STATIC CALCULATION
CULVERT CU037081

MINIMUM REINFORCEMENT
DISSIPATION OF HYDRATION HEAT

Project No.: **087453-24**

Construction project: NEW LINE FROM TALLINN TO RAPLA RAILWAY LINE / CULVERT / CU037081

Client:
OÜ Keskkonnaprojekt
Ringtee 12
50105 Tartu
Estonia

Installer:
Roxeler Ingenieurgesellschaft mbH
Otto-Hahn-Straße 7
48161 Münster

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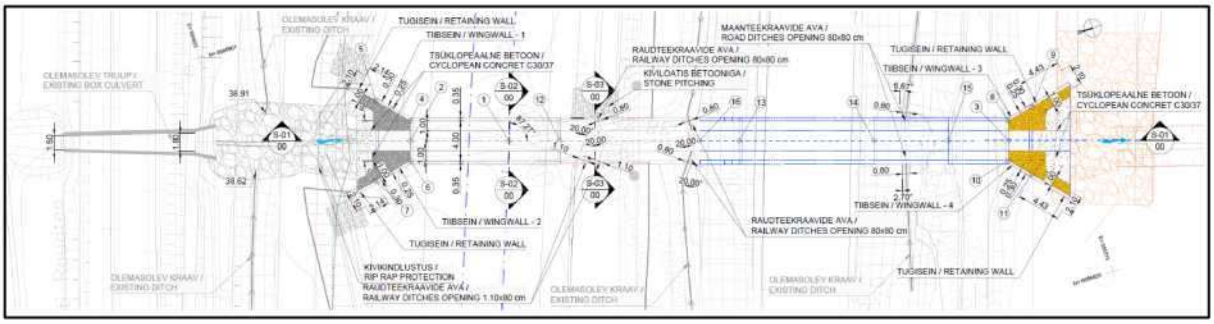
1 General information

1.1 Structure / Construction



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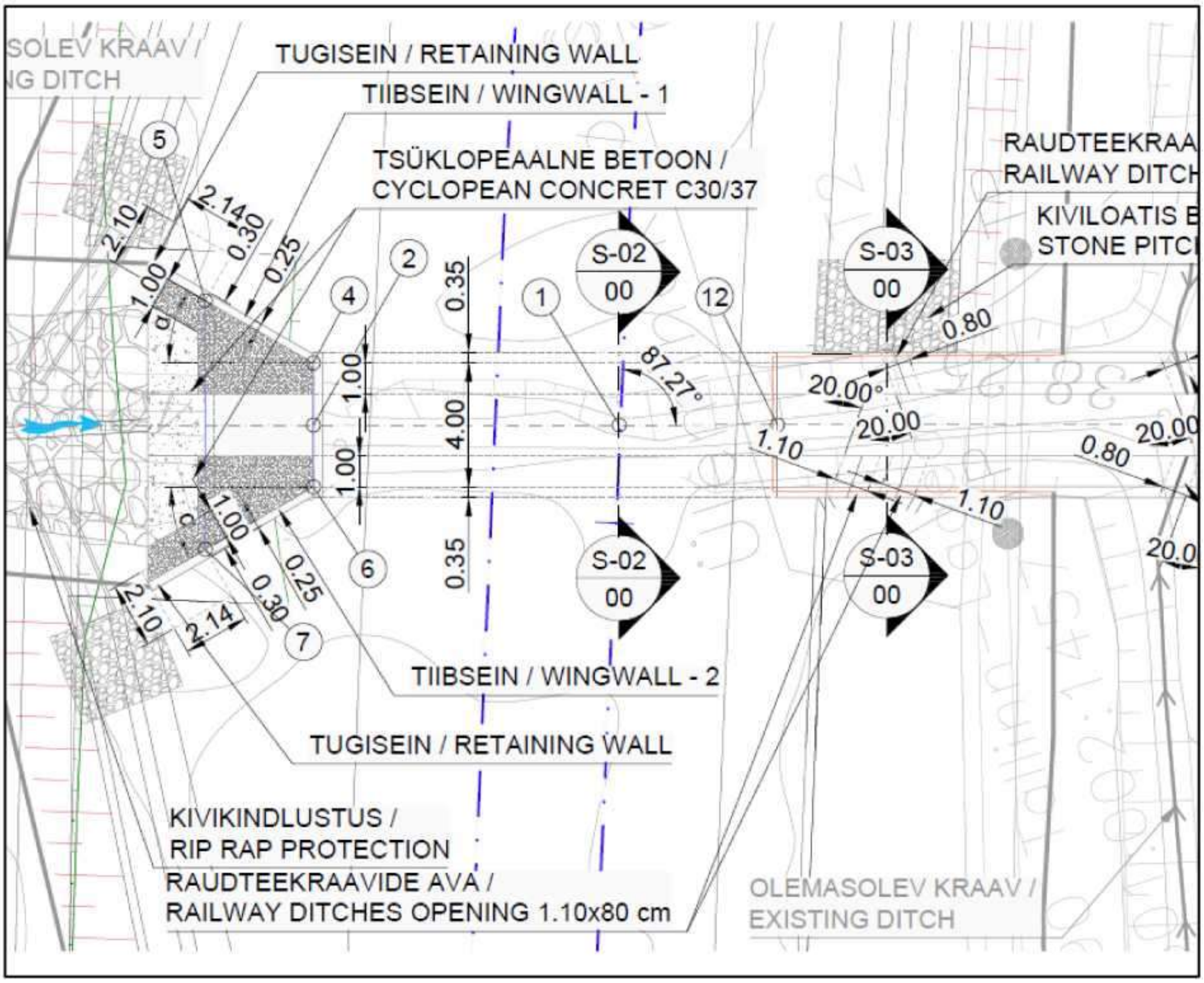

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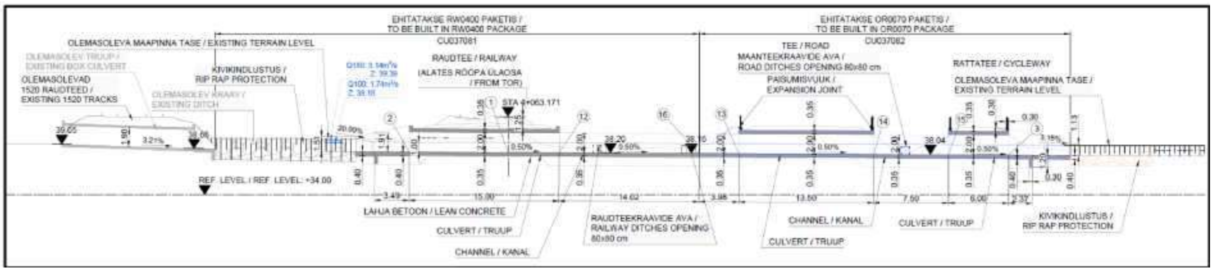

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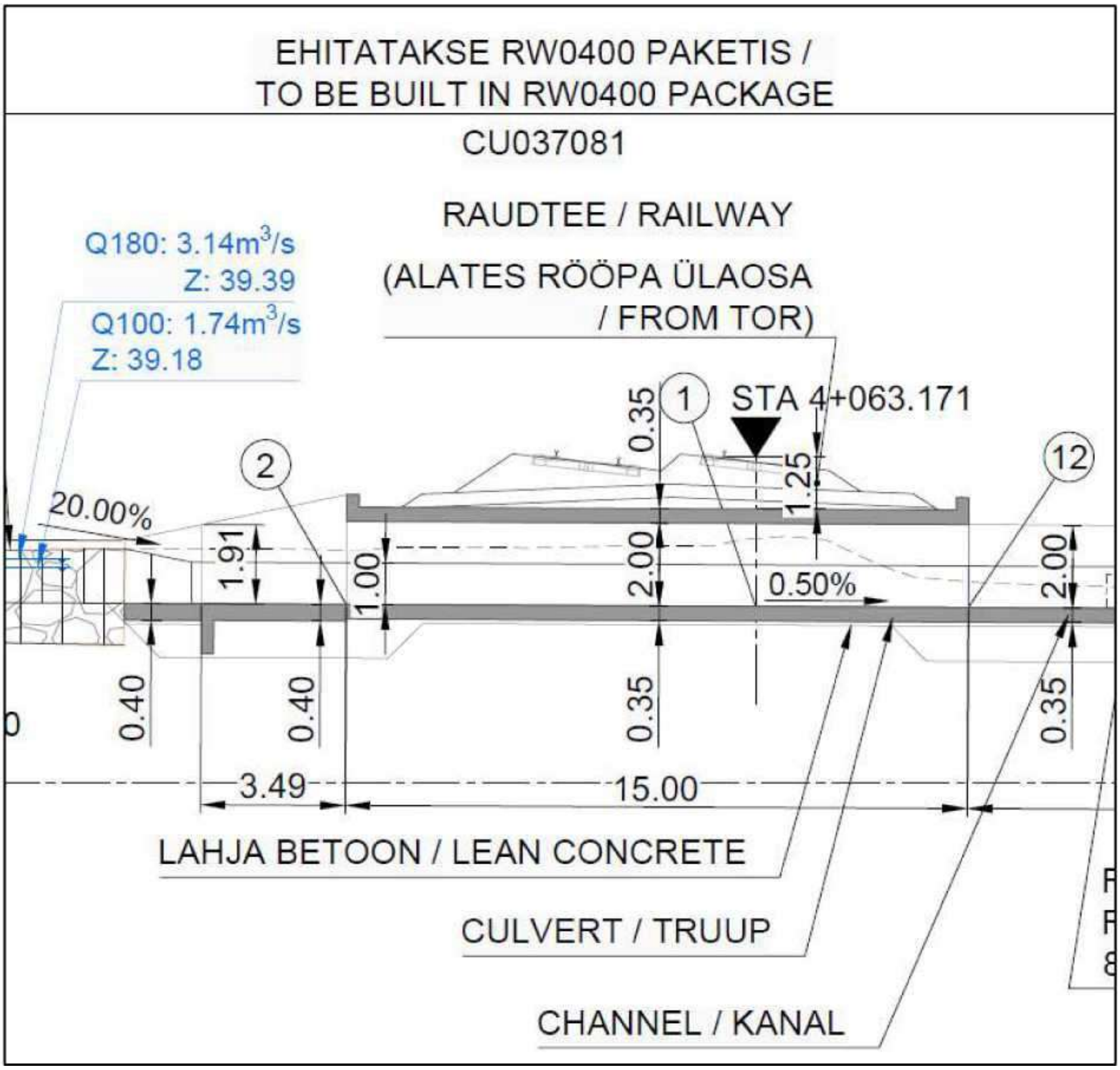

