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Analysis of alternative solutions for Terramesh system

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Abstract

Upon the request of the investor, alternative solutions for retaining structure on the South of graveyard Dubac are analysed. The structure was originally designed as Terramesh system founded on anchored reinforced concrete walls and piles. Three alternative solutions are suggested and analysed considering the effect on already constructed bottom structure, complexity of construction, economic and aesthetic aspect.

1 Location

Construction of local graveyard is planned on the location Dubac in Župa Dubrovačka, approximately 7 km south-east of Dubrovnik. The terrain is dominantly rocky (highland by the sea, around 153 meters above the sea level) with waste fill material (crushed stone with clay and construction waste) in the central part of plateau.

Due to characteristic configuration of the terrain, retaining structure, located at the south part of the location, was designed to ensure denivelation between terrain level and the level of future graveyard and safety of the slope.

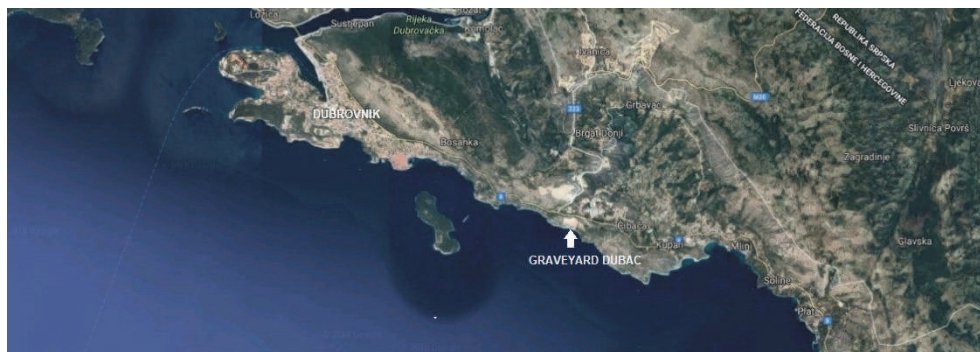


Fig. 1: Location of the graveyard Dubac



Fig. 2: View from the sea



Fig. 3: View from the south side

2 Geotechnical investigations

Geotechnical characteristics of soil and rock were determined based on geotechnical investigations which included: boring (4 boreholes drilled to a depth of 20 meters below ground surface), in-situ testing (standard penetration tests), geophysical exploration (seismic refraction analysis and multichannel analysis of surface waves – 9 geophysical profiles) and laboratory testing on collected samples.

According to geotechnical elaborates (Geotehnički studio Ltd. (2009) and APSIDA inženjering Ltd. (2016)) there are three main geotechnical layers on the location of graveyard Dubac:

- first geotechnical layer – waste fill material (crushed stone with clay and construction waste)
- second geotechnical layer – clay and weathered carbonate rock material,
- third geotechnical layer – rock mass (foraminiferal limestone and marl).

Rock mass boundary (approximately 15 m below ground level) was determined according to geophysical profiles of longitudinal waves. The profiles are result of the seismic refraction analysis which is based on the fact that seismic waves are refracted on soil layer boundaries and have different velocities in different soil types (Centar građevinskog fakulteta Ltd. (2016)). According to afore-mentioned profiles potential weak rock areas are recognised.

During geotechnical investigation underground water was not detected. Nevertheless, due to terrain morphology, water accumulation and percolation are possible during heavy rainfall.

Dubrovnik area, where graveyard Dubac is located, is very seismically active area. Therefore, it is very important to take behaviour of the structure under seismic loading into account. Reference peak ground acceleration for bedrock $a_{gR} = 0.297g$ for return period of 475 years was determined in accordance with map of seismic areas of Republic of Croatia.

Characteristic values of soil parameters were determined based on results of standard penetration tests. Rock mass parameters were determined based on results of laboratory testing of uniaxial compression strength of intact rock and point load test, according to the Hoek – Brown criterion.

