HT CONSTRUCTION
NUIS L81818018A
PROJEKTIM LIÇ N.6886/1
SUPERVIZION-KOLAUDIME LIÇ. MK. 3289

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EU4CULTURE

TECHNICAL ASSESSMENT REPORT AND INTERVENTIONS "PARTIAL NORTHERN WALL OF LEZHA CASTLE"

HT Construction (High Tech Construction)"shpk
Nr. Liç. N.6886/3
Ing. Hydajet TOTA
Ing. Lavdie BIRBO

Tetor 2022

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1. INTRODUCTION.

The structure that we will evaluate and for which we will design a suitable structural intervention is composed of: Massive retaining wall with stones of different construction periods, without mortar.
From the various reports received from the architecture, geology and from the field visit, we notice that the wall has serious damages which may cause the loss of its stability.
In this report, we will examine the current state of the wall and the need for intervention for this structure, referring to the Eurocode guidelines, the technical design conditions (K.T.P) as well as the government decision no. 1099 dated 20.12.2020.
For the approval of treatment methods, technical standards, criteria and intervention models in the field of preservation of cultural assets, we will refer to the UNOPS Design Manual.

2. DESIGN STANDARDS AND CODES.

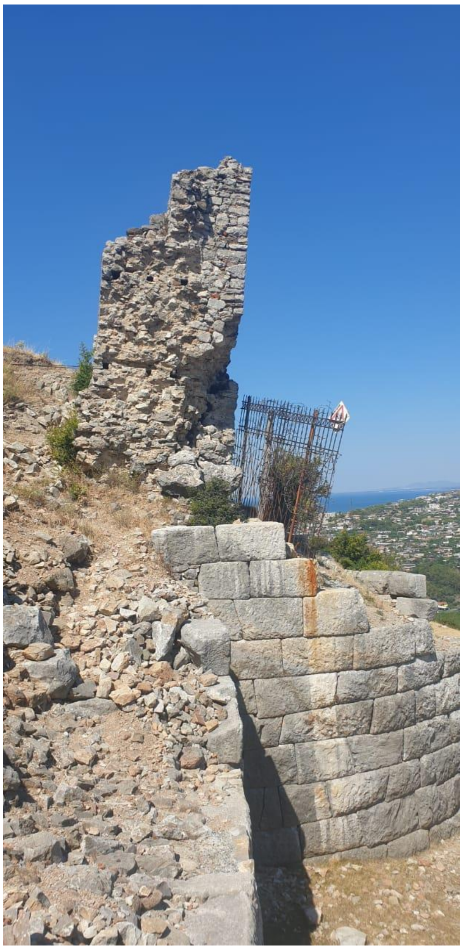
2.1. DESIGN CODES

Eurocode 0 - Basis of Structural design.
Eurocode 1 – Actions on structures.
Eurocode 2 – Design of Concrete Structures.
Eurocode 3- Design of Steel Structures.
Eurocode 4- Design of composite steel and concrete structures.
Eurocode 6 – Design of masonry structures.
Eurocode 7 - Geotechnical Design.
Eurocode 8 – Design of structures for earthquake resistance.
K.T.P- (Albanian Technical design conditions).

2.2. REFERENCES

Geology study. The studio **"GJON LEKA"** with author **GJON LEKA.** Received from **ATELIER 4** studio.
Seismic study. The studio **"GEO-ENG sh.p.k"** with author **LLAMBRO DUNI.** Received from **ATELIER 4** studio.
Topography Received from **ATELIER 4** studio.
Braja M Das "Principles of Geotechnical Engineering"
Design Planning Manual for Buildings (UNOPS).
VKM No.. 1099, datë 24.12.2020
For their approval, technical norms, criteria and models of care in the field of cultural property protection.

3. ASSESSEMENT OF THE EXISTING CONDITION OF THE WALL.



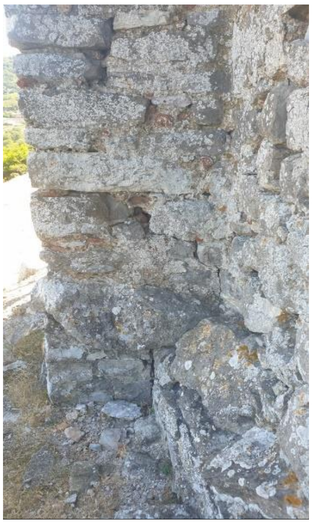
From the careful observations in the field, it is noticed that the wall has problems related to its stability since the wall has acquired a slope which causes it to be eccentric in the action of the normal force, a reason which can cause it to collapse and be destroyed.

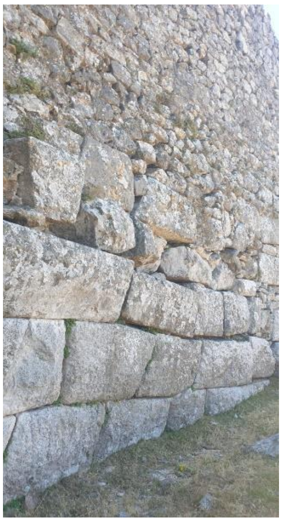
Also, a problem that is easily noticed is the crack in the wall at its end or even along the perimeter of the wall, which causes a loss of its bearing capacity.

These problems require immediate intervention, but below we will provide a more detailed study.

Possible reasons for the failure of the structure :

1. We are dealing with an old wall which dates back to the 4th century, with frequent interventions. The wall is exposed to atmospheric agents, causing a decrease in the bearing capacity of the wall itself. Its composition is wall built with different sections in different periods..





2. From the field visit, it is noticed that the wall being studied is part of a continuous wall, which has been destroyed in different parts of it. This has led to the loss of its structural connection. In our opinion, this is one of the main reasons why this wall is heading towards destruction.

Below with photos we present a part of the destroyed wall and the damaged wall, with two topologies. These are arguments that it was the same wall as the one missing in the photo below.

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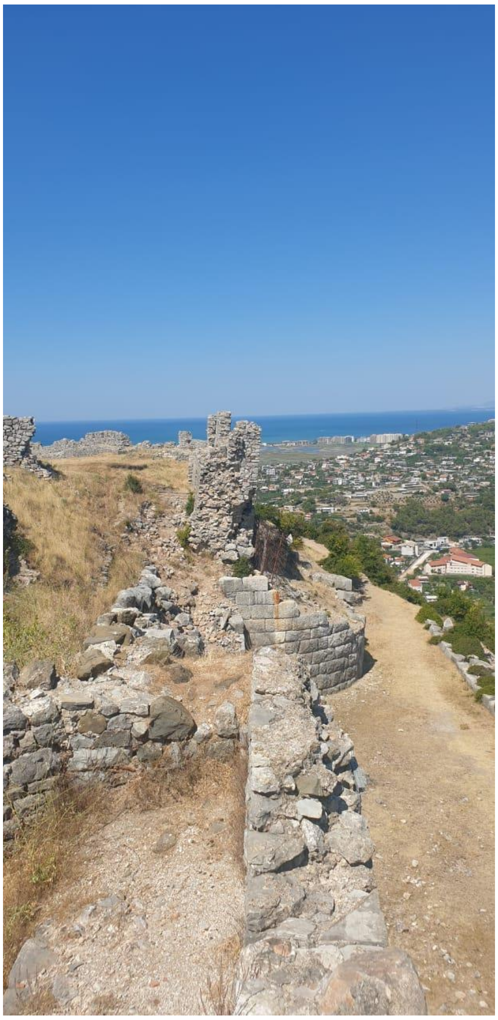
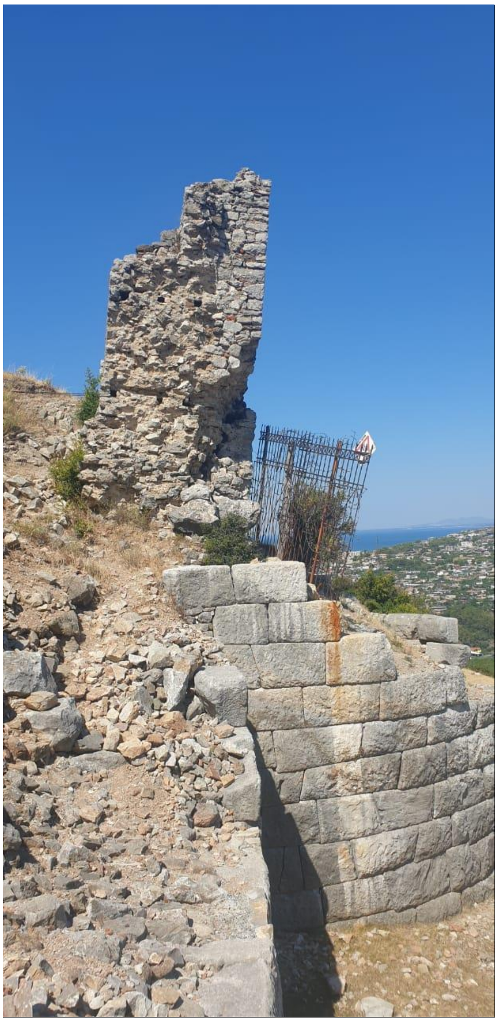
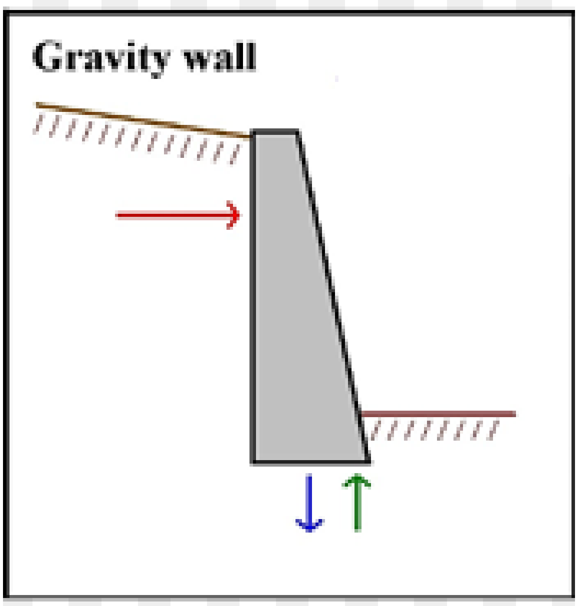




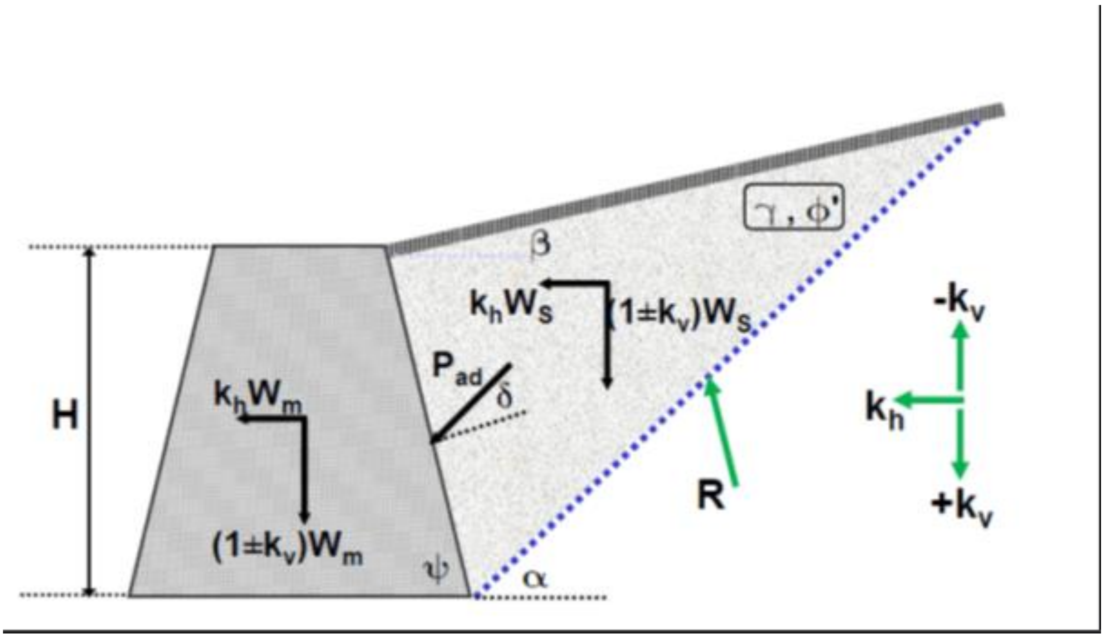
3. The increase of the soil level behind the wall over time, due to the movement of soils as a result of atmospheric agents, and not only. Since the wall in this area was the end part, it also served as a place for depositing soil. The increase in earth pressure on the wall has exceeded the bearing capacity of the wall, leading to its damage.

The schematic below shows the soil pressure before it fails..



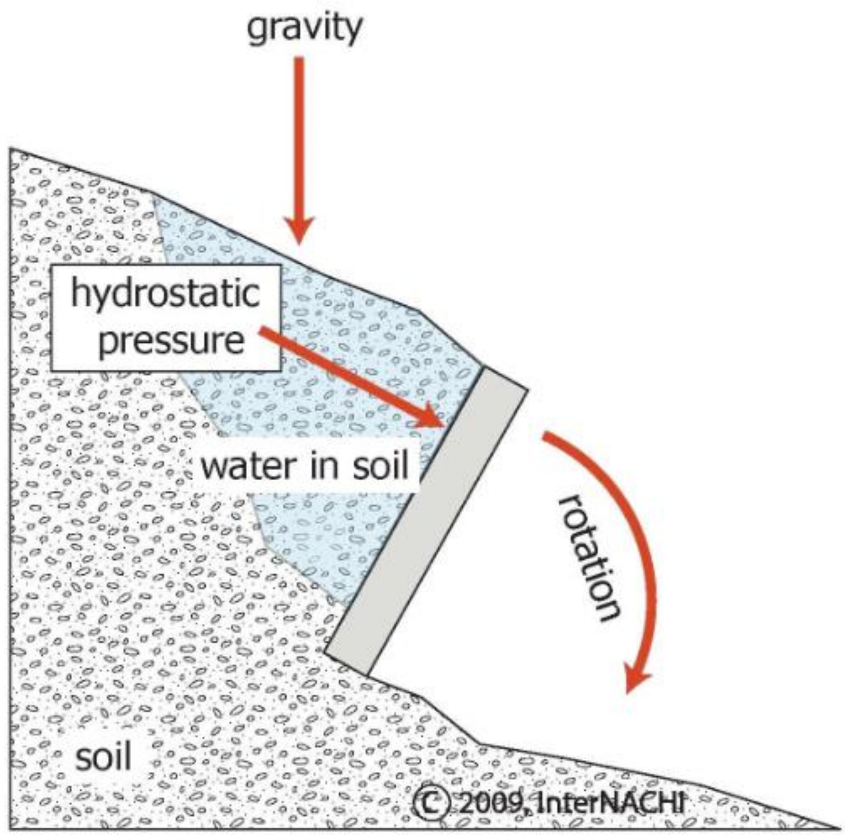
4. Additional action in seismic situation.

According to Eurocode 8.5 chapter 7 "Earth Retaining Structures", in case of a seismic situation, we have an increase in soil pressure due to the seismic situation. Below is a schematic presentation of the pressure in the seismic situation:

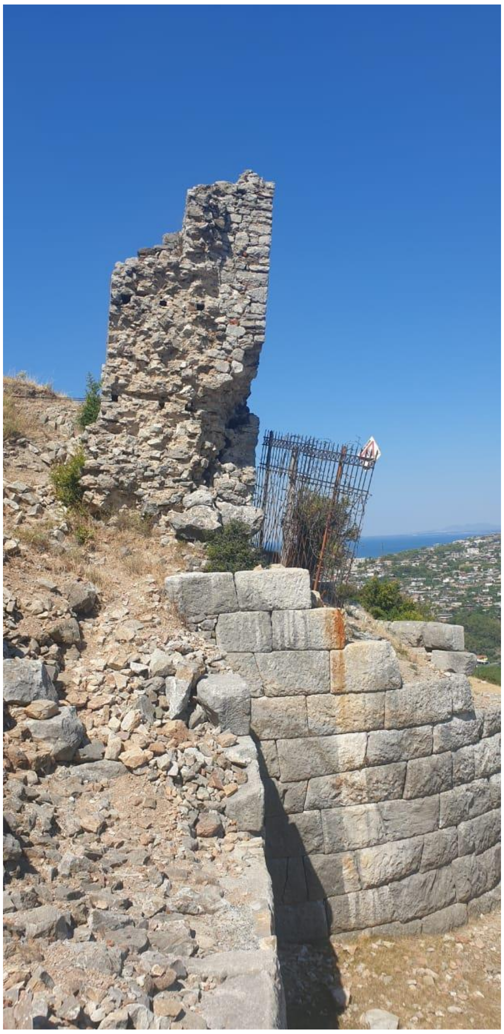


5. Non-drainage or malfunction of the existing drainage behind the retaining wall has resulted in increased pressure from the ground in the presence of water.