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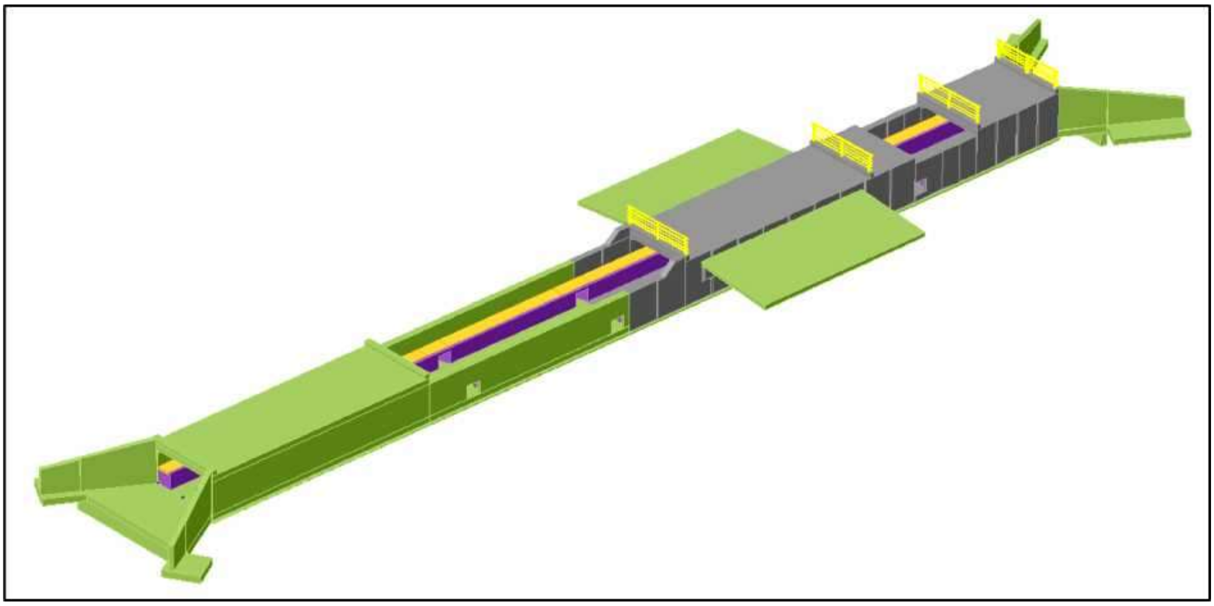
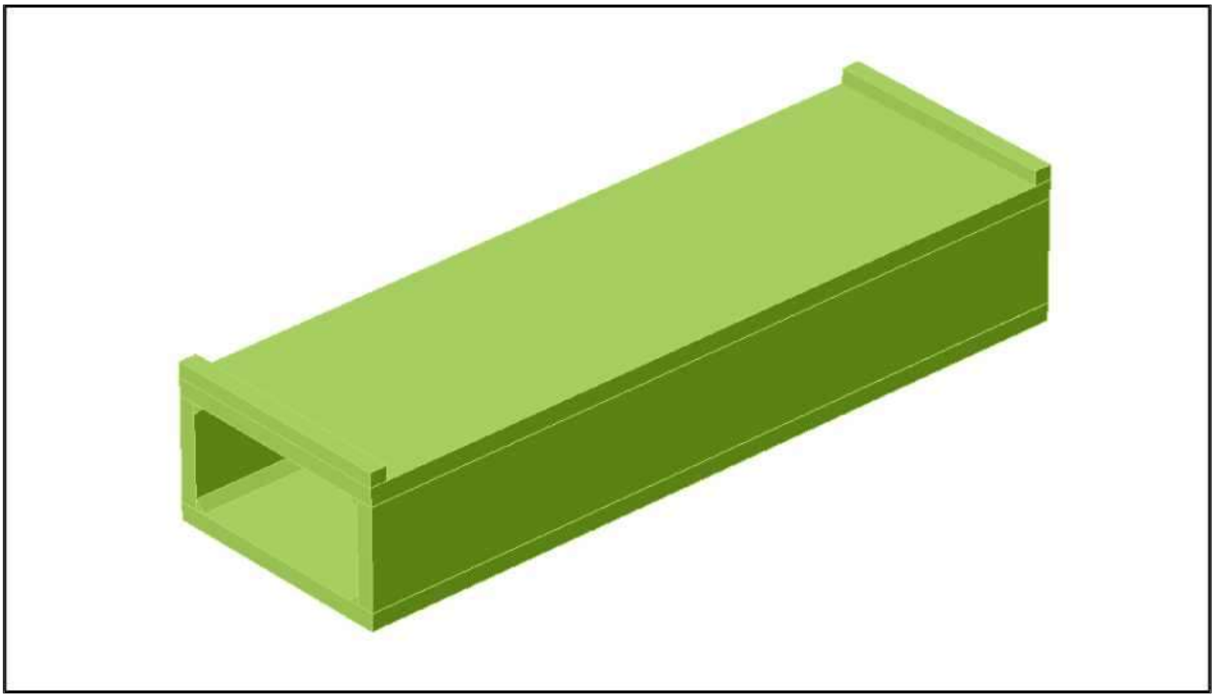
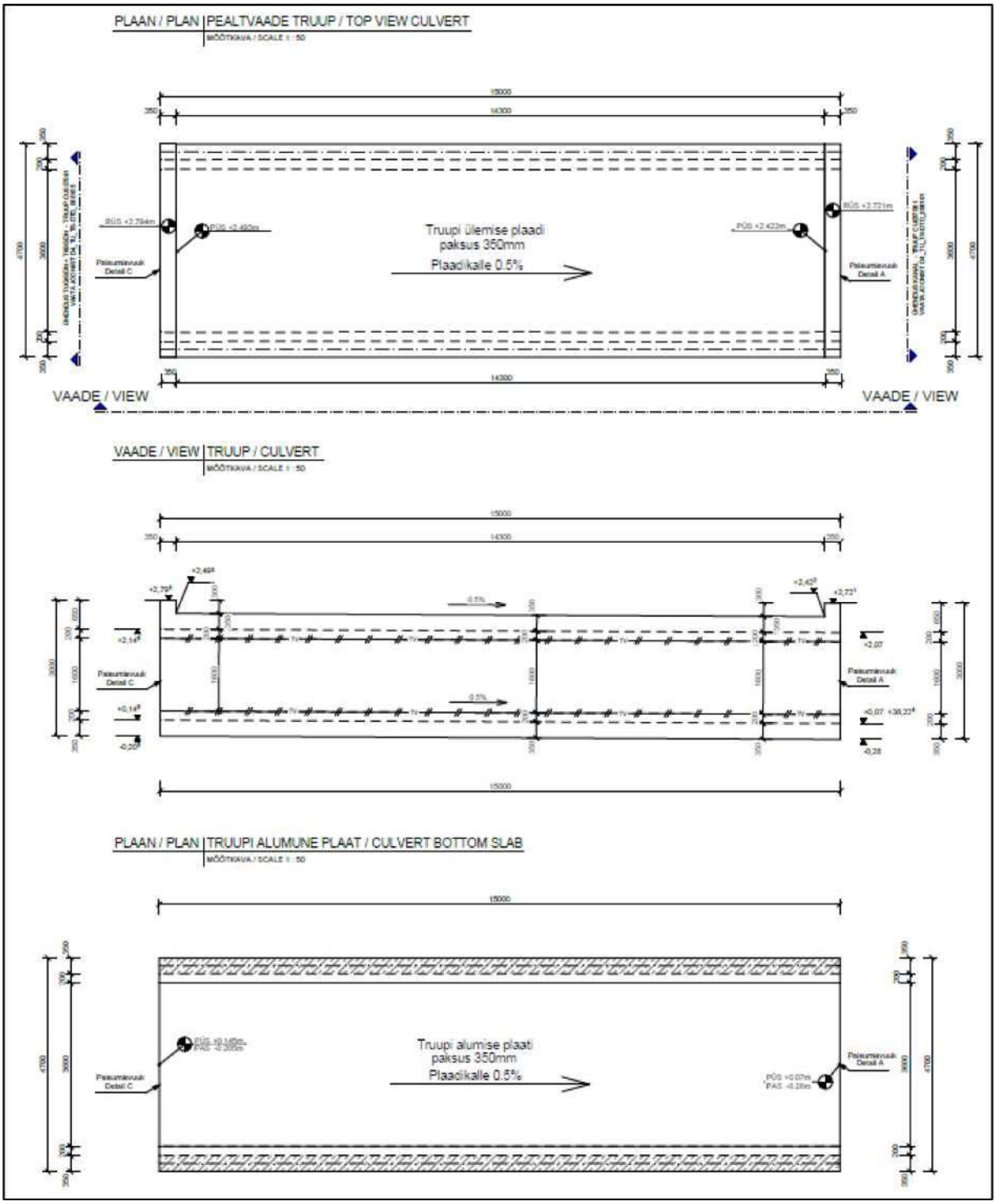


(3D model / IFC file)



(3D model / IFC file)

