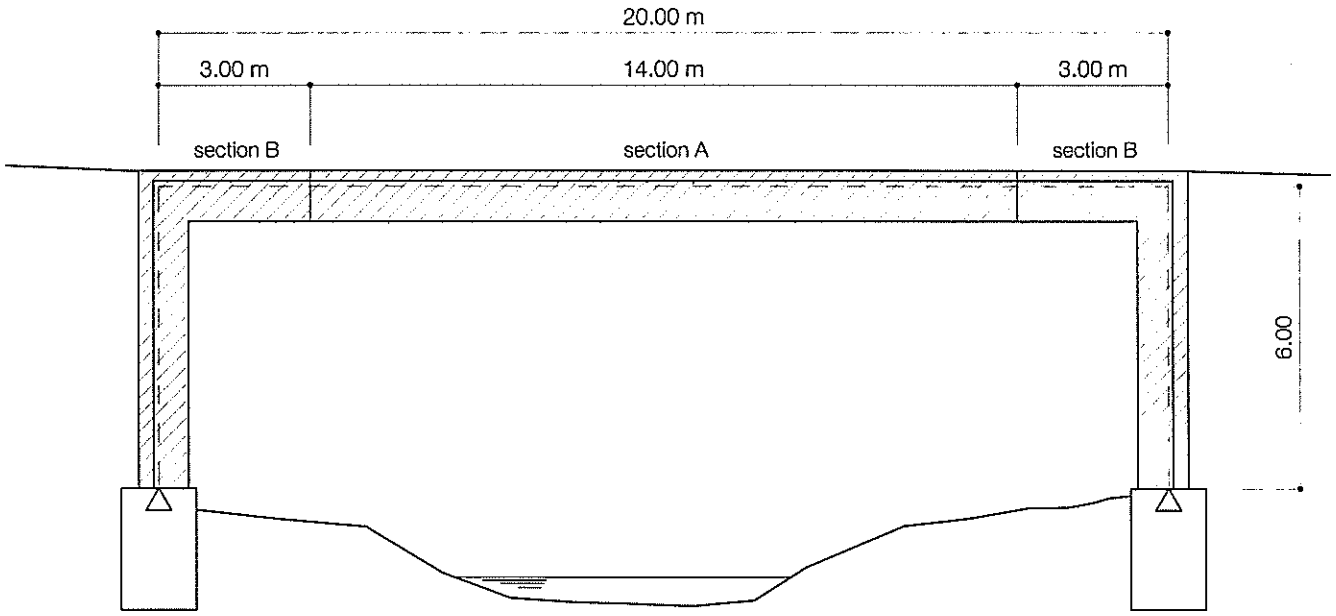
WORKED EXAMPLE
SCOPE: RC FRAME BRIDGE

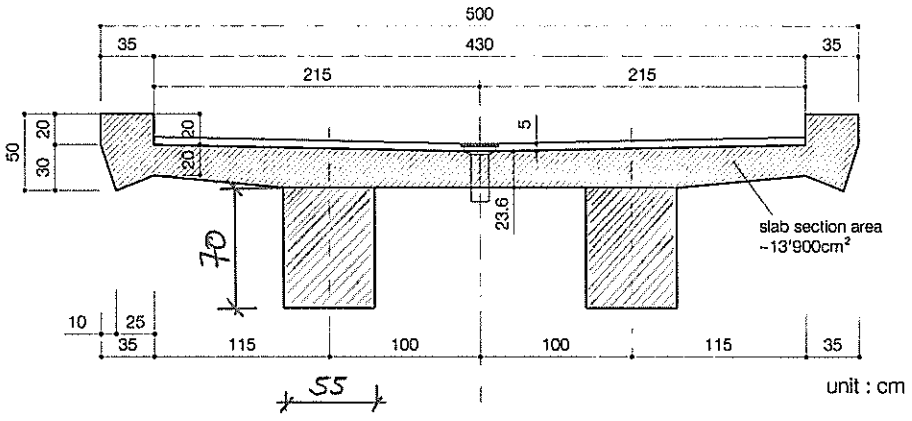
Project	Local Roads Bridges Programme (LRBP) Nepal
Client	Government of Nepal (MoFALD) Government of Switzerland (SDC)
Author	ITECO Ingenieurunternehmung AG WGG Schnetzer Puskas Ingenieure AG
Date	2nd August 2012

EXAMPLE : RC FRAME BRIDGE

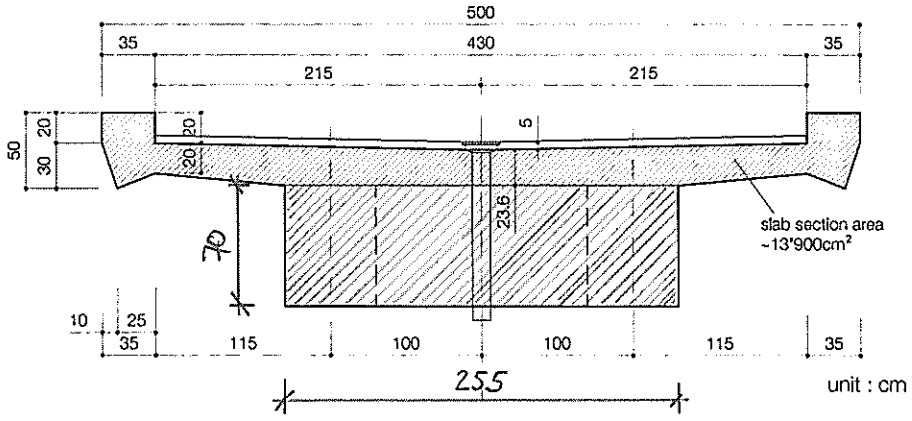
1. Elevation



2. Cross Section



section A



section B

3. Material

concrete : M30
reinforcement : Fe500

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CALCULATION: RC FRAME BRIDGE

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TABLE OF CONTENTS

1. BASIS OF DESIGN
   1.1. Indian Standards
   1.2. Eurocode

2. MATERIAL PROPERTIES
   2.1. Concrete
   2.2. Reinforcement
   2.3. Steel

3. GEOMETRY

4. LOADS
   4.1. Dead Load (DL)
      4.1.1. Self Weight
      4.1.2. Superimposed Dead Load (SDL)
   4.2. Live Load (LL)

5. DIMENSIONING OF STRUCTURE
   5.1. Geometry, Load and System
   5.2. Calculation of Bending Moment
   5.3. Dimensioning of Member – Axial Force and Bending Moment Resistance
   5.4. Dimensioning of Member – Shear Resistance
   5.5. Serviceability Limit State

1 BASIS OF DESIGN

1.1 Indian Standards

[1] IRC:6-2000; Standard Specifications and code of practice for road bridges; Section II: Loads and Stresses (4th revision); The Indian Roads Congress (New Delhi, 2000)

[2] IRC:21-2000; Standard Specifications and code of practice for road bridges; Section III: Cement Concrete (Plain and Reinforced, 3rd revision); The Indian Roads Congress (New Delhi, 2000)

