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Hofstad tunnel excavation

Plaxis analysis

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Preface

This project is carried out as a masters thesis in Geotechnics and Geohazards department at NTNU. The topic is proposed by Rambøll, Trondheim. Project work is led by NTNU in collaboration with industry partner Rambøll.

Trondheim, 2019-08-10

Mushfiq Hassan

Acknowledgment

I would like to thank Professor Steinar Nordal for supervising the project. A good direction is important to keep project work in track, which i have received from Professor.

I would like to thank external supervisor Par Arne Wangen from Rambøll, Trondheim, for his active role during full project work by providing ideas, documents and advice.

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Chapter 1

Introduction

1.1 Background

Hofstadtunnelen is situated under Melhus municipality, Trondheim. Tunnel was constructed back in 2003 to allow free traffic flow of a intercity highway called E6 by allowing two local roads passing over it. Plan is to upgrade highway (E6) under Melhus municipality from 2 lane to 4 lane highway to increase its capacity. Proposal is to construct a second tunnel right next to the old tunnel. Due to surrounding landscape both tunnels need to be in close proximity. To make room for the new tunnel construction, it requires partial excavation of the old tunnel. Excavation need to be performed along its long axis. In this report, process of this excavation is analysed from a geotechnical point of view. Plaxis software is used as analysis tool. Currently project is in designing phase.

Problem Formulation

Constructing a new tunnel close to a old tunnel is a complex and challenging task. After excavation, change in load distribution along tunnel profile is expected. Load redistribution can damage tunnel structure. Geotechnical analysis can estimate changes in earth pressure. By analysing several excavation method it is possible to select one, which is economical, safe and have minimum effect on tunnel structure.

1.2 Objectives

The main objective of this project are

- Collect and study documents related to Hofstadtunnelen project.
- Select a geometric for plaxis model.
- Collect and estimate input material parameters for plaxis model. Check the effect of estimated material parameters on plaxis output.
- Study structural design report from old tunnel.
- Check plaxis output result against structural design.
- Simulate different excavation methods - select one which is practical, economical and have minimum effect on old tunnel structure.

1.3 Limitations

The aim of this project is to determine a safe excavation method. Input material parameters are either collected or estimated. Collected material parameters are acceptable considering the sources. It is hard to say, if estimated material parameters are correct or not. Trial shows, estimated material parameters have low effect on output results. However, Unavailability of soil test report is a limitation, which can not be ignored.

1.4 Structure of the Report

The rest of the report is structured as follows. In Chapter 02, A short description of hardening soil model (small-strain) and structural design report from old tunnel is presented. Chapter 03 is presenting all the details related to plaxis modeling. Chapter 04 results and discussion from trials, which includes compaction, material parameters, proposed excavations. Also plaxis model evaluation is presented. Chapter 05 is summery and recommendation.

1.5 Hofstadtunnelen Site

As mentioned in introduction, Hofstadtunnelen is under Melhus municipalities. Steep mountain on the east side and river on the west side. Satellite image shows. tunnel was constructed by replacing a highway. It allowed local roads to pass over without interfering highway traffic flow. Tunnel was constructed in 2003. Tunnel top is covered by vegetation. Tunnel is not straight, rather curved on the long axis. According to the plan, new tunnel will be placed on the west side of the old tunnel (1.3).

Figure 1.1: North and South opening (Collected from https://www.google.com/maps)

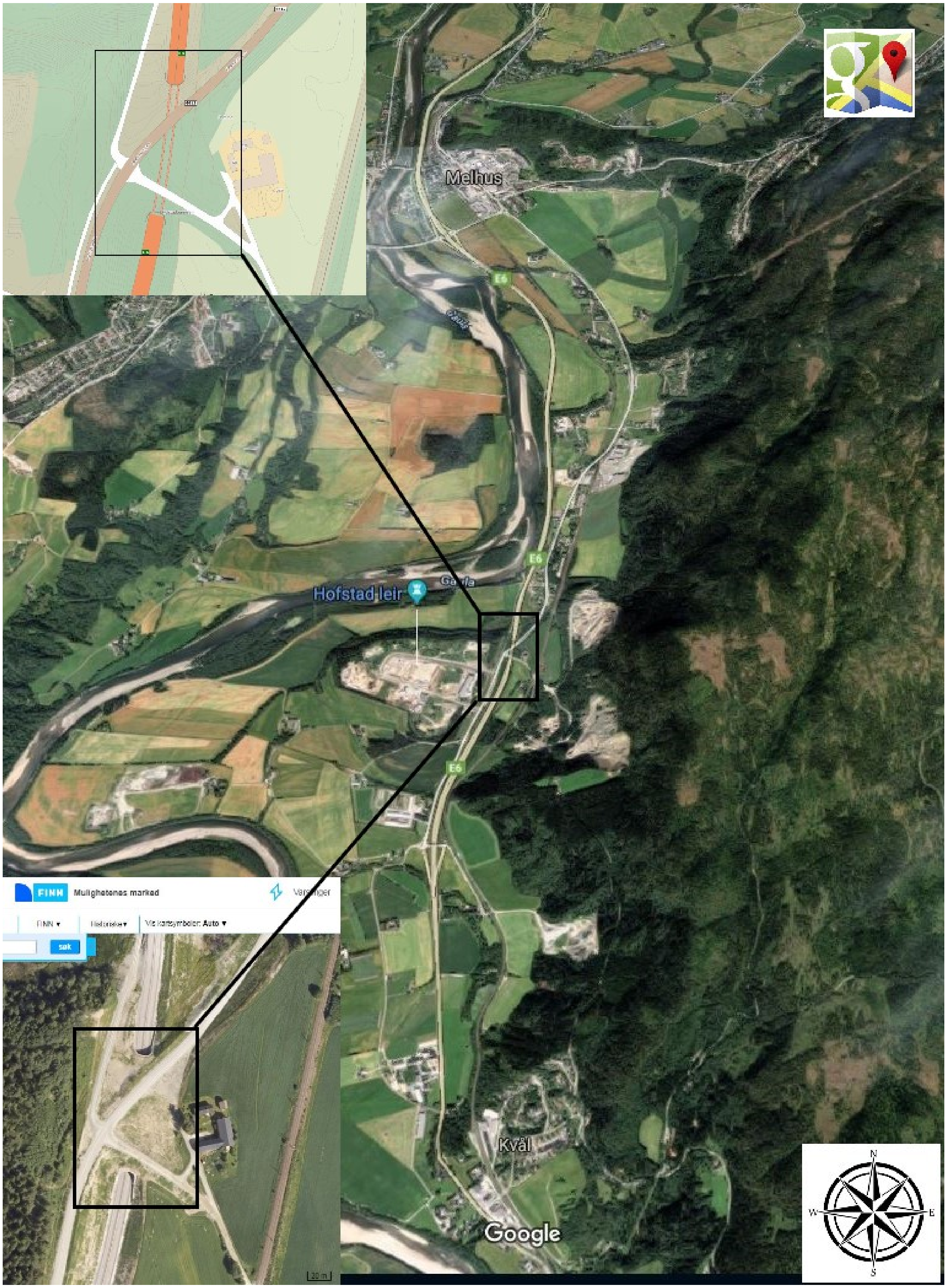


Figure 1.2: Site photo - Hofstadtunnelen (2019)[Collected from : https://kart.finn.no/ / https://www.google.com/maps

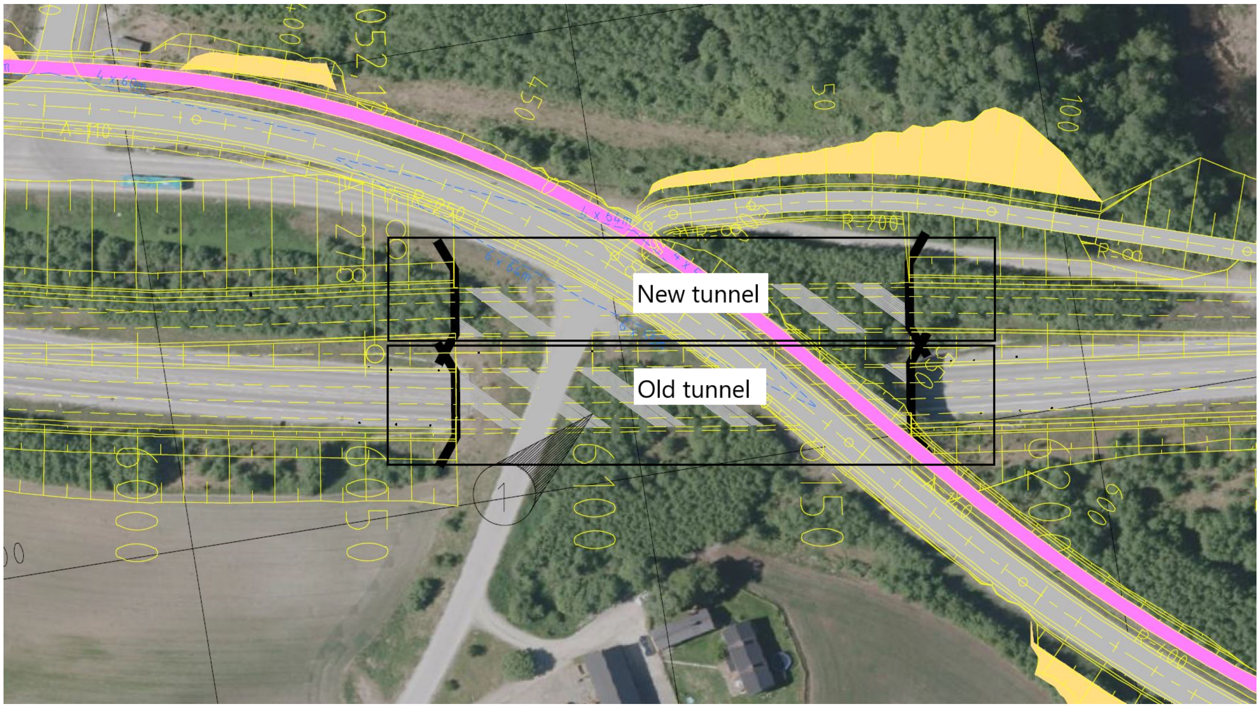


Figure 1.3: Plan view - New tunnel [Collected from : Nyeveier]

Chapter 2

Literature Review

2.1 Harding Soil Model With Small-Strain Stiffness (HS-SMALL)

According to plaxis material manual, soil stiffness used in the analysis of geotechnical structures is not the one that relates to the strain range at the end of construction. Instead, very small-strain soil stiffness and its non-linear dependency on strain amplitude should be taken into account. The Hardening Soil model with small-strain stiffness offers the possibility to control it. Hardening Soil model with small-strain model have all the parameters as hardening Soil model.Two extra parameters used to describe the variation of the stiffness with strain. Parameters used for the modeling are presented in figure 2.1.

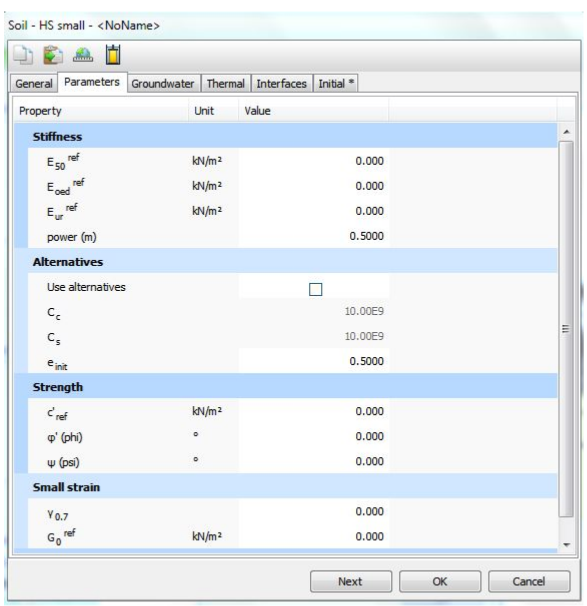


Figure 2.1: Harding soil model (small strain) parameters

Parameters for soil stiffness

Stress dependent stiffness according to a power law (Input parameter m). Janbu reports values of m around 0.5 for Norwegian sand and silts. It varies different values in range 0.5 to 1.0 .

Secant stiffness in standard drained triaxial test is represented by (E_{50}^{Ref}). Can be calculated using following (equation 2.1). It creates plastic straining due to primary deviatoric loading.

$$E_{50} = E_{50}^{Ref} \frac{C\cos\phi - \sigma_3{}' \sin\phi}{C\cos\phi + p^{Ref}\sin\phi}^{m} \tag{2.1}$$

Tangent stiffness for primary oedometer loading (E_{odo}^{ref}) can be calculated from Oedometer stiffness (E_{odo}) by using following equation. It creates plastic straining due to primary compression.

$$E_{oed} = E_{oed}^{ref}[\frac{c\cos\phi - \frac{\sigma_3'}{K_0^{nc}}\sin\phi}{c\cos\phi + P^{ref}\sin\phi}]^{m} \tag{2.2}$$

Another parameter used to define soil stiffness is reference Young's modulus for unloading and reloading (E_{ur}^{ref}).According to plaxis manual, it is common practice to estimate (E_{ur}^{ref}) as three times of (E_{50}^{ref}). Create an elastic unloading reloading. In combination with (ν_{ur}), it controls unloading reloading properties of the model. The unloading reloading modulus is related to modified swelling index κ^*. Approximate relation between standard cam-clay swelling index κ and modified swelling index is presented in equation 2.4.

$$E_{ur}^{ref} = 3E_{50}^{ref} \tag{2.3}$$

$$\kappa^* = \frac{\kappa}{(1+e_0)} \qquad E_{ur}^{ref} = \frac{2p^{ref}}{\kappa^*} \tag{2.4}$$

Other parameters

Other parameters that include in plaxis modeling are Mohr coulomb failure criterion and parameter influence small strain. Parameters define Mohr coulomb failure criterion are cohesion (C), friction angle (ϕ) and angle of dilatancy (ψ). Parameters that have influence on small strain, are shear modulus (G_0) and threshold shear strain ($\gamma_0.7$). As project is focused on using the model, for that reason detailed explanation on individual model parameters are not brifly discussed in this report. It can be found in plaxis website.

All the information presented in this section are collected from Plaxis 2D material manual. Which can be found on the following link.

https://www.plaxis.com/support/manuals/plaxis-2d-manuals/

2.2 Old tunnel design

Design consideration and calculation used for old tunnel, are presented in this section. Structural designing software called STATIK System was used for analysis. Tunnel is designed by carefully selecting 33 Nodes. Horizontal-vertical forces from soil and forces from traffic load are calculated for individual Nodes. Later corresponding forces are added in nodes. In total, three cross sections are selected for the design of the full tunnel. Each cross sections varies based on tunnel thickness and over burden height. Cross sections are presented in appendix (C).

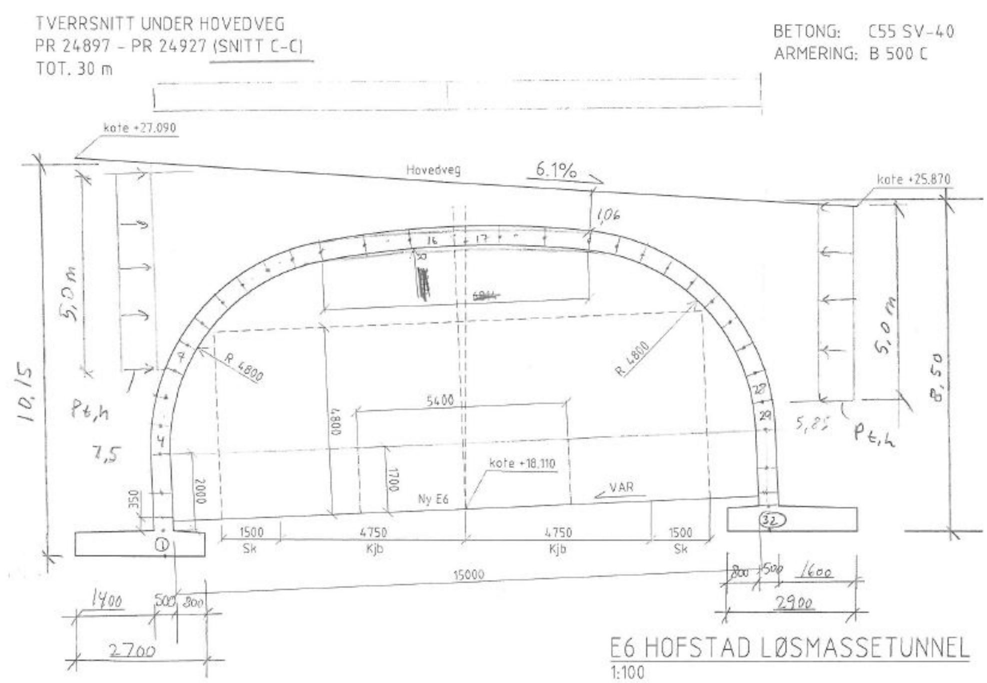


Figure 2.2: Cross section C-C

Force calculation from soil

As a design input vertical and horizontal forces from surrounding soil are calculated on 33 nodes. Forces are calculated for all three cross sections. As mentioned earlier, three cross sections have different overburden height which gives them different forces. Material properties for soil are selected considering, a mixture of gravel and silt. Soil density (γ) is 19 Kn/m3, Friction angle (ϕ) is 33 degree. Vertical forces from soil (P_A), is calculated by multiplying soil density (γ) and corresponding height. Later, earth pressure co-efficient $K_A = 0.4$ is considered to calculate corresponding horizontal forces (P_h). Some calculation process is presented in the following section.

$$r = 1/\gamma_m = 0.67$$

$$\tanh\rho = \tanh\phi/\gamma_m = 0.67/1.5 = 0.46$$

$$s = \tanh\beta/\tanh\rho = 0.06/0.43 = 0.14$$

$$t = (1+r)(1-s) = (1+0.67)(1-0.14) = 1.44$$

$$K_a = 0.4$$

Figure 3.4 from Håndbok 100 is used to estimated earth pressure co-efficient. For detailed calculation follow appendix C.