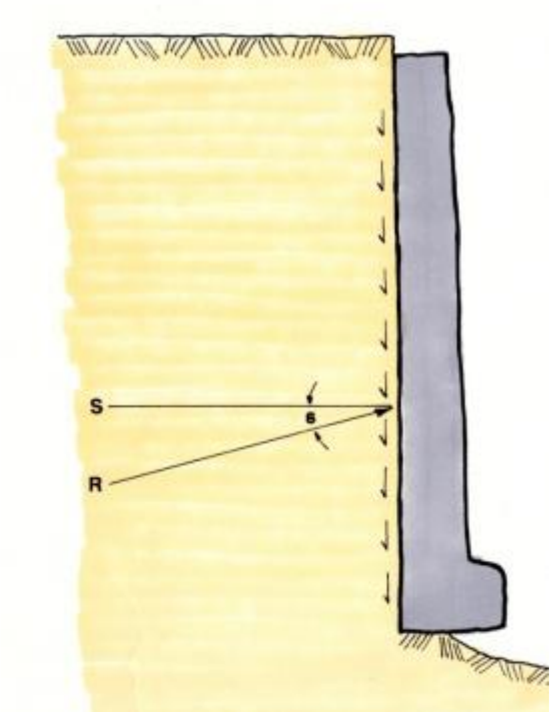
Below is a schematic of the pressure that may have resulted from the malfunction of the wall drain.



6. Loss of the bearing capacity at the base of the foundation, regardless of the fact that the exposed area may not be the true base of the retaining wall, there is a loss of the bearing capacity of this area, this is also reflected in local damage to the retaining wall near the foundation, something that has put the entire retaining wall in more difficult conditions and may be the main reason for the advancement of the further movement of this part of the wall.



In a schematic way in photo below, we are presenting the loss of stability of the base of the foundation:



4. INPUT DATA TO THE PROGRAM.

4.1. STRUCTURAL DESCRIPTION.

In order to have a more correct assessment of the existing structure, the structure will be classified as Retaining Wall built with stone without mortar - Gravitational Retaining Wall. EN 1998-5:2004 and Braja M. Das.

4.2. IDENTIFICATION OF FOUNDATION TYPE.

In terms of the construction time of this wall and the survey of the site, it should be said that the foundation is part of the wall with the same materials (stone without mortar).

4.3. DATA ON THE GEOLOGICAL-ENGINEERING CONDITIONS OF THE SOIL.

For the geological-engineering data of the soil on which the partial wall of the castle is built, we will refer ourselves on the geological-engineering study, carried out by the studio "GJON LEKA" authored by GJON LEKA.
The study was received by ATELIER 4 studio.
From this report we see that we are dealing with two main layers of soil.
Below are two photos, which are with the data of the layers obtained from the geological-engineering report carried out.

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22644-001_ALB_EU4C_RFP_01 - “Provision of Consultancy for Design services for EU4CULTURE Project - Support for revitalization of cultural heritage sites and monuments affected by Earthquake in Albania.”
22644-001_ALB_EU4C_RFP_01 - “Sigurimi i Konsulencës për Shërbimet e Projektimit për Projektin EU4CULTURE - Mbështetje për rijetëzimin e siteve dhe monumenteve të trashëgimisë kulturore të prekura nga Tërmeti në Shqipëri.”

Shtresa Nr. 1

Perben pjesen mbulesore te sheshit qe ne pjesen qe kemi ne studim ka trashesi deri nje meter. Jane suargjila me ngjyre kafe ne te kuqerremte me permbajtje guriçkash qe arrijne deri ne masen 30- 40 %, me pak lageshti, plastike mesatarisht te ngjeshura. Trashesia e kesaj shtrese eshte deri nje meter. Per kete shtrese po japim keto veti fiziko – mekanike si me poshte:

Perberja granulometrike	
Fraksioni zhavorror (>4.75 mm)	16.6%
Fraksioni rere (0.75 – 4.75mm)	30.4%
Fraksioni pluhur + argjil(<0.75mm)	53.0%

Lageshtia natyrale Wn= 23.8%
Kufiri i siperm i plasticitetit WL= 32.9%
Kufiri i poshtem Wp= 22.1%
Nr plasticitetit F = 10.8
Pesha specifike Δ = 2.69gr/cm3
Pesha volumore natyraleγ = 1.95 -2.06 gr/cm3
Poroziteti n = 42 %
Treguesi i porozitetit e = 0.545
Moduli i deformacionit E1-3 = 150kg/cm2
Kendi i ferkimit te brendshem φ = 20°
Kohezioni c = 0.25 kg/cm2
Ngarkesa e lejuar σ = 2.50 kg/cm2

PHOTO 1

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Shtresa Nr. 2

Jane shkembinj gelqeror te kretakut te siperm, kompakte, shtrese trashe, pak te perajruar ne siperfaqe. Ne kete shtrese jane mbeshtetur themelet e murit te kalase.
Ne materialin grafik bashkangjitur studimit, eshte paraqitur ne prerjen gjeologo litologjike 1-1 perkatesisht si shtresa nr 2.
Parametrat fiziko mekanike te shtreses gelqerore jane si me poshte:

Pesha specifike 2.70 g/cm3
Pesha vëllimore natyrale................2 63-2.65 g/cm3
Rezistence në shtypje njëboshtore...650-850 kg/cm2
Kohezioni......................................30-40 kg/cm2
Koeficienti i fortësisë V -VI
Kategoria e gërmimit VIII
Ngarkesa e lejuar Φ= 10 kg cm2

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PHOTO 2

4.4. DATA ON THE ENGINEERING-SEISMOLOGICAL CONDITIONS OF THE SOIL.

For the engineering-seismological data of the soil, we will refer to the study conducted by the studio "GEO-ENG sh.p.k" authored by LLAMBRO DUNI. The study was received by ATELIER 4 studio.

From the report of the engineering-seismological study carried out for the assessment of the seismic risk for the partial wall, we receive as final results:

The ground is classified as TYPE B,
The maximum acceleration at the base of this building square is accepted as PGA=0.264g,
The coefficient of the importance of the structure is accepted as γI=1, since the emergency stabilization of the part of the northern wall of the Lezha Castle was considered according to the requirements of the reference.

Below is a photo showing the above values in the conclusions of the engineering-seismological study.

4. PËRFUNDIME DHE REKOMANDIME

1.Trualli në sheshin e zhvillimit të projektit të nje pjese të murit verior te Kalase se Lezhes në kuadër të projektit "Sigurimi i konsulences per sherbimet e projektimit per Projektin EU4CULTURE Mbeshtetje per rivitalizimin te vendeve te trashegimise kulturore dhe monumenteve te prekura nga termeti ne Shqiperi", klasifikohet i **Tipit B** sipas Eurokodit 8 me V_{S30} = 540.3 m/sek.

2. Nxitimi maksimal për "kushtin e mos-shëmbjes" në bazamentin e këtij sheshi ndërtimi është vlerësuar nëpërmjet metodës probabilitare PGA=0.264g. Këtij parametri i korrespondon një periudhë përsëritje 475 vjet (90% mostejkalim në 50 vjet). Për nivelin 90 mostejkalin në 10 vjet (periudhë përsëritje 95 vjet) kemi vlerën PGA=0.125g. Si bazë për këtë vlerësim është pranuar rekomandimi i IGJEUM-it për vlerësimet probabilitare të rrezikut sizmik në territorin e Shqipërisë (IGJEUM, 2021).

3. Duke patur parasysh sizmicitetin përreth zonës së Bashkisë Tiranë, me tërmete me magnitudë më të madhe se 5.5, llogaritjet e spektrave horizontalë dhe vertikalë sipas Eurokodit 8 janë kryer duke patur parasysh Tipin 1 të spektrit sipas EC8.

4. **Rekomandojmë që të përdoret standardi i Eurokodit 8 për projektin e nje pjese të murit verior te Kalase se Lezhes në kuadër të projektit "Sigurimi i konsulences per sherbimet e projektimit per Projektin EU4CULTURE Mbeshtetje per rivitalizimin te vendeve te trashegimise kulturore dhe monumenteve te prekura nga termeti ne Shqiperi", duke marrë në konsideratë të dy nivelet e veprimit sizmik për kërkesën e "mos-shëmbjes" dhe për kërkesën e "dëmtimeve të kufizuara". Konkretisht**:

- Për kushtin e "mos-shëmbjes" për spektrin elastik horizontal të projektimit të merret në konsideratë Faktori i Rëndësisë sipas EC8 të barabartë me yI =1.2 (Ndërtesa, rezistenca sizmike e të cilave është me rëndësi në raport me shëmbjen e tyre, si, shkolla, salla mbledhjesh, institucione kulturore, etj.) Në këto kushte PGA referuese agR në truall të tipit A rezulton: agR=0.264g (Tabela 1, PGA per periudhe perseritje 475 vjet), kurse nxitimi projektues në truall të Tipit A: ag=0.264g*1.2=0.317g.
- Duke marrë në konsideratë Faktorin e Truallit për Tipin B, S=1.2, Nxitimi Projektues për kushtin e "mos-shëmbjes" për punimet që do të kryhen rezulton: ag*S=0.317*1.2=0.380g. Vlera e nxitimit 0.380g duhet përdorur për llogaritjet strukturore për këtë kusht. Parametrat e tjerë janë si vijon: T_B=0.15 sek; T_C= 0.50 sek; T_D=2.0 sek (Figura 4).
- Dëshirojmë të vemë në dukje se vlera e mësipërme 0.380g e nxitimit e rekomanduar për projektimin e strukturës për kushtin e "mos-shëmbjes" është produkt i nxitimit në truall të tipit A (ag=0.317g) me faktorin e Truallit (S=1.2). Nëqoftëse programi llogaritës me të cilin konstruktori dimensionon strukturën, kërkon që faktori i truallit S të llogaritet (të përfshihet në program) veças, atëherë duhen futur në program parametrat: ag=0.317g dhe S=1.2.
- Për kushtin e "dëmtimeve të kufizuara" për spektrin elastik horizontal të projektimit të

PHOTO 1

Seismic action for retaining walls shall be taken in accordance with EN 1998-5:2004, Chapter 7
Referring to EN 1998-5:2004, 7.3.2.2, point 4:
the seismic action will be given through the coefficients kh and kv, necessary coefficients in the calculation program described below.
Seismic coefficients kh and kv which affect all masses at the moment of seismic actions are estimated to be obtained as in the photo below:

7.3.2.2 Seismic action

(1)P For the purpose of the pseudo-static analysis, the seismic action shall be represented by a set of horizontal and vertical static forces equal to the product of the gravity forces and a seismic coefficient.

(2)P The vertical seismic action shall be considered as acting upward or downward so as to produce the most unfavourable effect.

(3) The intensity of such equivalent seismic forces depends, for a given seismic zone, on the amount of permanent displacement which is both acceptable and actually permitted by the adopted structural solution.

(4)P In the absence of specific studies, the horizontal (k_h) and vertical (k_v) seismic coefficients affecting all the masses shall be taken as:

$$k_h = \alpha \frac{S}{r} \quad (7.1)$$

$$k_v = \pm 0{,}5 k_h \quad \text{if } a_{vg}/a_g \text{ is larger than } 0{,}6 \quad (7.2)$$

$$k_v = \pm 0{,}33 k_h \quad \text{otherwise} \quad (7.3)$$

where the factor r takes the values listed in Table 7.1 depending on the type of retaining structure. For walls not higher than 10 m, the seismic coefficient shall be taken as being constant along the height.

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EN 1998-5:2004 (E)

Table 7.1 — Values of factor *r* for the calculation of the horizontal seismic coefficient

Type of retaining structure	r
Free gravity walls that can accept a displacement up to $d_r = 300\ \alpha \cdot S$ (mm)	2
Free gravity walls that can accept a displacement up to $d_r = 200\ \alpha \cdot S$ (mm)	1,5
Flexural reinforced concrete walls, anchored or braced walls, reinforced concrete walls founded on vertical piles, restrained basement walls and bridge abutments	1

PHOTO NGA EN 1998-5:2004

From the above admissions we have:
agR=0.264g
S= 1.2 (Ground TYPE B)
r=2 (From table 7.1 in EN 1998-5:2004 7.3.2.2, we judged it right to accept this value)
yi=1 (Coefficient of importance of the structure in accordance with the terms of reference)

Referring to the following formula found in EN 1998-5:2004 7.3.2.2 clause 4, (7.1)

kh=a*yI *(S/r)
kh= 0.264*1* (1.2/2)
kh= 0.1584, which was accepted with a value of kh=0.16

Referring to the following formula found in EN 1998-5:2004 7.3.2.2 clause 4, (7.2)

kv= ±0.5*kh
kv=0.5*0.16
kv=0.08 is accepted

5. WALL MODELING IN THE CALCULATION PROGRAM.

The GeoStructural Analysis computer program was used to model this wall.
The wall in the program is modeled straight in verticality. The reason why it is modeled this way is because the program does not accept the wall with a negative slope.
In order to get as close as possible to the modeling of the real state, based on the drawings from the architecture given by the actual survey of this wall (dimensions and quotas of the wall) we found the center of gravity of the wall in the real sloping state and the center of the gravity of the wall modeled by us. We notice that these two centers of gravity have a distance of 61 cm from each other.
In the calculation program, we have modeled the wall with its own weight of 0 kN, but we have set the real weight of the wall as a force acting with an eccentricity of 61 cm from the center of gravity of the modeled wall.
We emphasize once again that the equivalence of the wall in this form is the same as its modeling in its real state.

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The calculations below will consist of:

1. Calculation of the wall before structural intervention.
2. Calculation of the wall after structural intervention.

In both of the above cases, the calculations were made according to two combinations, which are permanent design action and the seismic design action.

6. COMPUTER CALCULATIONS.

6.1. CALCULATION OF THE WALL BEFORE STRUCTURAL INTERVENTION.

In the first case of calculations we have the BASIC COMBINATION.
We see that in this case the wall presents ACCEPTABLE results for:
1. The bearing capacity of the wall in overturning.
2. Bearing capacity of the wall for slip.
3. Its cross-sectional dimensions.

The wall presents UNACCEPTABLE results for:
1. The eccentricity of the action of the normal force.
2. The bearing capacity of the foundation soil.

It is worth noting that the **unacceptable** results obtained are a consequence of the large slope that the wall has taken. This causes a large eccentricity of the action of the normal force **(outside the allowed values).** It is this reason that makes the general bearing capacity of the foundation soil smalle **(outside the allowed values)** and unacceptable.
We also see from the results that **the wall is at its critical equilibrium point**, since even a small force acting on the wall can cause the wall to lose stability and collapse.

In the second case of calculations we have SEISMIC COMBINATION.
We see that in this case the wall presents UNACCEPTABLE results for:
1. The bearing capacity of the wall in overturning.
2. Bearing capacity of the wall for slip.
3. The bearing capacity of the foundation soil.
4. The eccentricity of the action of the normal force.

The wall presents ACCEPTABLE results for:
1. Its cross-sectional dimensions.

From the above results we see that in the case of the seismic combination, **the wall goes into total destruction collapse.**

We note that the slope stability is acceptable and gives SATISFACTORY results for the case of the seismic combination.

Below are the results obtained from the calculation program for the calculation of the wall before structural intervention.