[3] IRC:22-1986; Standard Specifications and code of practice for road bridges; Section VI: Composite Construction, 1st revision); The Indian Roads Congress (New Delhi, 1991)

[4] IS:800-2007; General Construction in steel - Code of practice (3rd revision); Bureau of Indian Standards (New Delhi, 2007)

[5] IS:816-1969; Code of Practice for use of Metal arc welding for general construction in mild steel (1st revision, reaffirmed 1992, 14th reprint 1997); Bureau of Indian Standards (New Delhi, 1971)

[6] IS:2062-1999; Steel for general structural purposes - Specification (5th revision); Bureau of Indian Standards (New Delhi, 1999)

[7] IS:2062;1999 Specification of hot rolled medium and high tensile structural steel (7th revision); Bureau of Indian Standards (New Delhi, 1999)

[8] IS:432-1982; Specifications for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement; Part II: Hard-drawn steel wire, 3rd revision, reaffirmed 1995, 6th reprint 1998); Bureau of Indian Standards (New Delhi, 1998)

[9] IS:2751-1979; Code of practice for welding of mild steel plain and deformed bars for reinforced concrete construction, 1st revision, reaffirmed 1998, 2nd reprint 1999); Bureau of Indian Standards (New Delhi, 1999)

[10] IS:1786-1985; Specification for high strength deformed steel bars for and wires for concrete reinforcement, 3rd revision, 3rd reprint 1992); Bureau of Indian Standards (New Delhi, 1985)

[11] IS:456-2000; Indian Standard - Plain and reinforced concrete (Code of practice, 4th revision); Bureau of Indian Standards (New Delhi, 2000)

1.2 Eurocode

[12] Eurocode 0: Basis of Structural design; European Standard; European Committee for Standardization (CEN, Brussels, 2010)

[13] Eurocode 1: Actions on Structures; European Standard; European Committee for Standardization (CEN, Brussels, 2010)

[14] Eurocode 2: Design of Concrete Structures; European Standard; European Committee for Standardization (CEN, Brussels, 2010)

[15] Eurocode 3: Design of Steel Structures; European Standard; European Committee for Standardization (CEN, Brussels, 2010)

[16] Eurocode 4: Design of Composite Steel and Concrete Structures; European Standard; European Committee for Standardization (CEN, Brussels, 2010)

2. MATERIAL PRORERTIES

2.1 Concrete

grade M30 ~ EC2: C25/30

$f_{ck} = 25\ N/mm^2$
$f_{ck,cube} = 30\ N/mm^2$
$f_{ctm} = 2.6\ N/mm^2$
$f_{cd} = 25/1.5 = 16.6\ N/mm^2$
$\tau_{cd} = 0.3 \times \sqrt{25}/1.5 = 1.00\ N/mm^2$
$\varepsilon_{cd} = 0.003$
$E_{cd} = 30\ kN/mm^2$

2.2 Reinforcement

grade Fe 500

$f_{sd} = 500\ N/mm^2$
$f_{s.d} = 500/1.15 = 435\ N/mm^2$
$E_s = 200\,000\ N/mm^2$
$\varepsilon = 0.02$

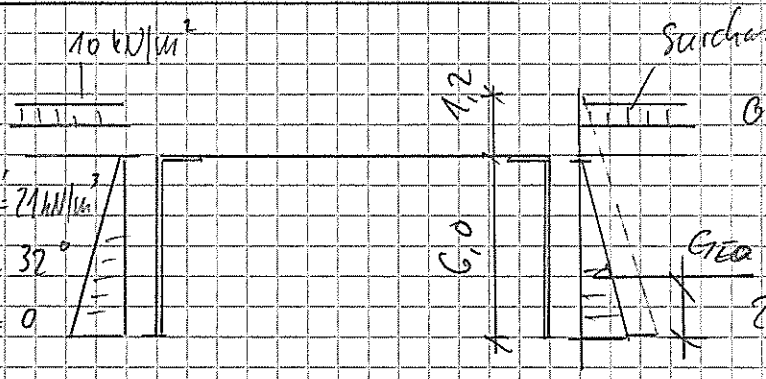
2.3 Steel

grade E250

$f_{yk} = 240\ N/mm^2$
$f_{uk} = 410\ N/mm^2$
$\varepsilon_u = 0.23$
$E_s = 210\,000\ N/mm^2$

Worked Example

Frame bridge (RC)



Loading

Program: $\rightarrow (K \cdot \gamma \cdot h \cdot 5) \cdot \frac{1}{2} \cdot h = 355 \cdot \frac{1}{2} \cdot 7{,}2$

earth pressure $G_{Ea} = 0{,}5 \cdot K_a \cdot \gamma \cdot h^2 \cdot b$ with $K_a = 1 - \tan^2(45 - \frac{\rho}{2})$

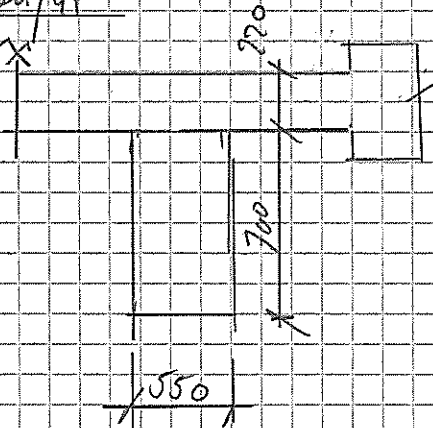
at-rest earth pr. $G_{E0} = 0{,}5 \cdot K_0 \cdot \gamma \cdot h^2 \cdot b$ with $K_0 = 1 - \sin\rho$