Traffic Load

Traffic load is calculated using manual from håndbok 100. The traffic load is calculated as if a strip of 1 m. The roads that are crossing over the tunnel are inclined. To make it simple, it is considered as if the roads are crossing at right angles to the tunnel direction. Following traffic loads are considered for corresponding cross section.

Vertical traffic load, cross section A-A : $P_t, v = 15KN/m^2$.

Vertical traffic load, Cross section C-C : $P_t, v = 17KN/m^2$.

Horizontal earth pressure from traffic load : $P_t, h = 0.4 * 20 = 8KN/m^2$.

Horizontal earth pressure from traffic load is also considered for cross section B-B between roads.

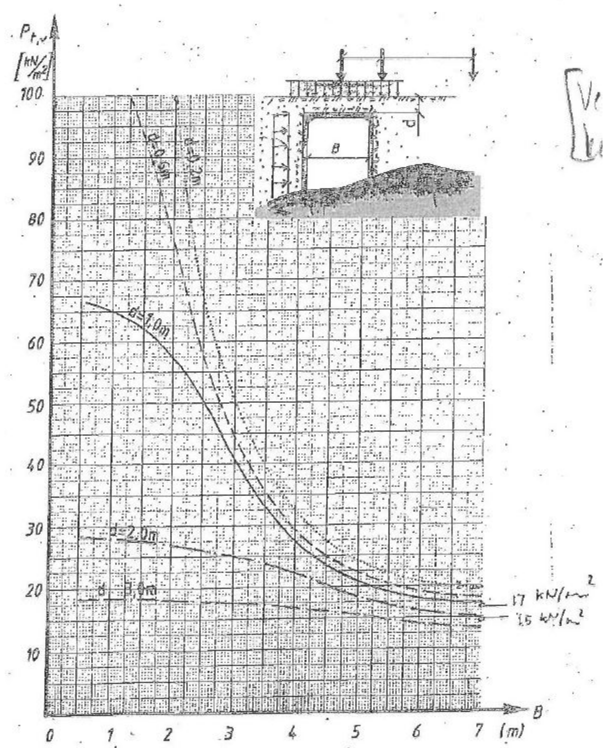


Figure 2.3: Hand book 100, chapter 12

Traffic load is presented with the figure of cross sections in Appendix C.

Design

As mentioned earlier, tunnel is designed using STATIk system software. Beside forces from soil and traffic load other forces like gravity, extra horizontal and vertical forces are also added. Bending moment and shear is calculated using different load combinations. Calculation is done for ultimate limit state and checked against minimum requirements. Following table (2.4) is used to design the tunnel.

	Snitt A		Snitt B		Snitt C	
Tykkelse	600		500		500	
Sted	Tak	Vegg	Tak	Vegg	Tak	Vegg
N (kN)	-455	-746	- 220	- 317	-363	-588
M_y (kNm)	511	-496	195	-206	389	-395
A_s (mm^2)	3599 2ø12 + 1ø20 c150	3013 4ø12 c150	2259 3ø12 c150	1506 2ø12 c150	3599 2ø12 + 1ø20 c150	3013 4ø12 c150
1/utnyttelse	1,698	1,830	2,371	1,754	1,688	1,663

Figure 2.4: Design consideration

It is possible to evaluate plaxis model by compare it against old tunnel design. Plaxis output can provide bending moment in unit of Kn m/m. From figure (2.4), it can be seen bending moment is in unit of Kn m. So, it is possible to directly compare plaxis output with structural design.

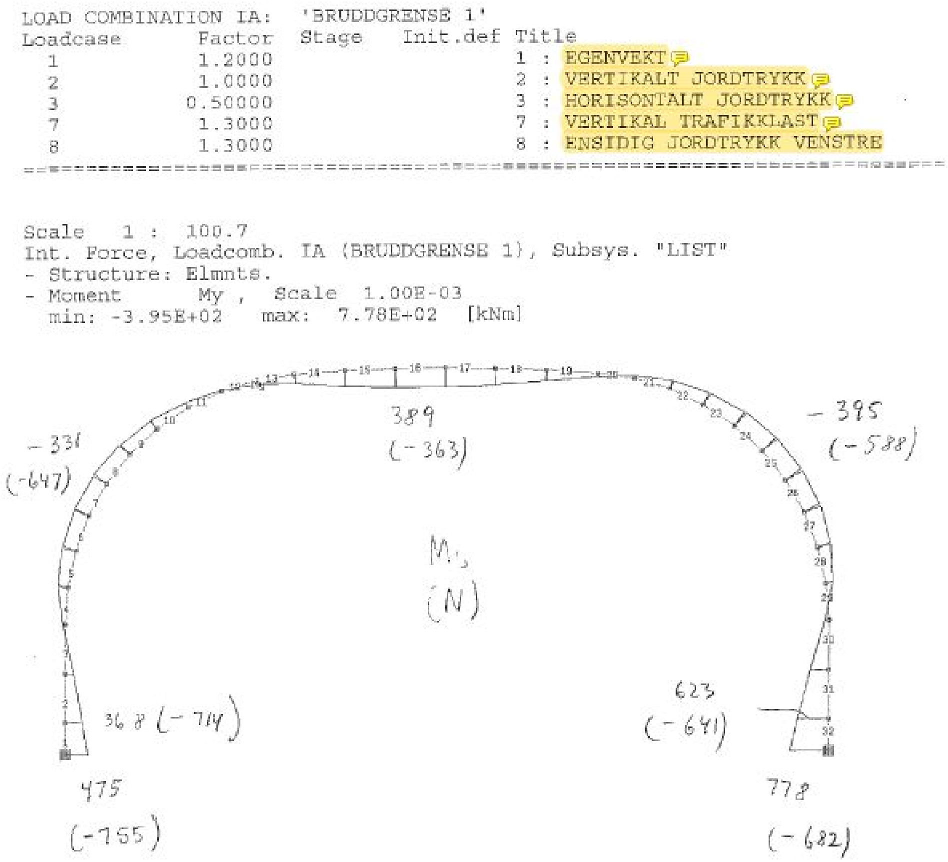


Figure 2.5: Output result from Statik system software

Structural design report have detailed explanation of foundation design process. In this report that process is not discussed. Due to horizontal force shifting of the position of vertical force known as $\triangle B$ distance occurs. After excavation this shifting distance $\triangle B$ should increase. However, this shifting is not analysed in this report.

2.3 Standards from States Vegsesen

Parameters selected for plaxis model are checked against standards from states vegvesen. It is collected from Håndbok V220. The parameters are standardized for the ground and supporting walls not for tunnel specifically. Supporting wall is considered to be sensitive structure and tunnel can be considered as sensitive structure as well. On that basis this standard is used. Details explanation on this parameter is given in section 2.9 from Håndbok V220 (published by Statens vegvesen) . For this report we considered the following figure 2.6 , which can be found in section 2.9.5.1 in the Håndbok V220.

2.9.5.1 *Dimensjonering av støttemur og landkar*

Plassering		Materiale		Dim. tyngde-tetthet γ	Karakteristisk indre friksjonsvinkel φ		Attraksjon a
				kN/m³	grader	tan φ	kN/m²
Bak og foran landkar og støttemur	**Tilførte komprimerte Masser ***	Sprengstein **		19	42	0,90	0 - 10
		Grus		19	38	0,78	0
		Sand		18	36	0,73	0
	Naturlige, ikke komprimerte masser	Grus		19	35	0,70	0
		Sand		17	33	0,65	0
		Silt		18	31	0,60	0
		Leire og leirig silt	Fast ***	20	26	0,49	0
			Bløt ***	19	20	0,36	0
Under landkar-såle	**Tilførte komprimerte Masser ***	Sprengstein ** og ****		19	42/45	0,90/1,0	10
		Grus *****		19	38/40	0,78/0,84	10
		Sand		18	36	0,73	10
	Naturlige, ikke komprimerte masser	Grus	Fast	19	38	0,78	0-10
			Løs	18	36	0,73	0-5
		Sand	Fast	18	36	0,73	0-10
			Løs	17	33	0,65	0-5
		Silt	Fast	19	33	0,65	0-10
			Bløt	18	31	0,60	0-5
		Leire og leirig silt	Fast ***	19	26	0,49	0-20
			Bløt ***	19	20	0,36	0-5

* Gjelder lagvis utlagte og komprimerte masser på land.
** Sprengstein. Gjelder også maskinkult. Høyere verdier av a kan vurderes avhengig av steinstørrelse.
*** Leire (eller leirig silt), fasthetsparametrene må bestemmes på uforstyrrede prøver.

Figure 2.6: Recommended soil parameters for the ground and supporting walls by Statens Vegvesen

Chapter 3

Plaxis modeling

3.1 Input geometric

Overburden

Land survey conducted by Nyveier shows height of the overburden on top of the old tunnel. Height varies along the tunnel length which is shown in figure (3.1). It shows a overburden with a gental slope going from west to east side. Looking at north direction left side of the old tunnel have ground with higher elevation than right side. Which is more or less same for the full tunnel length. Land survey have five cross section that cross tunnel. Grid 6100 is selected among five cross section. Because grid is representing highest elevation compared to other grids. Thinking behind this is, if tunnel is ok for this height then it should be fine for lower elevation. Initially instead of considering straight lines actual ground elevation profile was considered to make plaxis model. Later, after several trials in plaxis it became clear effect of using undulated line instead of straight line have little to no effect on output result. Straight line used to represent undulated ground elevation. Shown in the figure (3.2).

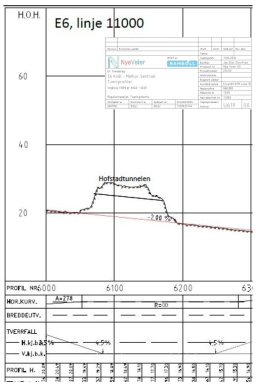
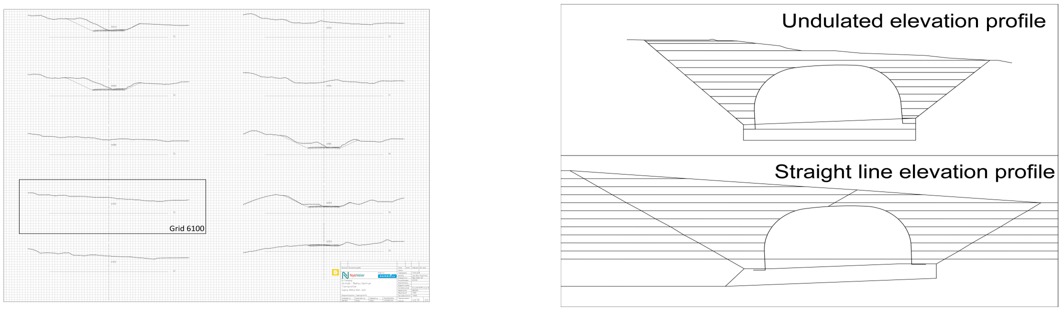


Figure 3.1: Ground elevation



(a) Land survey report from Nyveier - elevation profile

(b) Straight vs Undulated elevation profile

Figure 3.2: Geometric selection

Tunnel structure

Tunnel is divided in to 5 sections which include two vertical wall, two arches and one roof. Arches have a radius of 4.8 m. Tunnel have strip footing and not connected at the bottom. Tunnel is placed on top of 2 m thick crush rock layer. Outside of tunnel lining lintobent combiseal membrane is placed to make it water tight. Tunnel width is 15 m and height is around 7.5 m. Tunnel lining thickness varies between 600 mm and 500 m. During plaxis modeling special attention was given to maintain original dimensions. Selected tunnel lining thickness is 500 mm. Because cross section C-C from old tunnel design is 500 mm. It will make it possible to compare plaxis result with original design later.

Tunnel positioning

Initially placing tunnel in to the elevation profile was challenging. Because survey report does not include the positioning of the tunnel. Later tunnel is placed in a position where tunnel should have at least 1 m of overburden at the top. Which is same as cross section C-C from old tunnel design. Idea is to evaluated plaxis model against old tunnel design before staring excavation process. In the following figure cross section C-C from old tunnel design and considered cross section for plaxis model is showed side by side.

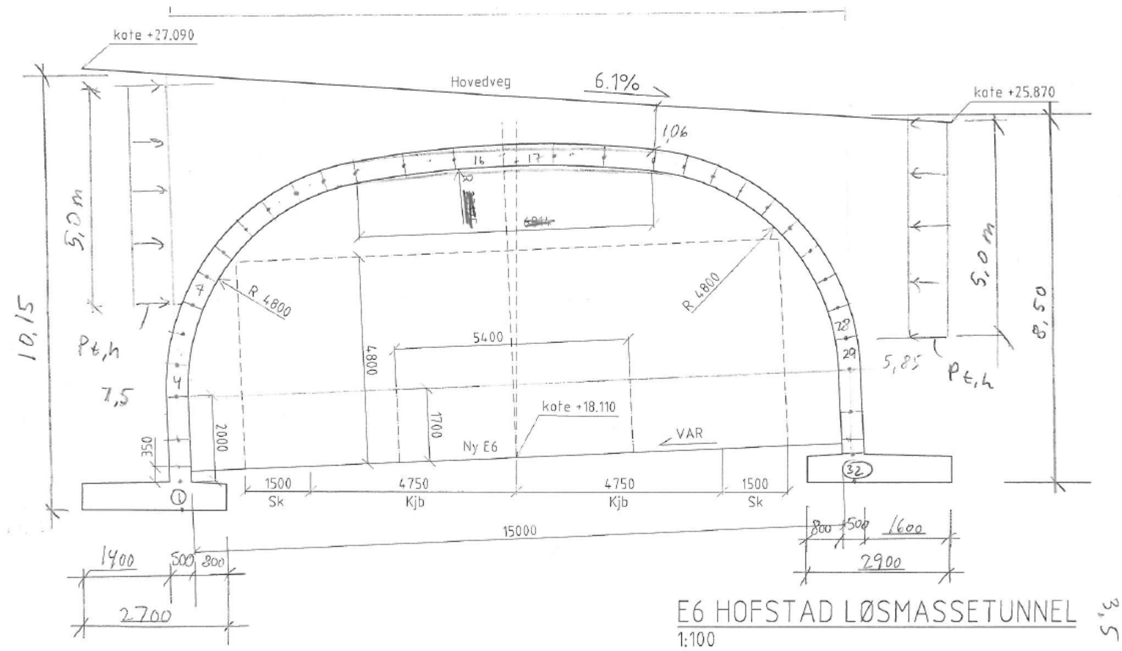


Figure 3.3: Cross section (C-C) - Old tunnel design

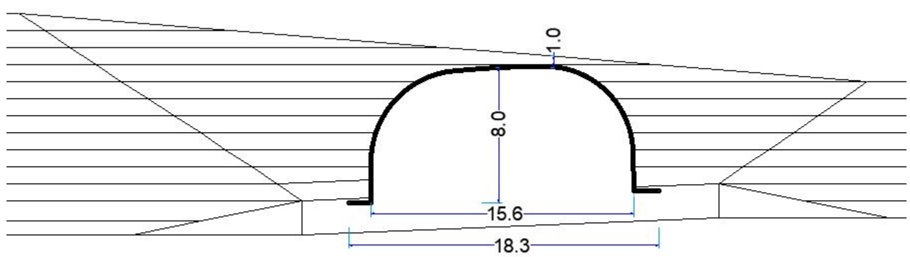


Figure 3.4: Cross section for plaxis modeling

3.2 Input material parameters

Based on the soil test report, old tunnel site is surrounded by a layer of silty-Sand type soil. On the South side, a thin layer of gravel is at the top. A mixture of gravel, sand and clay is placed layer by layer surrounding the tunnel. Tunnel is placed on top of a 2 m thick crushed rock layer. Soil test reports are collected from old tunnel, Which includes grain size distribution chart, pressure sounding test. Tests are attached in the appendix A. As input Plaxis model have in total three type of soil. Those are Fill material, Local soil and Crushed rock representing soil surrounding the tunnel, local soil and soil under tunnel foundation accordingly. We are using Harding soil model (Small) for numerical analysis. Input material parameters are collected from on old tunnel design, standard fixed by Statens Vegvesen, literature and trial. Placement of different soil is shown in figure (3.6). and Parameters used for plaxis model are presented in figure (3.5).