1.2 Structure / Geometry



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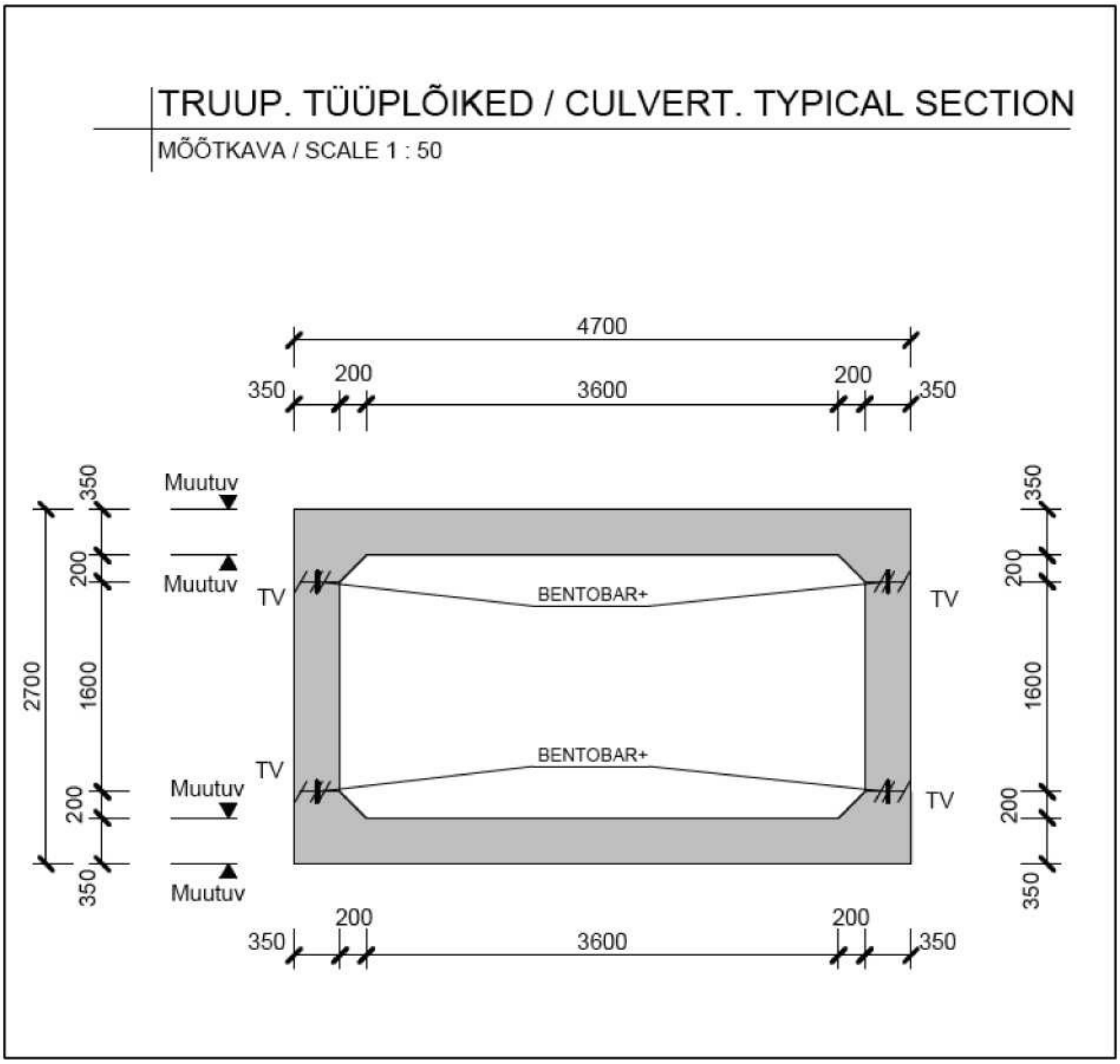

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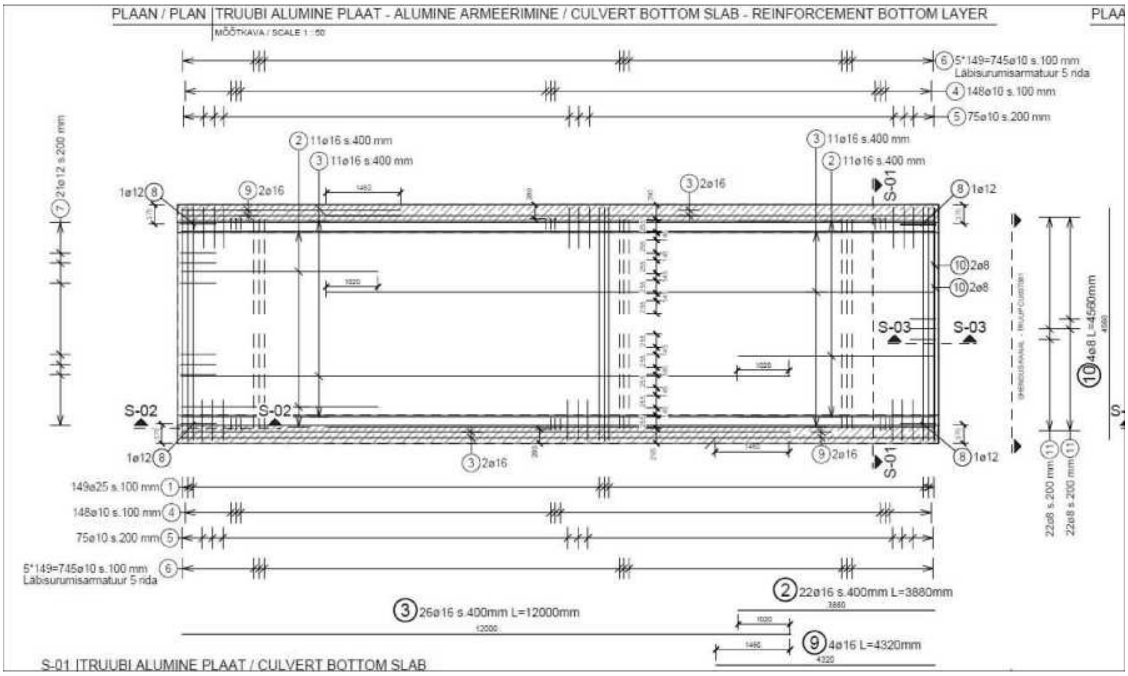
1.3 Structure / Reinforcement



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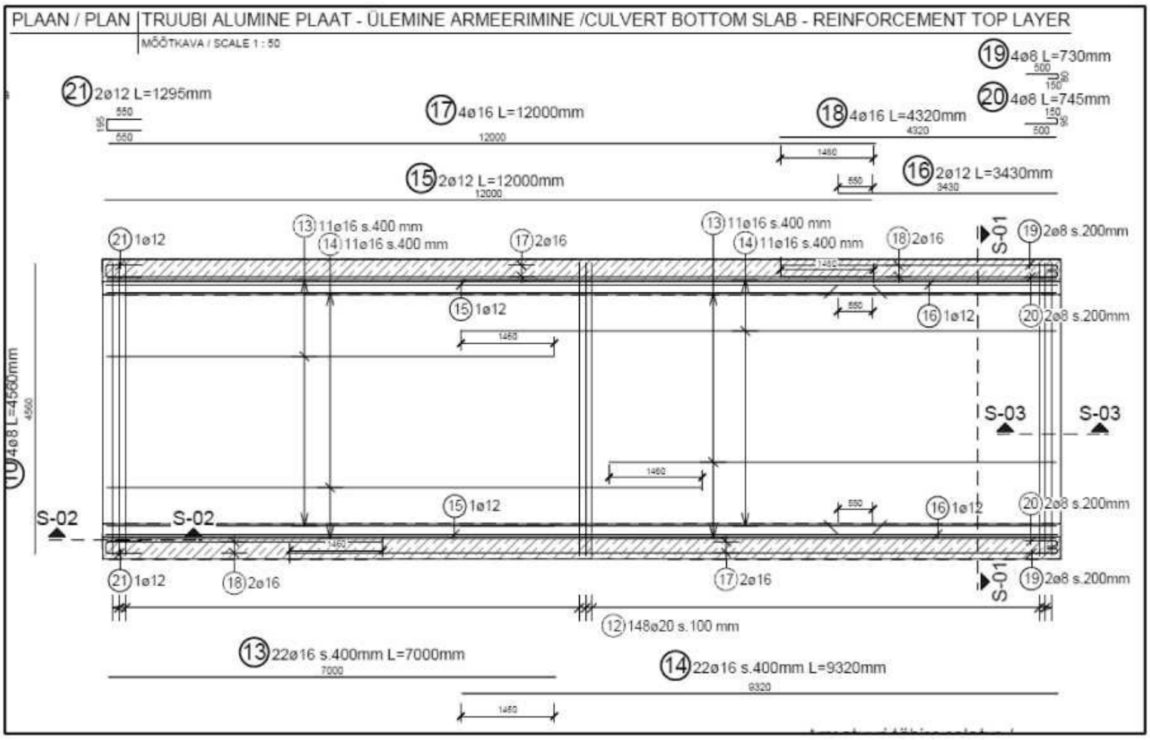