$K_0 = 0{,}47$

$G_{E0} = 0{,}5 \cdot 0{,}47 \cdot 21 \cdot 7{,}2^2 \cdot 2{,}55$

$= 256 \text{ kN/m} \cdot 5{,}0 \text{ m} = 1280 \text{ kN}$

DL: Self weight



$g_E = (1{,}39 + 2 \cdot 0{,}7 \cdot 0{,}55) \cdot 25 = 54 \text{ kN/m}$

SDL: Wearing course 5 cm

$g_A = 0{,}05 \cdot 24 = 1{,}2 \text{ kN/m}^2$ per area

$g_{A1} = 4{,}3 \text{ m} \cdot 1{,}2 = 5{,}2 \text{ kN/m}$ per m run

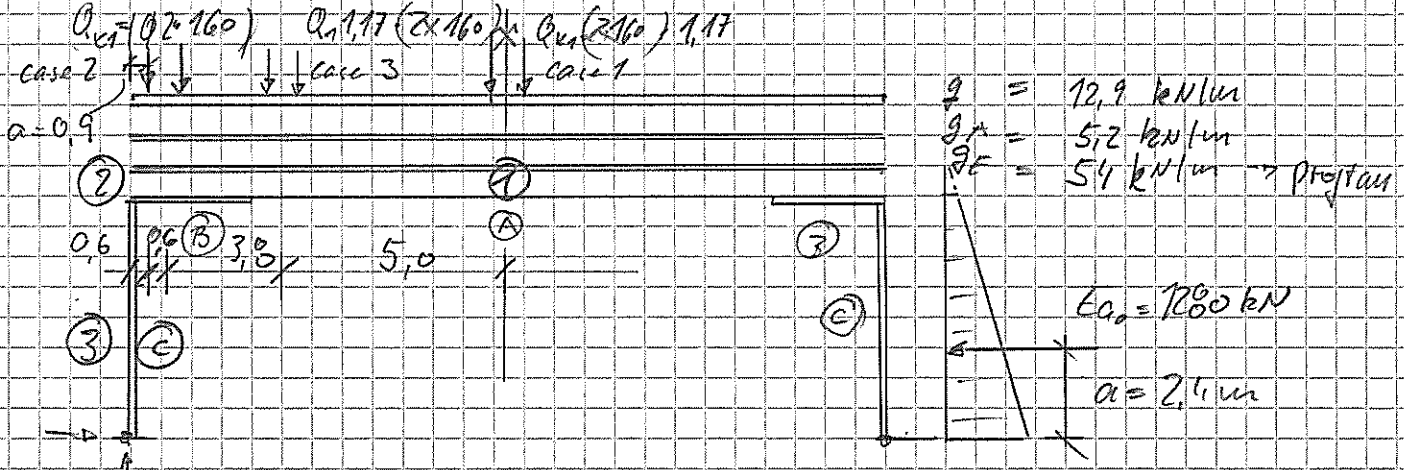
Live load : apply CRBP-16-Spa-2012

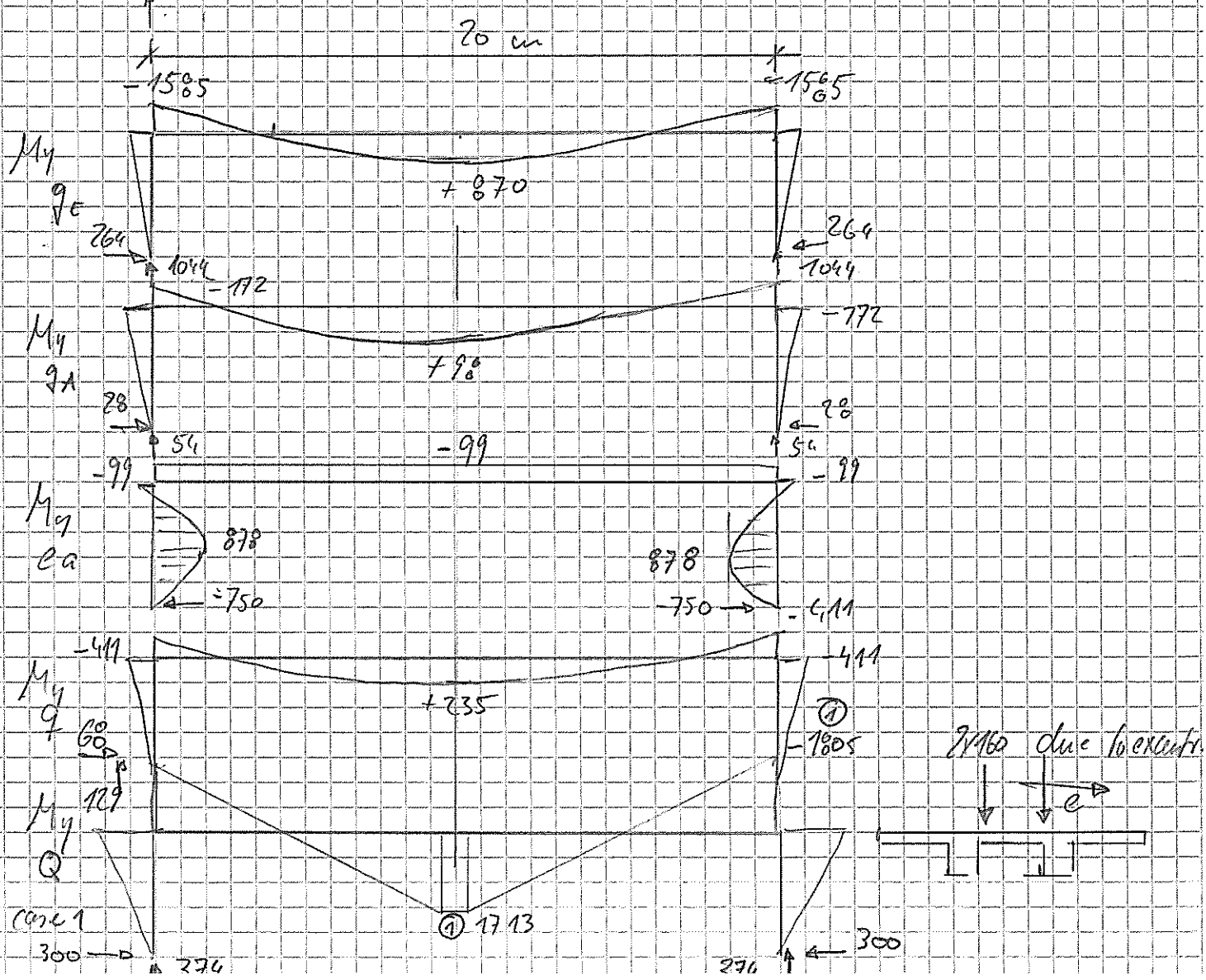
$q_k = 3,0 \text{ kN/m}^2$ — area load on width of lane

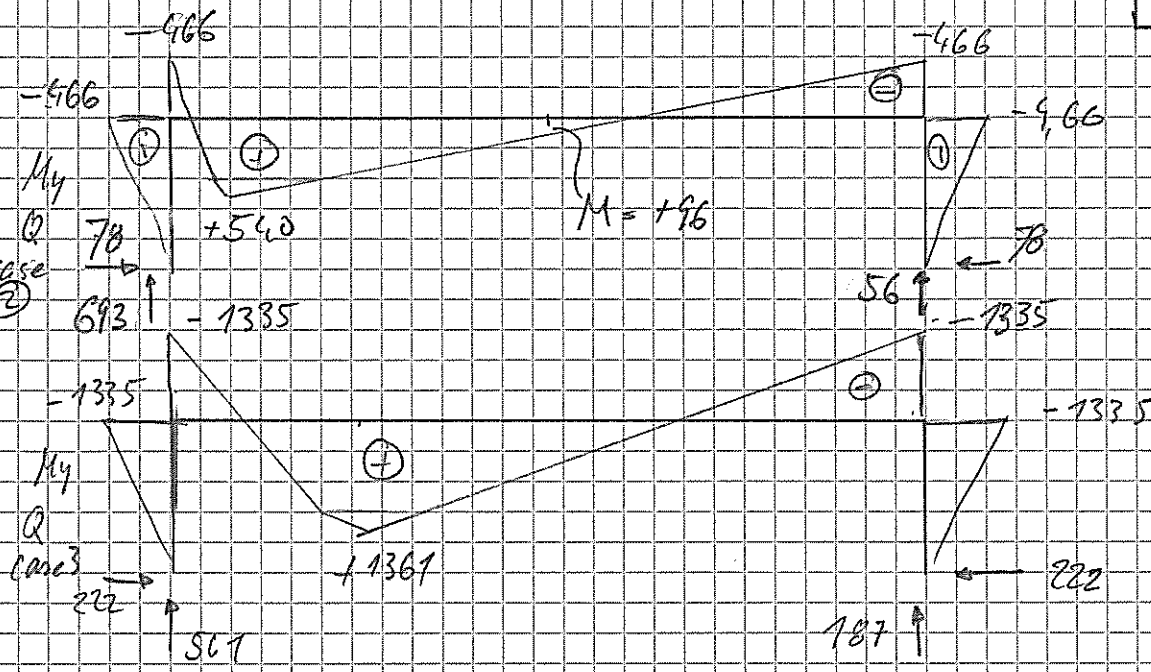
$q_{k1} = 3,0 \cdot 4,3 = 12,9 \text{ kN/m}$ — total load per m run