Material	Crushed Stone	Filling Material (Gravel+sand+clay)	Local soil (Silty Sand)	Foundation	Tunnel cross section (500 mm)	Unit
General properties	Drained	Drained	Drained	Elastic (Isotropic)	Elastic (Isotropic)	
Material model	HS small	HS small	HS small	Plate	Plate	
Unit weight_(Unsat)	19.00	19.00	19.00	24.00	24.00	Km3
Unit weight_(Sat)	19.00	19.00	19.00			Kn/m3
E_50_ref	70000.00	30000.00	15000.00			Kn/m2
E_oed_ref	58000.00	30000.00	15000.00			Kn/m2
E_ur_ref	210000.00	90000.00	45000.00			Kn/m2
m	0.50	0.50	0.50			
ϕ	42.00	33.00	36.00			°
tanϕ	0.90	0.65	0.73			
a	10.00	1.54	1.34			
C_ref	10.00	1.00	1.00			Kn/m2
Ψ	0.00	0.00	0.00			°
Y_0.7	2.0E-04	1.5E-04	1.0E-04			
G_0_ref	3.00E+05	2.00E+05	1.50E+05			Kn/m2
V'_ur	0.20	0.20	0.20			
Color						
Interface						
Strength	Rigid	Manual	Rigid			
R_inter	1.00	0.70	1.00			
Initial						
K_0 (K0,x = K0,z)	Automatic (0,3309)	Automatic (0,4554)	Automatic (0,4122)			
OCR	1.00	1.00	1.00			
POP	0.00	0.00	0.00			
w				24.00	24.00	Kn/m/m
d				1.00	0.50	m
E_A				17000000	8500000	Kn/m
E_I				1400000	180000	Kn/m2/m
V_12				0.15	0.15	

Figure 3.5: Input material parameters for plaxis model

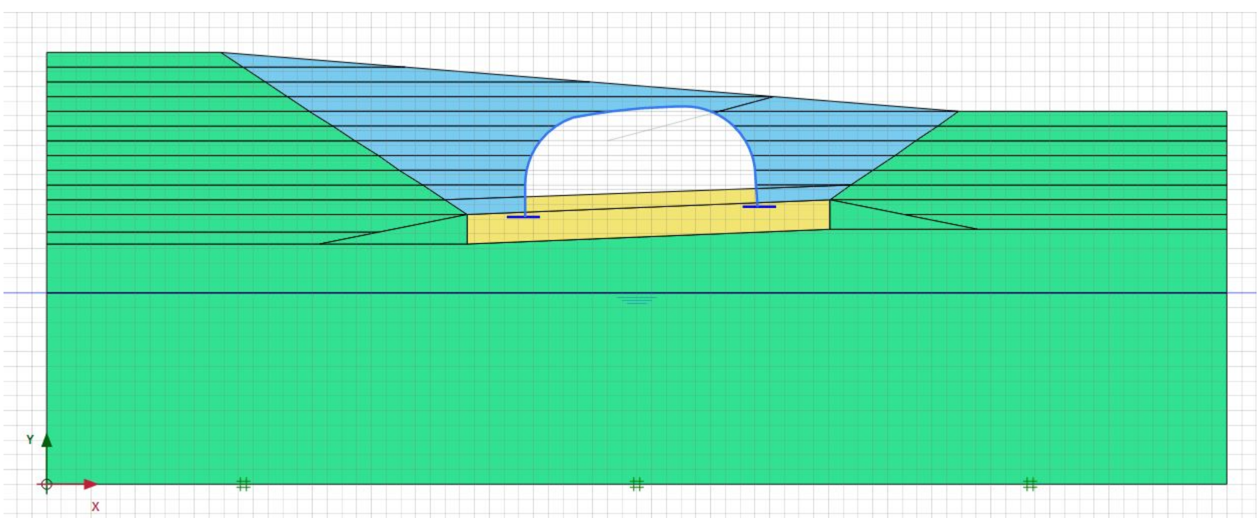


Figure 3.6: Input of soil in plaxis model

Filling material (Gravel+Sand+Clay)

As mentioned earlier a layer of grave, sand and clay mixture is placed surrounding the tunnel. Due to its nature, it is was difficult to estimated material properties for this layer. Strength parameters like attraction, cohesion, friction angle are collected from old tunnel design. It was validated against Standard fixed by Statens Vegvesen. For old tunnel design, designers calculated earth pressure as an input for structural design. Assumption is input parameters used for old tunnel design should provide a reasonable estimation for current plaxis design. Stiffness parameters are not mentioned in any report. Lead us to estimate it based on literature review and trial. Based on literature review we found sand have stiffness in between 15 Mpa to 50 Mpa (Salgado et al. (2000a)). Initially higher stiffness is used, which was around 50 Mpa. Later it was reduced to 40 Mpa and finally 30 Mpa. So, the stiffness parameter known as Plastic straining due to primary deviatoric loading E_{50}^{Ref} is 30 Mpa, Plastic straining due to primary compression E_{oed}^{ref} is same as E_{50}^{Ref} 30 Mpa and E_{ur}^{ref} is three times of E_{50}^{ref} around 90 Mpa. OCR (Over consolidation ratio) is considered to be 1. A layer of membrane called "lintobent combiseal" was placed out side of the tunnel. It should make rough concrete surface more slippery. To take it into account, interface 0.7 is considered.

Local soil (Silty-sand)

Local soil surrounding tunnel consist of silty sand. Soil test report from old tunnel confirms it. . According to literature, Strength of the soil decreases with increasing silt percentage. Close to north opening we can see from grain size distribution chart roughly about 5o percent silt and 50 percent sand with a bit of clay. Close to south opening 40 percent silt and 60 percent sand with a bit of gravel.Sand have stiffness around 15 to 50 Mpa. From literature Salgado et al. (2000b), with 15 percent silt content, the fines in the soil mixture start controlling soil behavior. At 20 percent silt content, they fully control soil response. Because soil fabric become more stable and the stiffness increase with fines content.

Like filling material there is no direct reference for this particular soil. So we took strength parameters from the standard fixed by States Vegvesen, which include unit weight, friction angle and cohesion. Just like filling material, initially we considered stiffness parameters quite high. Later it was reduced to lower value. It is reduced from 25 Mpa to 15 Mpa. It gives us, E_{50}^{Ref} around 15 Mpa. E_{oed}^{ref} is considered to be the same 15 Mpa. E_{ur}^{ref} is considered to be three times of E_{50}^{ref}

around 45 Mpa. OCR (Over consolidation ratio) is considered to be 1.

Crushed stone

As mentioned earlier, a layer of crushed stone is placed underneath the tunnel structure. It is 2 m thick. Some material properties collected from old tunnel design. Material properties like unit weight, friction angle and cohesion. It was checked against statens vegvesen standards. Values are kind of same considering tunnel is designed maintaining those standards at the first place. Just like other two materials stiffness parameters are collected from literature. But there is no trial performed because type of rock used to make crushed rock is not known. According to literature, crushed stone have stiffness around 70 Mpa (Theyse (2002)). So it lead us to estimate Plastic straining due to primary deviatoric loading E_{50}^{Ref} 70 Mpa. Parameter called Plastic straining due to primary compression E_{oed}^{ref} is same as E_{50}^{Ref} 70 Mpa and E_{ur}^{ref} is three times of E_{50}^{ref} 210 Mpa. Contact surface between crushed stone and concrete surface of the tunnel is considered to be rough. For that reason interfaces R_{inter} of crushed stone is considered to be rigid. OCR (Over consolidation ratio) is considered to be 1.

Plate (Tunnel Structure)

As mentioned earlier in this report old tunnel is designed for three cross sections. For this report we are considering only one cross Section. Cross section have 1 m overburden and thickness of 500 mm and foundation is 1m thick. c-55, sv-40 concrete is used with varying total amount of reinforcement. Plaxis is not a structural designing software thus it does not have particular input parameter to add reinforcement directly. According to a research paper from Statens Vegvensen (December,2013) suggest SV-40 concrete have stiffness in between 20 to 38 Gpa depending on aggregate quality. In plaxis, as an input we can add normal stiffness (EA_1) and bending stiffness EI and plaxis automatically calculates thickness of the plate. We considered normal stiffness (EA_1) is 8.5 Mpa and bending stiffness EI around 180 Kpa Which gives us thickness d around 500 mm. To be precise it is 0.5048 m. Same for plate considered as foundation.

$$w = \frac{A * \gamma_{concrete}}{d} Here, A = Permeter tunnel width \tag{3.1}$$

3.3 Traffic load

Traffic load is added in the model to compare plaxis output result with structural drawing. To simulate maximum bending moment from traffic load three trial is performed. Trials are presented in Appendix A. Depending on output result it is decided if traffic load is added just above the tunnel structure it provides maximum bending moment.

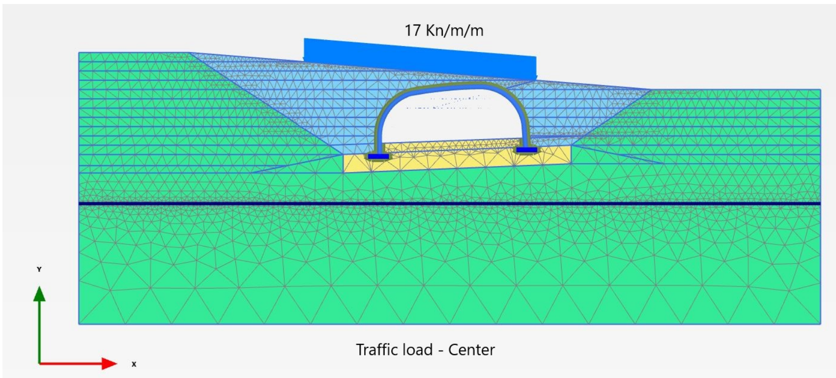


Figure 3.7: Position of the traffic load

3.4 Phase Selection

Phase selection for the Plaxis model is created maintaining the actual construction sequence. Compaction is added to receive a good result. Now each 1 m layer have loading and unloading phase. So, soil layer is contracting under loading and expanding due to unloading. It lead us to create several phases. Model is set to zero after applying traffic load and full model is activated. Because we did not wanted the displacement caused by compaction and construction to effect excavation later.

Chapter 4

Results and Discussion

4.1 Plaxis model evaluation

Bending Moment (M)

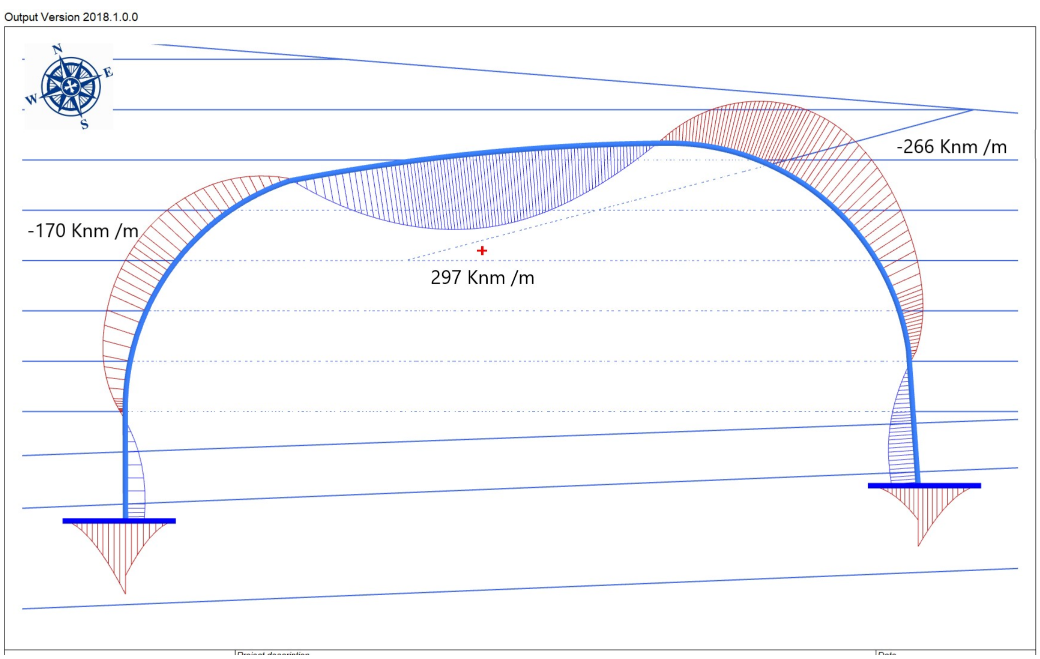


Figure 4.1: Bending moment from plaxis output

From plaxis output and old tunnel design resulting bending moment (M) along tunnel profile are collected. By comparing this two output results, it is possible to evaluate plaxis model. However, in a sense, it is not fare to compare this two results directly considering load combination is used for structural design. But did it anyway to observe the difference.

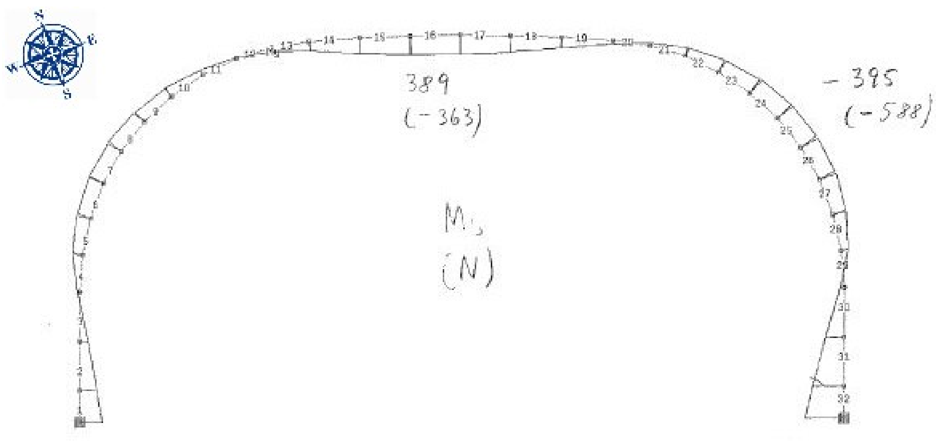


Figure 4.2: Bending moment from old tunnel design [Cross section C-C]

From structural design, tunnel roof and wall is designed for 389 Kn-m and -395 Kn-m respectively. In contrast, from plaxis output it is 297 Kn-m and -266 Kn-m respectively. Plaxis is giving 24 percent (Roof) and 33 percent (Wall) lower value compared to the structural design. Either tunnel is over designed or plaxis is giving lower value. There is a third possibility, if a factor of 1.24 (Roof) and 1.33 (Wall) is multiplied with plaxis output then it make sense. For structural design, they had to used several load combinations to simulate worst case scenario. In plaxis, it is not possible to add this load combinations. Maybe, it was possible to alternate conditions and material parameters in plaxis model to receive better numbers, then it is like manually trying to match some certain numbers. For given geometric, compaction and material parameters it is decided to used this plaxis model for excavation process, which is not perfect match but providing a reasonable estimation.

4.2 Compaction

Decision is taken to add some form of compaction in plaxis model. As compaction load, it is decided to add 2.5 tons, which is around 25 Kn/m/m. It is assumed, in reality some kind of vibrating roller is used for compaction process. In plaxis, load can be added as uniformly distributed or dynamic. Three trials are performed by interchanging between uniformly distributed load and dynamic load. Used values are presented in figure (4.9). To keep things similar, all material parameters (3.5) are kept same. Plus traffic load is add. Phase is selected based on a doctoral thesis conducted in KTH Wadi (2019). According to the thesis report, to receive proper compaction effect it is better to place soil in layers. Soil layer have to go through loading and unloading phase before next layer is placed on top of it.

Load consideration for compaction			
	Uniformly distributed load	Dynamic load	
Trial - 00	0	0	Kn /m/m
Trial - 01	25	0	Kn /m/m
Trial - 02	10	15	Kn /m/m
Trial - 03	15	15	Kn /m/m