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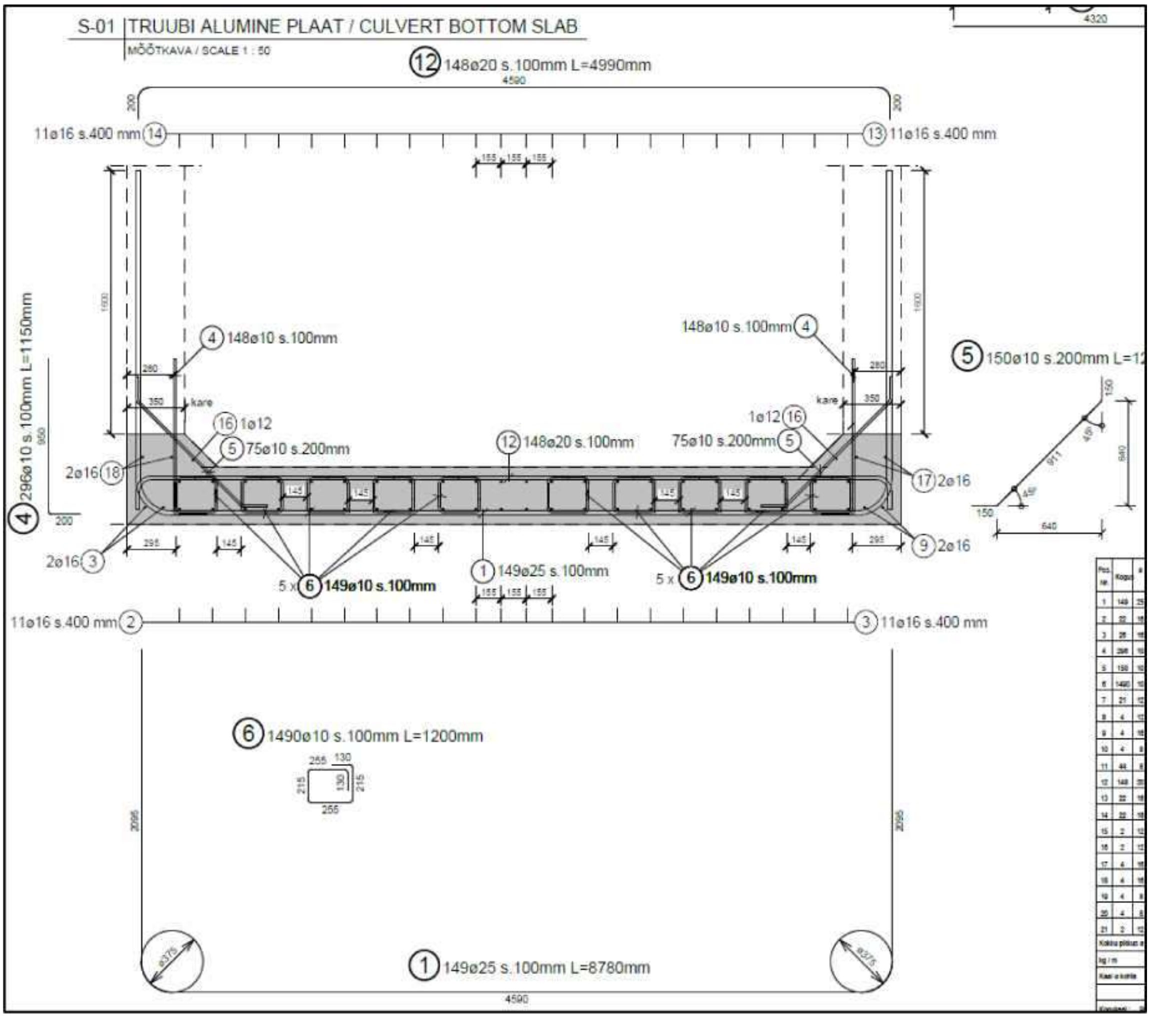

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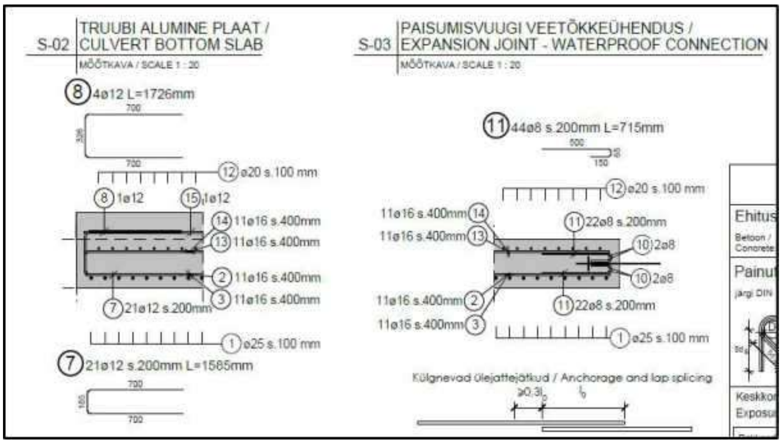

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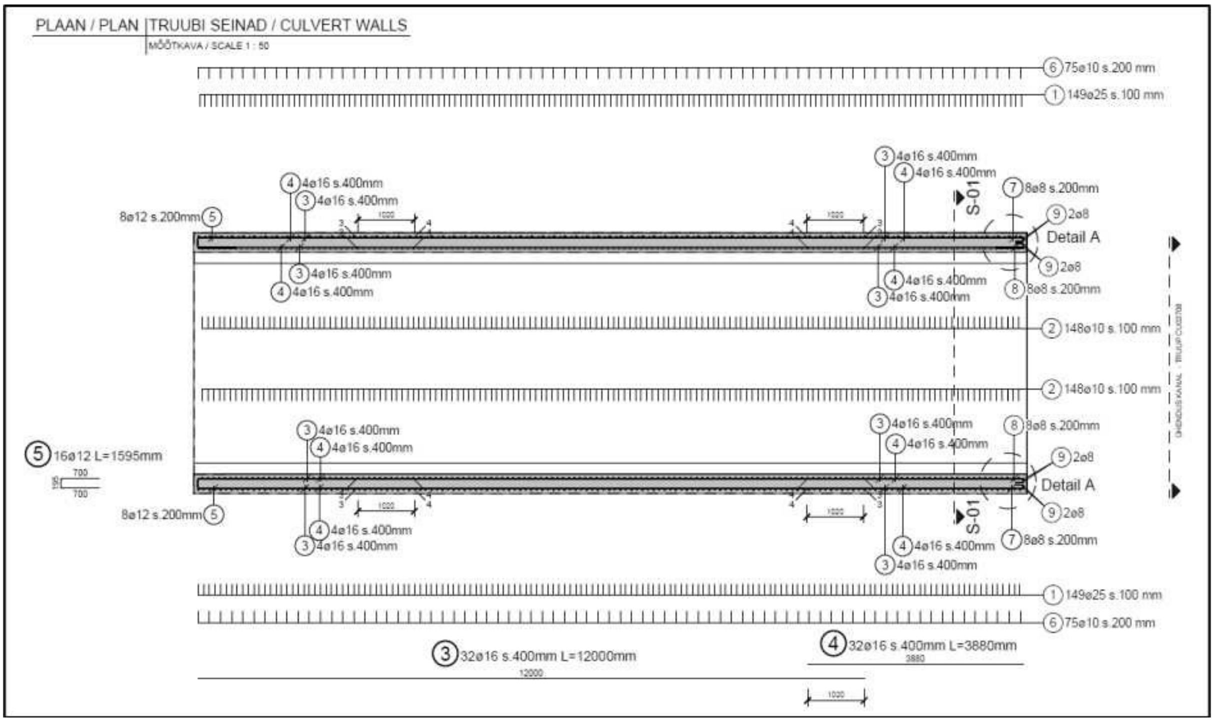

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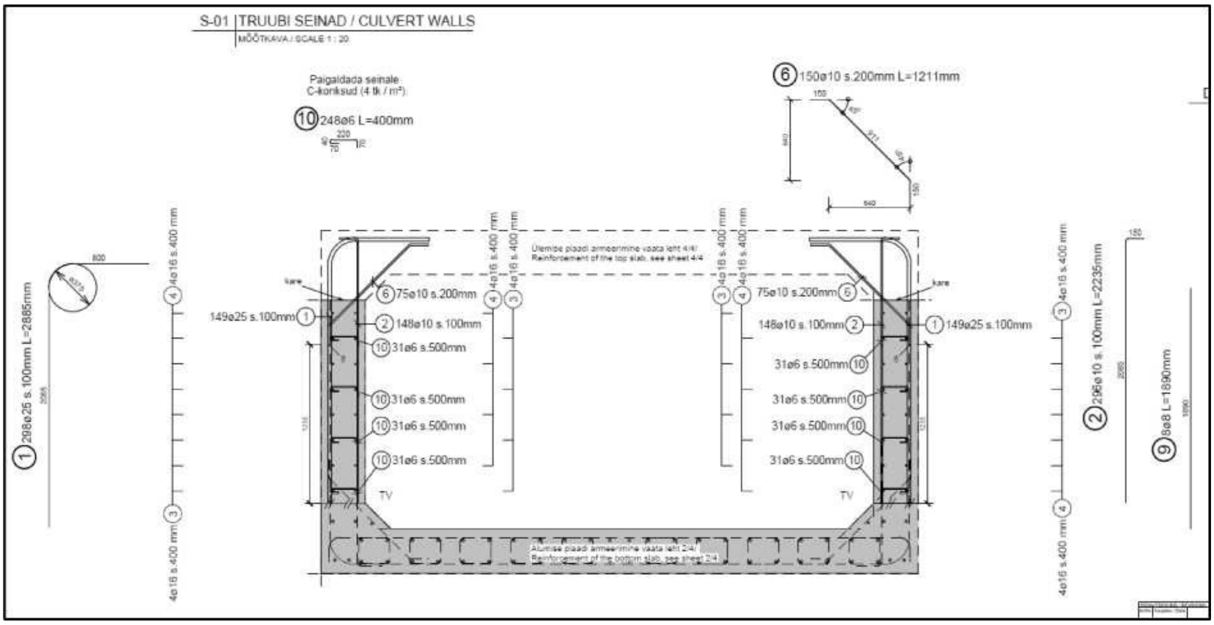