Tab. 1: Characteristic values of soil/rock parameters used in numerical analysis

Parameter	Waste fill	New rock fill	Clay	Weathered rock	Rock mass
γ (kN/m ³)	19	20	19	21	22
E_{50}^{ref} (kN/m ²)	30 000	40 000	-	-	-
E (kN/m ²)	-	-	5 000	980 000	3 500 000
E_{oed}^{ref} (kN/m ²)	30 000	40 000	-	-	-
E_{ur}^{ref} (kN/m ²)	90 000	120 000	-	-	-
m	0.5	0.5	-	-	-
ν_{ur} (ν)	0.2	0.2	0.25	0.25	0.25
c' (kN/m ²)	2	1	5	60	133
φ' (°)	32	35	22	41	51

γ – soil unit weight; E_{50}^{ref} – secant stiffness in standard drained triaxial test (*Hardening soil model*); E – Young’s modulus (*Mohr-Coulomb model*); E_{oed}^{ref} – tangent stiffness for primary oedometer loading (*Hardening soil model*); E_{ur}^{ref} – unloading/reloading stiffness (*Hardening soil model*); m – power of stress-level dependency of stiffness; ν_{ur} (ν) – Poisson’s ratio; c' – cohesion; φ' – friction angle

3 Numerical analysis

Numerical analysis of deformations and stability in characteristic phases of construction was performed in computer program Plaxis 2D. Plaxis 2D is two-dimensional finite element program used to perform deformation and stability analysis for various types of geotechnical applications (PLAXIS 2D Reference Manual (2012)).

Analysed retaining structures were modelled using:

- "plate" elements for piles and wall structures,
- "anchor" elements for free anchor lengths,
- "geogrid" elements for bond anchor lengths and tension elements,
- "embedded pile row" elements for micropiles.

Soil layers were modelled using *Hardening soil model* for 1st geotechnical layer and *Mohr – Coulomb model* for 2nd and 3rd geotechnical layer.

The results of analysis were: value of stress and strain in the structure and surrounding soil, internal forces in the structure and the value of global safety factor. The value of global safety factor was checked through "Safety analysis" option in the Plaxis 2D Calculations program. In the "Safety analysis", the strength parameters $\tan \varphi$ and c (friction angle and cohesion) of the soil are successively reduced until failure of structure occurs (PLAXIS 2D Reference Manual (2012)).

Seismic loading was modelled by inputting horizontal ($a_h=0.15g$) and vertical ($a_v=0.075g$) ground acceleration. The value of the horizontal and vertical acceleration was determined in accordance with Eurocode 8 ($a_{gR} = 0.297g$), using soil type A, elastic spectrum Type 1 and reduction factor $r=2.0$ for flexible retaining structures and slopes (reduction factor r is generally in the range of 1.0 to 2.0, depending on the type of the structure and allowable movement). The additional acceleration is activated in the Plaxis 2D Calculations program by the load multiplier " ΣM_{accel} ".

4 Original design solution

Original design solution in form of Terramesh system was designed as optimal solution considering drainage of surface and underground waters, structure behaviour under seismic loading (flexible structure resistant to earthquake) and financial aspect (Geotehnički studio Ltd. (2016)). Terramesh system (upper retaining structure) lies on anchored reinforced concrete walls and piles. The type of bottom/foundation structure depends on the depth of bedrock.

For this paper, characteristic cross section with anchored pile wall was analysed. The piles are bored cast-in-situ reinforced concrete piles (8 m long, 80 cm in diameter, distance between piles = 2.40 m), connected with reinforced concrete capping beam and supported with one row of permanent prestressed strand anchors (18 m long, distance between anchors = 2.40 m).

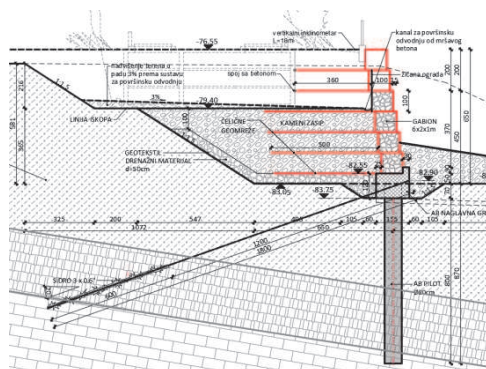


Fig. 4: Characteristic cross section (Terramesh system + anchored pile wall)

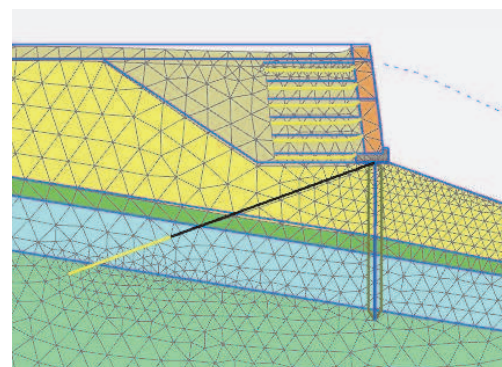


Fig. 5: Numerical model (Terramesh system + anchored pile wall)

5 Alternative solutions

Upon the request of investor, alternative solutions for Terramesh system were analysed. It was very important to validate the effect of upper structure on already constructed bottom part of the retaining structure.