Figure 4.3: Compaction Table

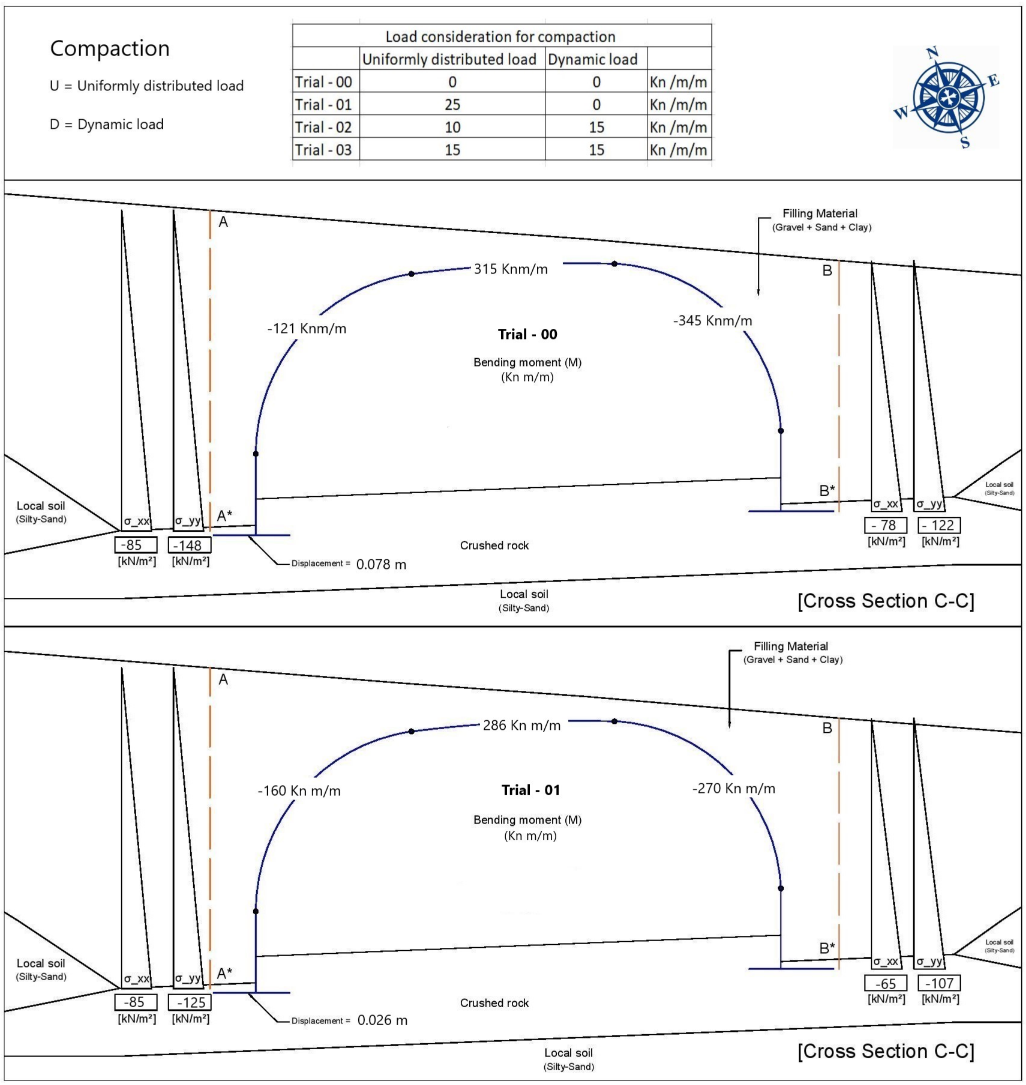


Figure 4.4: Plaxis output for trial 00 and 01

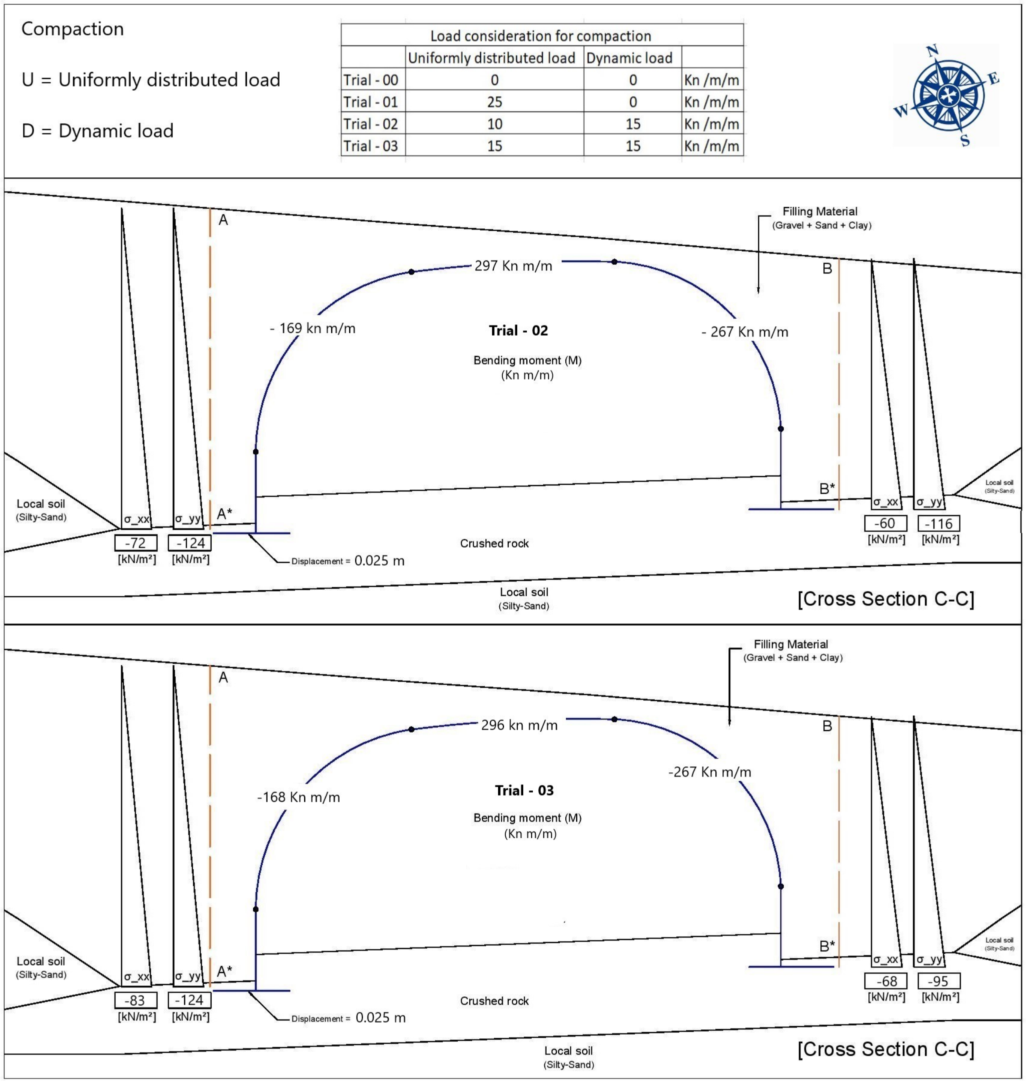


Figure 4.5: Plaxis output for trial 02 and 03

Discussion

By analysing plaxis output, it is clear that there is a significant difference between not compacted and compacted model. Mainly, soil displacement and earth pressure. Soil under west side foundation is considered as reference point to compare full model displacement. Model displacement is set to zero immediately after placing tunnel on top of crushed stone. Because displacement before back fill placement is not relevant if capturing the effect of back fill placement is the main goal of the analysis. Model with compaction showed the displacement is around 0.025 m. Model without compaction showed it is around 0.078 m. After compaction displacement is reduced. Maybe due to compaction process is causing this reduction. Compaction process is made out of several phases with loading and unloading cycle.

Bending moment profile shows earth pressure is better distributed along tunnel profile. Considering earth pressure always act perpendicular to the surface. If tunnel structure is unchanged then only thing have influence on bending moment profile is earth pressure. It seems like plaxis is giving lower bending moment due to compaction process.

Trial with different compaction load is showing close to no effect on soil displacement or bending moment. Any one of those compaction load can be used in the model. To keep things similar it is required to select one compaction load. 10 Kn/m/m Uniformly distributed load and 15 Kn/m/m for dynamic load is selected for final model.

4.3 Explanation behind Selected Material Parameters

As mentioned earlier for this analysis soil test results are not available. So it is important to understand effect/influence of some material parameters before finalizing it for plaxis model. However, some parameters like Unit weight (γ), Friction angle (ϕ) are directly taken from values recommended by States Vegvesen and tunnel design. For that reason it is kept same for all analysis of this report. Other parameters like poisons ratio (μ), K_0, OCR are by default or automatically generated values from plaxis.

4.3.1 Cohesion

For plaxis model, it is better to consider cohesion as low as possible, if effort is made to maintain States vegevesen standard. Still it is interesting to see if it have any significant effect on soil displacement, earth pressure and bending moment profile. Following trials are performed to analyse the effect. For analysis all other parameters, geometric, conditions are kept same expect cohesion.

Cohesion Trial (C)				
	Filling material	Local Soil	Crushed rock	
	Gravel + Sand + Clay	Silty-Sand		
Trial - 00	0	0	10	Kn /m/m
Trial - 01	5	5	10	Kn /m/m
Trial - 02	3	3	10	Kn /m/m
Trial - 03	1	1	10	Kn /m/m

Figure 4.6: Cohesion Table

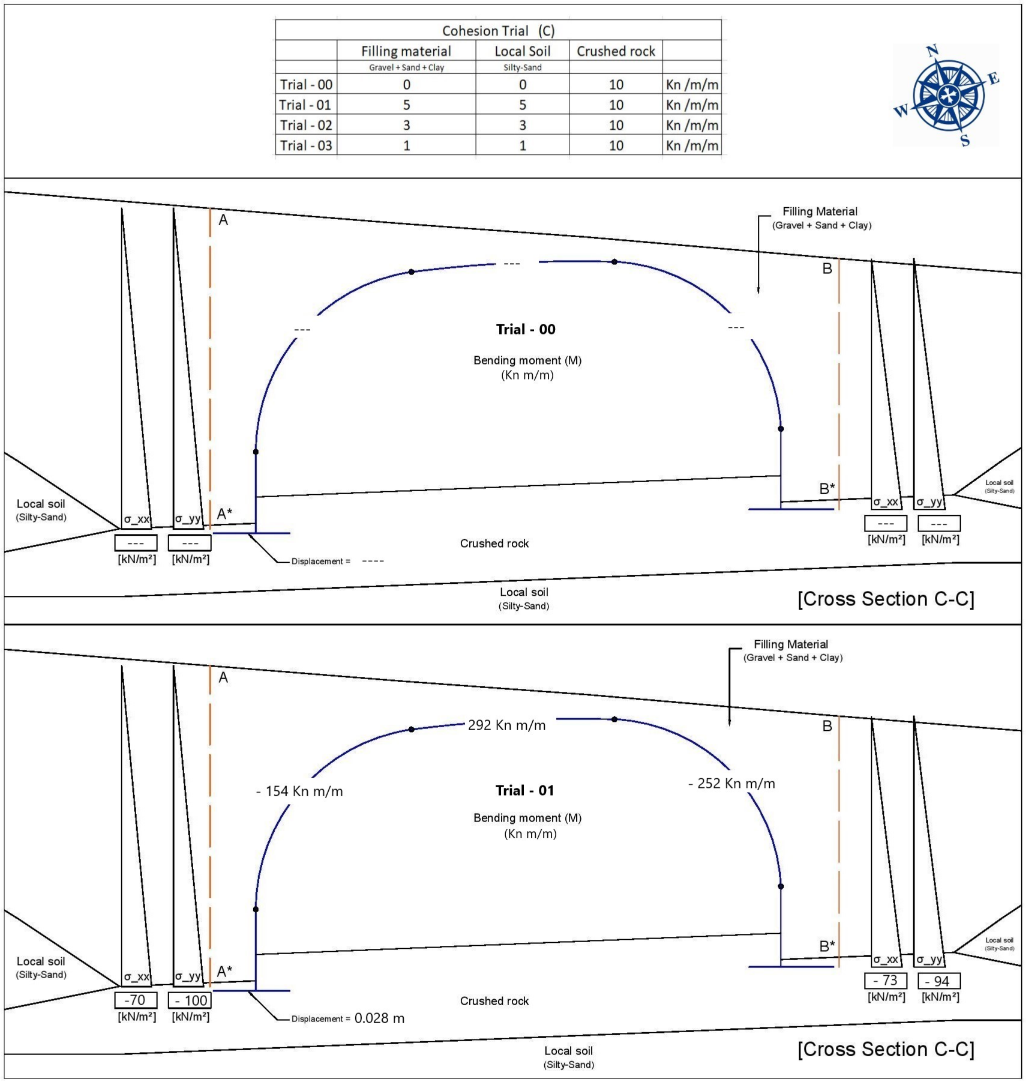


Figure 4.7: Plaxis output - Cohesion - Trial 00 and 01

Discussion

Initially considered cohesion for plaxis model was quite high considering there is no soil test report. In effort to reduce it in controlled way this analysis is performed. Analysis showed, cohesion (c) do not have any direct effect on output result. Output result such as bending moment or soil displacement. However, it should have some effect on soil displacement but analysis does not show it. Reason behind this can be the crushed rock layer under left side foundation. Cohesion for crushed rock layer is the same 10 kpa for all analysis. Standard from States Vegsesen shows crush rock should have cohesion of 10 Kpa. For final model considered cohesion is 10 Kpa for crushed rock and 1 Kpa for both filled material and local soil.

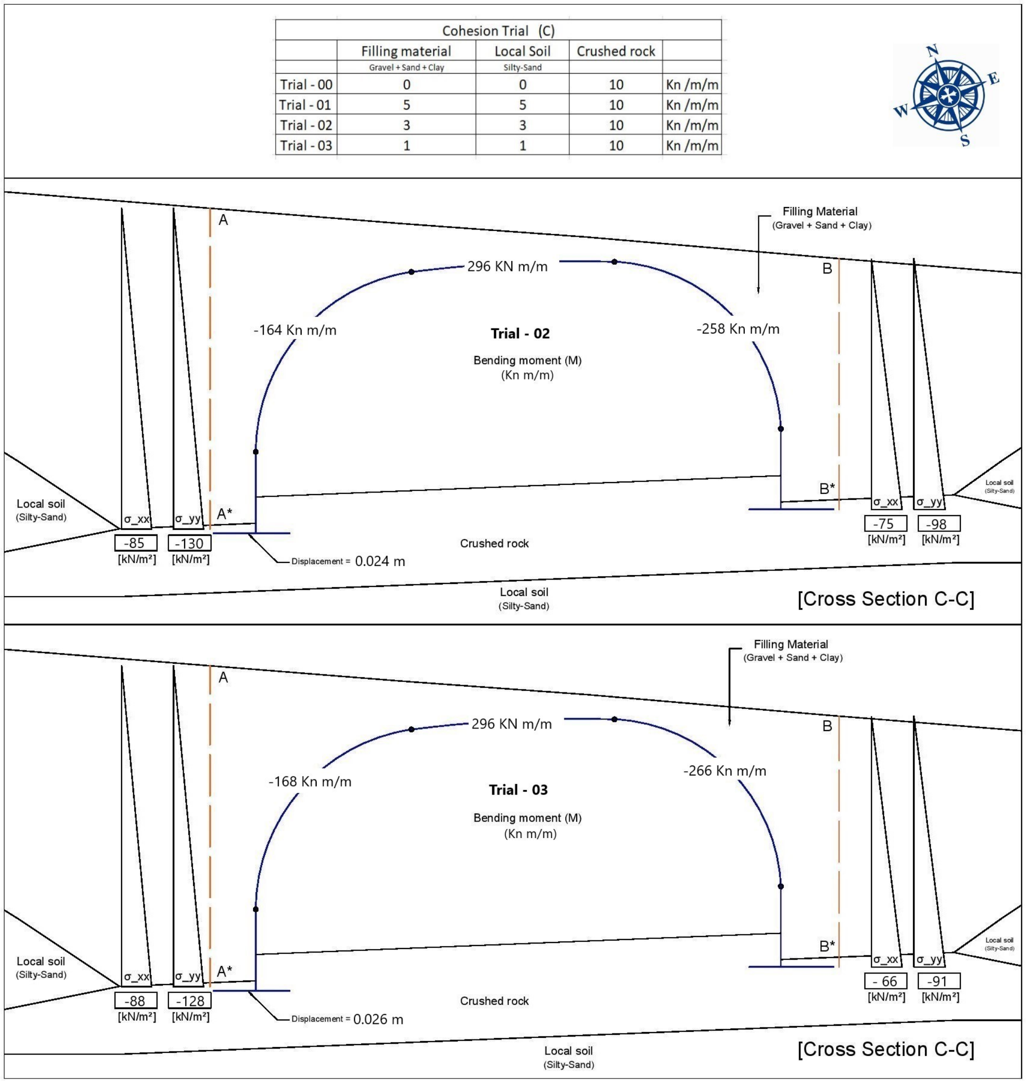


Figure 4.8: Plaxis output - Cohesion - Trial 02 and 03

4.3.2 Strength Parameters (Stiffness)

Explanation behind selecting stiffness parameter is already presented in section (3.2). In this section, just like cohesion analyse is performed to see, if stiffness parameters have any significant effect on plaxis output result. For trial purpose only Filling material and Local soil are changed. Assumption is, crushed rock should stiffness at least 70 Mpa, so there is no need to reduce it.

Stiffness parameters										
	Filling material			Local Soil			Crushed rock			Unit
	Gravel + Sand + Clay			Silty-Sand						
	E_50	E_oedo	E_ur	E_50	E_oedo	E_ur	E_50	E_oedo	E_ur	
Trial - 00	50	50	150	25	25	75	70	58	210	Mpa
Trial - 01	40	40	120	15	15	45	70	58	210	Mpa
Trial - 02	30	30	90	15	15	45	70	58	210	Mpa
Trial - 03	20	20	60	15	15	45	70	58	210	Mpa

Figure 4.9: Stiffness Table

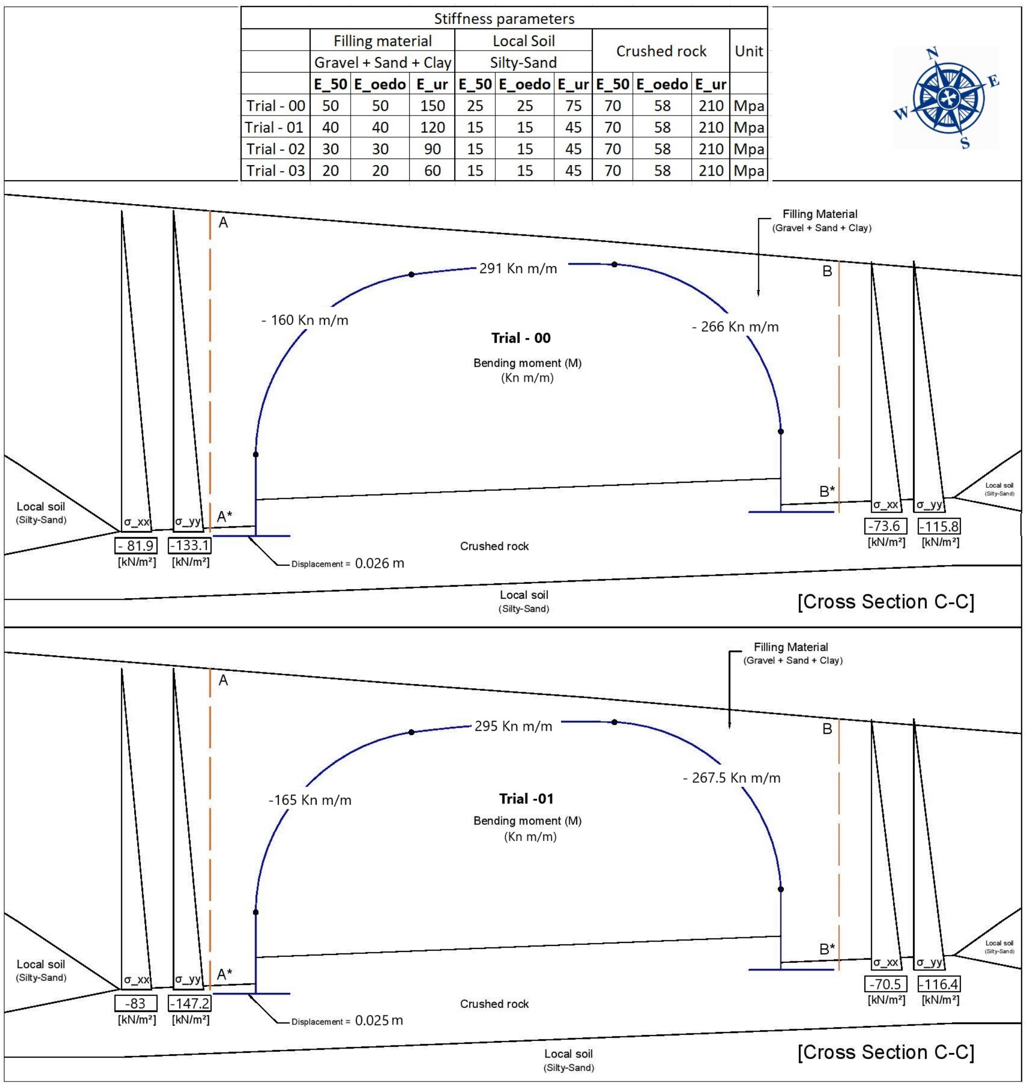


Figure 4.10: Plaxis output - Stiffness - Trial 00 and 01

Stiffness parameters										
	Filling material			Local Soil			Crushed rock			Unit
	Gravel + Sand + Clay			Silty-Sand						
	E_50	E_oedo	E_ur	E_50	E_oedo	E_ur	E_50	E_oedo	E_ur	
Trial - 00	50	50	150	25	25	75	70	58	210	Mpa
Trial - 01	40	40	120	15	15	45	70	58	210	Mpa
Trial - 02	30	30	90	15	15	45	70	58	210	Mpa
Trial - 03	20	20	60	15	15	45	70	58	210	Mpa