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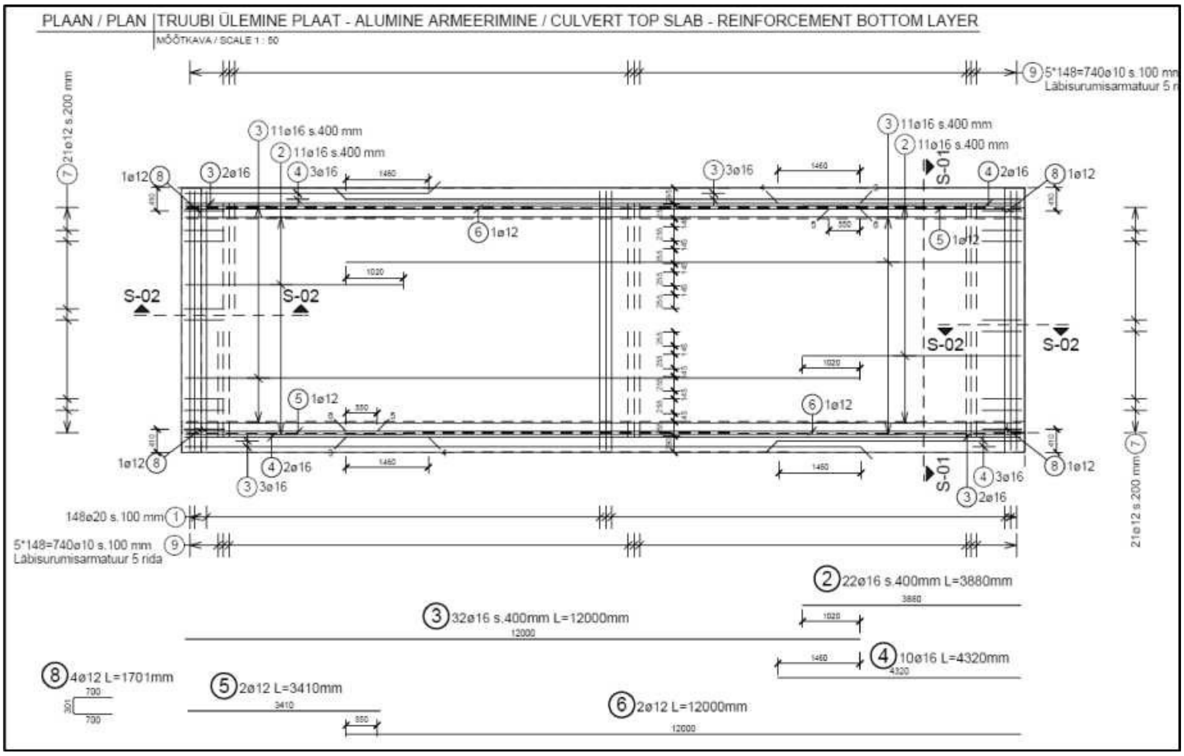
AUTHOR:	Roxeler Ingenieurgesellschaft	Otto-Hahn-Str. 7 48161 Münster Tel. (02534) 6200-0, Fax -32	PROJECT NO.: 087453-24
CONSTRUCTION PROJECT: CLIENT:	NEW LINE FROM TALLINN TO RAPLA OÜ Keskkonnaprojekt / Ringtee 12 / 50105 Tartu / Estonia		Culvert: CU037081 DATE: 16.11.2024



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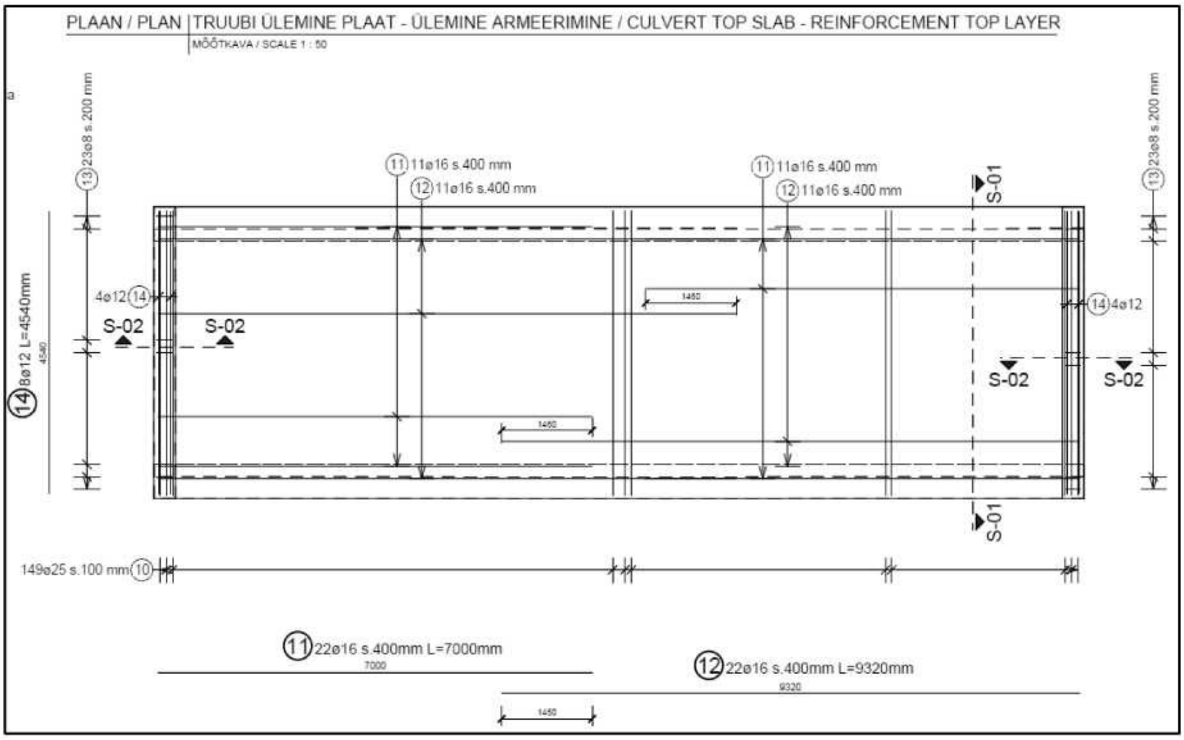

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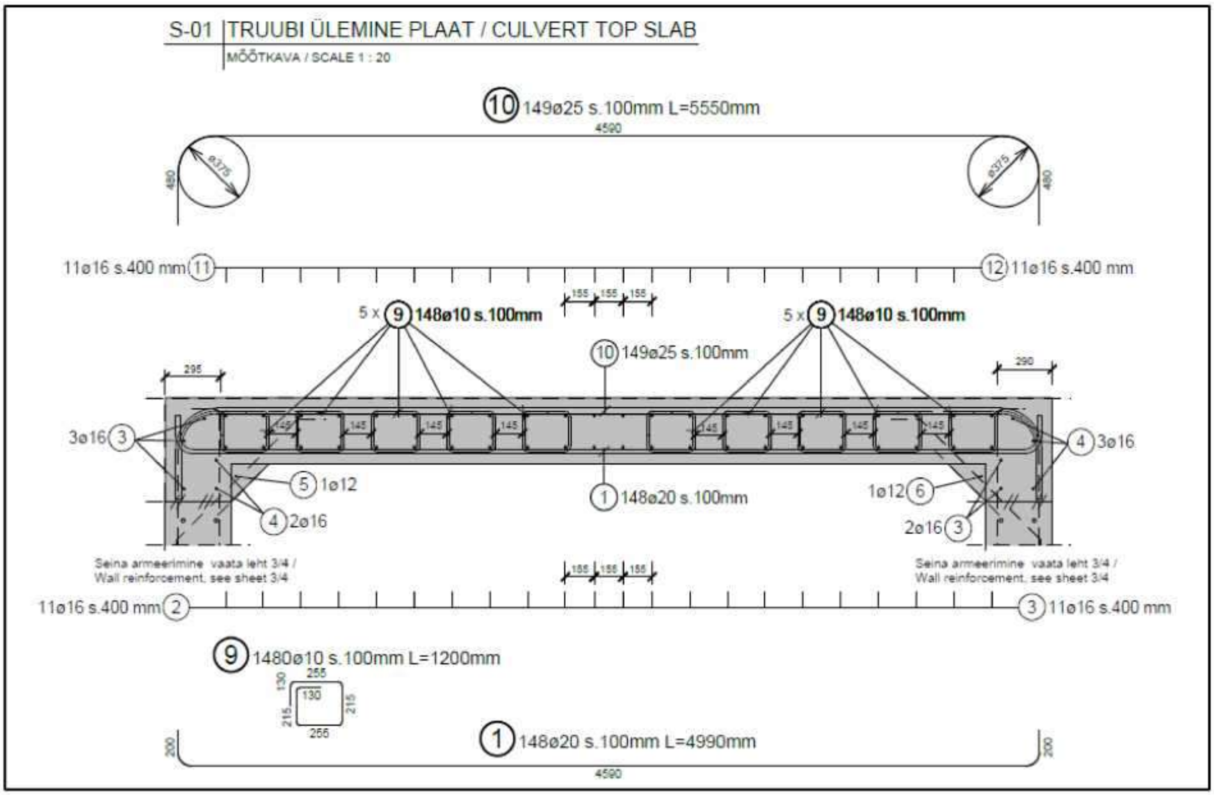
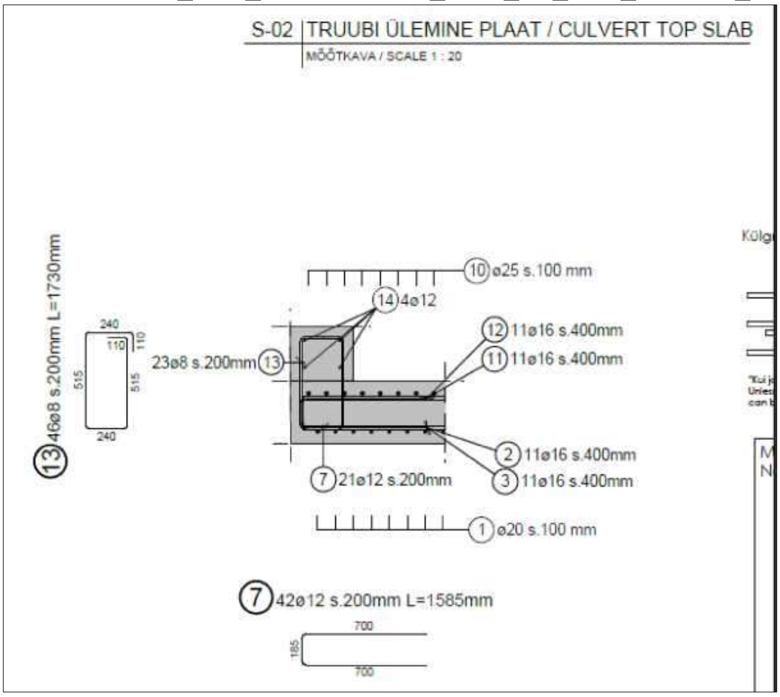