Cantilever wall analysis

Input data

Project

Date : 10/28/2022

Settings

EN STANDART (2)

Materials and standards

Concrete structures : EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 : standard

Wall analysis

Active earth pressure calculation : Coulomb
Passive earth pressure calculation : Mazindrani (Rankin)
Earthquake analysis : Mononobe-Okabe
Shape of earth wedge : Calculate as skew
Base key : The base key is considered as inclined footing bottom
Allowable eccentricity : 0.333
Verification methodology : according to EN 1997
Design approach : 3 - reduction of actions (GEO, STR) and soil parameters

Partial factors on actions (A)
Permanent design situation

		State STR				State GEO			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]
Variable actions :	γ_Q =	1.50	[–]	0.00	[–]	1.30	[–]	0.00	[–]
Water load :	γ_w =					1.00	[–]		

Partial factors for soil parameters (M)
Permanent design situation

Partial factor on internal friction :	γ_ϕ =	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.40	[–]
Partial factor on Poisson's ratio :	γ_v =	1.00	[–]

Partial factors for variable actions			
Permanent design situation			
Factor for combination value :	ψ_0 =	0.70	[–]
Factor for frequent value :	ψ_1 =	0.50	[–]
Factor for quasi-permanent value :	ψ_2 =	0.30	[–]

Partial factors on actions (A)									
Seismic design situation									
		State STR				State GEO			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.00	[–]	1.00	[–]	1.00	[–]	1.00	[–]
Variable actions :	γ_Q =	1.00	[–]	0.00	[–]	1.00	[–]	0.00	[–]
Water load :	γ_w =					1.00	[–]		

Partial factors for soil parameters (M)			
Seismic design situation			
Partial factor on internal friction :	γ_ϕ =	1.00	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]
Partial factor on Poisson's ratio :	γ_v =	1.00	[–]

Material of structure

Unit weight γ = 0.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 12/15
Cylinder compressive strength f_{ck} = 12.00 MPa
Tensile strength f_{ctm} = 1.60 MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500.00 MPa

Geometry of structure

No.	Coordinate X [m]	Depth Z [m]
1	0.00	0.00
2	0.22	4.50
3	0.22	5.00
4	-1.40	5.00
5	-1.40	4.50
6	-1.40	0.00

The origin [0,0] is located at the most upper right point of the wall.
Wall section area = 7.62 m^2.

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m3]	γ_{su} [kN/m3]	δ [°]
1	LAYER 1		20.00	25.00	20.60	16.90	12.00
2	LAYER 2		10.00	300.00	26.50	17.00	5.00

All soils are considered as cohesionless for at rest pressure analysis.

Soil parameters

LAYER 1

Unit weight :	γ = 20.60 kN/m3
Stress-state :	effective
Angle of internal friction :	φ_{ef} = 20.00 °
Cohesion of soil :	c_{ef} = 25.00 kPa
Angle of friction struc.-soil :	δ = 12.00 °
Soil :	cohesionless
Saturated unit weight :	γ_{sat} = 26.90 kN/m3

LAYER 2

Unit weight :	γ = 26.50 kN/m3
Stress-state :	effective
Angle of internal friction :	φ_{ef} = 10.00 °
Cohesion of soil :	c_{ef} = 300.00 kPa
Angle of friction struc.-soil :	δ = 5.00 °
Soil :	cohesionless
Saturated unit weight :	γ_{sat} = 27.00 kN/m3

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	1.50	LAYER 1	
2	-	LAYER 2	

Foundation

Type of foundation : soil from geological profile

Terrain profile

Terrain behind construction has the slope 1: 10.00 (slope angle is 5.71 °).

Water influence

Ground water table is located below the structure.

Input surface surcharges

No.	Surcharge new	change	Action	Mag.1 [kN/m^2]	Mag.2 [kN/m^2]	Ord.x x [m]	Length l [m]	Depth z [m]
1	YES		variable	10.00				on terrain

Resistance on front face of the structure

Resistance on front face of the structure: at rest
Soil on front face of the structure - LAYER 2
Soil thickness in front of structure $h = 0.30$ m
Soil slope in front of structure $\beta = -30.00$ °

Applied forces acting on the structure

No.	Force new	modification	Name	Action	F_x [kN/m]	F_z [kN/m]	M [kNm/m]	x [m]	z [m]
1	YES		Force No. 1	permanent	0.00	200.00	0.00	-1.20	0.80

Settings of the stage of construction

Design situation : permanent
The wall is free to move. Active earth pressure is therefore assumed.

Verification No. 1 (Stage of construction 1)

Pressure at rest on front face of the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m^3]	K_r	Comment
1	0.30	0.00	8.03	240.00	26.50	0.860	

Pressure at rest distribution on front face of the structure

Layer No.	Start [m] End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	0.30	7.95	0.00	1.85	1.85	0.00

Active pressure behind the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m^3]	δ_d [°]	K_a	Comment
1	1.50	2.86	16.23	20.00	20.60	9.74	0.587	
2	3.00	2.86	8.03	240.00	26.50	4.01	0.806	
3	0.50	0.00	8.03	240.00	26.50	4.01	0.791	

Active pressure distribution behind the structure (without surcharge)

Layer No.	Start [m] End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	1.50	30.90	0.00	0.00	0.00	0.00
2	1.50	30.90	0.00	0.00	0.00	0.00
	4.50	110.40	0.00	0.00	0.00	0.00
3	4.50	110.40	0.00	0.00	0.00	0.00
	5.00	123.65	0.00	0.00	0.00	0.00

Pressure profile due to surcharge - Surch.1 - surface

Point No.	Depth [m]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	5.73	1.28
2	1.50	5.73	1.28
3	1.50	8.00	0.97
4	4.50	8.00	0.97
5	4.50	7.89	0.55
6	5.00	7.89	0.55

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-2.43	0.00	0.76	1.000	1.000	1.000
FF resistance	-0.28	-0.10	0.00	0.00	1.000	1.000	1.000
Active pressure	0.00	-5.00	0.00	1.40	1.000	1.000	1.000
Surch.1 - surface	0.00	-5.00	5.10	1.51	0.000	0.000	1.300
Force No. 1	0.00	-4.20	200.00	0.20	1.000	1.000	1.350

Verification of complete wall

Check for overturning stability

Resisting moment M_{res} = 40.00 kNm/m
Overturning moment M_{ovr} = -0.03 kNm/m

Wall for overturning is SATISFACTORY

Check for slip

Resisting horizontal force H_{res} = 124.28 kN/m
Active horizontal force H_{act} = -0.28 kN/m

Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Maximum stress in footing bottom : 597.44 kPa

Bearing capacity of foundation soil (Stage of construction 1)

Design load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]	Eccentricity [–]	Stress [kPa]
1	160.72	276.62	-0.28	0.358	597.44
2	122.47	200.00	-0.28	0.377	499.65

Service load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]
1	118.76	205.31	-0.27
2	122.47	200.00	-0.27

Verification of foundation soil

Eccentricity verification

Max. eccentricity of normal force e = 0.358
Maximum allowable eccentricity e_{alw} = 0.333

Eccentricity of the normal force is NOT SATISFACTORY

Verification of bearing capacity

Max. stress at footing bottom σ = 597.44 kPa
Bearing capacity of foundation soil R_d = 1000.00 kPa

Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is NOT SATISFACTORY

Dimensioning No. 1 (Stage of construction 1)

Pressure at rest behind the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m³]	K_r	Comment
1	1.50	2.86	16.23	20.00	20.60	0.743	
2	3.00	2.86	8.03	240.00	26.50	0.896	

Pressure at rest distribution behind the structure (without surcharge)

Layer No.	Start [m] End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	1.50	30.90	0.00	22.99	22.94	1.54
2	1.50	30.90	0.00	27.70	27.66	1.54
	4.50	110.37	0.00	98.95	98.80	5.51

Pressure profile due to surcharge - Surch.1 - surface

Point No.	Depth [m]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	7.41	0.67
2	1.50	7.41	0.67
3	1.50	8.95	0.56
4	4.50	8.95	0.56

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. moment	Coeff. norm.force	Coeff. shear for.
Weight - wall	0.00	-2.19	0.00	0.76	1.000	1.000	1.000
Pressure at rest	206.81	-1.41	11.73	1.55	1.000	1.000	1.000
Surch.1 - surface	37.96	-2.16	2.68	1.51	1.300	1.300	1.300
Force No. 1	0.00	-3.70	200.00	0.20	1.350	1.350	1.000

Wall stem check

Reinforcement and dimensions of the cross-section

Bar diameter	=	20.0 mm
Number of bars	=	10
Reinforcement cover	=	30.0 mm
Cross-section width	=	1.00 m
Cross-section depth	=	1.62 m

Reinforcement ratio	ρ	=	0.20	%	>	0.13	%	=	ρ_{min}
Position of neutral axis	x	=	0.21	m	<	0.98	m	=	x_{max}
Ultimate shear force	V_{Rd}	=	344.07	kN	>	256.15	kN	=	V_{Ed}
Ultimate moment	M_{Rd}	=	2048.28	kNm	>	551.94	kNm	=	M_{Ed}

Cross-section is SATISFACTORY.

Input data (Stage of construction 2)

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	1.50	LAYER 1	
2	-	LAYER 2	

Foundation

Type of foundation : soil from geological profile

Terrain profile

Terrain behind construction has the slope 1: 11.43 (slope angle is 5.00 °).

Water influence

Ground water table is located below the structure.

Resistance on front face of the structure

Resistance on front face of the structure: at rest
Soil on front face of the structure - LAYER 2
Soil thickness in front of structure $h = 0.10$ m
Soil slope in front of structure $\beta = -30.00$ °

Applied forces acting on the structure

No.	Force new	Force modification	Name	Action	F_x [kN/m]	F_z [kN/m]	M [kNm/m]	x [m]	z [m]
1	NO	NO	Force No. 1	permanent	0.00	200.00	0.00	-1.20	0.80

Earthquake

Factor of horizontal acceleration $K_h = 0.1600$
Factor of vertical acceleration $K_v = 0.0800$

Water below the GWT is restricted.

Settings of the stage of construction

Design situation : seismic
The wall is free to move. Active earth pressure is therefore assumed.

Verification No. 1 (Stage of construction 2)

Pressure at rest on front face of the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m³]	K_r	Comment
1	0.10	0.00	10.00	300.00	26.50	0.826	

Pressure at rest distribution on front face of the structure

Layer No.	Start [m] / End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	0.10	2.65	0.00	0.59	0.59	0.00

Active pressure behind the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m³]	δ_d [°]	K_a	Comment
1	1.50	2.86	20.00	25.00	20.60	12.00	0.500	
2	3.00	2.86	10.00	300.00	26.50	5.00	0.732	

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m^3]	δ_d [°]	K_a	Comment
3	0.50	0.00	10.00	300.00	26.50	5.00	0.715	

Active pressure distribution behind the structure (without surcharge)

Layer No.	Start [m] End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	1.50	30.90	0.00	0.00	0.00	0.00
2	1.50	30.90	0.00	0.00	0.00	0.00
	4.50	110.40	0.00	0.00	0.00	0.00
3	4.50	110.40	0.00	0.00	0.00	0.00
	5.00	123.65	0.00	0.00	0.00	0.00

Earthquake effects (active earth pressure) - partial results

Layer No.	Thickness [m]	φ_d [°]	β [°]	ψ [°]	K_a	K_{ae}	K_{ae}-K_a	Comment
1	1.50	20.00	5.00	9.87	0.500	0.730	0.231	
2	3.00	10.00	5.00(0.13)	9.87	0.679	1.066	0.387	MODIFIED
3	0.50	10.00	5.00(0.13)	9.87	0.664	1.050	0.386	MODIFIED

Earthquake effects (active earth pressure)

Layer No.	Start [m] End [m]	σ_z [kPa]	σ_D [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vertical comp. [kPa]
1	0.00	0.00	113.76	26.24	25.36	6.73
	1.50	28.43	85.33	19.68	19.02	5.05
2	1.50	28.43	85.33	33.04	32.73	4.52
	4.50	101.57	12.19	4.72	4.68	0.65
3	4.50	101.57	12.19	4.71	4.69	0.41
	5.00	113.76	0.00	0.00	0.00	0.00

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-2.43	0.00	0.76	1.000	1.000	1.000
Earthq.- constr.	0.00	-2.43	0.00	0.76	1.000	1.000	1.000
FF resistance	-0.03	-0.03	0.00	0.00	1.000	1.000	1.000
Active pressure	0.00	-5.00	0.00	1.40	1.000	1.000	1.000
Earthq.- act.pressure	90.57	-3.05	16.69	1.48	1.000	1.000	1.000
Force No. 1	0.00	-4.20	200.00	0.20	1.000	1.000	1.000

Verification of complete wall

Check for overturning stability
Resisting moment M_{res} = 64.72 kNm/m
Overturning moment M_{ovr} = 276.33 kNm/m

Wall for overturning is NOT SATISFACTORY

Check for slip
Resisting horizontal force H_{res} = 38.21 kN/m
Active horizontal force H_{act} = 90.54 kN/m

Wall for slip is NOT SATISFACTORY

Overall check - WALL is NOT SATISFACTORY

Maximum stress in footing bottom : 10000.00 kPa
Warning - allowable range of input data exceeded during earthquake analysis!
The analysis is carried out with the modified value of terrain inclination β.

Bearing capacity of foundation soil (Stage of construction 2)

Design load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]	Eccentricity [–]	Stress [kPa]
1	387.67	216.69	90.54	1.101	10000.00

Service load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]
1	387.67	216.69	90.54

Verification of foundation soil

Eccentricity verification
Max. eccentricity of normal force e = 1.101
Maximum allowable eccentricity e_{alw} = 0.333

Eccentricity of the normal force is NOT SATISFACTORY

Verification of bearing capacity
Max. stress at footing bottom σ = 10000.00 kPa
Bearing capacity of foundation soil R_d = 1000.00 kPa

Bearing capacity of foundation soil is NOT SATISFACTORY

Overall verification - bearing capacity of found. soil is NOT SATISFACTORY

Dimensioning No. 1 (Stage of construction 2)

Pressure at rest behind the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m^3]	K_r	Comment
1	1.50	2.86	20.00	25.00	20.60	0.670	
2	3.00	2.86	10.00	300.00	26.50	0.847	

Pressure at rest distribution behind the structure (without surcharge)

Layer No.	Start [m] End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	1.50	30.90	0.00	20.75	20.69	1.54
2	1.50	30.90	0.00	26.18	26.14	1.54
	4.50	110.37	0.00	93.52	93.35	5.51

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. moment	Coeff. norm.force	Coeff. shear for.
Weight - wall	0.00	-2.19	0.00	0.76	1.000	1.000	1.000
Earthq.- constr.	0.00	-2.19	0.00	0.76	1.000	1.000	1.000
Pressure at rest	194.68	-1.40	11.73	1.55	1.000	1.000	1.000
Earthquake - pressure at rest	73.09	-2.25	0.00	1.40	1.000	1.000	1.000
Force No. 1	0.00	-3.70	200.00	0.20	1.000	1.000	1.000

Wall stem check

Reinforcement and dimensions of the cross-section
Bar diameter = 20.0 mm
Number of bars = 10
Reinforcement cover = 30.0 mm
Cross-section width = 1.00 m
Cross-section depth = 1.62 m

Reinforcement ratio ρ = 0.20 % > 0.13 % = ρ_{min}
Position of neutral axis x = 0.21 m < 0.98 m = x_{max}
Ultimate shear force V_{Rd} = 344.07 kN > 267.77 kN = V_{Ed}
Ultimate moment M_{Rd} = 2048.28 kNm > 550.76 kNm = M_{Ed}

Cross-section is SATISFACTORY.