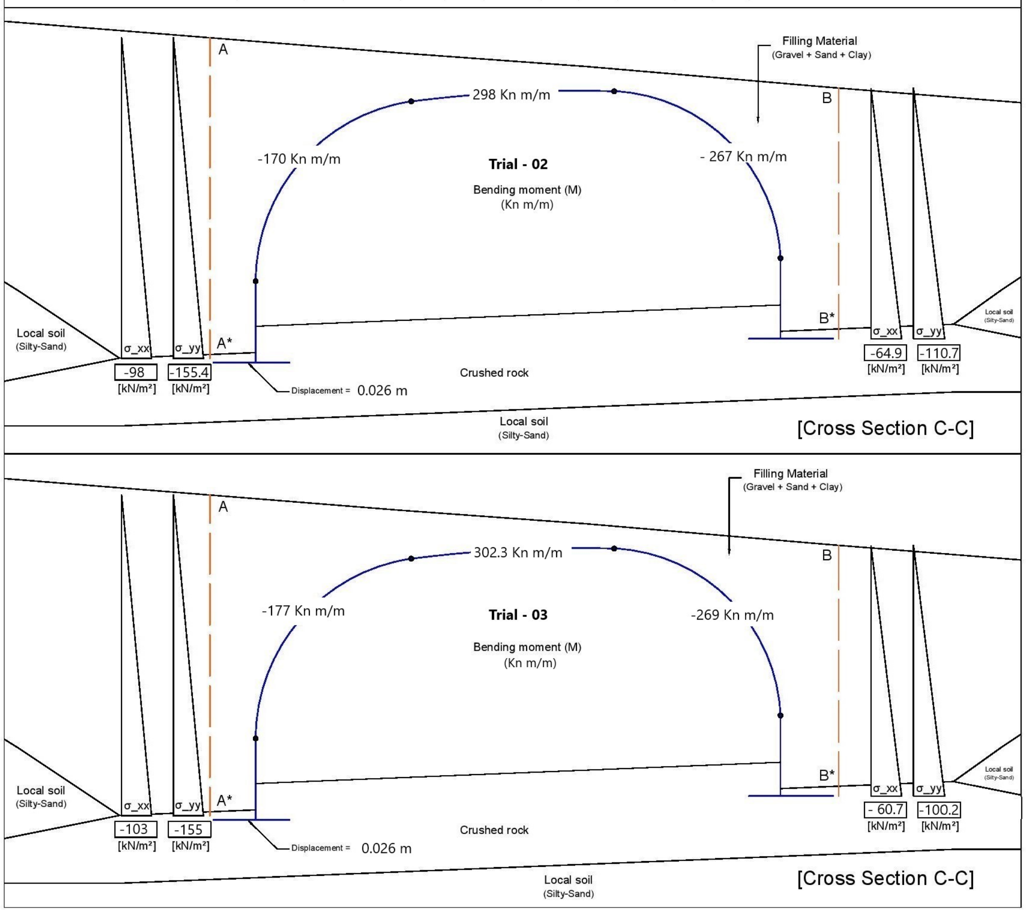


Figure 4.11: Plaxis output - Stiffness - Trial 02 and 03

Discussion

Analysis shows, lower stiffness is increasing earth pressure thus increasing bending moment. Also horizontal and vertical earth pressure is increasing. But it does not have any significant effect on output result. Just like cohesion displacement is measured under west foundation where stiffness is constant in all trials.

Sand have stiffness between 15 Mpa to 50 Mpa. Both filling material and local soil have sand. As filling material is made of gravel, sand and clay mixture, assumption is this material should have higher stiffness then local soil. So, stiffness for this material is considered to be 30 Mpa. However, for local soil, stiffness is 15 Mpa, which is the lower range for sand stiffness.

4.4 Proposed Excavation and Corresponding Output Results

Purpose of the following analysis, is to observe changes in earth pressure after excavation. Excavation can be done by several different ways. Among other possibilities, three specific method of excavation is analysed. As an output total horizontal stress, bending moment (M) and displacements are presented. During discussion, intentionally direct comparison between plaxis result and old tunnel design is avoided. Instead, comparison between different excavation method and their positive or negative sides are discussed.

4.4.1 Proposed Excavation Trial - 01

Trial 01 is featuring a scenario where minimum excavation is required. Before excavation, model displacement is set to zero. So, the displacement showed under west foundation is due to excavation. Excavation is performed in several stages to simulate actual construction sequence.

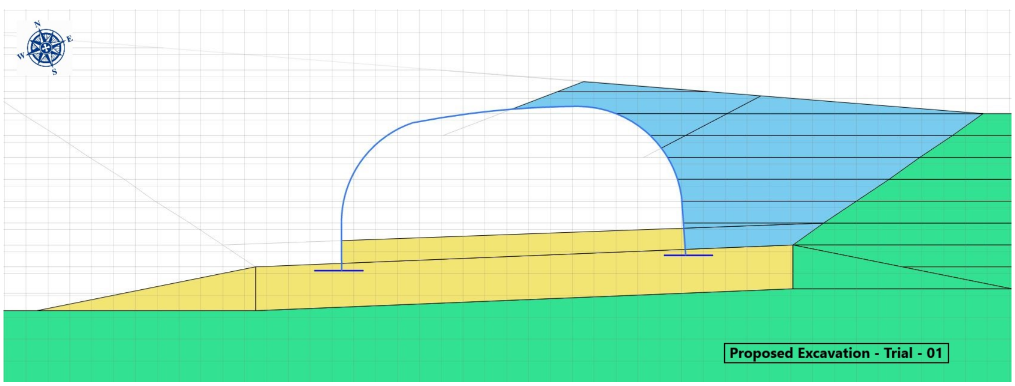


Figure 4.12: Plan view - Proposed Excavation - Trial 01

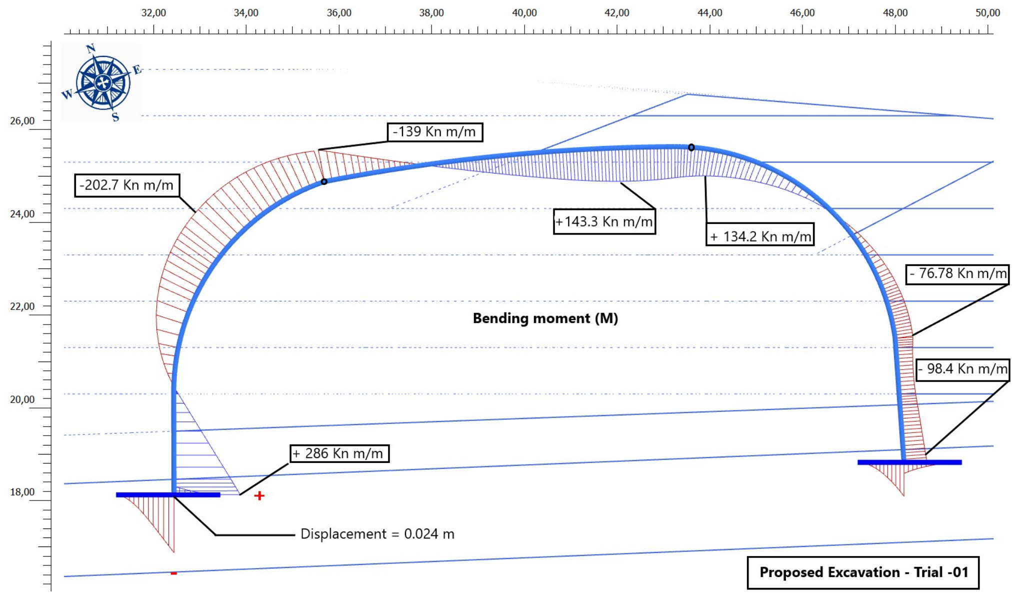


Figure 4.13: Bending moment - Proposed Excavation - Trial 01

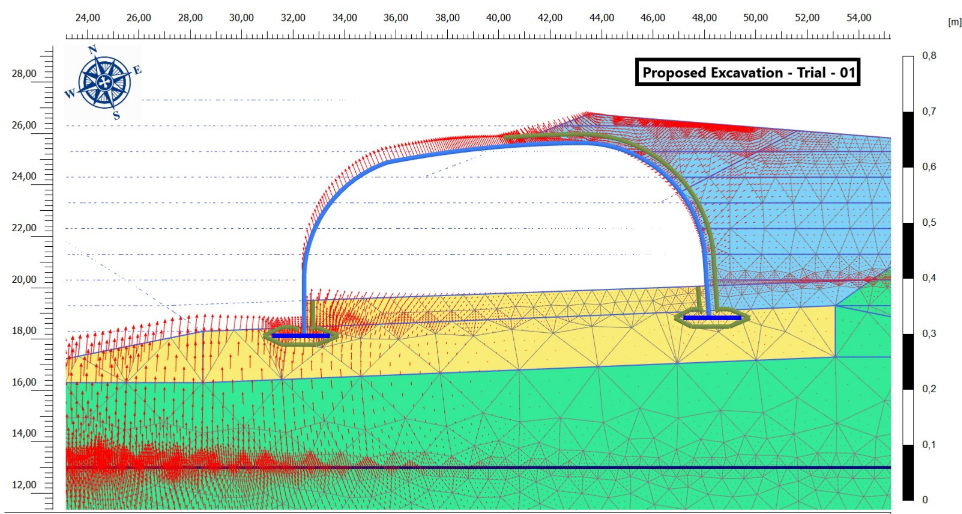


Figure 4.14: Displacement - Proposed Excavation - Trial 01

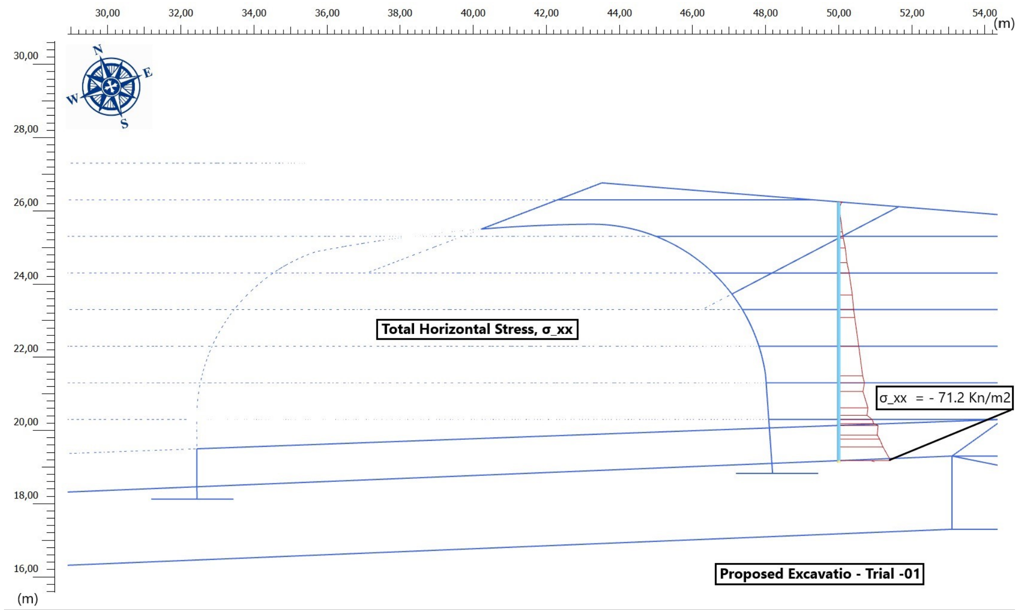


Figure 4.15: Total Horizontal Stress - Proposed Excavation - Trial 01

Discussion

Plaxis output shows changes in bending moment profile. Bending moment of west side arch and wall is increasing, while it is decreasing for roof and wall for the east side. West-side wall is expected to experience a positive bending moment of 286 Kn m/m, which is maximum compared to others. However, on east side vertical wall is expected to experience tension. Reinforcement setup (4.17) of the old tunnel shows this wall is not designed to carry tension. Because it does not have extra reinforcement like roof and arches. For this reason it is not recommended to leave any soil on top of the tunnel.

[To be noted : Old tunnel is designed to take bending moment (M) of - 395 Kn m/m and 389 Kn m/m for Arch-wall and Roof.]

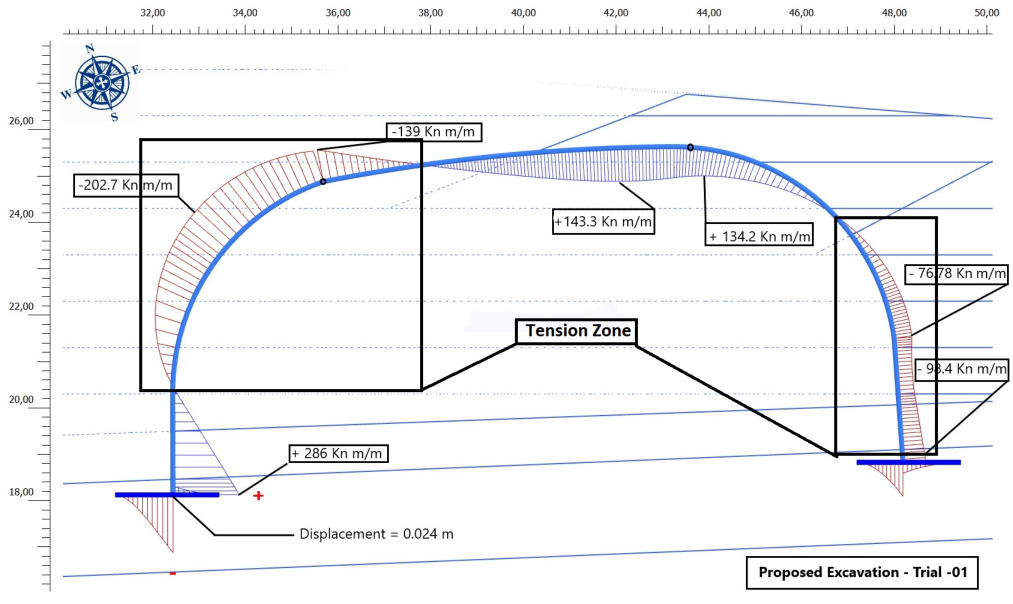


Figure 4.16: Tension zone - Proposed Excavation - Trial 01 - Analysis

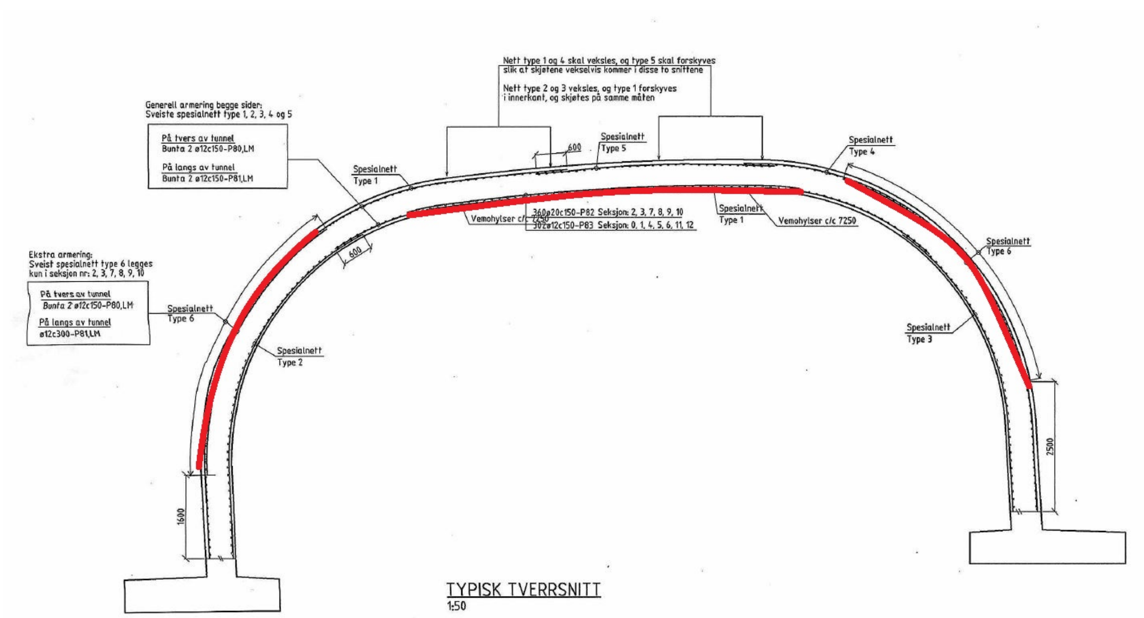


Figure 4.17: Extra reinforcement - Tension - old tunnel

4.4.2 Proposed Excavation Trial - 02

Trial 02 is featuring a scenario where roof and half of east side arch is released from loading. Just like trial 01 before excavation, model displacement is set to zero and excavation is performed in several stages to simulate actual construction sequence. All other model parameters and conditions are the same.