(Map detail / RBDTD-EE-DS2-DPS1_TRE_CU037081-ZZ_0005_D4_STR_EK-DTD_000102_003)



(Map detail / RBDTD-EE-DS2-DPS1_TRE_CU037081-ZZ_0005_D4_STR_EK-DTD_000102_003)

1.4 Technical regulations

DIN EN 1990 DIN EN 1990/NA	Basis of structural design. Basis of structural design – National Annex
DIN EN 1992-1-1	Design of concrete structures General rules and rules for buildings
DIN EN 1992-1-1/NA	Design of concrete structures General rules and rules for buildings – National Annex
DIN EN 1992-2	Design of concrete structures Concrete bridges – Design and detailing rules
DIN EN 1992-2/NA	Design of concrete structures Concrete bridges – Design and detailing rules – National Annex
DIN EN 206	Concrete Specification, performance, production and conformity

1.5 **Materials**

Reinforced concrete: C 35/45

Reinforcing steel: B 500

Ehitusmaterjali kirjeldus / Description of construction material			
Betoon / Concrete:	C 35/45	Sarruse klaas / Reinforcement grade:	B 500

(Detail / RBDTD-EE-DS2-DPS1_TRE_CU037081-ZZ_0005_D4_STR_EK-DTD_000102_003)

1.6 Exposure classes

Exposure classes XC4, XD1, XF3

Rakkendusala / Application area	Keskkonnaklass /Exposure class	Betoonkaitsekiht /Concrete cover
Truubi alumine plaat / Culvert bottom slab	XC4, XD1,XF3	c_v = 55 mm c_{dev} = 15 mm

(Detail / RBDTD-EE-DS2-DPS1_TRE_CU037081-ZZ_0005_D4_STR_EK-DTD_000102_003)

1.7 Concrete cover

Concrete cover: c_{min} = 40 mm

$\triangle c_{dev}$ = 15 mm

c_{nom} = 55 mm

Rakkendusala / Application area	Keskkonnaklass /Exposure class	Betoonkaitsekiht /Concrete cover
Truubi alumine plaat / Culvert bottom slab	XC4, XD1,XF3	c_v = 55 mm c_{dev} = 15 mm

(Detail / RBDTD-EE-DS2-DPS1_TRE_CU037081-ZZ_0005_D4_STR_EK-DTD_000102_003)

1.8 Crack width limitation

The permissible crack width is w_{max} = 0.30 mm

1.9 Strength development of concrete

Strength development: Medium (r < 0.5)

[2] When determining the duration of the curing process, information on the strength development of the concrete may be provided either by values according to Table 16 or by a strength development curve at 20°C between 2 days and 28 days.

Table 16 – Strength development of concrete at 20 °C

Strength development	**Strength ratio** $r = f_{cm,2} / f_{cm,28}$
Fast	≥ 0.5
Medium	≥ 0.3 to < 0.5
Slow	≥ 0.15 to < 0.3
Very slow	< 0.15

[3] The strength ratio for designating the strength development is the ratio of the mean compressive strength after 2 days ($f_{cm,2}$) to the mean compressive strength after 28 days ($f_{cm,28}$) from the initial test or on the basis of the known behaviour of concrete with a comparable composition. For the respective initial tests, the test specimens for strength determination are to be taken, produced, cured and tested in accordance with EN 12350-1, EN 12390-1, EN 12390-2 or EN 12390-3.

(DIN EN 206)

1.10 Loads

1.10.1. *Permanent loads with constant values*

1.10.1.1. *Dead loads*

According to the design bases document „Road Bridges design basis. Master design RBDTD-EE-DS2-ZZ_IDO_ZZZZ-ZZ_ZZZZ_RP_BR-TS_MD_00002“

The self-weight of the structure will be considered in each model. Following design bases indications, the density value of the reinforced concrete will be 25 kN/m³.

1.10.1.2. *Superimposed dead loads*

According to the design bases document „Road Bridges design basis. Master design RBDTD-EE-DS2-ZZ_IDO_ZZZZ-ZZ_ZZZZ_RP_BR-TS_MD_00002“

For this structure, the following values are considered.

- Ballast: With a density of 20kN/m3, (Mean value and its hypothetical increment or decrement of 30%)
- Sleepers: 4.8kN/m per track (9.6kN/m)
- Rails: 1.5kN/m/track (3.0kN/m)
- Concrete channel for cables: Nominal value 3.0kN/m/channel (Nominal value 6.0kN/m with a deviation of 20%)
- Electrification and OCS Pole: 1.5kN/m/track (3.0kN/m). Railing: 0,7 kN/m on both edges.
- Terrain cover. backfill material to reach the rail level in each case, the typical backfill material has a density of 20 $kN/m^{3.}$

1.10.2. *Permanent loads with variable values*

1.10.2.1. *Prestress loads*

Not applicable as this is a reinforced concrete structure.

1.10.2.2. *Creep and shrinkage*

Does not apply to the structure. No relevant in this type of structure.

1.10.2.3. *Geotechnical actions*

1.10.2.3.1. Horizontal earth pressure load

According to the design bases document „Road Bridges design basis. Master design RBDTD-EE-DS2-ZZ_IDO_ZZZZ-ZZ_ZZZZ_RP_BR-TS_MD_00002“

In this structure, for the earth and surcharge pressure the most unfavourable of at rest and active pressure has been considered.

The backfill material has been considered with the following characteristics:

- ɣ = 20 kN/m^3 (bulk unit weight)

- ϕ = 35º (internal friction angle)
- c = nil (value of cohesion).

1.10.2.3.2. Differential settlement

Does not apply to the structure.

1.10.3. Friction forces at pot bearings

Not applicable as the structure does not have pot bearings.

1.10.4. Variable actions

1.10.4.1. Vertical loads due to rail traffic

According to the design bases document „Road Bridges design basis. Master design RBDTD-EE-DS2-ZZ_IDO_ZZZZ-ZZ_ZZZZ_RP_BR-TS_MD_00002"

The loads applied at the top of the terrain cover will be distributed along the ballast and the backfill with a ¼ proportion in the ballast and a 35º cone in the backfill. This will reduce their influence on the structure according its depth. Also, the interference between the loads coming from two parallels lines will be taken in consideration in case of intersection of mentioned loads distributions along the terrain.

Load Model 71, SW/0 and SW/2 have been considered in the structural calculation.

A classification coefficient of 1.33 has been applied to the following load models:

- Axle vertical loads and uniformly distributed load of Load Model 71.
- Axle vertical loads and uniformly distributed load of Load Model SW/0.
- Equivalent vertical loading for earthworks and earth pressure effects.

The results of the static analysis for load models LM71, SW/0 and SW/2, shall be multiplied by the dynamic factor ϕ_3.

The dynamic factor ϕ_3 which enhances the static load effects shall be taken as ϕ_3 (track with standard maintenance, as per the recommendation of the Technical Specification (RBDG-MAN-017-0103, section 3.3.1.2)):

With 1,0 ≤ ϕ_3 ≤ 2,0.

Lϕ_3 "Determinant" length (length associated with ϕ_3) defined in EN 1991-2 Table 6.2 [m].

In the case of arch bridges and concrete bridges of all type, with a cover of more than 1,0 m, dynamic factor ϕ_3 may be reduced as follow:

$$red\Phi_3 = \Phi_3 - \frac{h - 1{,}0}{10} \geq 1{,}0$$

In the following table the dynamic factor applied to load models LM71, SW/0 & SW/2, reduced due to the cover of earths over the structure, is shown for all the culverts.

CODE MD	DP Station	Description	Dynamic factor
CU037081	4+063	CULVERT + ANIMAL CROSSING	1.918

Culverts dynamic factors

In order to obtain the horizontal thrust due to the vertical loads of the rail traffic, a simplified uniform surcharge of 30 kN/m2 has been used extended to the total width of the platform, considering the classification coefficient of 1.33.

1.10.4.2. HORIZONTAL ACTIONS DUE TO RAIL TRAFFIC

1.10.4.2.1. Brake and traction actions have been applied to the box culverts.

According to the design bases document „Road Bridges design basis. Master design RBDTD-EE-DS2-ZZ_IDO_ZZZZ-ZZ_ZZZZ_RP_BR-TS_MD_00002"

1.10.4.2.2. Centrifugal forces

Centrifugal forces are not relevant in the design of the culverts since this type of forces act in the longitudinal direction of the culvert, which has large stiffness. Centrifugal loads are transmitted and absorbed by the embankment in which the culvert is embedded.

1.10.4.2.3. Nosing force

Similar to centrifugal forces, nosing forces are not relevant in the design of the culverts. Nosing forces are transmitted by the terrain surrounding the culvert, up to the foundation.

1.10.4.2.4. Aerodynamic effects

The aerodynamic effects are not relevant for the design of the culvert as there are no elements above the railway platform.

1.10.4.2.5. Others

Does not apply to the structure.

1.10.4.3. Groups of Traffic Loads on Road Bridges (EN 1991-2:2003 Table 4.4.a)

Does not apply to the structure.

1.10.4.4. Actions for non-public footpaths

Does not apply to the structure.

1.10.4.5. Temperature

Does not apply to the structure. No relevant in this type of structure.

1.10.5. Accidental actions

1.10.5.1. Accidental actions due to road traffic (EN 1991-2:2003 Clause 6.7)

Does not apply to the structure.

1.10.5.2. Accidental actions due to road traffic (EN 1991-1-7:2006 Clause 4.3)

Does not apply to the structure.