Slope stability analysis

Input data

Project

Settings

EN STANDART (2)

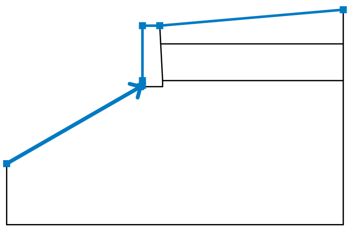
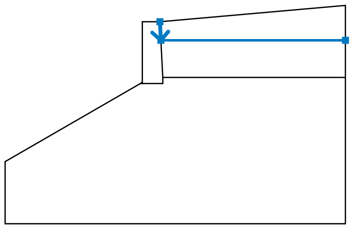
Stability analysis

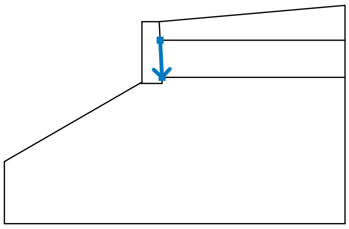
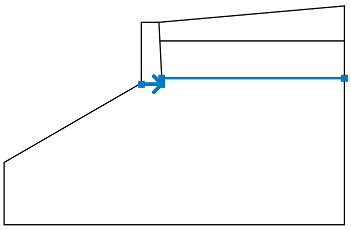
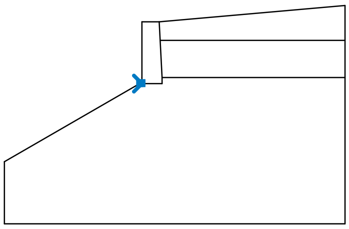
Earthquake analysis : Standard
Verification methodology : according to EN 1997
Design approach : 3 - reduction of actions (GEO, STR) and soil parameters

Partial factors on actions (A)										
Seismic design situation										
		State STR				State GEO				
		Unfavourable		Favourable		Unfavourable		Favourable		
Permanent actions :	γ_G =	1.00	[–]	1.00	[–]	1.00	[–]	1.00	[–]
Variable actions :	γ_Q =	1.00	[–]	0.00	[–]	1.00	[–]	0.00	[–]
Water load :	γ_w =					1.00	[–]		

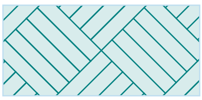
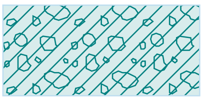
Partial factors for soil parameters (M)			
Seismic design situation			
Partial factor on internal friction :	γ_ϕ =	1.00	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]

Interface

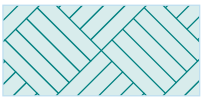
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		-12.50	-11.31	-1.57	-5.00	-1.40	-4.90
		-1.40	-4.50	-1.40	0.00	0.00	0.00
		15.00	1.31				
2		0.00	0.00	0.08	-1.50	15.00	-1.50

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
3		0.08	-1.50	0.23	-4.50		
4		-1.40	-5.00	0.23	-5.00	0.23	-4.50
		15.00	-4.50				
5		-1.57	-5.00	-1.40	-5.00	-1.40	-4.90

Soil parameters - effective stress state

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]
1	LAYER 1		20.00	25.00	20.60
2	LAYER 2		10.00	300.00	26.50

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m^3]	γ_s [kN/m^3]	n [–]
1	LAYER 1		26.90		

No.	Name	Pattern	γ_{sat} [kN/m3]	γ_s [kN/m3]	n [–]
2	LAYER 2		27.00		

Soil parameters

LAYER 1

Unit weight :	γ	=	20.60 kN/m3
Stress-state :	effective		
Angle of internal friction :	φ_{ef}	=	20.00 °
Cohesion of soil :	c_{ef}	=	25.00 kPa
Saturated unit weight :	γ_{sat}	=	26.90 kN/m3

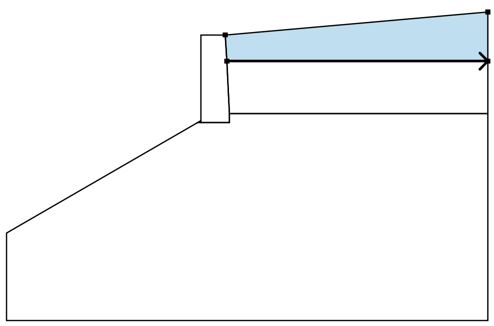
LAYER 2

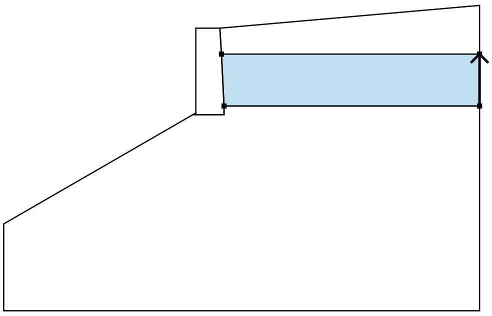
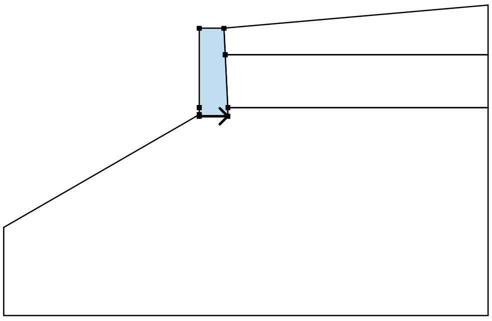
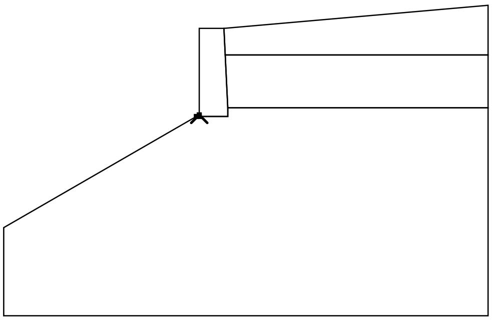
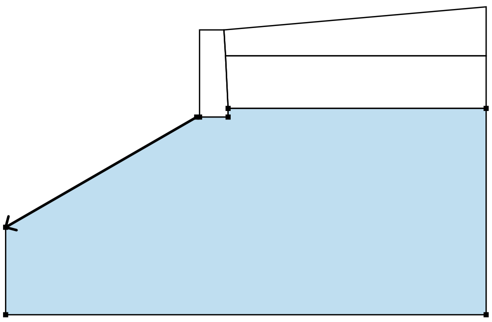
Unit weight :	γ	=	26.50 kN/m3
Stress-state :	effective		
Angle of internal friction :	φ_{ef}	=	10.00 °
Cohesion of soil :	c_{ef}	=	300.00 kPa
Saturated unit weight :	γ_{sat}	=	27.00 kN/m3

Rigid bodies

No.	Name	Sample	γ [kN/m3]
1	Wall material		0.00

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m] x	z	x	z	Assigned soil
1		0.08	-1.50	15.00	-1.50	LAYER 1
		15.00	1.31	0.00	0.00	

No.	Surface position	Coordinates of surface points [m] x	z	x	z	Assigned soil
2		15.00	-4.50	15.00	-1.50	LAYER 2
		0.08	-1.50	0.23	-4.50	
3		-1.40	-5.00	0.23	-5.00	Wall material
		0.23	-4.50	0.08	-1.50	
		0.00	0.00	-1.40	0.00	
		-1.40	-4.50	-1.40	-4.90	
4		-1.40	-5.00	-1.40	-4.90	LAYER 2
		-1.57	-5.00			
5		-1.57	-5.00	-12.50	-11.31	LAYER 2
		-12.50	-16.31	15.00	-16.31	
		15.00	-4.50	0.23	-4.50	
		0.23	-5.00	-1.40	-5.00	

Water

Water type : No water

Tensile crack

Tensile crack not inputted.

Earthquake

Horizontal seismic coefficient : $K_h = 0.16$
Vertical seismic coefficient : $K_v = 0.08$

Settings of the stage of construction

Design situation : seismic

Results (Stage of construction 1)

Analysis 1

Circular slip surface

Slip surface parameters							
Center :	x =	-10.22	[m]	Angles :	α_1 =	9.64	[°]
	z =	37.78	[m]		α_2 =	34.18	[°]
Radius :	R =	44.13	[m]				
Analysis of the slip surface without optimization.							

Slope stability verification (Bishop)

Sum of active forces : $F_a = 486.35$ kN/m
Sum of passive forces : $F_p = 4352.27$ kN/m
Sliding moment : $M_a = 21462.82$ kNm/m
Resisting moment : $M_p = 192065.90$ kNm/m
Utilization : 11.2 %

Slope stability ACCEPTABLE

6.2. CALCULATION OF THE WALL AFTER STRUCTURAL INTERVENTION.

In the first case of calculations we have the BASIC COMBINATION.
We see that in this case the wall presents SATISFACTORY results for:
1. The bearing capacity of the wall in overturning.
2. Bearing capacity of the wall for slip.
3. The bearing capacity of the foundation soil.
4. Its cross-sectional dimensions.
5. The eccentricity of the action of the normal force.

In the second case of calculations we have SEISMIC COMBINATION.
We see that in this case the wall presents SATISFACTORY results for:
1. The bearing capacity of the wall in overturning.
2. Bearing capacity of the wall for slip.
3. The bearing capacity of the foundation soil.
4. The eccentricity of the action of the normal force.
5. Its cross-sectional dimensions.

From the above results we notice that the calculation after structural intervention gives SATISFACTORY results for both combinations used.
We also see that the slope stability check gives ACCEPTABLE results with both combinations.
We emphasize that in the calculation program the structural intervention has been replaced with a positive horizontal force acting on the wall.
The results obtained from the calculation program for the calculation of the wall after structural intervention are presented below.

Cantilever wall analysis

Input data

Project

Date : 10/28/2022

Settings

EN STANDART (2)

Materials and standards

Concrete structures : EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 : standard

Wall analysis

Active earth pressure calculation : Coulomb
Passive earth pressure calculation : Mazindrani (Rankin)
Earthquake analysis : Mononobe-Okabe

Shape of earth wedge :	Calculate as skew
Base key :	The base key is considered as inclined footing bottom
Allowable eccentricity :	0.333
Verification methodology :	according to EN 1997
Design approach :	3 - reduction of actions (GEO, STR) and soil parameters

Partial factors on actions (A)
Permanent design situation

		State STR				State GEO			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]
Variable actions :	γ_Q =	1.50	[–]	0.00	[–]	1.30	[–]	0.00	[–]
Water load :	γ_w =					1.00	[–]		

Partial factors for soil parameters (M)
Permanent design situation

Partial factor on internal friction :	γ_ϕ =	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.40	[–]
Partial factor on Poisson's ratio :	γ_v =	1.00	[–]

Partial factors for variable actions
Permanent design situation

Factor for combination value :	ψ_0 =	0.70	[–]
Factor for frequent value :	ψ_1 =	0.50	[–]
Factor for quasi-permanent value :	ψ_2 =	0.30	[–]

Partial factors on actions (A)
Seismic design situation

		State STR				State GEO			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.00	[–]	1.00	[–]	1.00	[–]	1.00	[–]
Variable actions :	γ_Q =	1.00	[–]	0.00	[–]	1.00	[–]	0.00	[–]
Water load :	γ_w =					1.00	[–]		

Partial factors for soil parameters (M)
Seismic design situation

Partial factor on internal friction :	γ_ϕ =	1.00	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]
Partial factor on Poisson's ratio :	γ_v =	1.00	[–]

Material of structure

Unit weight γ = 0.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 12/15
Cylinder compressive strength f_{ck} = 12.00 MPa
Tensile strength f_{ctm} = 1.60 MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500.00 MPa

Geometry of structure

No.	Coordinate X [m]	Depth Z [m]
1	0.00	0.00
2	0.22	4.50
3	0.22	5.00
4	-1.40	5.00
5	-1.40	4.50
6	-1.40	0.00

The origin [0,0] is located at the most upper right point of the wall.
Wall section area = 7.62 m^2.

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
1	LAYER 1		20.00	25.00	20.60	16.90	12.00
2	LAYER 2		10.00	300.00	26.50	17.00	5.00

All soils are considered as cohesionless for at rest pressure analysis.

Soil parameters

LAYER 1

Unit weight : γ = 20.60 kN/m^3
Stress-state : effective
Angle of internal friction : φ_{ef} = 20.00 °
Cohesion of soil : c_{ef} = 25.00 kPa
Angle of friction struc.-soil : δ = 12.00 °
Soil : cohesionless
Saturated unit weight : γ_{sat} = 26.90 kN/m^3

LAYER 2

Unit weight :	γ =	26.50	kN/m3
Stress-state :	effective		
Angle of internal friction :	φ_{ef} =	10.00	°
Cohesion of soil :	c_{ef} =	300.00	kPa
Angle of friction struc.-soil :	δ =	5.00	°
Soil :	cohesionless		
Saturated unit weight :	γ_{sat} =	27.00	kN/m3

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	1.50	LAYER 1	
2	-	LAYER 2	

Foundation

Type of foundation : soil from geological profile

Terrain profile

Terrain behind construction has the slope 1: 10.00 (slope angle is 5.71 °).

Water influence

Ground water table is located below the structure.

Input surface surcharges

No.	Surcharge new	Surcharge change	Action	Mag.1 [kN/m2]	Mag.2 [kN/m2]	Ord.x x [m]	Length l [m]	Depth z [m]
1	YES		variable	10.00				on terrain

Resistance on front face of the structure

Resistance on front face of the structure: at rest
Soil on front face of the structure - LAYER 2

Soil thickness in front of structure	h =	0.30	m
Soil slope in front of structure	β =	-30.00	°

Applied forces acting on the structure

No.	Force new	Force modification	Name	Action	F_x [kN/m]	F_z [kN/m]	M [kNm/m]	x [m]	z [m]
1	YES		Force No. 1	permanent	0.00	200.00	0.00	-1.20	0.80
2	YES		Force No. 2	permanent	110.00	0.00	0.00	-1.40	2.30

Settings of the stage of construction

Design situation : permanent

The wall is free to move. Active earth pressure is therefore assumed.

Verification No. 1 (Stage of construction 1)

Pressure at rest on front face of the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m^3]	K_r	Comment
1	0.30	0.00	8.03	240.00	26.50	0.860	

Pressure at rest distribution on front face of the structure

Layer No.	Start [m] End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	0.30	7.95	0.00	1.85	1.85	0.00

Active pressure behind the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m^3]	δ_d [°]	K_a	Comment
1	1.50	2.86	16.23	20.00	20.60	9.74	0.587	
2	3.00	2.86	8.03	240.00	26.50	4.01	0.806	
3	0.50	0.00	8.03	240.00	26.50	4.01	0.791	

Active pressure distribution behind the structure (without surcharge)

Layer No.	Start [m] End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	1.50	30.90	0.00	0.00	0.00	0.00
2	1.50	30.90	0.00	0.00	0.00	0.00
	4.50	110.40	0.00	0.00	0.00	0.00
3	4.50	110.40	0.00	0.00	0.00	0.00
	5.00	123.65	0.00	0.00	0.00	0.00

Pressure profile due to surcharge - Surch.1 - surface

Point No.	Depth [m]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	5.73	1.28
2	1.50	5.73	1.28
3	1.50	8.00	0.97
4	4.50	8.00	0.97
5	4.50	7.89	0.55
6	5.00	7.89	0.55

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-2.43	0.00	0.76	1.000	1.000	1.000
FF resistance	-0.28	-0.10	0.00	0.00	1.000	1.000	1.000
Active pressure	0.00	-5.00	0.00	1.40	1.000	1.000	1.000
Surch.1 - surface	0.00	-5.00	5.10	1.51	0.000	0.000	1.300
Force No. 1	0.00	-4.20	200.00	0.20	1.000	1.000	1.350
Force No. 2	-110.00	-2.70	0.00	0.00	1.000	1.000	1.000

Verification of complete wall

Check for overturning stability

Resisting moment M_{res} = 337.00 kNm/m
Overturning moment M_{ovr} = -0.03 kNm/m

Wall for overturning is SATISFACTORY

Check for slip

Resisting horizontal force H_{res} = 418.21 kN/m
Active horizontal force H_{act} = -110.28 kN/m

Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Maximum stress in footing bottom : 170.23 kPa

Bearing capacity of foundation soil (Stage of construction 1)

Design load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]	Eccentricity [–]	Stress [kPa]
1	-136.28	276.62	-110.28	0.000	170.23
2	-174.53	200.00	-110.28	0.000	123.08

Service load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]
1	-178.24	205.31	-110.27
2	-174.53	200.00	-110.27

Verification of foundation soil

Eccentricity verification

Max. eccentricity of normal force e = 0.000
Maximum allowable eccentricity e_{alw} = 0.333

Eccentricity of the normal force is SATISFACTORY

Verification of bearing capacity
Max. stress at footing bottom σ = 170.23 kPa
Bearing capacity of foundation soil R_d = 1000.00 kPa

Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is SATISFACTORY

Dimensioning No. 1 (Stage of construction 1)

Pressure at rest behind the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m^3]	K_r	Comment
1	1.50	2.86	16.23	20.00	20.60	0.743	
2	3.00	2.86	8.03	240.00	26.50	0.896	

Pressure at rest distribution behind the structure (without surcharge)

Layer No.	Start [m] End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	1.50	30.90	0.00	22.99	22.94	1.54
2	1.50	30.90	0.00	27.70	27.66	1.54
	4.50	110.37	0.00	98.95	98.80	5.51

Pressure profile due to surcharge - Surch.1 - surface

Point No.	Depth [m]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	7.41	0.67
2	1.50	7.41	0.67
3	1.50	8.95	0.56
4	4.50	8.95	0.56

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. moment	Coeff. norm.force	Coeff. shear for.
Weight - wall	0.00	-2.19	0.00	0.76	1.000	1.000	1.000
Pressure at rest	206.81	-1.41	11.73	1.55	1.000	1.000	1.000
Surch.1 - surface	37.96	-2.16	2.68	1.51	1.300	1.300	1.300
Force No. 1	0.00	-3.70	200.00	0.20	1.350	1.350	1.000
Force No. 2	-110.00	-2.20	0.00	0.00	1.000	1.000	1.000

Wall stem check

Reinforcement and dimensions of the cross-section
Bar diameter = 20.0 mm

Number of bars = 10
Reinforcement cover = 30.0 mm
Cross-section width = 1.00 m
Cross-section depth = 1.62 m

Reinforcement ratio	ρ	=	0.20	%	>	0.13	%	= ρ_{min}
Position of neutral axis	x	=	0.21	m	<	0.98	m	= x_{max}
Ultimate shear force	V_{Rd}	=	344.07	kN	>	146.15	kN	= V_{Ed}
Ultimate moment	M_{Rd}	=	2048.28	kNm	>	310.07	kNm	= M_{Ed}

Cross-section is SATISFACTORY.