Fig. 6: Constructed anchored pile wall (bottom retaining structure)

Three alternative solutions were analysed:

- reinforced concrete L wall with micropiles,
- anchored reinforced concrete L wall with reduced footing,
- reinforced earth system.

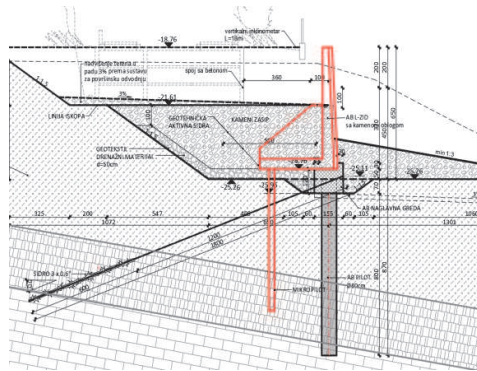
For suggested alternative solutions preliminary cost analysis, as well as preliminary static analysis and pseudo-static analysis of seismic loading were performed on characteristic retaining structure cross section.

5.1 Reinforced concrete L wall with micropiles

First alternative solution is reinforced concrete L wall 6 m high, with footing 3.50 m long and buttresses on the back side of the wall. The wall partly lies on the bottom structure and partly on the rock fill behind the wall. For improved aesthetics, stone wall facing is predicted.

Result of numerical analysis in Plaxis 2D is the effect of the first alternative solution on the bottom structure. Increase in system stiffness, in comparison with Terramesh system, results in increase of contact stress on the bottom structure. Furthermore, on the part where the footing lies on the rock fill, settlement of the L wall is noted, which leads to the rotation of the wall and additional concentrated loads on the bottom structure. For the prevention of wall settlement, it is recommended to perform bored micropiles with steel profiles (length ≈ 7 m, distance between piles = 2.40 m) to support the foundation of the wall.

Considering impermeability of reinforced wall system, reconstruction of drainage system is required to ensure surface and underground water evacuation.



5.3 Reinforced earth system

Third alternative solution is reinforced earth system with precast reinforced concrete blocks facing and geogrid reinforcement. Geogrid reinforcement is locked between the concrete blocks and placed horizontally within compacted rock fill behind the wall.

The structure is very similar to originally designed Terramesh system so the effect on bottom retaining structure is nearly equal. It is important to retain the same length of tension element (geogrid length) as in Terramesh system, to achieve the same effect on the bottom structure. Application of precast reinforced concrete blocks instead of rock filled gabions results in enhanced flatness of the wall face and improved aesthetics.

Disadvantage of the solution is in availability of precast elements in the subject area, as well as specificity of technical solution which requires staff training and enhanced construction supervision.

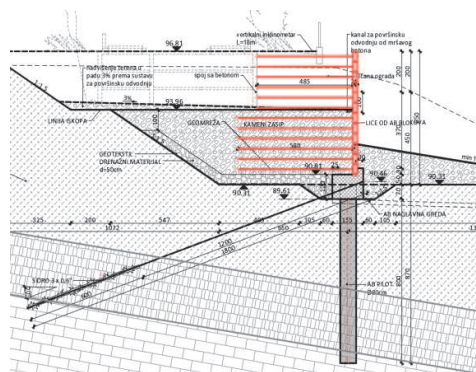


Fig. 11: Characteristic cross section (reinforced earth system + anchored pile wall)

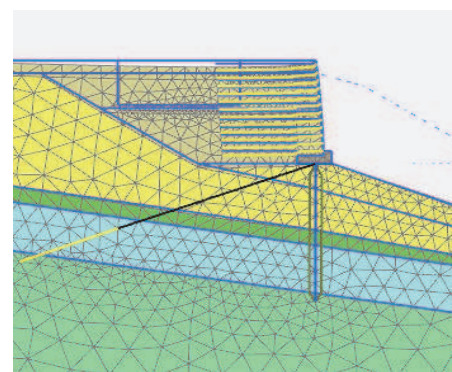


Fig. 12: Numerical model (reinforced earth system + anchored pile wall)

6 Comparison of alternatives

Four selection criteria for optimal alternative solution are:

- the effect on bottom retaining structure (static criterion),
- complexity of construction,
- economic criterion,
- aesthetic criterion.