2 Static design / minimum reinforcement

2.1 Static design / PC programs

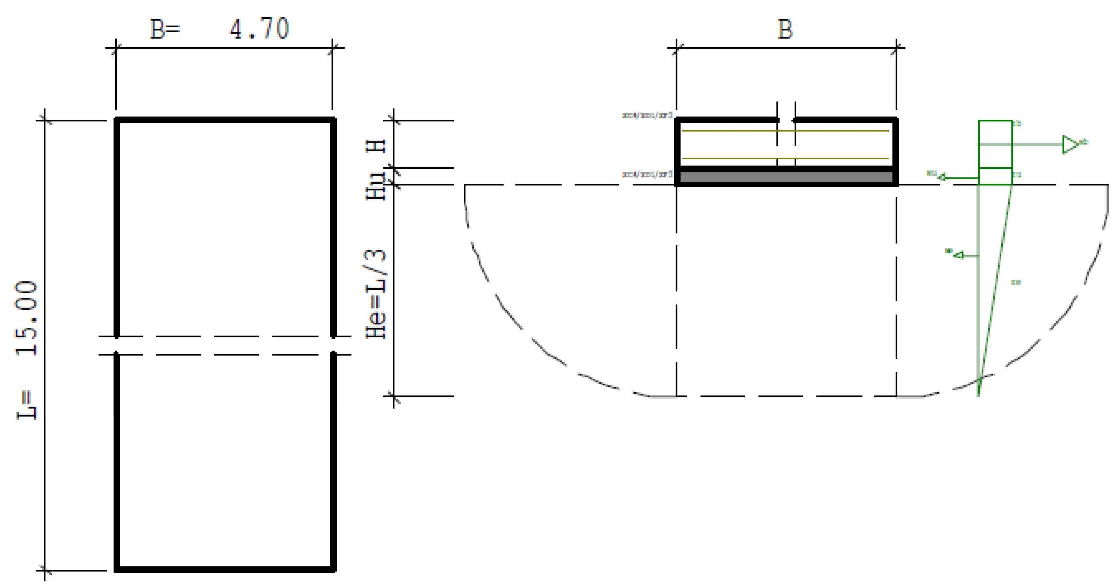
The design calculations are shown on the following pages, using the PC programs FRILO / R-2025-1 / B11 and Risse from InfoGraph, Version 24.00

2.2 Culvert CU037081 / Floor slab

Position: Culvert / Bodenplatte

Crack Width Verification (x64) B11 01/25 (FRILO R-2025-1)

Scale 1 : 50



PROOF OF CRACK WIDTH acc.DIN EN 1992-1-1/NA/A1:2015-12			
reinforcing steel	B500B		
concrete	C 35/45		
	t= 5d (normal hard.)		
tens. strength concrete	kFct(t)=	0.71 (Eq. 3.4)	fcteff= 2.28 N/mm2
E-Modul Conc.	αE =	1.00 (aggregates)	
	kEc(t) =	0.90 (acc. MC90)	Ecm= 30688 N/mm2

MODULUS OF CREEP			
concrete age	t	=	5 days
joung concrete	ϕt	=	0.60 (acc. Lohmeyer)

Requirements durability:

attack on concrete			XF3/WF	
reinforc. corrosion			XC4/XD1	
min. concrete class			C 35/45	
long. reinforcement	$d_{s,l}$	=	16	mm
allowance in design	Δc_{dev}	=	15	mm
longitudinal bars	$c_{min,m}$	=	40	mm
concrete coverage	$c_{nom,m}$	=	55	mm
laying dist. link	$c_{,l}$	=	55	mm
all. crack width	w_{max}	=	0.30	mm

FRILO / Pos. Floor slab)

FLOOR SLAB

Dimensions B = 4.70 m H = 0.35 m
L = 15.00 m
reinforcem. dtop= 8.3 cm dbot= 8.8 cm

RESTRAINT FROM HYDRATION (PREVIOUSLY RESTRAINT)

The constraining force in the direction of the side L is determined.
Method acc. to DAfStb booklet 466
foundation slab:
ΔT = -25.00 K αT= 10.00*10-6 1/K
εb = -0.250 o/oo Cb= 1.0741e+05 kN/cm

RESTRAINT FROM HYDRATION (PREVIOUSLY RESTRAINT)

subsoil:
Ee = 50.00 MN/m2 Ce= 1.2420e+06 KN
bottom concrete: C 16/20
αE = 1.00 kEc(t)= 1.00 Ecm= 29000 N/mm2
Hu = 0.10 m Cu= 2.9000e+04 kN/cm εs= 0.000 o/oo
Nzw= 611.05 kN/m
restraint from soil friction (top limit)
γ = 25.00 kN/m3 q = 0.00 kN/m2
cal ϕ= 32.5 Grd μ = 0.56
γ_R = 1.35 μ_d = 0.75
Nzw= 49.39 kN/m
decisive: Nzw= 49.39 kN/m

PROOF CRACK WIDTH

most unfavourable assumptions (top,bottom):
distance of reinforcement max(top,bot)
w_{max}= 0.30 mm ds = 16.0 mm

restraint from hydration (permanent load kt = 0.4)
centric restraint Nx = 49.39 kN/m
$\varepsilon 2s$ = 1.13 o/oo Fs = 49.4 kN/m
heff = 35.0 cm Fcre = 798.4 kN/m
required: Asbot= 1.09 cm2/m Astop= 1.09 cm2/m
The reinforcement is to be distributed over the side B.
It is necessary to verify whether a proof of later restraint is decisive.

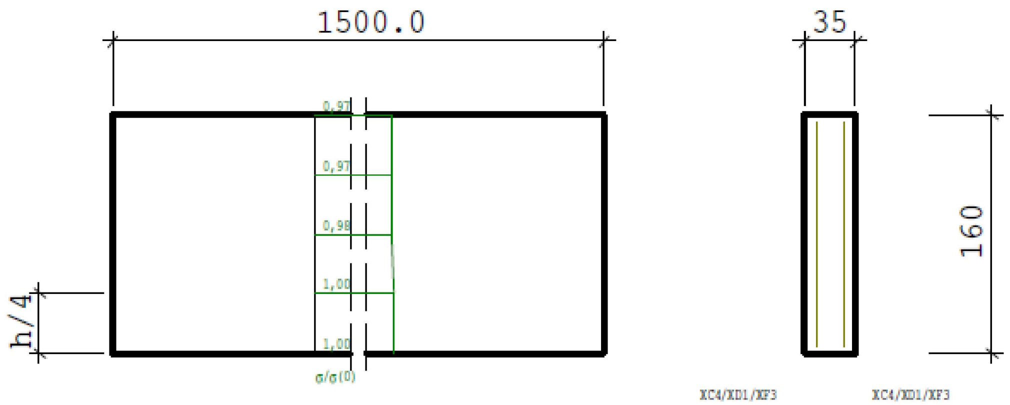
(FRILO / Pos. Floor slab)

2.3 Culvert CU037081 / Walls

Position: Culvert / Wände

Crack Width Verification (x64) B11 01/25 (FRILO R-2025-1)

Scale 1 : 50



PROOF OF CRACK WIDTH acc.DIN EN 1992-1-1/NA/A1:2015-12			
reinforcing steel	B500B		
concrete	C 35/45		
	t= 5d (normal hard.)		
tens. strength concrete	kFct(t)=	0.71 (Eq. 3.4)	fcteff= 2.28 N/mm2
E-Modul Conc.	αE =	1.00 (aggregates)	
	kEc(t) =	0.90 (acc. MC90)	Ecm= 30688 N/mm2

MODULUS OF CREEP			
concrete age	t	=	5 days
joung concrete	ϕt	=	0.60 (acc. Lohmeyer)

Requirements durability:

attack on concrete		XF3/WF		
reinforc. corrosion		XC4/XD1		
min. concrete class		C 35/45		
long. reinforcement	$d_{s,l}$	=	16	mm
allowance in design	Δc_{dev}	=	15	mm
longitudinal bars	$c_{min,m}$	=	40	mm
concrete coverage	$c_{nom,m}$	=	55	mm
laying dist. link	$c_{,l}$	=	55	mm
all. crack width	w_{max}	=	0.30	mm

WALL ON FOUNDATION					
Dimensions	B =	0.35 m		H =	1.60 m
	L =	15.00 m			
reinforcem.	dli =	8.8 cm		dri =	8.8 cm

FRILO / Pos. walls)

RESTRAINT FROM HYDRATION (PREVIOUSLY RESTRAINT)

procedure acc. Lohmeyer 9. edition

Cement	: 32.5R;42.5		Z =	340 kg/m3	
tm	=	1.28 d	QH =	195 kJ/kg	
αb	=	0.74	TbH =	19.7 K	
TcO	=	20.0 °C	ktV =	0.50	
Tb,m	=	29.7 K	T_F =	15.0 ºC	
αT	=	10 10-6/K	kV =	1.00	

restraint stresses at the f oot: σct = 4.50 N/mm2
design value for stress at H/4: kc t,d= 1.00
σct,d= 4.50 N/mm2 > fcteff
Nzw,hydr= σct,d* Ac = 1575.15 kN/m
Nzw,max= k* fcteff* Ac= 616.35 kN/m k= 0.77 relevant

RESTRAINT FROM HYDRATION (PREVIOUSLY RESTRAINT)

PROOF CRACK WIDTH

w_{max}= 0.30 mm ds = 16.0 mm

restraint from hydration (permanent load kt = 0.4)

centric restraint	Nx	=	616.35 kN/m			
	ε2s	=	1.13 o/oo	Fs	=	616.3 kN/m
	heff	=	35.0 cm	Fcre	=	798.4 kN/m
required:	Asli	=	13.60 cm2/m	Asri	=	13.60 cm2/m

It is necessary to verify whether a proof of later restraint is decisive.