Input data (Stage of construction 2)

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	1.50	LAYER 1	
2	-	LAYER 2	

Foundation

Type of foundation : soil from geological profile

Terrain profile

Terrain behind construction has the slope 1: 11.43 (slope angle is 5.00 °).

Water influence

Ground water table is located below the structure.

Resistance on front face of the structure

Resistance on front face of the structure: at rest
Soil on front face of the structure - LAYER 2
Soil thickness in front of structure h = 0.10 m
Soil slope in front of structure β = -30.00 °

Applied forces acting on the structure

No.	Force new	Force modification	Name	Action	F_x [kN/m]	F_z [kN/m]	M [kNm/m]	x [m]	z [m]
1	NO	NO	Force No. 1	permanent	0.00	200.00	0.00	-1.20	0.80
2	NO	NO	Force No. 2	permanent	110.00	0.00	0.00	-1.40	2.30

Earthquake

Factor of horizontal acceleration K_h = 0.1600

Factor of vertical acceleration K_v = 0.0800

Water below the GWT is restricted.

Settings of the stage of construction

Design situation : seismic
The wall is free to move. Active earth pressure is therefore assumed.

Verification No. 1 (Stage of construction 2)

Pressure at rest on front face of the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m³]	K_r	Comment
1	0.10	0.00	10.00	300.00	26.50	0.826	

Pressure at rest distribution on front face of the structure

Layer No.	Start [m] / End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	0.10	2.65	0.00	0.59	0.59	0.00

Active pressure behind the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m³]	δ_d [°]	K_a	Comment
1	1.50	2.86	20.00	25.00	20.60	12.00	0.500	
2	3.00	2.86	10.00	300.00	26.50	5.00	0.732	
3	0.50	0.00	10.00	300.00	26.50	5.00	0.715	

Active pressure distribution behind the structure (without surcharge)

Layer No.	Start [m] / End [m]	σ_z [kPa]	σ_w [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	1.50	30.90	0.00	0.00	0.00	0.00
2	1.50	30.90	0.00	0.00	0.00	0.00
	4.50	110.40	0.00	0.00	0.00	0.00
3	4.50	110.40	0.00	0.00	0.00	0.00
	5.00	123.65	0.00	0.00	0.00	0.00

Earthquake effects (active earth pressure) - partial results

Layer No.	Thickness [m]	φ_d [°]	β [°]	ψ [°]	K_a	K_{ae}	K_{ae}-K_a	Comment
1	1.50	20.00	5.00	9.87	0.500	0.730	0.231	
2	3.00	10.00	5.00(0.13)	9.87	0.679	1.066	0.387	MODIFIED

Layer No.	Thickness [m]	φ_d [°]	β [°]	ψ [°]	K_a	K_{ae}	$K_{ae}-K_a$	Comment
3	0.50	10.00	5.00(0.13)	9.87	0.664	1.050	0.386	MODIFIED

Earthquake effects (active earth pressure)

Layer No.	Start [m] End [m]	σ_Z [kPa]	σ_D [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vertical comp. [kPa]
1	0.00	0.00	113.76	26.24	25.36	6.73
	1.50	28.43	85.33	19.68	19.02	5.05
2	1.50	28.43	85.33	33.04	32.73	4.52
	4.50	101.57	12.19	4.72	4.68	0.65
3	4.50	101.57	12.19	4.71	4.69	0.41
	5.00	113.76	0.00	0.00	0.00	0.00

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-2.43	0.00	0.76	1.000	1.000	1.000
Earthq.- constr.	0.00	-2.43	0.00	0.76	1.000	1.000	1.000
FF resistance	-0.03	-0.03	0.00	0.00	1.000	1.000	1.000
Active pressure	0.00	-5.00	0.00	1.40	1.000	1.000	1.000
Earthq.- act.pressure	90.57	-3.05	16.69	1.48	1.000	1.000	1.000
Force No. 1	0.00	-4.20	200.00	0.20	1.000	1.000	1.000
Force No. 2	-110.00	-2.70	0.00	0.00	1.000	1.000	1.000

Verification of complete wall

Check for overturning stability

Resisting moment M_{res} = 361.72 kNm/m
Overturning moment M_{ovr} = 276.33 kNm/m

Wall for overturning is SATISFACTORY

Check for slip

Resisting horizontal force H_{res} = 274.65 kN/m
Active horizontal force H_{act} = -19.46 kN/m

Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Maximum stress in footing bottom : 274.94 kPa
Warning - allowable range of input data exceeded during earthquake analysis!
The analysis is carried out with the modified value of terrain inclination β.

Bearing capacity of foundation soil (Stage of construction 2)

Design load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]	Eccentricity [–]	Stress [kPa]
1	90.67	216.69	-19.46	0.257	274.94

Service load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]
1	90.67	216.69	-19.46

Verification of foundation soil

Eccentricity verification

Max. eccentricity of normal force $e = 0.257$
Maximum allowable eccentricity $e_{alw} = 0.333$

Eccentricity of the normal force is SATISFACTORY

Verification of bearing capacity

Max. stress at footing bottom $\sigma = 274.94$ kPa
Bearing capacity of foundation soil $R_d = 1000.00$ kPa

Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is SATISFACTORY

Dimensioning No. 1 (Stage of construction 2)

Pressure at rest behind the structure - partial results

Layer No.	Thickness [m]	α [°]	φ_d [°]	c_d [kPa]	γ [kN/m³]	K_r	Comment
1	1.50	2.86	20.00	25.00	20.60	0.670	
2	3.00	2.86	10.00	300.00	26.50	0.847	

Pressure at rest distribution behind the structure (without surcharge)

Layer No.	Start [m] / End [m]	σ_Z [kPa]	σ_W [kPa]	Pressure [kPa]	Hor. comp. [kPa]	Vert. comp. [kPa]
1	0.00	0.00	0.00	0.00	0.00	0.00
	1.50	30.90	0.00	20.75	20.69	1.54
2	1.50	30.90	0.00	26.18	26.14	1.54
	4.50	110.37	0.00	93.52	93.35	5.51

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. moment	Coeff. norm.force	Coeff. shear for.
Weight - wall	0.00	-2.19	0.00	0.76	1.000	1.000	1.000

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. moment	Coeff. norm.force	Coeff. shear for.
Earthq.- constr.	0.00	-2.19	0.00	0.76	1.000	1.000	1.000
Pressure at rest	194.68	-1.40	11.73	1.55	1.000	1.000	1.000
Earthquake - pressure at rest	73.09	-2.25	0.00	1.40	1.000	1.000	1.000
Force No. 1	0.00	-3.70	200.00	0.20	1.000	1.000	1.000
Force No. 2	-110.00	-2.20	0.00	0.00	1.000	1.000	1.000

Wall stem check

Reinforcement and dimensions of the cross-section

Bar diameter	=	20.0	mm
Number of bars	=	10	
Reinforcement cover	=	30.0	mm
Cross-section width	=	1.00	m
Cross-section depth	=	1.62	m

Reinforcement ratio	ρ	=	0.20	%	>	0.13	%	=	ρ_{min}
Position of neutral axis	x	=	0.21	m	<	0.98	m	=	x_{max}
Ultimate shear force	V_{Rd}	=	344.07	kN	>	157.77	kN	=	V_{Ed}
Ultimate moment	M_{Rd}	=	2048.28	kNm	>	308.89	kNm	=	M_{Ed}

Cross-section is SATISFACTORY.

Slope stability analysis

Input data

Project

Settings

EN STANDART (2)

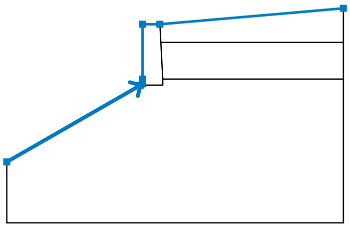
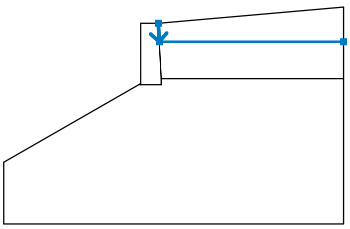
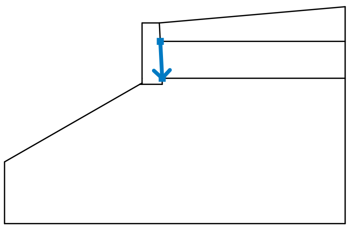
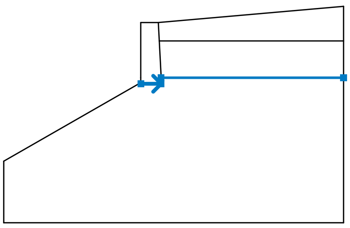
Stability analysis

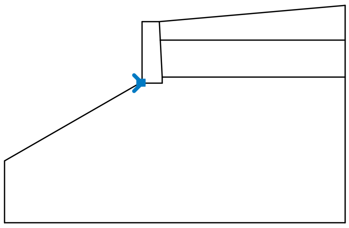
Earthquake analysis : Standard
Verification methodology : according to EN 1997
Design approach : 3 - reduction of actions (GEO, STR) and soil parameters

Partial factors on actions (A)									
Seismic design situation									
		State STR				State GEO			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.00	[–]	1.00	[–]	1.00	[–]	1.00	[–]
Variable actions :	γ_Q =	1.00	[–]	0.00	[–]	1.00	[–]	0.00	[–]
Water load :	γ_w =					1.00	[–]		

Partial factors for soil parameters (M)			
Seismic design situation			
Partial factor on internal friction :	γ_ϕ =	1.00	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]

Interface

No.	Interface location	Coordinates of interface points [m] x	z	x	z	x	z
1		-12.50	-11.31	-1.57	-5.00	-1.40	-4.90
		-1.40	-4.50	-1.40	0.00	0.00	0.00
		15.00	1.31				
2		0.00	0.00	0.08	-1.50	15.00	-1.50
3		0.08	-1.50	0.23	-4.50		
4		-1.40	-5.00	0.23	-5.00	0.23	-4.50
		15.00	-4.50				

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
5		-1.57	-5.00	-1.40	-5.00	-1.40	-4.90

Soil parameters - effective stress state

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]
1	LAYER 1		20.00	25.00	20.60
2	LAYER 2		10.00	300.00	26.50

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m^3]	γ_s [kN/m^3]	n [–]
1	LAYER 1		26.90		
2	LAYER 2		27.00		

Soil parameters

LAYER 1

Unit weight : γ = 20.60 kN/m^3
Stress-state : effective
Angle of internal friction : φ_{ef} = 20.00 °
Cohesion of soil : c_{ef} = 25.00 kPa
Saturated unit weight : γ_{sat} = 26.90 kN/m^3

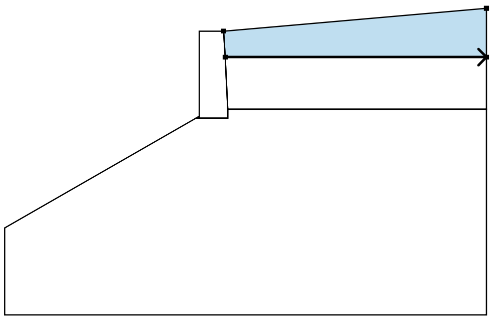
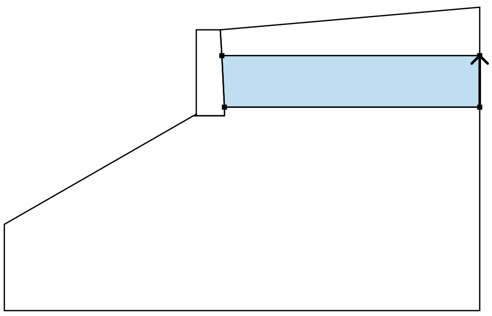
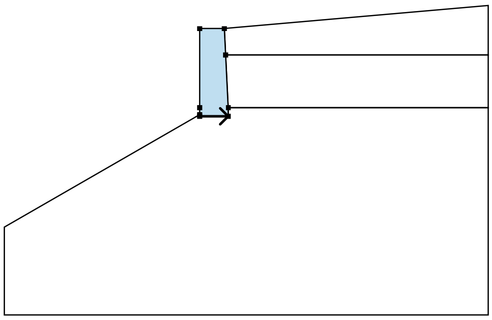
LAYER 2

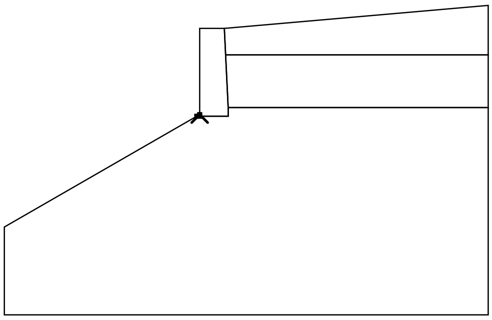
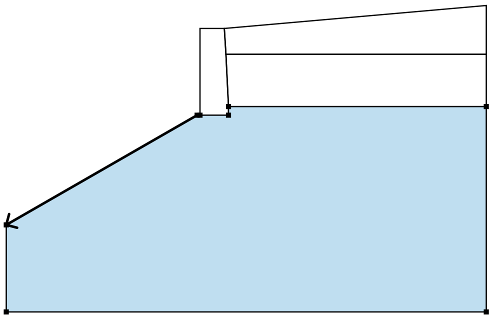
Unit weight : γ = 26.50 kN/m^3
Stress-state : effective
Angle of internal friction : φ_{ef} = 10.00 °
Cohesion of soil : c_{ef} = 300.00 kPa
Saturated unit weight : γ_{sat} = 27.00 kN/m^3

Rigid bodies

No.	Name	Sample	γ [kN/m3]
1	Wall material		0.00

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m] x	z	x	z	Assigned soil
1		0.08	-1.50	15.00	-1.50	LAYER 1
		15.00	1.31	0.00	0.00	
2		15.00	-4.50	15.00	-1.50	LAYER 2
		0.08	-1.50	0.23	-4.50	
3		-1.40	-5.00	0.23	-5.00	Wall material
		0.23	-4.50	0.08	-1.50	
		0.00	0.00	-1.40	0.00	
		-1.40	-4.50	-1.40	-4.90	

No.	Surface position	Coordinates of surface points [m] x	z	x	z	Assigned soil
4		-1.40	-5.00	-1.40	-4.90	LAYER 2
		-1.57	-5.00			
5		-1.57	-5.00	-12.50	-11.31	LAYER 2
		-12.50	-16.31	15.00	-16.31	
		15.00	-4.50	0.23	-4.50	
		0.23	-5.00	-1.40	-5.00	

Water

Water type : No water

Tensile crack

Tensile crack not inputted.

Earthquake

Horizontal seismic coefficient : K_h = 0.16
Vertical seismic coefficient : K_v = 0.08

Settings of the stage of construction

Design situation : seismic

Results (Stage of construction 1)

Analysis 1

Circular slip surface

Slip surface parameters							
Center :	x =	-10.22	[m]	Angles :	α_1 =	9.64	[°]
	z =	37.78	[m]		α_2 =	34.18	[°]
Radius :	R =	44.13	[m]				
Analysis of the slip surface without optimization.							