$Q_{k1} = 160 \text{ kN} \; ; \; \Phi = 0,17$ — axle load

$\Phi \cdot Q_{k1} = 1,17 \cdot 160 = 187 \text{ kN}$







Section Details

Sect. A: $A_A = 1,87\ m^2$ $I_y = 0,1317\ m^4$

Sect. B: $A_B = 2,91\ m^2$ $I_y = 0,225\ m^4$

Sect. C: $A_C = 3,33\ m^2$ $I_y = 0,225$

including upstand beam

$A_{up} = 0,2 \cdot 0,35 = 0,07$

$\Sigma A_A = 1,94\ m^2$ incl. upstand

$\Sigma A_B = 2,98\ m^2$ " "

Check manually

$A_A = 0,74 \cdot 2,55 + 0,25 \cdot 2,45 + 2 \cdot 0,2 \cdot 0,35 + \pi \cdot 0,75 \cdot 0,1 \cdot \frac{1}{2}$

$+ 0,55 \cdot 0,7 \cdot 2$

$A_A = 2,16\ m^2$

$A_B = 1,39 + 2,55 \cdot 0,7 = 3,17\ m^2$

$A_C = 3,04 + 2,55 \cdot 0,32 = 3,38\ m^2$

Max. positive Moment @ midspan ①

↓ decreasing Moment

$M_{d①} = 1,35 (M_{DL} + M_{SD}) + 1,5 (M_{LLg} + M_{LLQ}) + 0,8 M_E$

$V_{d①} = 1,5 V_{LLQ}$

Max neg. Moment at frame end ②

↓ increasing BM

$M_{d②} = 1,35 (M_{DL} + M_{SD}) + 1,5 (M_{LLg} + M_{LLQ}) + 1,35 M_E$

$V_{u②} = 1,35 (V_{DL} + V_{SD}) + 1,5 (V_{LLg} + V_{LLQ})$

max. BM at frame post ③

$M_{d③} = 1,35 (M_{DL} + M_{SD}) + 1,35 M_E$

↓

$0,8 (M_{DL} + M_{SD}) + 1,35 M_E$

$V_{d③} = 0,8 (V_{DL} + V_{SD}) + 1,35 M_E$

↓

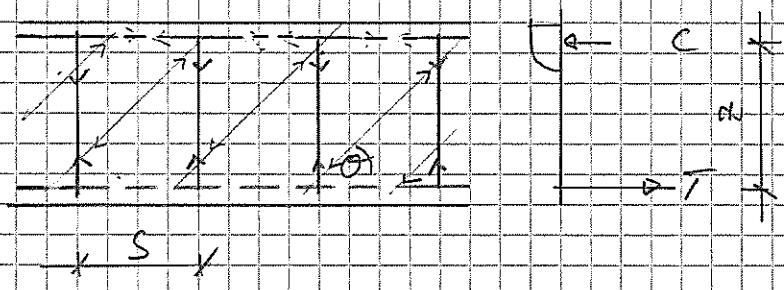
1,35

Design Forces taken from program

LCC1 $M_{d①}$ =	+4200 kNm	$N_{d①}$ =	-1330 kN	$V_{d①}$ = 0
LCC16 $M_{d②}$ =	-5830	$N_{d②}$ =	-1605 kN	$V_{d②}$ = 1565 kN
LCC6 $M_{d③}$ =	-3820	$N_{d③}$ =	-1270	$V_{d②}$ = 2042 kN
				$V_{d③}$ = 1471 kN

Design for Shear

Model: Strut & Tie



Steel:

$$V_{Rds} = \frac{A_{sw}}{s} \cdot z \cdot \frac{f_{yk}}{1{,}15} \cot\theta$$

Concrete

$$V_{Rdc} = \delta_w \cdot z \cdot k_c \cdot f_{cd} \cdot \sin\theta \cdot \cos\theta$$

Design for $V_{Ed} = 2042$ kN - Section 3

Concrete fc30: $f_{cd} = 16{,}4$ N/mm²; Steel Fe500: $f_{yd} = 435$ N/mm²

$$\frac{A_{sw}}{s} = \frac{V_d}{z \cdot f_{yd} \cdot \cot\theta}$$

$\theta = 30° \rightarrow \cot\theta = 1{,}73$

$$a_{sw} = \frac{2042 \text{ kN}}{0{,}9 \cdot 0{,}88 \cdot 0{,}435 \cdot 1{,}73} = 3926 \text{ mm}^2/\text{m}$$

1 Ø 12 = 113 mm²; Layout:

6 x 113 = 678 mm² ($8 \cdot 113 = 904$ mm²)

@ 300 mm: $a_{sw} = 2260$ mm²/m ✗ | @ 300: $a_{sw} = 3013$ mm²/m

@ 200: $a_{sw} = 3390$ mm²/m ✗ | @ 250: $a_{sw} = 3616$ mm²/m ✓

@ 175: $a_{sw} = 3874$ mm²/m ✓

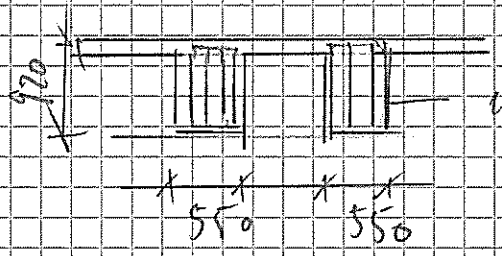
Check concrete

$$V_{Rdc} = 2550 \cdot 0{,}9 \cdot 0{,}880 \cdot 0{,}6 \cdot 16{,}4 \cdot \sin 30 \cdot \cos 30 = 8605 \text{ kN} \checkmark$$

Section A:

Design for $V_{Ed3} = 1471$ kN

Section



$w = 4$ legs

each WS: $\frac{1}{2} V_{Rd3} = 736$ kN

$$a_{sw} = \frac{736 \text{ kN}}{0{,}9 \cdot 0{,}80 \cdot 0{,}435 \cdot 1{,}17} = 1235 \text{ mm}^2/\text{m} \text{ (per web)}$$

$a_{sw4} = 113 \cdot 4 = 452 \text{ mm}^2$

Spacing @300: $a_{sw1} = 1506 \text{ mm}^2/\text{m}$ ✓

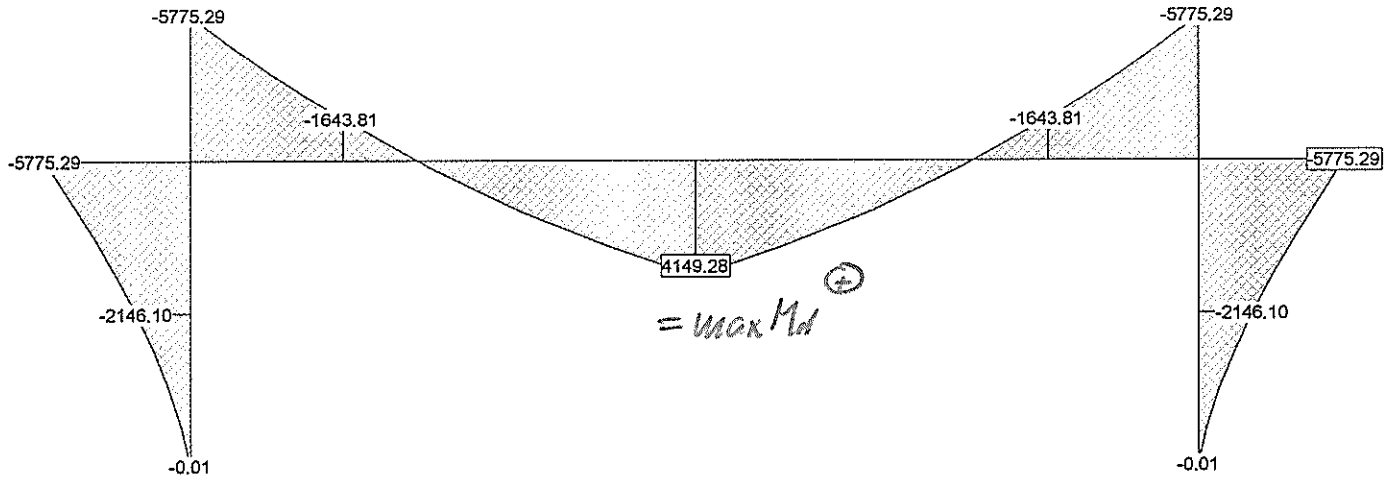
@350 $a_{sw2} = 1290 \text{ mm}^2/\text{m}$ ✓ max. effective

Check concrete:

$V_{Rd} = 550 \cdot 0{,}9 \cdot 0{,}80 \cdot 0{,}6 \cdot 16{,}4 \cdot \sin 30 \cdot \cos 30 = 1856$ kN ✓

Section force My [kNm] for: ULS-08Ea+135g+150q-1

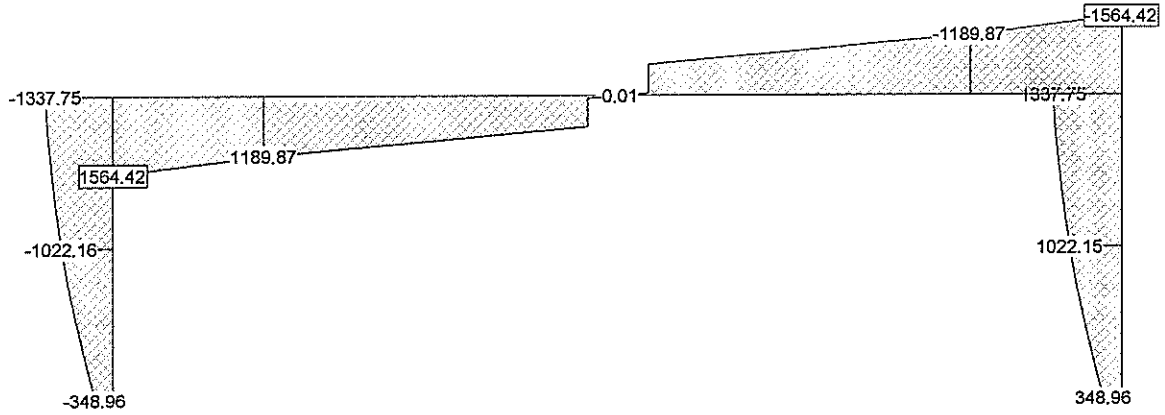
Scale 1 :150.0



= max M_d ⊕

Section force Vz [kN] for: ULS-08Ea+135g+150q-1

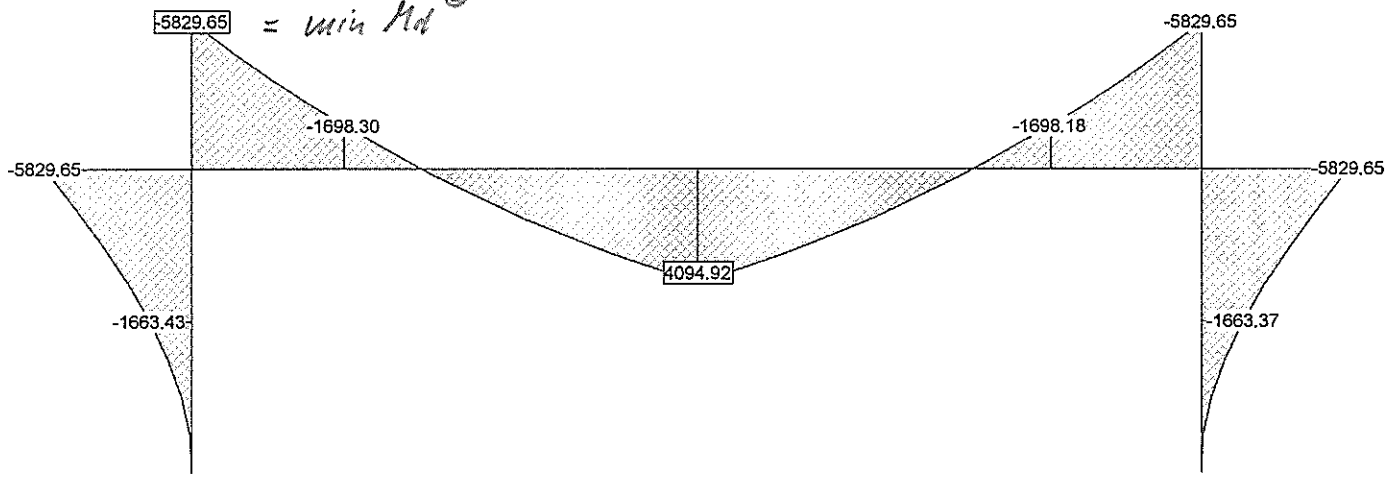
Scale 1 :150.0



Nr.:

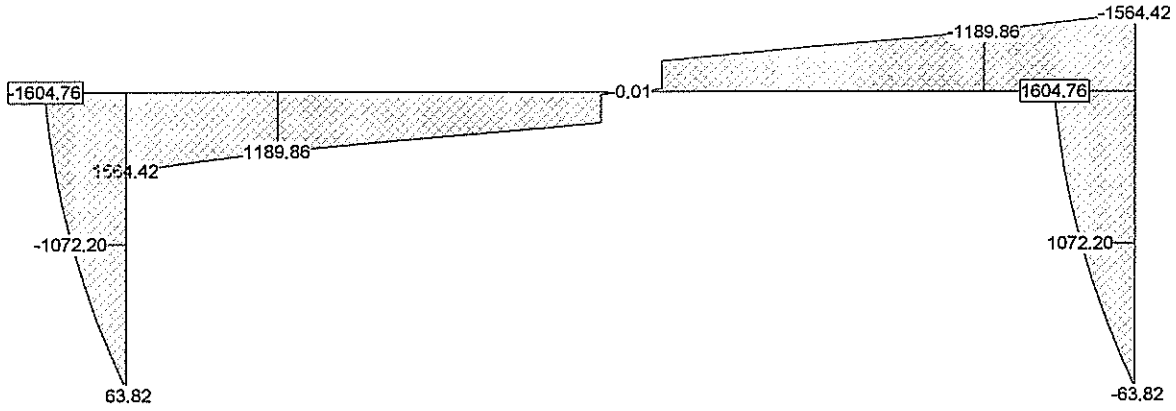
Section force My [kNm] for: ULS135g+150q-case1

Scale 1 :150.0



Section force Vz [kN] for: ULS135g+150q-case1

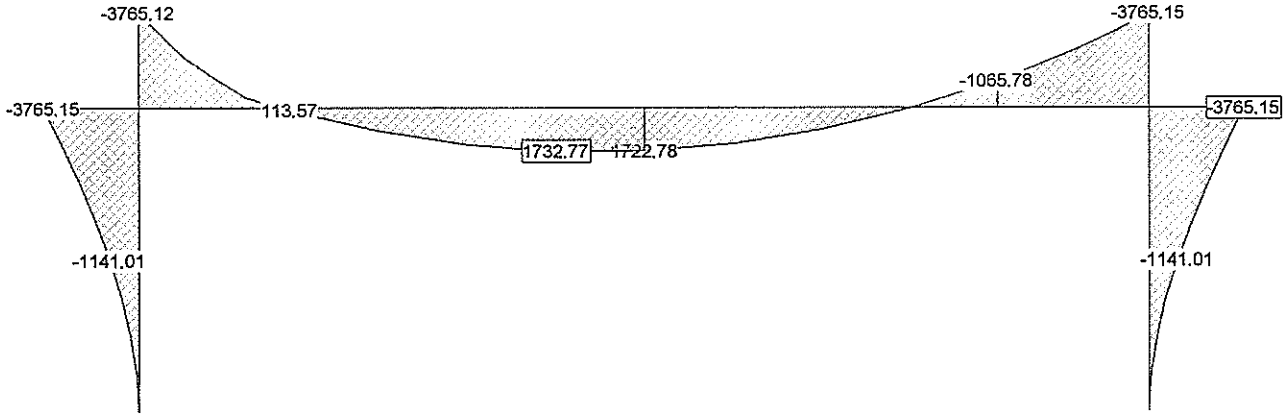
Scale 1 :150.0



Nr.:

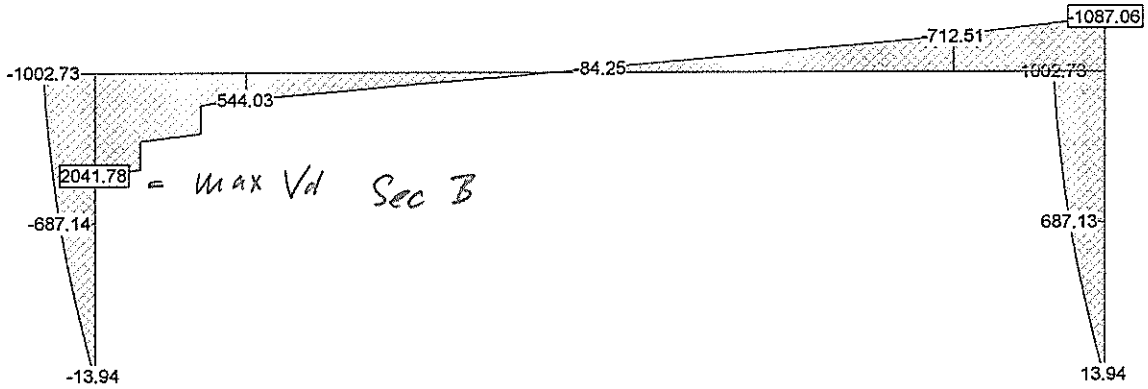
Section force My [kNm] for: ULS-08Ea+135g+150q-2

Scale 1 :150.0



Section force Vz [kN] for: ULS-08Ea+135g+150q-2

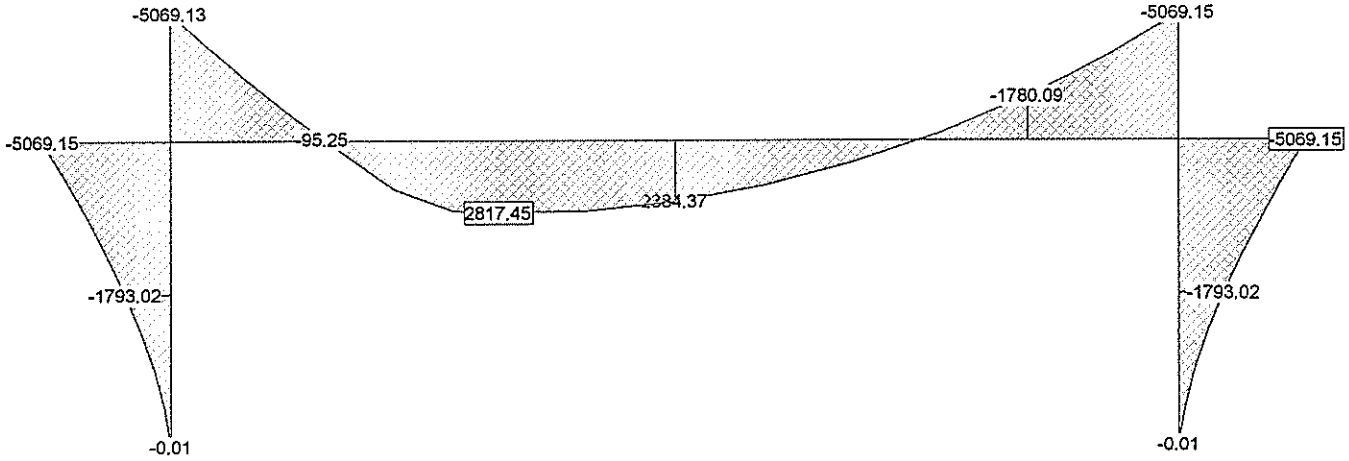
Scale 1 :150.0



Nr.:

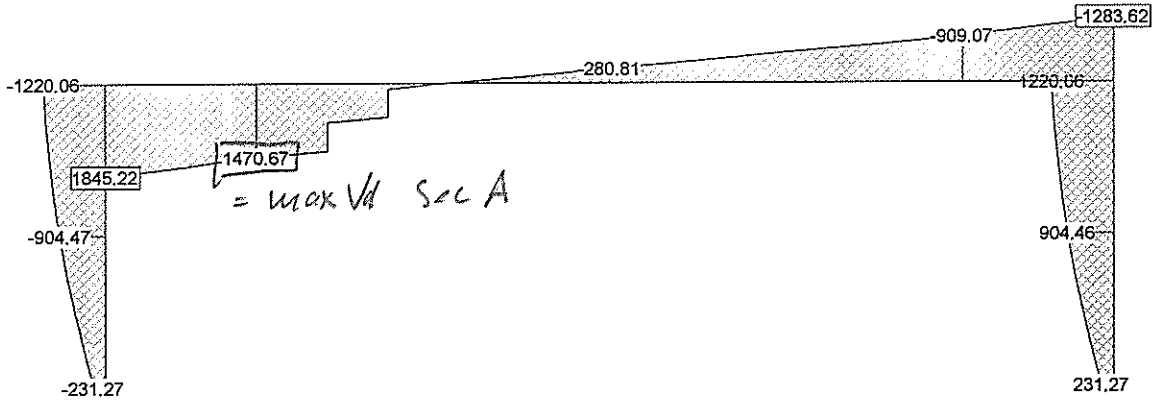
Section force My [kNm] for: ULS-08Ea+135g+158q-3

Scale 1 :150.0



Section force Vz [kN] for: ULS-08Ea+135g+158q-3

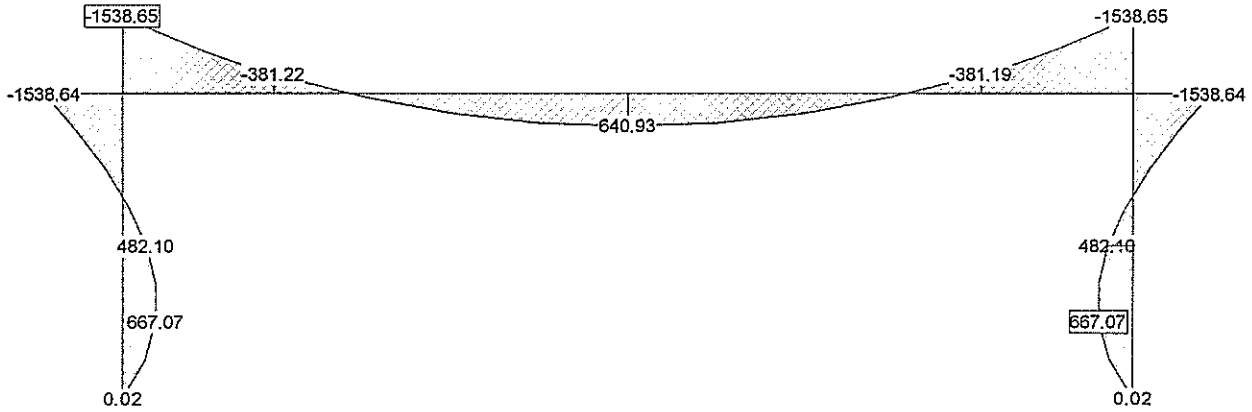
Scale 1 :150.0



Nr.:

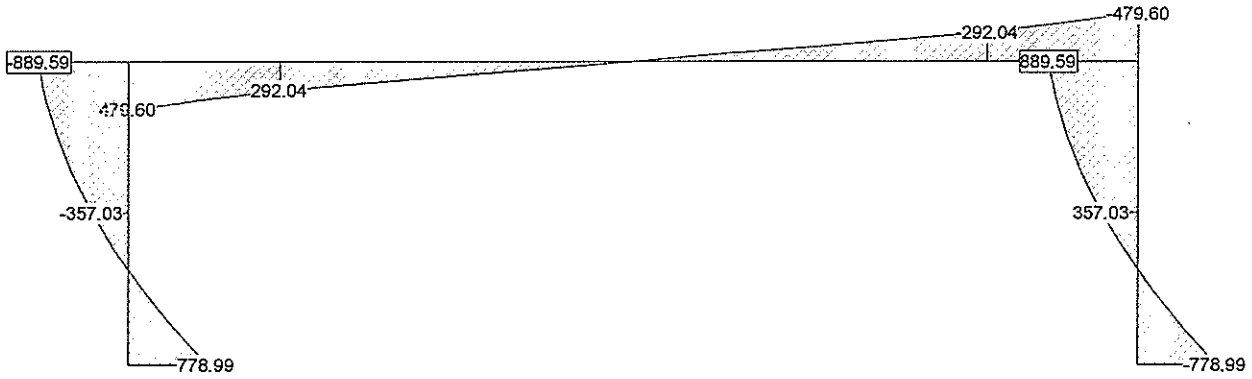
Section force My [kNm] for: ULS-135gE+08g

Scale 1 :150.0



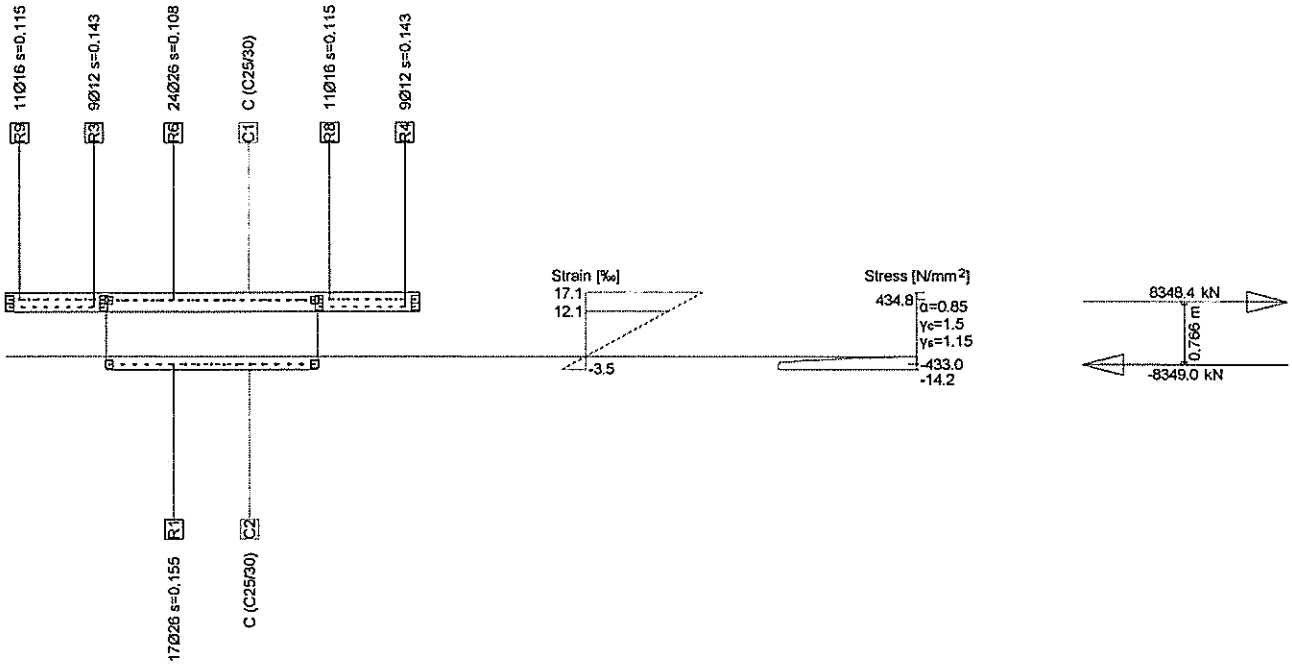
Section force Vz [kN] for: ULS-135gE+08g