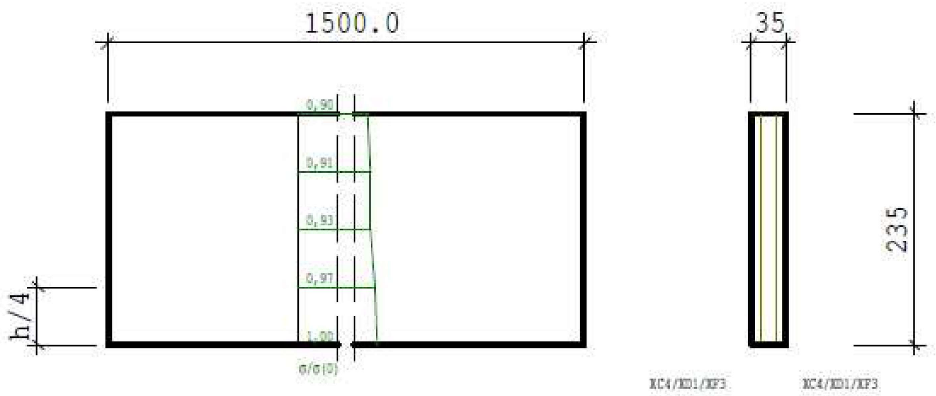
FRILO / Pos. walls)

2.4 Culvert CU037081 / Ceiling slab

Position: Culvert / Deckenplatte

Crack Width Verification (x64) B11 01/25 (FRILO R-2025-1)

Scale 1 : 75



PROOF OF CRACK WIDTH acc.DIN EN 1992-1-1/NA/A1:2015-12			
reinforcing steel	B500B		
concrete	C 35/45		
	t= 5d (normal hard.)		
tens. strength concrete	kFct(t)=	0.71 (Eq. 3.4)	fcteff= 2.28 N/mm2
E-Modul Conc.	αE =	1.00 (aggregates)	
	kEc(t) =	0.90 (acc. MC90)	Ecm= 30688 N/mm2

MODULUS OF CREEP			
concrete age	t	=	5 days
joung concrete	ϕt	=	0.60 (acc. Lohmeyer)

Requirements durability:

attack on concrete			XF3/WF
reinforc. corrosion			XC4/XD1
min. concrete class			C 35/45
long. reinforcement	$d_{s,l}$	=	16 mm
allowance in design	Δc_{dev}	=	15 mm
longitudinal bars	$c_{min,m}$	=	40 mm
concrete coverage	$c_{nom,m}$	=	55 mm
laying dist. link	$c_{,l}$	=	55 mm
all. crack width	w_{max}	=	0.30 mm

WALL ON FOUNDATION					
Dimensions	B =	0.35 m	H =	2.35 m	
	L =	15.00 m			
reinforcem.	dli =	8.8 cm	dri =	8.8 cm	

(FRILO / Pos. ceiling slab)

RESTRAINT FROM HYDRATION (PREVIOUSLY RESTRAINT)

procedure acc. Lohmeyer 9. edition

Cement	: 32.5R;42.5		Z =	340 kg/m3
tm	=	1.28 d	QH =	195 kJ/kg
αb	=	0.74	TbH =	19.7 K
TcO	=	20.0 °C	ktV =	0.50
Tb,m	=	29.7 K	T_F =	15.0 °C
αT	=	10 10-6/K	kV =	1.00

restraint stresses at the f oot: σct = 4.50 N/mm2

design value for stress at H/4: kc t,d= 0.87

σct,d= 3.91 N/mm2 > fcteff

Nzw,hydr= σct,d* Ac = 1369.04 kN/m

Nzw,max= k* fcteff* Ac= 616.35 kN/m k= 0.77 relevant

PROOF CRACK WIDTH

w_{max}= 0.30 mm ds = 16.0 mm

restraint from hydration (permanent load kt = 0.4)

centric restraint	Nx =	616.35 kN/m				
	ε2s =	1.13 o/oo	Fs	=	616.3	kN/m
	heff =	35.0 cm	Fcre	=	798.4	kN/m
required:	Asli =	13.60 cm2/m	Asri	=	13.60	cm2/m

It is necessary to verify whether a proof of later restraint is decisive.

(FRILO / Pos. ceiling slab)

2.5 Minimum reinforcement / General

Crack width limitation acc. to DIN EN 1992-1-1: 2015 with NA: 2015-12

Requirements

Permissible crack width w_{max} = 0,30 mm.

Materials, geometry

Rectangular cross section with height = 35,0 cm; width = 100,0 cm
Concrete quality: C35/45
Type of cement: CEM 32,5 R, CEM 42,5 N
Concrete cover c: 5,5 cm
Bar diameter: $d_{s,given}$ = 16,0 mm (Reinforcing steel)
Reinf. steel: f_{yk} = 500 MN/m²

Check of the minimum reinforcement

Action: Centrical tension
Location of restraint: Inside of the component
Concrete age at time of cracking: 5 days

$$A_{s,min} \cdot \sigma_s = k_c \cdot k \cdot f_{ct,eff} \cdot A_{ct} \qquad (7.1)$$

with $k_c = 1,00$ $k = 0,77$ $f_{ct,eff} = 2,27$ N/mm²
$A_{ct} = 3500,0$ cm² σ_s = see following calculation

The limiting of crack width can be proved by limiting of the bar diameter.

$$\phi_s = \phi_s^* \cdot \frac{k_c \cdot k \cdot h_{cr}}{8 \cdot (h-d)} \cdot \frac{f_{ct,eff}}{2.9} \geq \phi_s^* \cdot \frac{f_{ct,eff}}{2.9} \qquad (7.7DE)$$

with $k = 0,77$ $h_{cr} = 35,0$ cm $f_{ct,eff} = 2,27$ N/mm²
$h = 35,0$ cm $d = 28,7$ cm $\phi_s = d_{s,given} = 16$ mm

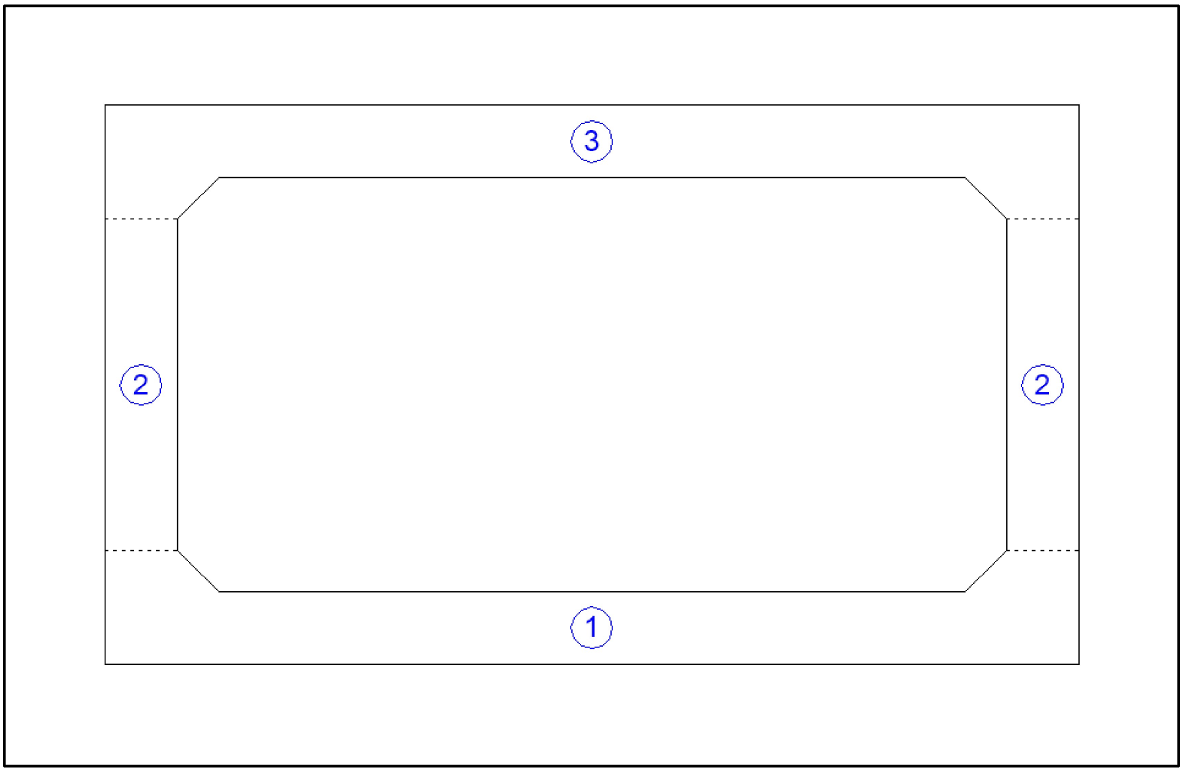
⇒ $\phi_s = \phi_s^* \cdot 0,42 < \phi_s^* \cdot 0,78$ ⇒ $\phi_s^* = 16,0 \text{ mm} / 0,78 = 20,40$ mm
⇒ $\sigma_s = \sqrt{(3.48 \cdot 10^6 \cdot w_k / d_s^*)} = 226,20$ N/mm² as per Table 7.2DE with $\sigma_s \leq f_{yk}$

$A_{s,min}$ = 13,58 cm² per layer

(Crack width restriction 24.00 / InfoGraph)

3 Reinforcement / Additional reinforcement

3.1 Culvert CU037081



(Drawing / culvert CU037081)

Longitudinal reinforcement / additional reinforcement

1 <u>Floor slab (reinforcement / inside and outside)</u>

Longitudinal reinforcement **Ø16/200**

2 <u>Walls (reinforcement / inside and outside)</u>

Longitudinal reinforcement **Ø6/200** + additional reinforcement **010/200**

3 <u>Ceiling slab (reinforcement / inside and outside)</u>

Longitudinal reinforcement **Ø16/200** + additional reinforcement **010/200**

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Ingenieurkammer-Bau Nordrhein-Westfalen
Mitglied
726138

p. p. A. Henning, graduate engineer

Roxeler Ingenieurgesellschaft

Tel. 0 25 34 / 62 00 - 86
Fax. 0 25 34 / 62 00 - 32