Slope stability verification (Bishop)

Sum of active forces :	F_a =	486.35	kN/m
Sum of passive forces :	F_p =	4352.27	kN/m

Sliding moment :	M_a =	21462.82	kNm/m
Resisting moment :	M_p =	192065.90	kNm/m

Utilization : 11.2 %

Slope stability ACCEPTABLE

7. CONCLUSIONS

After reviewing numerous analyzes and calculations, we come to the conclusion that the wall urgently needs structural interventions.
The reasons that lead us to the above conclusion are because we have problems with the global bearing capacity according to the calculations that were performed above, as well as problems with the local bearing capacity of the wall.
The problems with the global bearing capacity of the wall from the calculations consist of two points:
1. The wall presents major problems and collapses to destruction under the calculation conditions with the basic combination and the seismic one.
2. The slope that the wall has taken causes a great eccentricity of the action of the forces on the wall (larger than allowed values), causing the potential possibility of the wall collapsing as a result of the loss of its stability. The wall is presented by calculations in critical equilibrium conditions.

The problems with the local bearing capacity of the wall from the calculations consist in the fact that the wall has destroyed parts of it in the end part and they need to be repaired.

Based on Eurocodes, we have several ways to cope with external actions on the wall, both seismic and non-seismic.
Some of the ways of coping with these forces are either to make the structure stronger, or to remove the loads and masses acting on the structure. This method is also recommended in EN 1998-3 dealing with retrofitting.
Starting from the above logic and based on the recommendations of EN 1998-3 we conclude that in order to return the wall to normality and to keep it safe according to the terms of reference in the cases of the basic combination and the seismic one, a structural intervention should be made which consists of several points:

1. Unbanking of a part of the soil that exerts a negative pressure force on the wall.
2. The creation of a positive horizontal force acting on the wall with a value of 550 kN.

In no way should this force be smaller, but neither should it be bigger.
The reason why the positive horizontal acting force (the positive horizontal force that should create the structural intervention) for the wall should be fixed at the value of 550 kN is:

a. If it is smaller, it does not achieve the appropriate positive effect to keep the wall in the condition of the reference terms in the cases of the basic combination and the seismic one according to the above calculations.
b. If it is bigger, then it will cause the opposite effect on the wall, creating other additional stresses on the wall on the opposite side and risking the collapse of the wall on the other side.

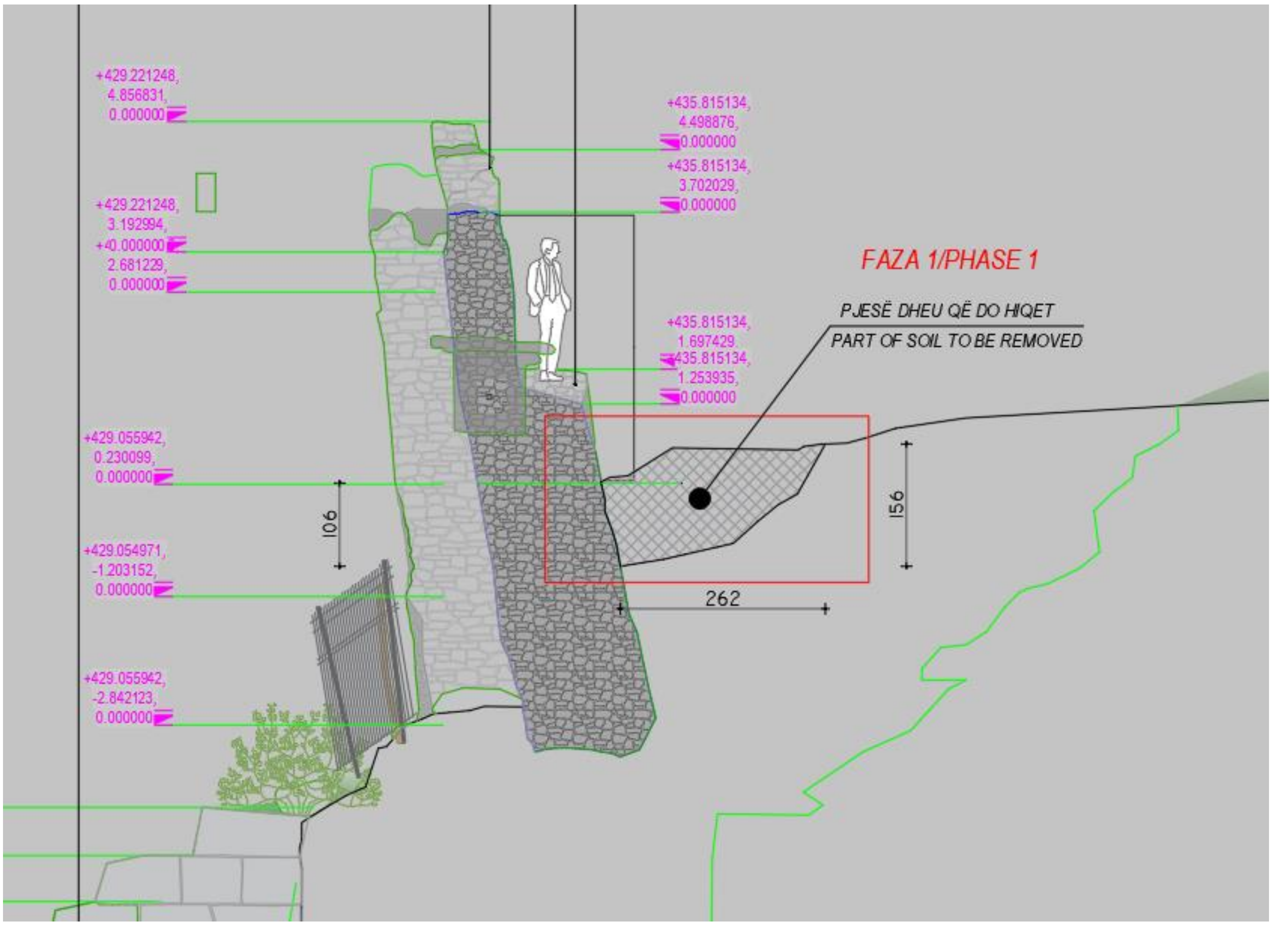
3. Injection of grouting in the part of the base of the wall that risks collapse. This kind of intervention is done to increase the foundation stability soil of the wall and to give a positive impact to the bearing capacity of the wall.
4. Removal of the damaged wall in the foundation(bottom) part and its repair.

7.1. METHOD OF REALIZING THE STRUCTURAL INTERVENTION.

The way the structural intervention should be done is with different phases in time. These phases will be applied as explained below:

1. PHASE 1

First we will remove part of the soil deposit which causes negative pressure force on the wall. This will be done in order to free the wall from negative pressures so that we can make the structural intervention of the second phase as efficient and less risky as possible. **As a result of the lack of a report from the archaeologist, it should be kept in mind that the excavation of the soil should be done with archaeological works and with great care.**

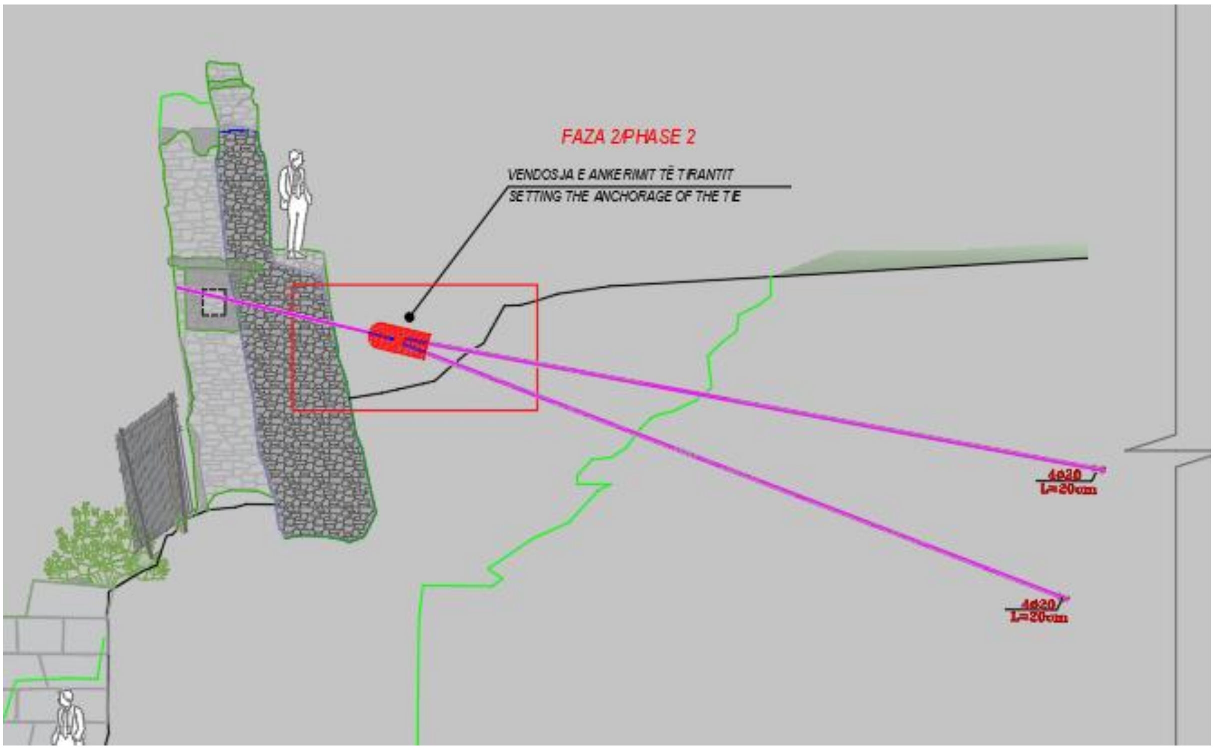


2. PHASE 2

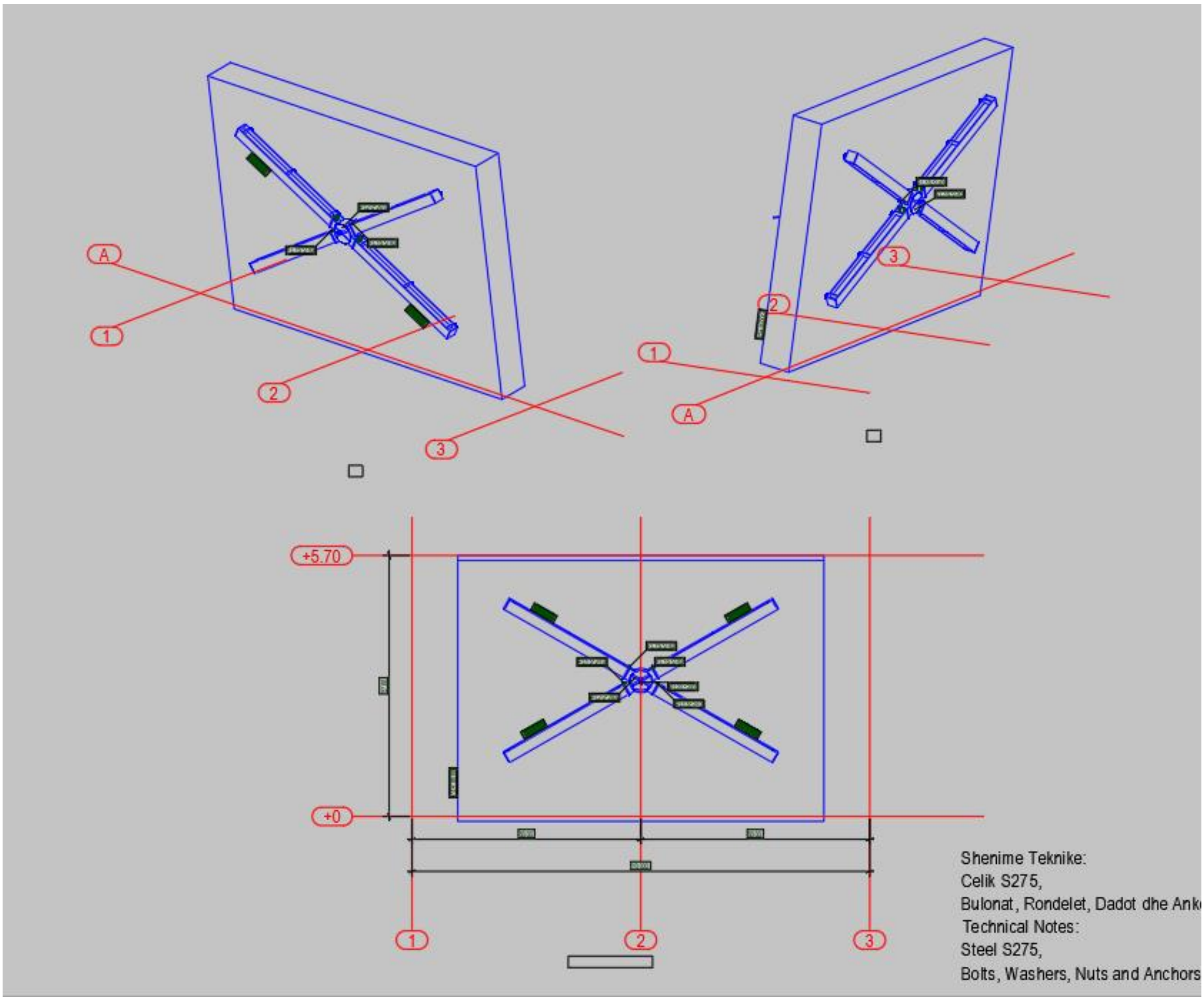
After successfully applying the first phase, we will move on to the second phase, which consists in creating a positive horizontal force on the wall with a value of 550 kN.
To achieve this strength that we need, there are two ways that can be done:
1. Placing a counterforce on the side from which the wall is losing stability.
2. Anchoring.

Regarding the first method mentioned above, we do not consider it suitable to be used in this case also because of the terrain that is from outside and it is more invasive as a solution.

The structural intervention is intended to be done according to the second method mentioned above **(by anchoring)**, which will replace the positive horizontal acting force that the wall needs in order to meet the terms of reference mentioned above in point 4.4 of this relation.
The reason why the anchoring was chosen is because, considering the good geological-engineering conditions we have in the area near the wall, we think that we will achieve a very good anchoring. This is because the area where the anchoring will take place is a rocky area. **It should be carefully taken into account that anchoring must be done only in layer number two referring to the geologist's study and not in archaeological objects or in layer 1.**
Another reason why it is thought for an anchor is the conditions of the wall. Having a hole in the middle of the wall we can use it to make a very good anchoring and not causing negative effects to the wall.
We have to keep in mind that the angle that we have to anchor should be conform to the project drawings.