According to the results of numerical analysis (table 2), all considered alternative solutions have similar effect on the bottom retaining structure as originally designed Terramesh system. Therefore, they all satisfy the static criterion.

However, in case of reinforced concrete walls (stiff structures), increase of contact stress with the bottom structure might lead to problems with bottom structure stability during earthquake and need for additional strengthening to maintain the same safety factor for seismic loading as originally designed.

Tab. 2: Results of numerical analysis in *Plaxis 2D*

		PILES				ANCHORS
		u_x (cm)	M_d (kNm)	T_d (kN)	N_d (kN)	F_d (kN)
ORIGINAL SOLUTION	STATIC	0.15	211	314	1199	259
	ϕ/c ANALYSIS	-	511	432	811	192
	PSEUDOSTATIC ANALYSIS	2.30	936	679	1097	439
1 ST ALTERNATIVE	STATIC	0.19	622	304	1798	259
	ϕ/c ANALYSIS	-	590	384	1495	290
	PSEUDOSTATIC ANALYSIS	2.20	960	660	1937	439
2 ND ALTERNATIVE	STATIC	0.18	308	356	1552	217
	ϕ/c ANALYSIS	-	377	494	1097	212
	PSEUDOSTATIC ANALYSIS	1.80	782	773	1493	348
3 RD ALTERNATIVE	STATIC	0.20	227	301	1273	275
	ϕ/c ANALYSIS	-	538	398	943	343
	PSEUDOSTATIC ANALYSIS	2.30	893	667	1138	461

First and second given alternative are rated as technically complex solutions that require performance of special geotechnical works (bored micropiles and prestressed anchors). Consequently, they do not satisfy the complexity of construction criterion.

For installation of micropiles it is necessary to provide working area for boring. During the installation it is important to pay attention to the location of bottom structure anchors. Also, vibrations from the pile boring equipment could cause damage on the bottom retaining structure.

For installation and prestressing of anchors it is necessary to prepare temporary scaffold and ramp for equipment.

Construction of the third alternative solution is based on the same principles as construction of Terramesh system – installation of precast reinforced concrete blocks, installation of geogrid reinforcement, placing and compaction of rock fill material in layers. All installation works are placed in the back of the structure, so no additional scaffolds or ramps are needed.

Preliminary cost analysis was made according to price lists of construction works given in December 2017.

For original solution Terramesh system segments (gabions with tendons) are considered. For one meter of structure 6 m³ of Terramesh system segments are required. Price for one meter of structure is approximately 1 150 €.

For cost estimate of the first alternative it is necessary to consider the cost of:

- formwork (15 m²/m' of structure)
- reinforcement (750 kg/m' of structure)
- concrete (5 m³/m' of structure)
- stone facing of the wall (1.20 m³/m' of structure)
- micropiles (2.90 m'/m' of structure).

Total price for one meter of structure is approximately 2 620 €.

For cost estimate of the second alternative it is necessary to consider the cost of:

- formwork (13 m²/m' of structure)
- reinforcement (525 kg/m' of structure)
- concrete (3.50 m³/m' of structure)
- stone facing of the wall (1.20 m³/m' of structure)
- anchors (10 m'/m' of structure).

Total price for one meter of structure is approximately 2 900 €.

For cost estimate of the third alternative it is necessary to consider the cost of:

- precast reinforced concrete blocks with couplings (1.20 m²/m' of structure)
- geogrid reinforcement (70 m'/m' of structure).

Total price for one meter of structure is approximately 950 €.

Based on the cost analysis, the first and the second alternatives are 2 – 3 times more expensive than original solution. The third alternative solution is the most cost-effective solution. Differences in the prices are a result of performance of special geotechnical works (installation of micropiles and installation and prestressing of anchors).

All suggested alternative solutions fulfil aesthetic criterion – flatness of the wall facing and fitting into design of the future graveyard.

7 Conclusion

Based on the analysis results, all given alternative solutions satisfy static and aesthetic criterion. Possible problems with bottom structure stability, for the first and the second alternative solution, could occur for earthquake loading due to increased contact stress.

As a result of performance of special geotechnical works, reinforced concrete wall systems do not satisfy complexity of construction nor economic criterion.

Third given alternative solution – reinforced earth system fulfils all selection criterions and is rated as optimal alternative for Terramesh system.

8 References

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