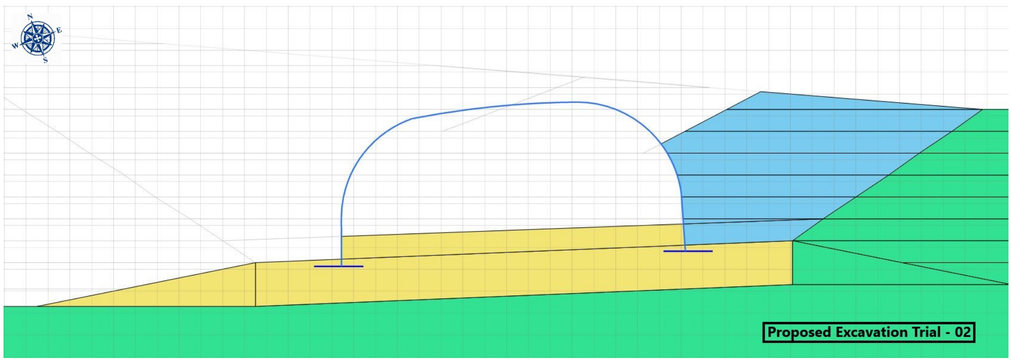


Figure 4.18: Plan view - Proposed Excavation - Trial 02

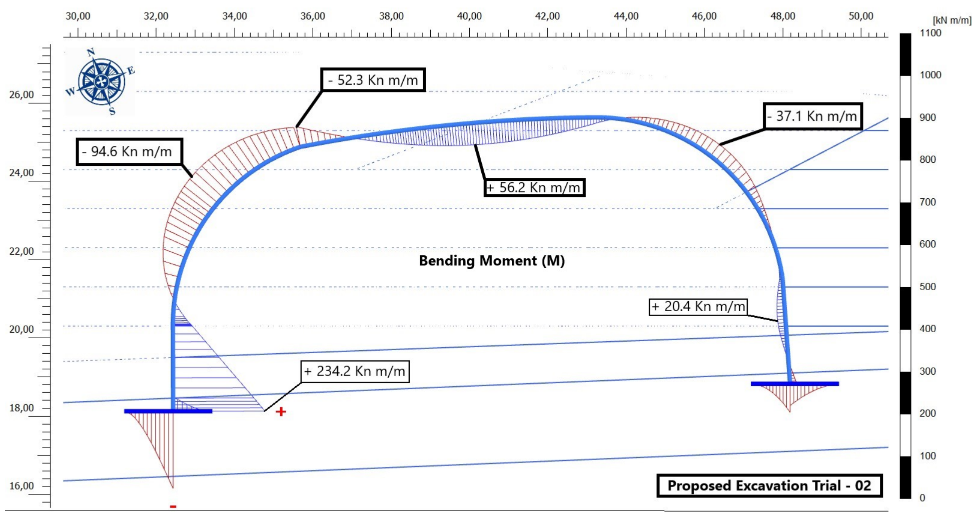


Figure 4.19: Bending moment - Proposed Excavation - Trial 02

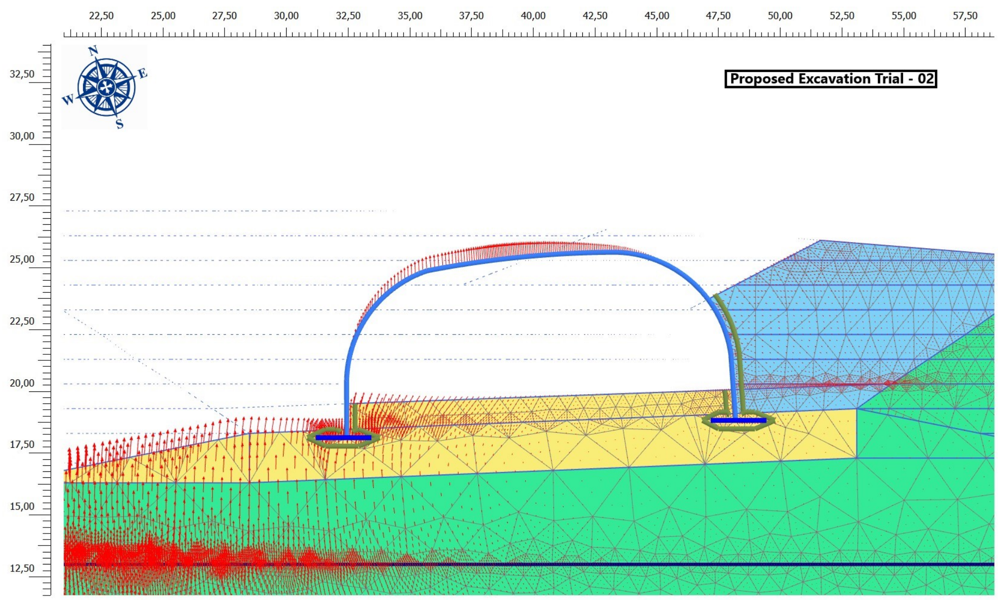


Figure 4.20: Displacement - Proposed Excavation - Trial 02

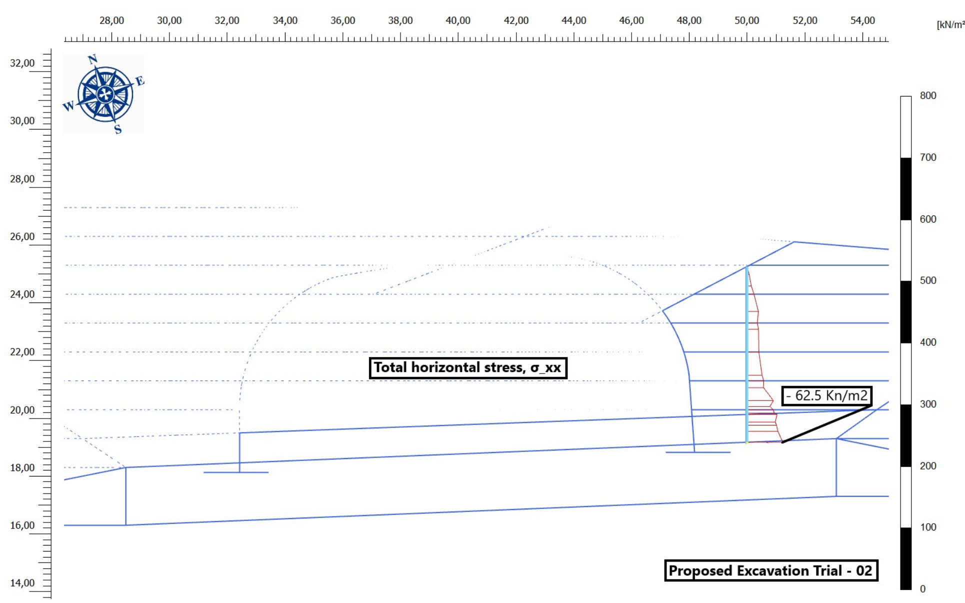


Figure 4.21: Total Horizontal Stress - Proposed Excavation - Trial 02

Discussion

Output results from trial 02 seems promising. Compared to trial 01, bending moment is reduced . West side wall is featuring highest bending moment of + 234.2 Kn m/m. Unlike trial 01, direction of compression loading is not changing. Bending moment profile have similar shape as before excavation, with lower value. Horizontal stress on east of the tunnel is reduced compared to trial 01. Trial 02 shows no change in the direction of compression loading for east side wall, which is good for tunnel structure.

[To be noted : Old tunnel is designed to take bending moment (M) of - 395 Kn m/m and 389 Kn m/m for Arch-wall and Roof.]

4.4.3 Proposed Excavation Trial - 03

Trial 03 is featuring a scenario where Maximum excavation is required. Tunnel roof and east arch is completely unloaded. Just like previous two method, before excavation plaxis model is set to zero displacement. So, the displacement showed under west foundation is due to excavation. Excavation is performed in several stages to simulate actual construction sequence. Excavation is done by 1 m layer on both side simultaneously.

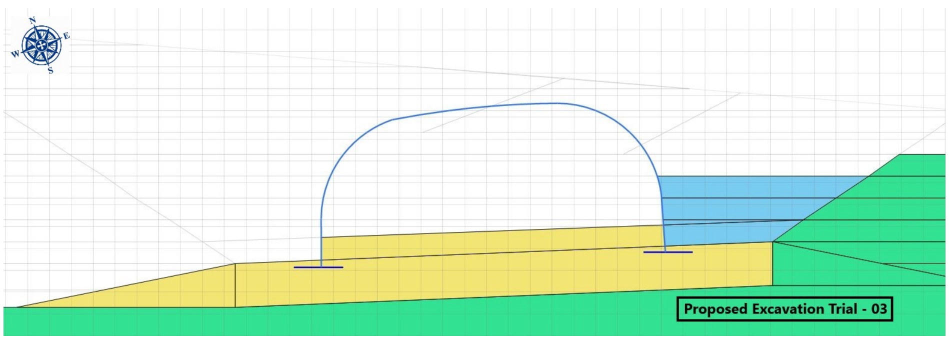


Figure 4.22: Plan view - Proposed Excavation - Trial 03

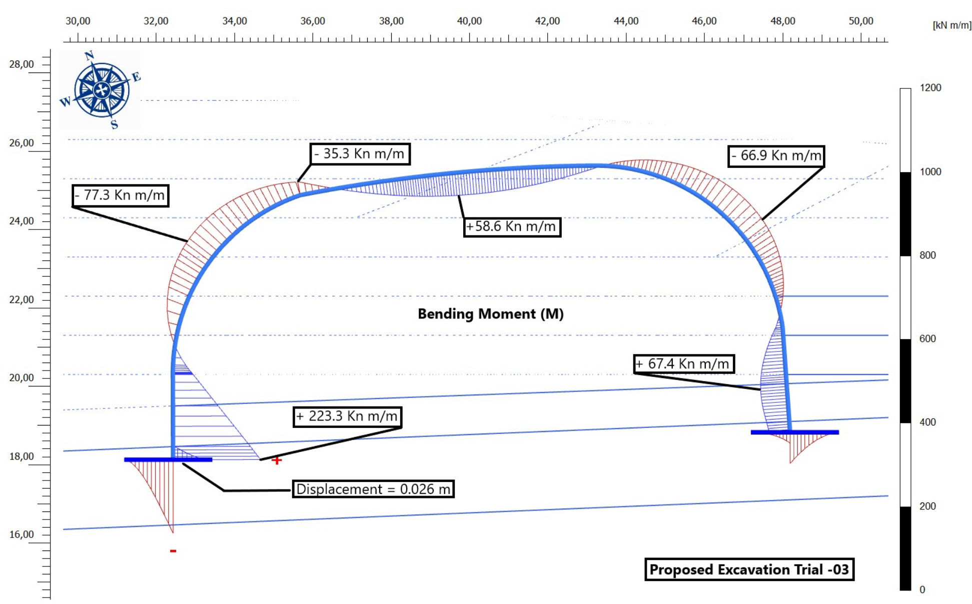


Figure 4.23: Bending moment - Proposed Excavation - Trial 03

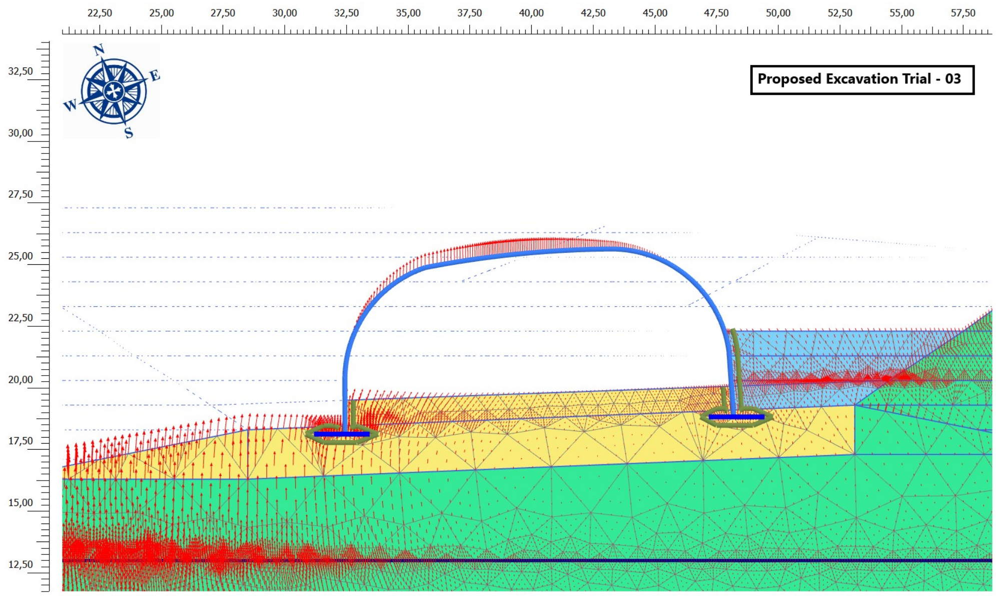


Figure 4.24: Displacement - Proposed Excavation - Trial 03

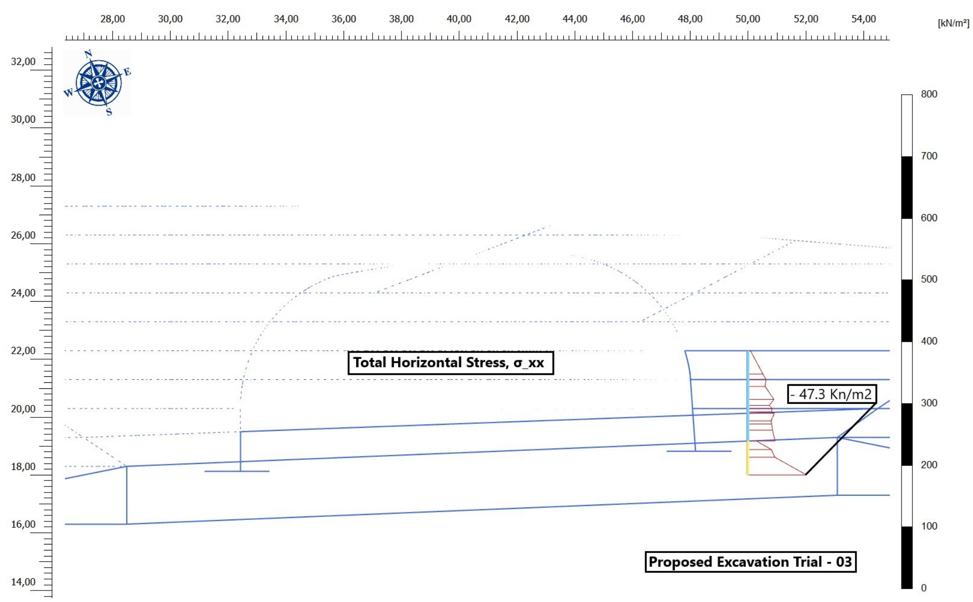


Figure 4.25: Total Horizontal Stress - Proposed Excavation - Trial 03

Discussion

By analysing plaxis output further reduction of bending moment (M) is observed. just like other two trials, west wall is expected to experience maximum bending moment. Because earth pressure is acting from east side thus giving high bending moment on west side wall. Most of the resulting moment is coming from structure it self. Unlike trial 01, loading direction from compression is not changing at all. This method of excavation is expected to put lowest stress on the tunnel structure.

Chapter 5

Summary and Recommendations for Further Work

5.1 Summary and Conclusions

Analysis is performed using Plaxis 2D, which is simple to used and make analysis process more flexible. Some material parameters are collected, while some are estimated. 25 Kn m/m compaction is added in layers. Analysis shows, compaction is providing better load distribution and lower soil displacement, but have lower effect on soil horizontal stress. Water level is considered 3 m below foundation. Plaxis model is checked against original structural design from old tunnel. Structural design of the old tunnel is performed using STATIK software. Load is added with several load combinations. Load combinations simulate a worst case scenario and the structure is designed to withstand such scenarios.

Main topic of the thesis is to analyse, if it is possible to excavate full length of the tunnel at once. Analysis shows it is possible. However, it will require delicate excavation technique. Analysis shows, plaxis model is providing 20 to 35 percent lower bending moment (M) compared to structural design. Which is reasonable considering the difference in structural and geotechnical analysis. After model evaluation, three method of excavation is selected and analysed. It shows, excavation method 02 is safer and more economical. However, it is suggested to consider following recommendations if tunnel is going to be excavated full length at once.

5.2 Recommendations

Layered excavation

Soil is placed on both side of the tunnel simultaneously to keep the load equally distributed, during construction of the old tunnel. Tunnel is 115 m long. Partial excavation along the full length of the tunnel, can create twisting stress on the structure. It is recommend not to excavate partially, instead excavation should be performed layer by layer on both side simultaneously along full length. Layered excavation should not be more then 1 m. Excavator and trucks need to have sufficient contact surface with the ground. Because tunnel is designed to carry 15 Kn/m2 traffic load, which is around 1.5 tons/m2. In figure (5.1), marked green area showing cross section of the excavation. Layers are shown in the figure.