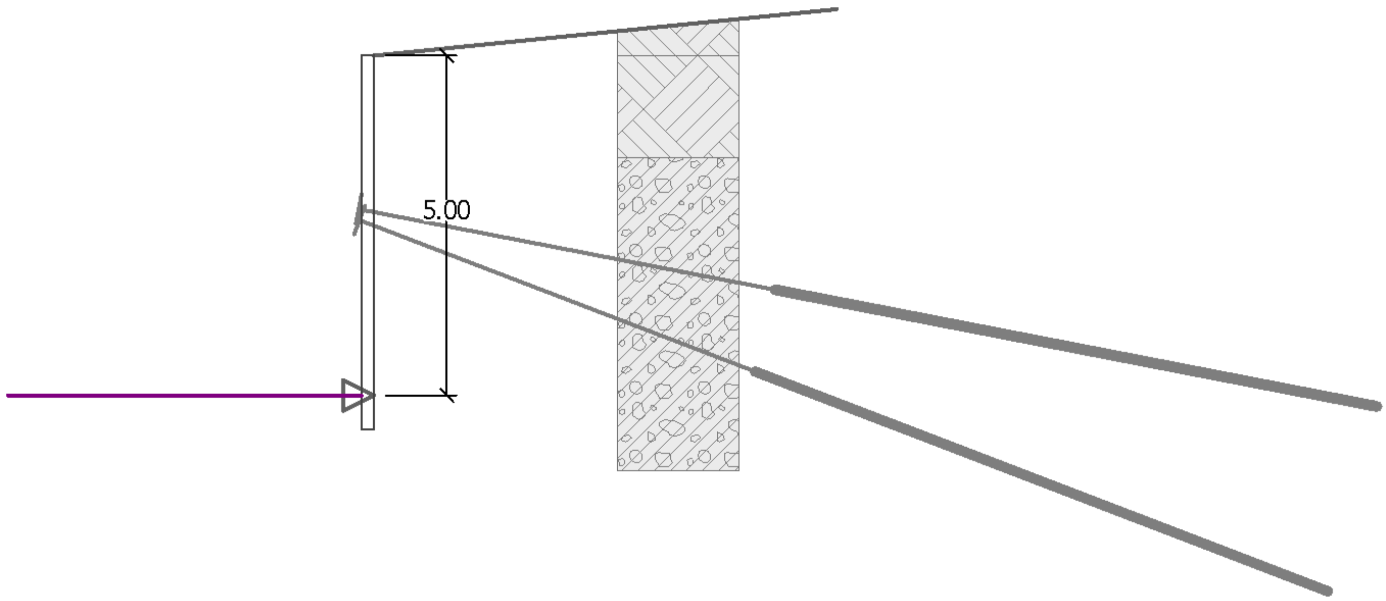


We should also consider placing a recorder when tightening the tie rod in order to check and accurately reach the value we need in the horizontal direction (550 kN)



7.1.1. ANALYTICAL ANCHORAGE CALCULATIONS

Structure verification (anchors)



Input data

Project

Date : 3/17/2023

Settings

Standard - EN 1997 - DA3

Materials and standards

Concrete structures :	EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 :	standard
Steel structures :	EN 1993-1-1 (EC3)
Partial factor on bearing capacity of steel cross section :	$\gamma_{M0} = 1.00$

Excavations

Active earth pressure calculation :	Coulomb
Passive earth pressure calculation :	Caquot-Kerisel
Earthquake analysis :	Mononobe-Okabe
Consider reduction of the modulus of subsoil reaction for a braced sheeting	
Verification methodology :	according to EN 1997
Design approach :	3 - reduction of actions (GEO, STR) and soil parameters

Partial factors on actions (A)									
Permanent design situation									
		State STR				State GEO			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]
Variable actions :	γ_Q =	1.50	[–]	0.00	[–]	1.30	[–]	0.00	[–]
Water load :	γ_w =					1.00	[–]		

Partial factors for soil parameters (M)			
Permanent design situation			
Partial factor on internal friction :	γ_ϕ =	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.40	[–]
Partial factor on Poisson's ratio :	γ_v =	1.00	[–]

Geometry of structure

Structure length = 5.50 m

Cross-section name : RC rectangular wall h = 1.00 m

Area of cross-section	A =	1.00E+00	m^2/m
Moment of inertia	I =	8.33E-02	m^4/m
Elastic modulus	E =	30000.00	MPa
Shear modulus	G =	12500.00	MPa

Material of structure

Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25

Cylinder compressive strength	f_{ck} =	20.00	MPa
Tensile strength	f_{ctm} =	2.20	MPa
Elasticity modulus	E_{cm} =	30000.00	MPa
Shear modulus	G =	12500.00	MPa

Longitudinal steel : B500

Yield strength	f_{yk} =	500.00	MPa

Modulus of subsoil reaction determined according to the Schmitt theory.

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m3]	γ_{su} [kN/m3]	δ [°]
1	LAYER 1		20.00	25.00	20.60	16.90	12.00

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
2	LAYER 2		10.00	300.00	26.50	17.00	5.00

All soils are considered as cohesionless for at rest pressure analysis.

Parameters of soils to compute modulus of subsoil reaction (Schmitt)

No.	Name	Pattern	ν [–]	E_{oed} [MPa]	E_{def} [MPa]
1	LAYER 1		0.30	-	10.00
2	LAYER 2		0.30	-	10.00

Soil parameters

LAYER 1

Unit weight :	γ	=	20.60 kN/m^3
Stress-state :	effective		
Angle of internal friction :	φ_{ef}	=	20.00 °
Cohesion of soil :	c_{ef}	=	25.00 kPa
Angle of friction struc.-soil :	δ	=	12.00 °
Soil :	cohesionless		
Deformation modulus :	E_{def}	=	10.00 MPa
Poisson's ratio :	ν	=	0.30
Saturated unit weight :	γ_{sat}	=	26.90 kN/m^3

LAYER 2

Unit weight :	γ	=	26.50 kN/m^3
Stress-state :	effective		
Angle of internal friction :	φ_{ef}	=	10.00 °
Cohesion of soil :	c_{ef}	=	300.00 kPa
Angle of friction struc.-soil :	δ	=	5.00 °
Soil :	cohesionless		
Deformation modulus :	E_{def}	=	10.00 MPa
Poisson's ratio :	ν	=	0.30
Saturated unit weight :	γ_{sat}	=	27.00 kN/m^3

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	1.50	LAYER 1	

No.	Layer [m]	Assigned soil	Pattern
2	-	LAYER 2	

Excavation

Soil in front of wall is excavated to a depth of 5.00 m.

Terrain profile

Terrain behind construction has the slope 1: 10.00 (slope angle is 5.71 °).

Water influence

Ground water table is located below the structure.

Input anchors

No.	New anchor	Depth z [m]	Length l [m]	Root l_k [m]	Slope α [°]	Spacing b [m]
1	YES	2.30	6.00	9.00	11.00	1.00
2	YES	2.50	6.00	9.00	21.00	1.00

No.	Diameter d [mm]	Area A [mm^2]	Modulus E [MPa]	Post-stressing	Force F [kN]
1	16.0		210000.00		350.00
2	16.0		210000.00		350.00

Inserted supports

No.	New support	Depth z [m]	Spacing b [m]
1	YES	5.00	1.00

No.	Type displacement	Spring [kN/m]	Forced displ. [mm]	Type spring	Spring [kNm/rad]	Forced displ. [rad]
1	Fixed		0.00	Fixed		

Global settings

Number of FEs to discretize wall = 40
Analysis of depending pressures : do not reduce
Minimum dimensioning pressure is considered as $\sigma_{a,min} = 0.20\sigma_z$

Settings of the stage of construction

Design situation : permanent

Analysis results

Distribution of pressures acting on the structure (in front and behind the wall)

Depth [m]	Ta,p [kPa]	Tk,p [kPa]	Tp,p [kPa]	Ta,z [kPa]	Tk,z [kPa]	Tp,z [kPa]
0.00	-0.00	-0.00	-0.00	0.00	0.00	86.93
1.50	-0.00	-0.00	-0.00	6.18	20.83	182.43
1.50	0.00	0.00	0.00	6.18	26.37	829.97
5.00	-0.00	-0.00	-0.00	24.73	105.52	986.44
5.00	-0.00	-0.00	-744.30	24.73	105.52	986.44
5.50	-0.00	-10.95	-764.77	27.38	116.83	1008.79

Distributions of the modulus of subsoil reaction and internal forces on the structure

Depth [m]	kh,p [MN/m3]	kh,z [MN/m3]	Displacement [mm]	Pressure [kPa]	Shear Force [kN/m]	Moment [kNm/m]
0.00	0.00	0.00	41.57	86.93	-0.00	-0.00
0.14	0.00	0.00	40.44	95.69	-12.56	0.85
0.28	0.00	0.00	39.32	104.44	-26.31	3.51
0.41	0.00	0.00	38.19	113.20	-41.28	8.14
0.55	0.00	0.00	37.06	121.95	-57.44	14.91
0.69	0.00	0.00	35.94	130.70	-74.81	23.99
0.82	0.00	0.00	34.81	139.46	-93.39	35.54
0.96	0.00	0.00	33.68	148.21	-113.16	49.73
1.10	0.00	0.00	32.56	156.97	-134.14	66.72
1.24	0.00	0.00	31.43	165.72	-156.33	86.67
1.38	0.00	4.95	30.30	169.22	-179.55	110.12
1.51	0.00	4.95	29.17	171.18	-202.95	136.40
1.65	0.00	4.95	28.04	168.69	-226.32	165.92
1.79	0.00	4.95	26.91	166.19	-249.34	198.62
1.93	0.00	4.95	25.77	163.68	-272.02	234.47
2.06	0.00	4.95	24.64	161.17	-294.35	273.41
2.20	0.00	4.95	23.50	158.64	-316.34	315.39
2.30	0.00	4.95	22.67	156.80	-332.11	347.82
2.30	0.00	4.95	22.67	156.80	11.46	347.82
2.34	0.00	4.95	22.36	156.10	5.59	347.50
2.34	0.00	4.95	22.36	156.10	5.59	347.50
2.48	0.00	4.95	21.22	153.55	-15.70	348.19
2.48	0.00	4.95	21.22	153.55	-15.70	348.19
2.50	0.00	4.95	21.01	153.09	-19.53	348.63
2.50	0.00	4.95	21.01	153.09	307.22	348.63
2.61	0.00	4.95	20.07	150.99	290.12	315.03

Depth [m]	kh,p [MN/m³]	kh,z [MN/m³]	Displacement [mm]	Pressure [kPa]	Shear Force [kN/m]	Moment [kNm/m]
2.75	0.00	4.95	18.93	148.42	269.53	276.56
2.89	0.00	4.95	17.78	145.83	249.30	240.89
3.02	0.00	4.95	16.63	143.24	229.43	207.98
3.16	0.00	4.95	15.47	140.63	209.91	177.78
3.30	0.00	4.95	14.32	138.02	190.76	150.23
3.44	0.00	4.95	13.16	135.41	171.96	125.30
3.58	0.00	4.95	12.01	132.79	153.52	102.92
3.71	0.00	4.95	10.85	130.17	135.44	83.06
3.85	0.00	4.95	9.69	127.54	117.72	65.65
3.99	0.00	4.95	8.53	124.91	100.37	50.66
4.13	0.00	4.95	7.38	122.28	83.37	38.03
4.26	0.00	4.95	6.22	119.65	66.74	27.71
4.40	0.00	4.95	5.06	117.02	50.47	19.66
4.54	0.00	4.95	3.90	114.38	34.56	13.81
4.67	0.00	4.95	2.74	111.75	19.01	10.13
4.81	0.00	4.95	1.58	109.11	3.83	8.56
4.95	0.00	4.95	0.42	106.48	-10.99	9.06
4.99	0.00	4.95	0.07	105.67	-15.45	9.61
5.01	4.95	4.95	-0.07	104.86	41.56	9.40
5.09	4.95	4.95	-0.74	98.27	33.49	6.42
5.22	4.95	4.95	-1.90	86.88	20.76	2.71
5.36	4.95	4.95	-3.06	75.49	9.60	0.64
5.50	4.95	4.95	-4.22	64.09	0.00	-0.00

Maximum shear force = 332.11 kN/m
Maximum moment = 348.63 kNm/m
Maximum displacement = 41.6 mm

Reactions in supports

No.	Depth [m]	Displacement [mm]	Reaction [kN]
1	5.00	0.0	58.70

Anchors forces

No.	Depth [m]	Displacement [mm]	Anchor force [kN]
1	2.30	22.7	350.00
2	2.50	21.0	350.00

Internal stability of anchor system - partial results

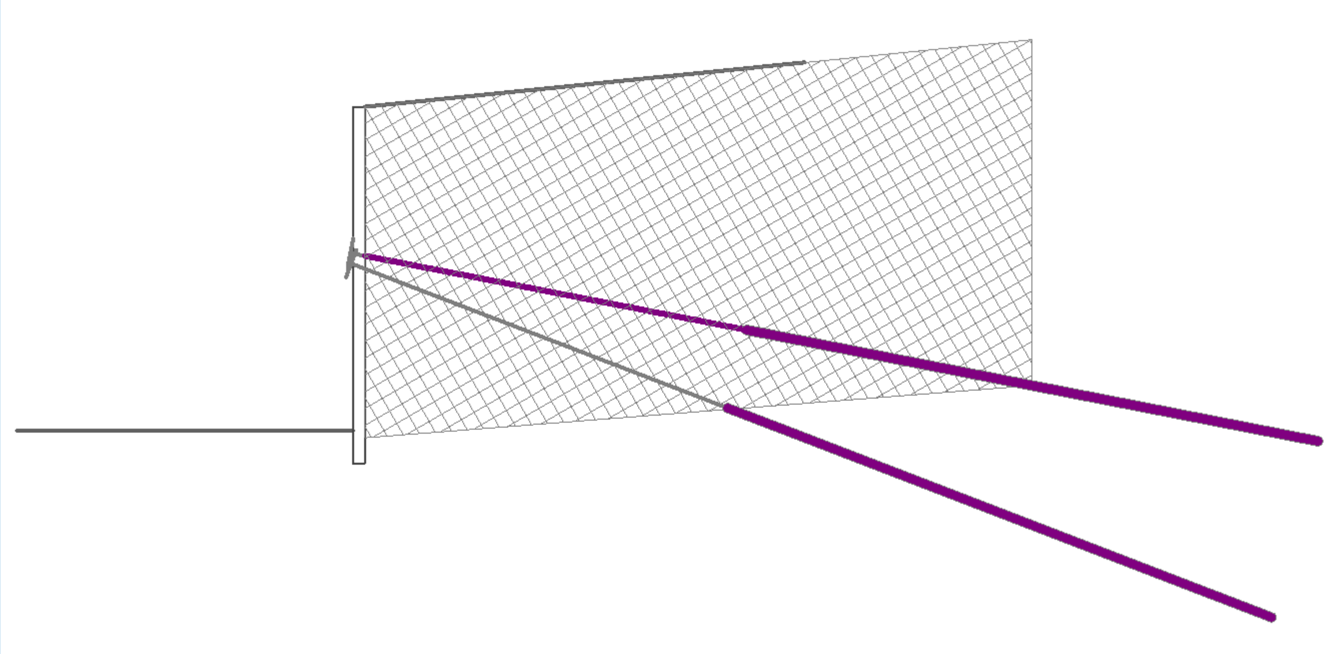
E_A = 61.48 kN/m δ = 0.00 °

Depth of theoretical footing under bottom of the pit H_0 = 0.11 m

Row of anchors	E_{A1} [kN/m]	δ_1 [°]	G [kN/m]	C [kN/m]	θ [°]	Included rows of anchors	Q [kN/m]	F [kN/m]	FK_{MAX} [kN]
1	63.25	0.06	1303.78	2481.26	4.47		40516.35	2557.58	2557.58
2	121.45	0.02	1489.37	2368.84	-6.71	1	8339.80	2208.17	2208.17

Internal stability of anchor system check

Name : Internal stability	Stage - analysis : 1 - 1



No.	Anchor force [kN]	Max.allow.force in anchor [kN]	Verification
1	350.00	2557.58	Is satisfied
2	350.00	2208.17	Is satisfied

Decisive anchor row : 2
Max. allowable force F_{max} = 2208.17 kN > 350.00 kN = F_{inp}
Overall verification of internal stability is SATISFACTORY

7.1.2. ANALYTICAL CALCULATIONS FOR WELDS

As mentioned in the drawings, the anchoring must be ensured with the angles shown above and the tie rod must be tightened until the point when we reach the horizontal acting force at the value of 55 Tons equivalent to the value of 550 kN.

This means that the welding that will be performed to join the tie rod and the anchors to the steel plate must withstand such a force.

Based on Eurocode 8.3-8, where it is mentioned that the design resistance per unit length of the weld is:

$F_{w,Rd} = f_{vw.d} * a$ (4.3)

Where:

$f_{vw.d}$ is the design shear strength of the weld.

Design shear strength $f_{vw.d}$ of welding should be determined by:

$$f_{vw.d} = \frac{f_u / \sqrt{3}}{\beta_w \gamma_{M2}} \qquad \text{... (4.4)}$$

Where:

$f_u = 490\ N/mm^2$

and β_w is defined in 4.5.3.2(6).