Scale 1 :150.0



Nr.:

Cross-section SECB (C25/30;S420): Efficiency My=-5830.0; eff(M,N) = 0.91 OK Scale 1 :91.3



Ultimate strength analysis Girder-Cross section: SECB

Action forces / Efficiency factors: eff(M,N) = 0.91 OK

No.	AP	P	Bending and axial force N [kN]	M_y [kNm]	M_z [kNm]	eff(M,N) [-]	Shear forces and torsion V_y [kN]	V_z [kN]	T [kNm]	eff(V,T) [-]	Complete CS eff(M,N,V,T) [-]
1	!ULS		0	-5830.0	0	0.91					

Analysis-Parameters "!ULS", Code: Eurocode EN

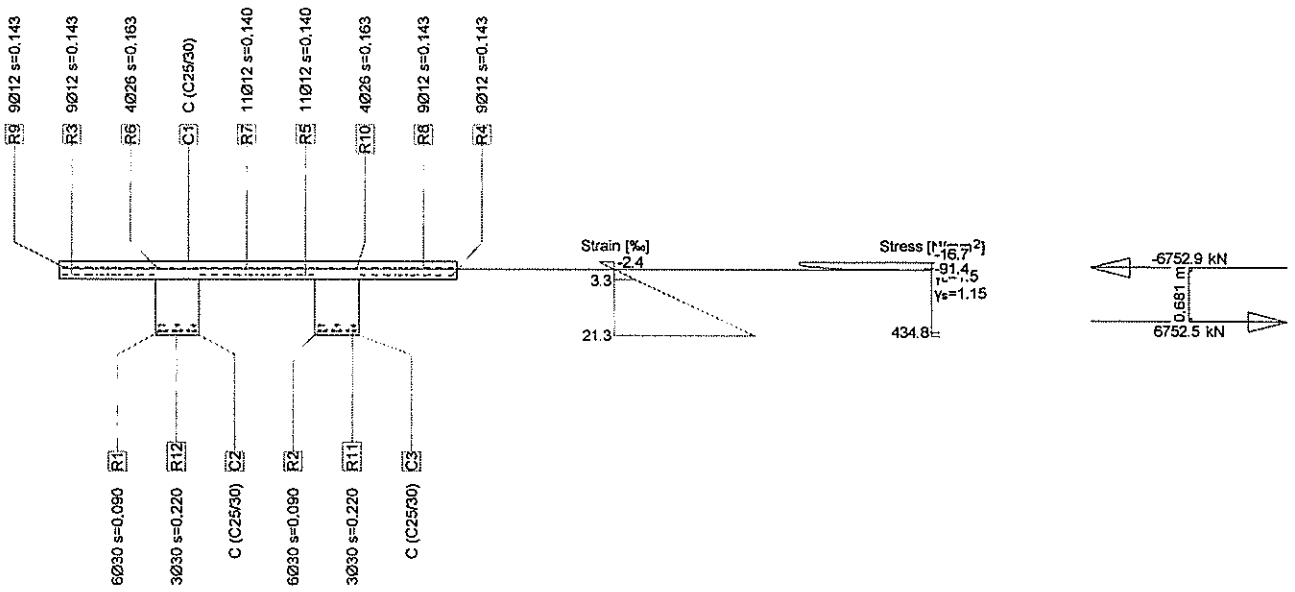
ID	σ-ε-Diagram c	s			Strain Limits ε_{c1d} [‰]	ε_{c2d} [‰]	ε_{ud} [‰]	σ_s [N/mm²]		Partial safety factor γ_c [-]	γ_s [-]			Various parameters θ [-]	ϕ [-]		
!ULS	2/0	1			-2.0	-3.5	20.0		0.85	1.50	1.15			45.00	0		

Extreme stresses and strain

Name	Class	y_q [m]	z_q [m]	ε [‰]	σ_d [N/mm²]	γ [-]
C2	C25/30	-1.275	0.100	-3.5	-14.2	1.76
C1	C25/30	2.500	1.025	17.1	0	1.76
R1	FE500	-1.240	0.160	-2.2	-433.0	1.15
R8	FE500	2.445	0.945	15.3	434.8	1.15

Cross-section SEC-A (C25/30;FE500): Efficiency My=4200.0; eff(M,N) = 0.91 OK

Scale 1 :95.3



Ultimate strength analysis Girder-Cross section: SEC-A

Action forces / Efficiency factors: eff(M,N) = 0.91 OK

No.	AP	P	Bending and axial force N [kN]	M_y [kNm]	M_z [kNm]	eff(M,N) [-]	Shear forces and torsion V_y [kN]	V_z [kN]	T [kNm]	eff(V,T) [-]	Complete CS eff(M,N,V,T) [-]
1	!ULS		0	4200.0	0	0.91					

Analysis-Parameters "!ULS", Code: SIA (2003)

ID	σ-ε-Diagram c	s	Strain Limits ε_{c1d} [‰]	ε_{c2d} [‰]	ε_{ud} [‰]	σ_s [N/mm²]	Partial factors γ_c [-]	γ_s [-]	Various parameters α [-]	ϕ [-]
!ULS	4/0	1	-2.0	-3.0	20.0		1.50	1.15	45.00	0

σ-ε : SIA262 Fig 11 + Fig 15

Extreme stresses and strain

Name	Class	y_q [m]	z_q [m]	ε [‰]	σ_d [N/mm²]	γ [-]
C1	C25/30	-2.500	1.020	-2.4	-16.7	1.50
C3	C25/30	1.275	0.100	21.3	0	1.50
R9	FE500	-2.445	0.945	-0.5	-91.4	1.15
R2	FE500	1.225	0.150	20.0	434.8	1.15