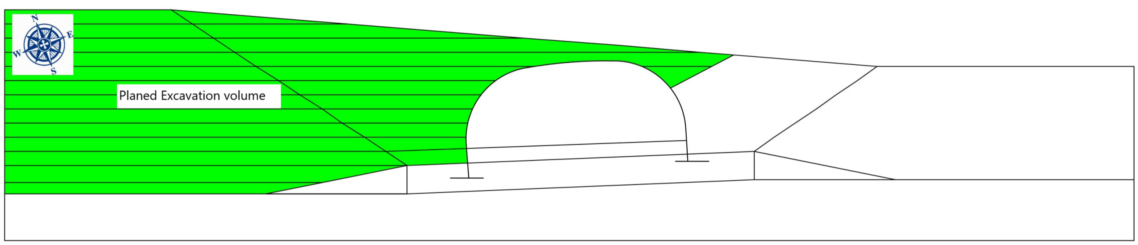


Figure 5.1: 1 m layered excavation

Cut angle and position

As mentioned earlier, three different excavation methods are analysed. Excavation trial 02 seems more economical and reasonably safe. On the east side, minimum excavation depth should be up to the mid point of the east arch, which is shown as doted line in the figure (5.2). Cut angle should be at least 30 degree to the horizontal line.

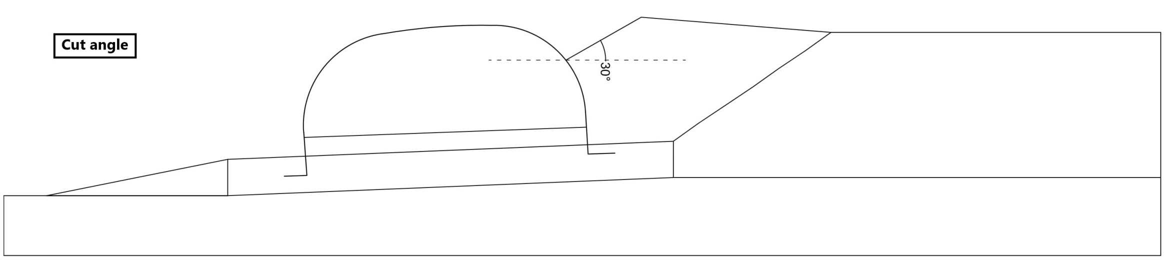


Figure 5.2: Cut angle and position

Extra filling - crushed rock

Crushed rock under tunnel foundation is expected to expand after excavation. Soil under new tunnel foundation will be replaced by at least 2 m of crushed rock. It will require excavation. After excavation crushed rock under old tunnel will be expose on the west side and expand. On top of it, resulting vertical force acting on top of west side foundation, should shift its position toward wast side because horizontal force is coming from east side only. In technical terms, this is known as eccentric loading, where position of the vertical force shift at a distance of $\triangle B$ due to acting horizontal force . It can be avoided by placing crushed rock with compaction immediately after excavation. marked as yellow triangle in figure (5.3). (1:10)

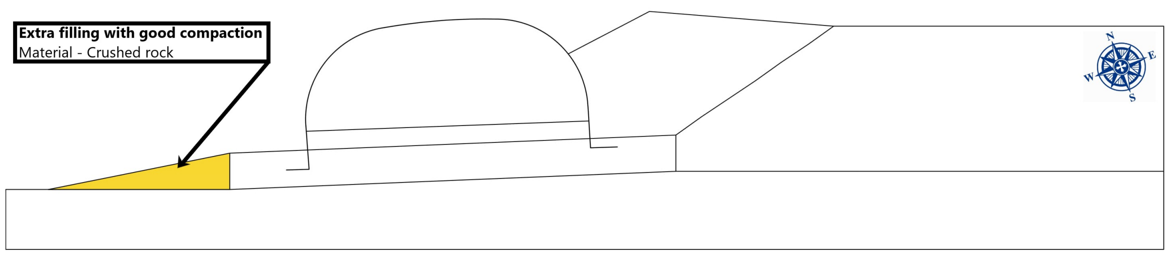


Figure 5.3: Extra filling to consider

5.3 Further Work

New tunnel is under designing phase as of this moment. Soil test reports are not available yet. When reports are available, it is possible to update this plaxis model.

- Collect soil test reports. Perform proper interpretation and update input parameters.
- Add new tunnel in plaxis model next to the old tunnel. Gap between two tunnels, will be filled with some filling material. Due to shortage of space, it will be difficult to perform proper compaction. Loading condition will not be the same as before for the old tunnel. Analysis can be perform to check what can be done to reduce this changes.

Appendix A

Available Information - Soil

Description in structural design

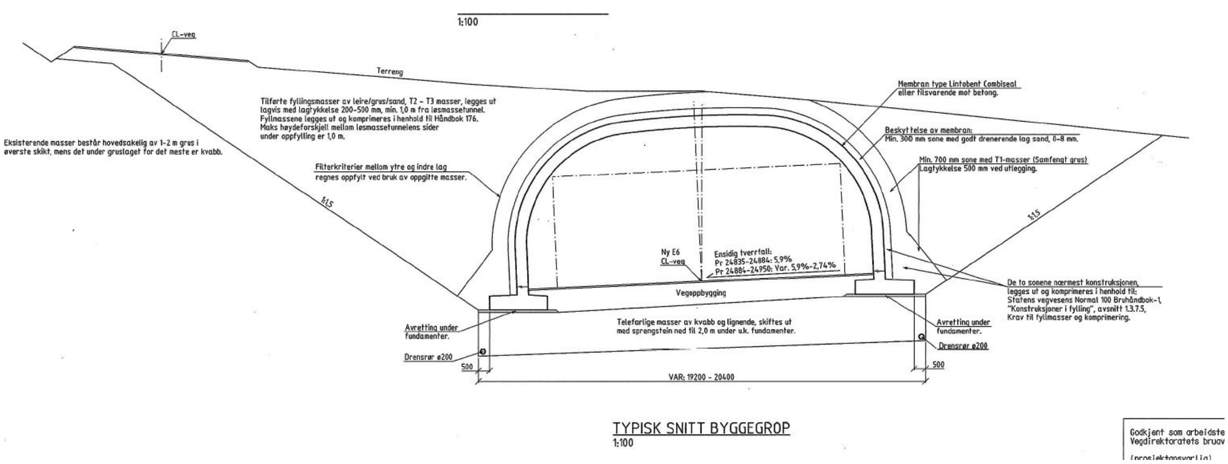


Figure A.1: Soil surrounding old tunnel - Structural design

Site map

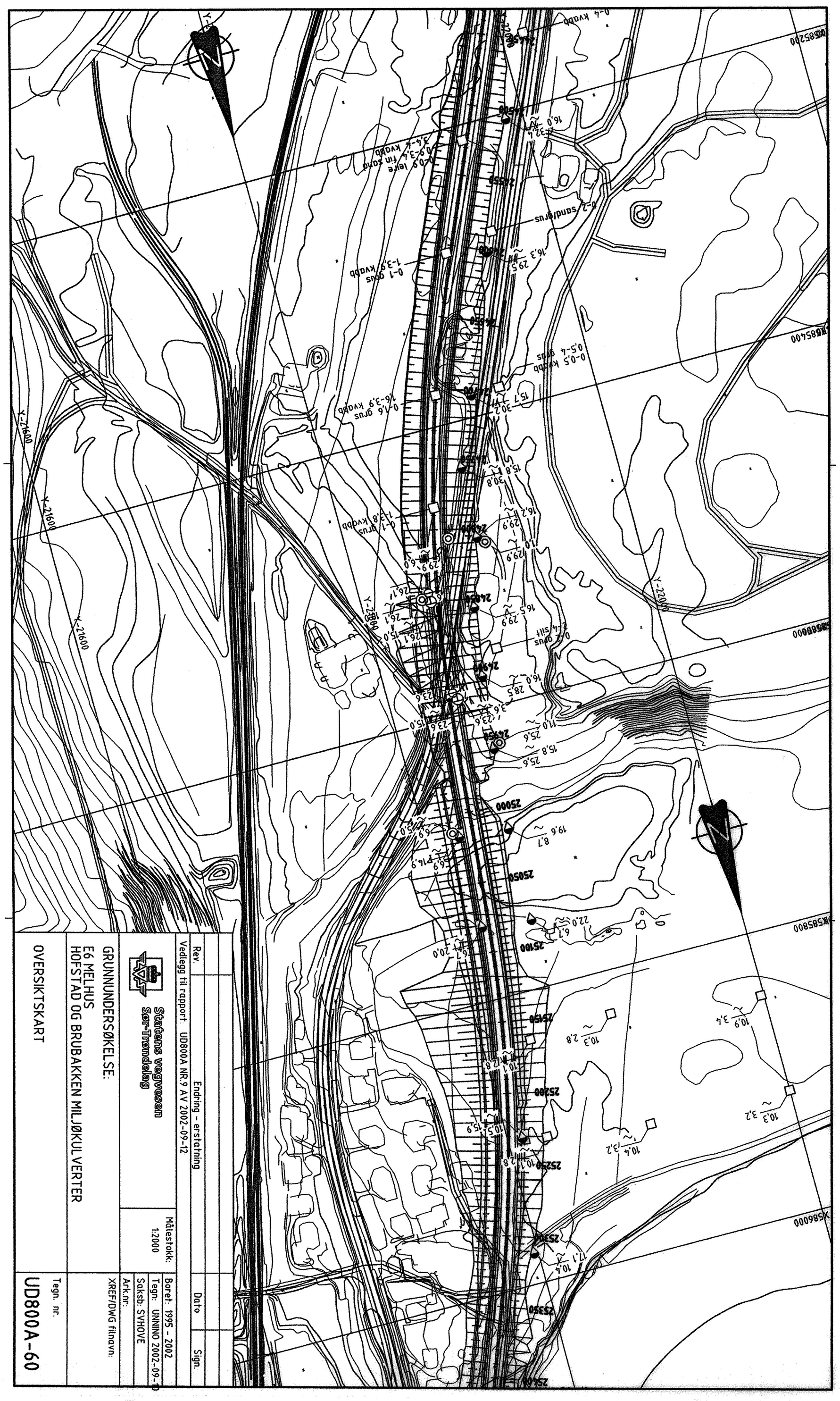


Figure A.2: Site map with grid lines

Soil test reports

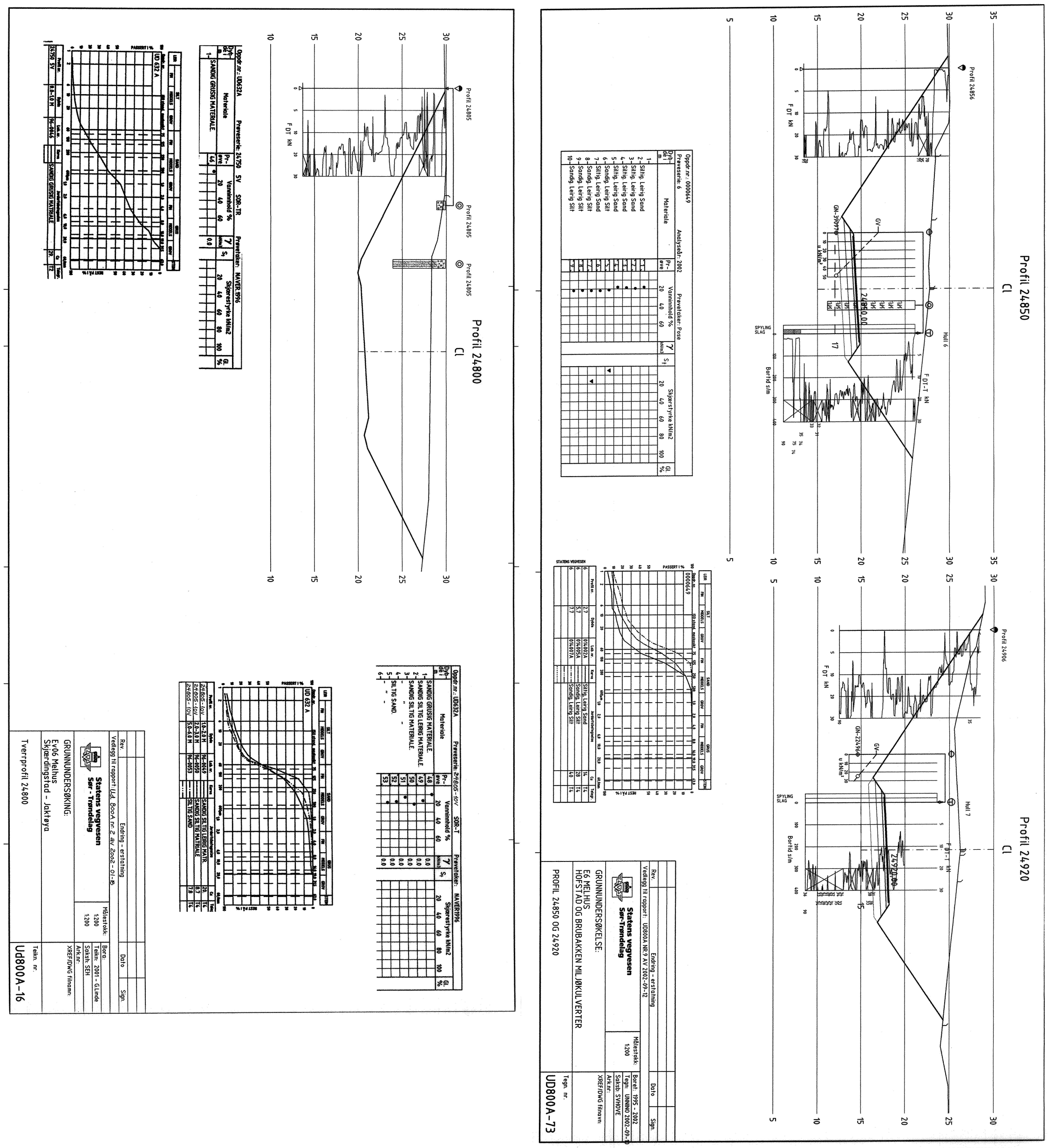


Figure A.3: Position of the traffic load

Appendix B

Traffic load - Trial and Results

Traffic load is placed in three different positions in the model. Traffic load position which is resulting in higher resulting bending moment (M) is considered for final model.