EN 1993-1-8 : 2005 (E)

Table 4.1: Correlation factor β_w for fillet welds

Standard and steel grade			Correlation factor β_w
EN 10025	**EN 10210**	**EN 10219**	
S 235 S 235 W	S 235 H	S 235 H	0,8
S 275 S 275 N/NL S 275 M/ML	S 275 H S 275 NH/NLH	S 275 H S 275 NH/NLH S 275 MH/MLH	0,85
S 355 S 355 N/NL S 355 M/ML S 355 W	S 355 H S 355 NH/NLH	S 355 H S 355 NH/NLH S 355 MH/MLH	0,9
S 420 N/NL S 420 M/ML		S 420 MH/MLH	1,0
S 460 N/NL S 460 M/ML S 460 Q/QL/QL1	S 460 NH/NLH	S 460 NH/NLH S 460 MH/MLH	1,0

In this specific case:

$f_u = 490\ N/mm^2$

$\beta_w = 0.9$

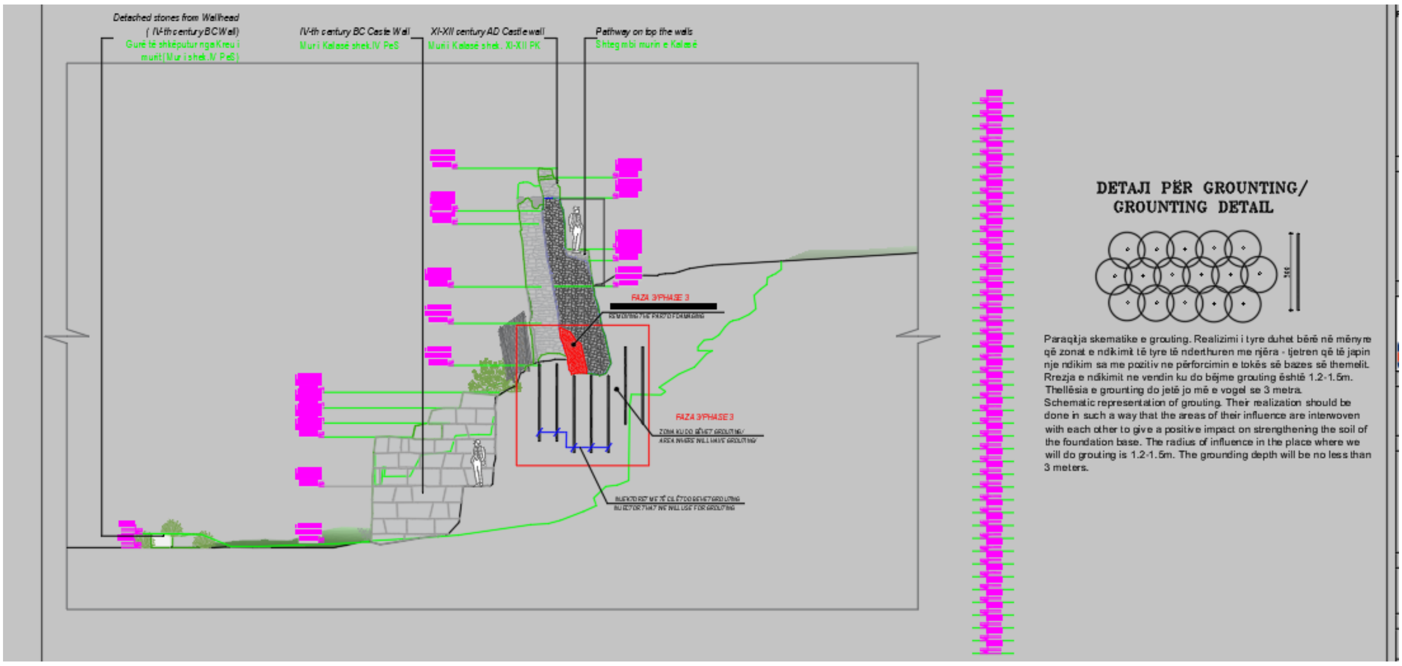
$\gamma_{M2} = 1.25$

a = 7 mm (the thickness of the welding throat)

Consequently, $f_{vw.d}$ = 252 N/mm^2
$F_{w,Rd}$ = 252 * 4 * 7=7056 N/mm

Since the length of the welding seam is 40 cm and the force per unit length is 7056 N/mm, it results that the total force is 7056 * 400 = 2822400 N = 2822.4 KN > 550 KN

3. PHASE 3
After the first two phases have been completed and the wall has reached the target stability, we will continue with phase 3, which consists in removing the damaged part at the bottom of the wall. This bottom part will be replaced with a wall with the same materials and the same construction technique.
Also at this stage, the grouting of the base foundation of the wall **(not on the wall)** around it from the outside is foreseen.
To keep in mind, to verify carefully before doing the grouting works and repairing the damaged wall in order not to damage, but to achieve the required results efficiently.



7.1.2. ANALYTICAL CALCULATIONS FOR THE REINFORCEMENT OF THE GROUND AND BEARING CAPACITY

Slope stability analysis

Input data

Project

Settings

EN STANDART (2)

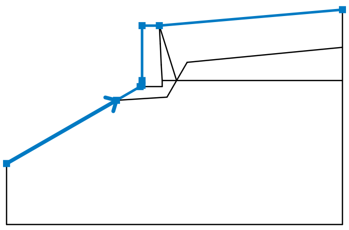
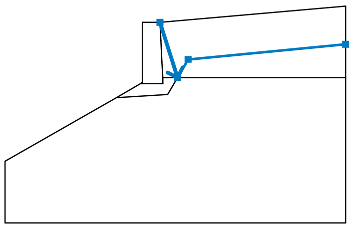
Stability analysis

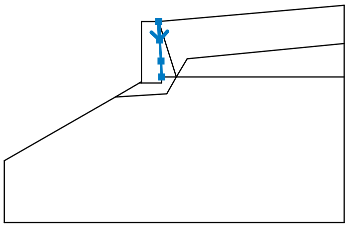
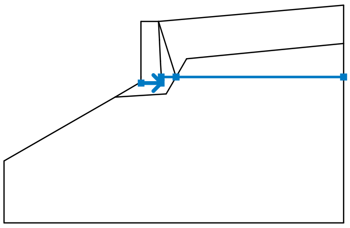
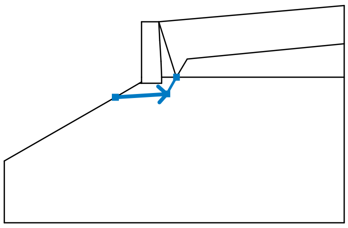
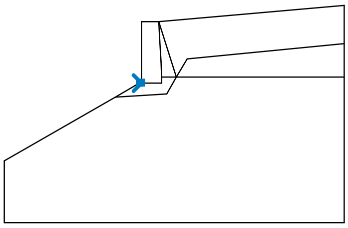
Earthquake analysis : Standard
Verification methodology : according to EN 1997
Design approach : 3 - reduction of actions (GEO, STR) and soil parameters

Partial factors on actions (A)									
Seismic design situation									
		State STR				State GEO			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.00	[–]	1.00	[–]	1.00	[–]	1.00	[–]
Variable actions :	γ_Q =	1.00	[–]	0.00	[–]	1.00	[–]	0.00	[–]
Water load :	γ_w =					1.00	[–]		

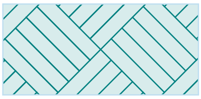
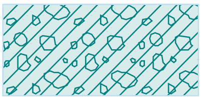
Partial factors for soil parameters (M)			
Seismic design situation			
Partial factor on internal friction :	γ_ϕ =	1.00	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]

Interface

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		-12.50	-11.31	-3.51	-6.13	-1.57	-5.00
		-1.40	-4.90	-1.40	-4.50	-1.40	0.00
		0.00	0.00	15.00	1.31		
2		0.00	0.00	1.43	-4.50	2.29	-3.02
		15.00	-1.79				

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
3		0.00	0.00	0.08	-1.50	0.17	-3.22
		0.23	-4.50				
4		-1.40	-5.00	0.23	-5.00	0.23	-4.50
		1.43	-4.50	15.00	-4.50		
5		-3.51	-6.13	0.64	-5.86	1.43	-4.50
6		-1.57	-5.00	-1.40	-5.00	-1.40	-4.90

Soil parameters - effective stress state

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m³]
1	LAYER 1		20.00	25.00	20.60
2	LAYER 2		10.00	300.00	26.50

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m^3]	γ_s [kN/m^3]	n [–]
1	LAYER 1		26.90		
2	LAYER 2		27.00		

Soil parameters

LAYER 1

Unit weight :	γ =	20.60 kN/m^3
Stress-state :	effective	
Angle of internal friction :	φ_{ef} =	20.00 °
Cohesion of soil :	c_{ef} =	25.00 kPa
Saturated unit weight :	γ_{sat} =	26.90 kN/m^3

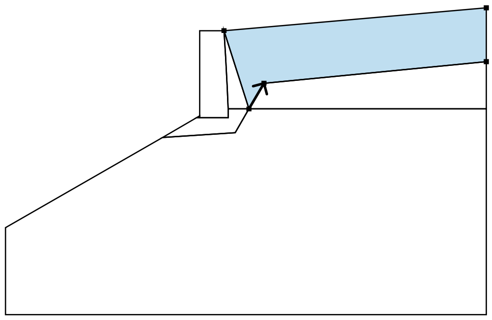
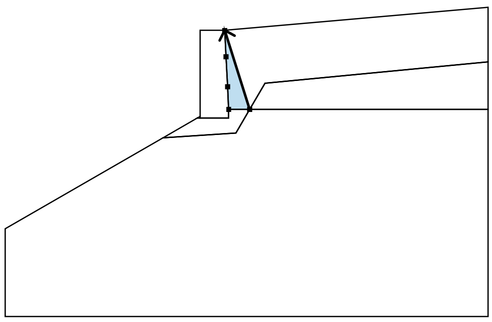
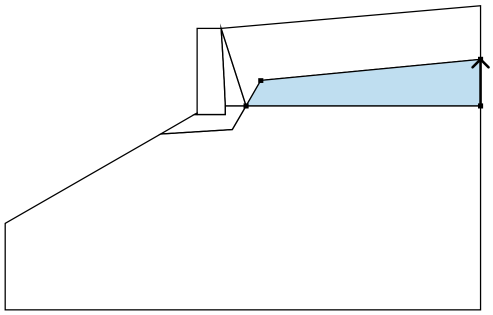
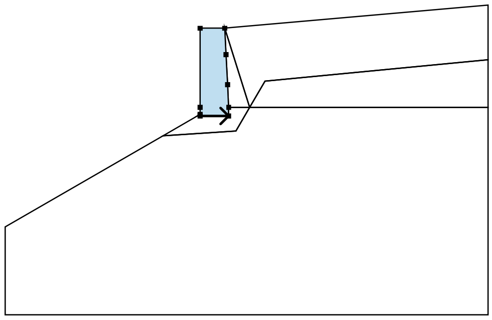
LAYER 2

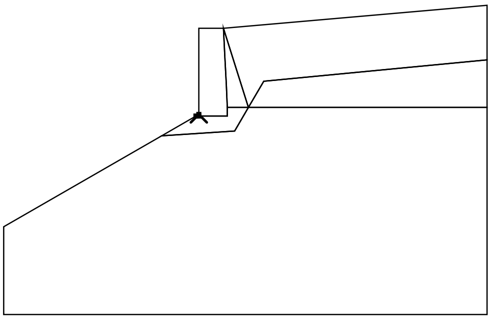
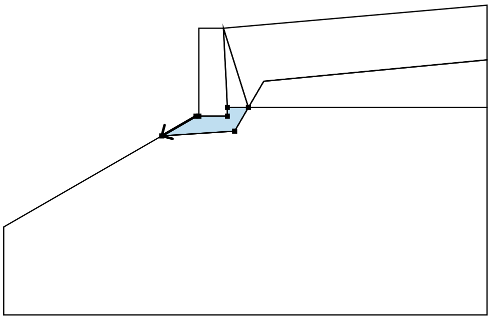
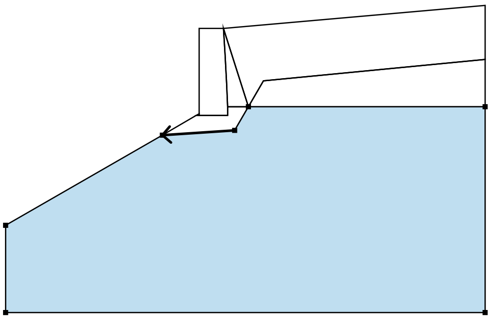
Unit weight :	γ =	26.50 kN/m^3
Stress-state :	effective	
Angle of internal friction :	φ_{ef} =	10.00 °
Cohesion of soil :	c_{ef} =	300.00 kPa
Saturated unit weight :	γ_{sat} =	27.00 kN/m^3

Rigid bodies

No.	Name	Sample	γ [kN/m^3]
1	Wall material		0.00

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		1.43	-4.50	2.29	-3.02	LAYER 1
		15.00	-1.79	15.00	1.31	
		0.00	0.00			
2		1.43	-4.50	0.00	0.00	LAYER 1
		0.08	-1.50	0.17	-3.22	
		0.23	-4.50			
3		15.00	-4.50	15.00	-1.79	LAYER 2
		2.29	-3.02	1.43	-4.50	
4		-1.40	-5.00	0.23	-5.00	Wall material
		0.23	-4.50	0.17	-3.22	
		0.08	-1.50	0.00	0.00	
		-1.40	0.00	-1.40	-4.50	
		-1.40	-4.90			

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
5		-1.40	-5.00	-1.40	-4.90	LAYER 2
		-1.57	-5.00			
6		-1.57	-5.00	-3.51	-6.13	LAYER 1
		0.64	-5.86	1.43	-4.50	
		0.23	-4.50	0.23	-5.00	
		-1.40	-5.00			
7		0.64	-5.86	-3.51	-6.13	LAYER 2
		-12.50	-11.31	-12.50	-16.31	
		15.00	-16.31	15.00	-4.50	
		1.43	-4.50			

Anchors

No.	Origin		Length and slope / coordinates		Anchor spacing	Diameter / area	Elastic modulus	Tensile strength	Active	Force
	x [m]	z [m]	l [m] / x [m]	α [°] / z [m]	b [m]	d [mm] / A [mm2]	E [MPa]	F_c [kN]	in compress.	F [kN]
1	-1.40	-2.00	l = 15.00	α = 11.00	1.00	d =			No	110.00
2	-1.40	-2.00	l = 15.00	α = 21.00	1.00	d =			No	110.00

Water

Water type : No water

Tensile crack

Tensile crack not inputted.

Earthquake

Horizontal seismic coefficient : K_h = 0.16
Vertical seismic coefficient : K_v = 0.08

Settings of the stage of construction

Design situation : seismic

Results (Stage of construction 1)

Analysis 1

Circular slip surface

Slip surface parameters							
Center :	x =	-10.22	[m]	Angles :	α_1 =	9.66	[°]
	z =	37.78	[m]		α_2 =	34.18	[°]
Radius :	R =	44.13	[m]				
Analysis of the slip surface without optimization.							

Slope stability verification (Bishop)
Sum of active forces : F_a = 448.33 kN/m
Sum of passive forces : F_p = 2815.56 kN/m

Sliding moment : M_a = 19784.69 kNm/m
Resisting moment : M_p = 124250.71 kNm/m
Utilization : 15.9 %

Slope stability ACCEPTABLE

8. ANNEX

Attached to this document you will also find the drawings for the structural intervention of the anchored wall. The drawings are detailed and provide the right explanations to make the structural intervention efficient and safe as possible.

Technical Specification for Grouting

Product	Ultra Low Strength	Standard Strength	Ultra High Strength
Description	An ultra low strength grout which has the charactaristics of a stiff clay when set. Used for underbase grouting of gravity-based structures and pipeline tunnel filling, where soil-like properties are required. The low specific gravity of the mix means that large volumes can be produced using small cement quantities.	The original industry standard grout commonly used for grouting platform main legs, where ultra high strengths are not required. Can be injected using conventional displacement or pressure grouting techniques. Also used for filling fabric formwork pipeline supports.	Ultra high strength grouts are used for offshore wind turbine foundations which require grout strengths of 100 MPa or greater. They are also used for member filling of aging or damaged offshore platforms to improve member strength and increase its life expectancy.
Mean Strength* at 8°C at 28 days MPa	0.5 - 2	55 - 80	95 - 110
Mean Strength* at 20°C at 28 days MPa	0.5 - 2	55 - 80	> 135
Mean Strength* at 28 days PSI	75 - 290	7975 - 11600	> 19500
Flexural Strength MPa	--	5 - 8	15 - 18
Young's Modulus GPa	--	18 - 24	38 - 42
Mixed Density SG	1.1 - 1.3	1.92 - 2.05	2.35 - 2.45
Mixed Density lb/US gal	9 - 11	16 - 17	19 - 20
Application(s)	• Underbase grouting • Pipline tunnel annulus filling	• Structural pile grouting • Fabric Formwork filling • Structural repair clamps • Platform member strengthening	• Monopile Transition Piece grouting • Structural Pile grouting • Platform member strengthening • Caisson repair
Formulation	Cement, Seawater and Silicate	Cement and Seawater	Cementitious material and Freshwater
Cement type	OPC / CEM I / ASTM Class 1	OPC / CEM I / ASTM Class 1 or 2 / Oilwell G	Masterflow 9500
Mixing Method	RJM & Silicate Metering System	RJM & Colloidal Batch Mixer	Proprietry Batch Mixer
Optimum Delivery Hose Diameter (inch)	2	2	3
Mixing Rate (m^3/hr)	40	25	8
Transportation	Bulk tank	Bulk tank	Big bags