Right side

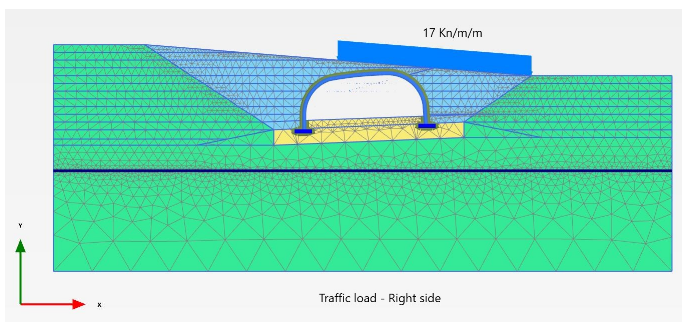


Figure B.1: Position of the traffic load

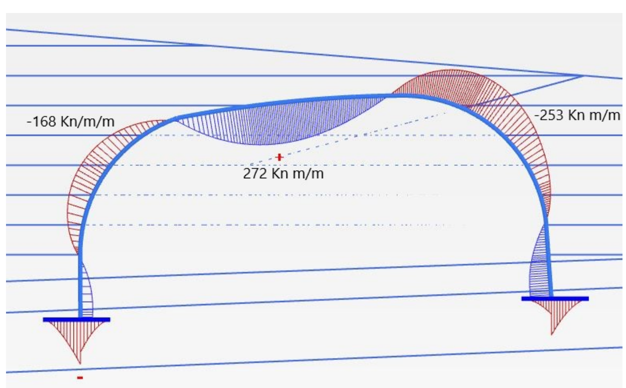


Figure B.2: Output Bending moment profile

Center

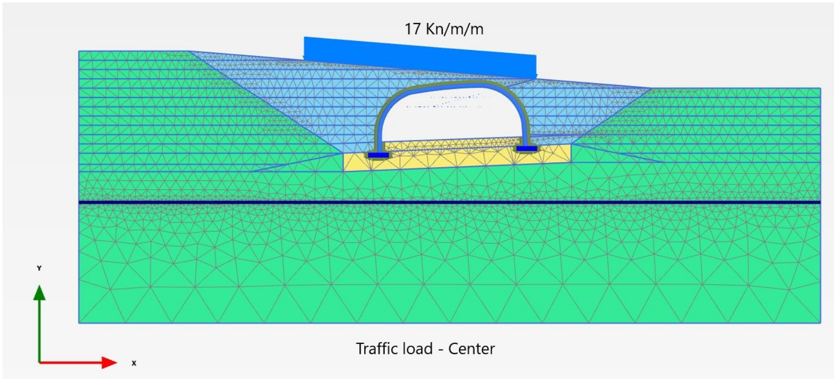


Figure B.3: Position of the traffic load

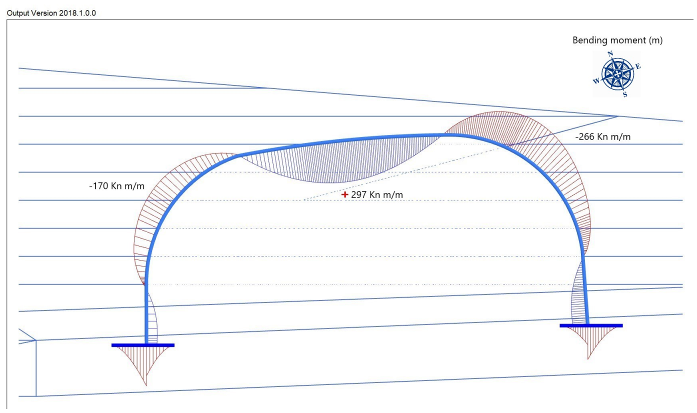


Figure B.4: Output Bending moment profile

i

Left side

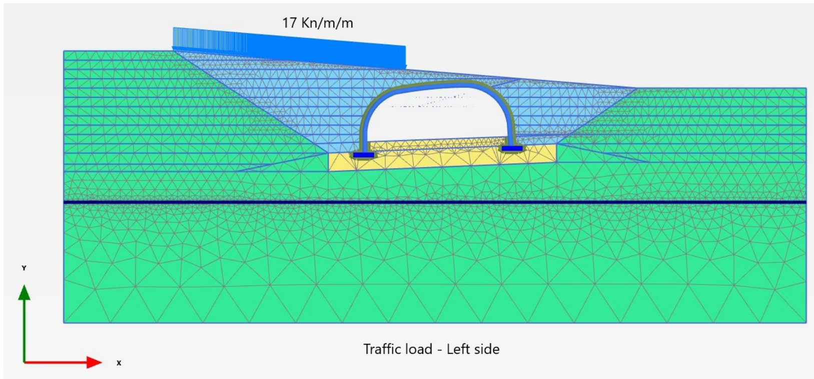


Figure B.5: Position of the traffic load

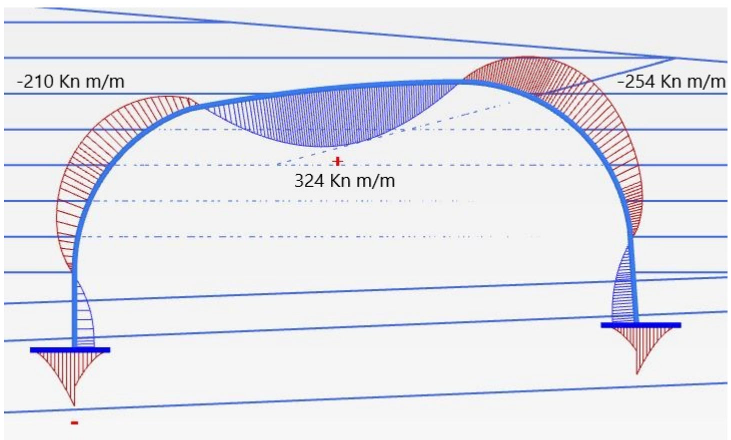


Figure B.6: Output Bending moment profile

Appendix C

Structural design report from old tunnel

Cross-sections

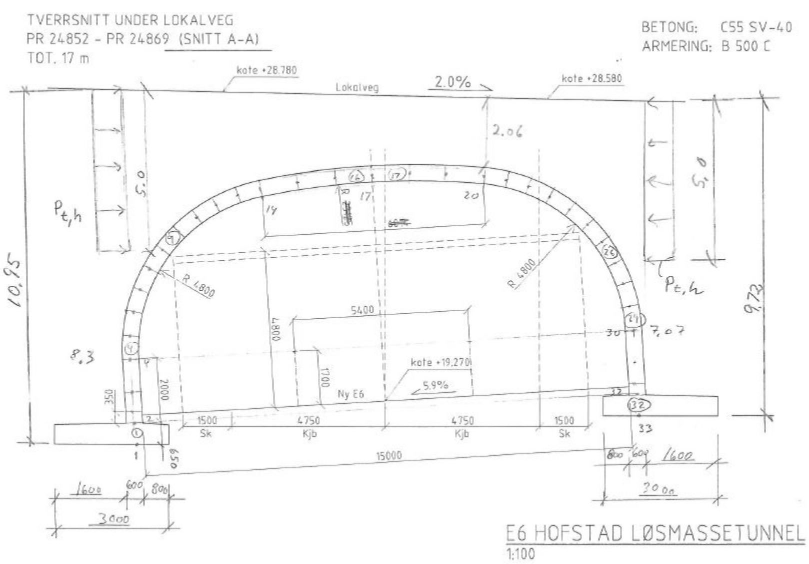


Figure C.1: Cross section A-A

i

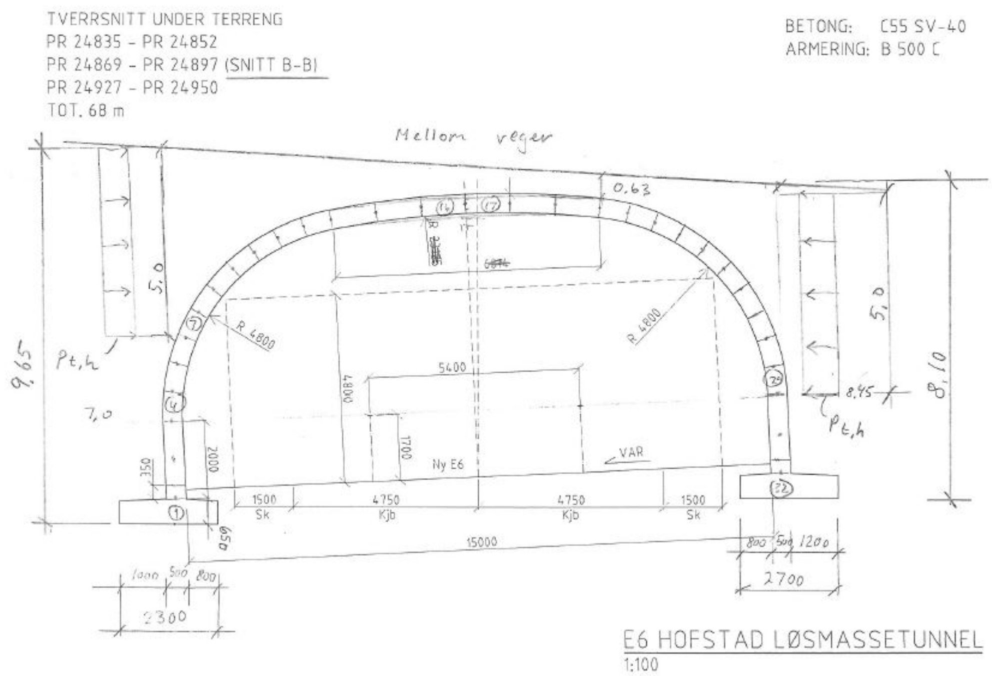


Figure C.2: Cross section B-B

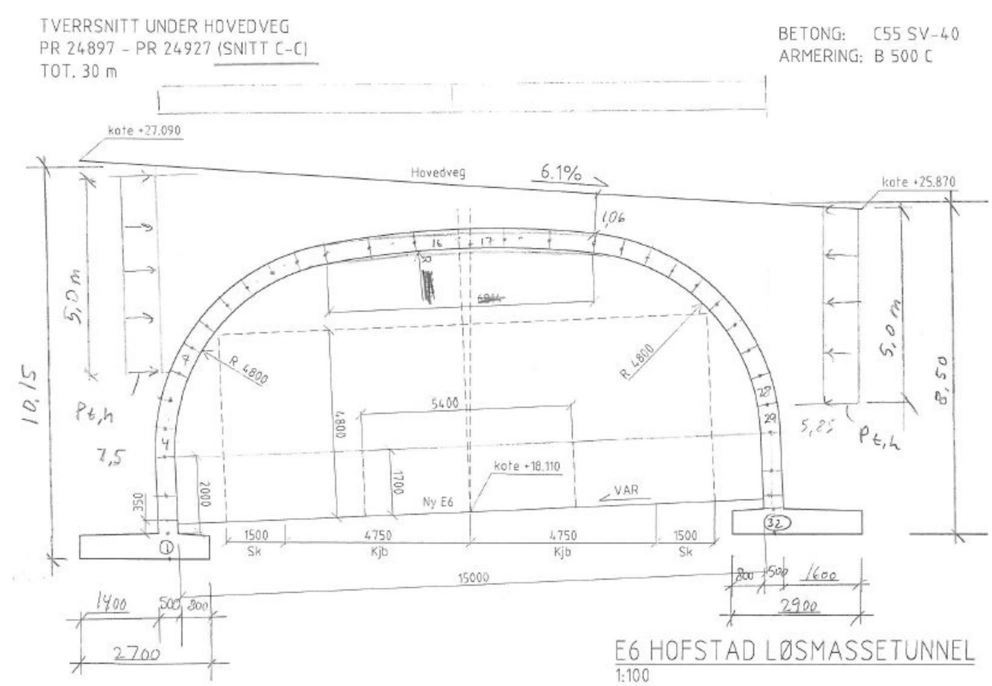


Figure C.3: Cross section C-C

Force calculation from soil

3, 6

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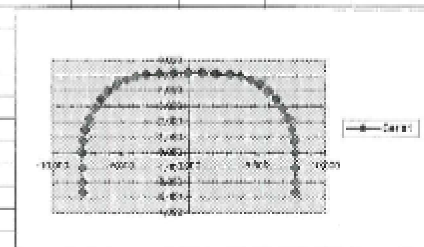
HOFSTAD LØSMASSETUNNEL

R1 =	4,800	α1 =	86,759	R2 =	41,300	α2 =	4,2421				
t =	0,600	ro =	19,0	Ho =	8,30	Helning	-0,079	Kvenstre =	0,4	Khoyre =	0,4
node	grad	X	Z	H	Pv	Ph					
1	0,000	-7,800	-2,650	10,95	208,1	83,2					
2	0,000	-7,800	-2,000	10,30	195,7	78,3					
3	0,000	-7,800	-1,000	9,30	176,7	70,7					
4	0,000	-7,800	0,000	8,30	157,7	63,1					
5	8,576	-7,743	0,761	7,49	142,3	56,9					
6	17,152	-7,573	1,504	6,69	127,1	50,8					
7	25,728	-7,294	2,214	5,92	112,4	45,0					
8	34,303	-6,913	2,874	5,19	98,5	39,4					
9	42,879	-6,437	3,470	4,52	85,8	34,3					
10	51,455	-5,878	3,989	3,92	74,6	29,8					
11	60,031	-5,248	4,416	3,42	65,0	26,0					
12	68,607	-4,550	4,749	3,02	57,3	22,9					
13	77,183	-3,831	4,973	2,72	51,7	20,7					
14	85,759	-3,077	5,086	2,54	48,3	19,3					
15	87,173	-2,052	5,149	2,40	45,5	18,2					
16	88,587	-1,026	5,187	2,28	43,3	17,3					
17	90,001	0,001	5,200	2,18	41,5	0,0					
18	88,587	1,026	5,187	2,12	40,2	-16,1					
19	87,173	2,052	5,149	2,07	39,4	-15,8					
20	85,759	3,077	5,086	2,06	39,1	-15,6					
21	77,183	3,831	4,973	2,12	40,2	-16,1					
22	68,607	4,550	4,749	2,30	43,6	-17,4					
23	60,031	5,248	4,416	2,59	49,2	-19,7					
24	51,455	5,878	3,989	3,00	56,9	-22,8					
25	42,879	6,437	3,470	3,50	66,5	-26,6					
26	34,303	6,913	2,874	4,09	77,8	-31,1					
27	25,728	7,294	2,214	4,76	90,5	-36,2					
28	17,152	7,573	1,504	5,40	104,4	-41,7					
29	8,576	7,743	0,761	6,27	119,1	-47,6					
30	0,000	7,800	0,000	7,07	134,3	-53,7					
31	0,000	7,800	-1,000	8,07	153,3	-61,3					
32	0,000	7,800	-2,000	9,07	172,3	-68,9					
33	0,000	7,800	-2,650	9,72	184,6	-73,9					



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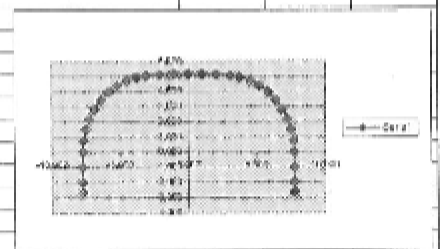
Tykkelse 600 mm (A)

Figure C.4: Cross section A-A

INSTANES AS
HOFSTAD LØSMASSETUNNEL

R1 =	4,800	α1 =	85,759	R2 =	41,300	α2 =	4,2421				
t =	0,500	ro =	19,0	Ho =	7,00	Helning	-0,1	Kvenstre =	0,4	Khoyre =	0,4

node	grad	X	Z	H	Pv	Ph
1	0,000	-7,750	-2,650	9,65	183,4	73,3
2	0,000	-7,750	-2,000	9,00	171,0	68,4
3	0,000	-7,750	-1,000	8,00	152,0	60,8
4	0,000	-7,750	0,000	7,00	133,0	53,2
5	8,576	-7,694	0,753	6,20	117,9	47,2
6	17,152	-7,525	1,489	5,41	102,9	41,2
7	25,728	-7,249	2,192	4,65	88,3	35,3
8	34,303	-6,872	2,846	3,93	74,6	29,8
9	42,879	-6,401	3,436	3,26	61,9	24,8
10	51,455	-5,847	3,950	2,66	50,6	20,2
11	60,031	-5,223	4,375	2,16	41,0	16,4
12	68,607	-4,542	4,702	1,74	33,1	13,3
13	77,183	-3,820	4,924	1,44	27,3	10,9
14	85,759	-3,073	5,036	1,25	23,7	9,5
15	87,173	-2,050	5,099	1,08	20,5	8,2
16	88,587	-1,025	5,137	0,94	17,9	7,1
17	90,001	0,001	5,150	0,82	15,7	0,0
18	88,587	1,026	5,137	0,74	14,0	-5,6
19	87,173	2,050	5,099	0,67	12,7	-5,1
20	85,759	3,073	5,036	0,63	12,0	-4,8
21	77,183	3,820	4,924	0,68	12,8	-5,1
22	68,607	4,542	4,702	0,84	15,9	-6,4
23	60,031	5,223	4,375	1,11	21,1	-8,4
24	51,455	5,847	3,950	1,50	28,4	-11,4
25	42,879	6,401	3,436	1,98	37,6	-15,0
26	34,303	6,872	2,846	2,55	48,5	-19,4
27	25,728	7,249	2,192	3,20	60,8	-24,3
28	17,152	7,525	1,489	3,91	74,3	-29,7
29	8,576	7,694	0,753	4,67	88,8	-35,5
30	0,000	7,750	0,000	5,45	103,6	-41,4
31	0,000	7,750	-1,000	6,45	122,6	-49,0
32	0,000	7,750	-2,000	7,45	141,6	-56,6
33	0,000	7,750	-2,650	8,10	153,9	-61,6



3,7

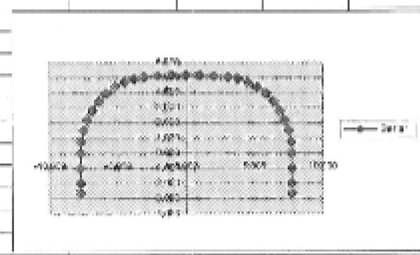
portalkoor.xls

Tykkelse 500 mm (B)

Figure C.5: Cross section B-B

INSTANES AS
HOFSTAD LØSMASSETUNNEL

R1 =	4,800	α1 =	85,759	R2 =	41,300	α2 =	4,2421			
t =	0,500	γo =	19,0	Ho =	7,50	Helning	-0,1065	Kvenstre =	0,4	Khoyre =	0,4
node	grad	X	Z	H	Pv	Ph				
1	0,000	-7,750	-2,650	10,15	192,9	77,1				
2	0,000	-7,750	-2,000	9,50	180,5	72,2				
3	0,000	-7,750	-1,000	8,50	161,5	64,6				
4	0,000	-7,750	0,000	7,50	142,5	57,0				
5	8,576	-7,694	0,753	6,70	127,4	50,9				
6	17,152	-7,525	1,489	5,91	112,3	44,9				
7	25,728	-7,249	2,192	5,15	97,8	39,1				
8	34,303	-6,872	2,846	4,42	84,0	33,6				
9	42,879	-6,401	3,436	3,75	71,2	28,5				
10	51,455	-5,847	3,950	3,15	59,9	24,0				
11	60,031	-5,223	4,375	2,64	50,1	20,1				
12	68,607	-4,542	4,702	2,22	42,2	18,9				
13	77,183	-3,820	4,924	1,91	36,4	14,5				
14	85,759	-3,073	5,036	1,72	32,6	13,0				
15	87,173	-2,050	5,099	1,54	29,3	11,7				
16	88,567	-1,025	5,137	1,40	26,5	10,6				
17	90,001	0,001	5,150	1,27	24,2	0,0				
18	88,567	1,025	5,137	1,18	22,4	-9,0				
19	87,173	2,050	5,099	1,11	21,0	-8,4				
20	85,759	3,073	5,036	1,06	20,2	-8,1				
21	77,183	3,820	4,924	1,10	20,9	-8,4				
22	68,607	4,542	4,702	1,26	23,9	-9,5				
23	60,031	5,223	4,375	1,53	29,0	-11,6				
24	51,455	5,847	3,950	1,91	36,2	-14,5				
25	42,879	6,401	3,436	2,39	45,3	-18,1				
26	34,303	6,872	2,846	2,96	56,2	-22,5				
27	25,728	7,249	2,192	3,60	68,4	-27,4				
28	17,152	7,525	1,489	4,31	81,9	-32,8				
29	8,576	7,694	0,753	5,06	96,2	-38,5				
30	0,000	7,750	0,000	5,85	111,1	-44,5				
31	0,000	7,750	-1,000	6,85	130,1	-52,1				
32	0,000	7,750	-2,000	7,85	149,1	-59,7				
33	0,000	7,750	-2,650	8,50	161,5	-64,6				



portalkoor.xls

Tykkelse 500 mm (C) 3,8

Figure C.6: Cross section C-C

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