

Slope's design for quarry's remediation using ground materials of Piraeus subway excavation

M. Chatziangelou¹, B. Christaras¹, K. Botsou², Em. Malliaroudakis³

¹Department of Geology, Aristotle University of Thessaloniki, Greece.
mcha@geo.auth.gr

christar@geo.auth.gr, tel. +30 2310 998506, +30 6944332554

² 7, Kirillou & Methodiou st. Kalamaria, Thessaloniki, Greece.

³ J&P-AVAX Group, 16 Amarousiou-Halandriou str., 151 25, Marousi, Greece

Abstract

Chaidari-Piraeus subway is the under construction line of Athens subway extension driving to Piraeus city. At subway's beginning, metamorphic rocks are placed, which are replaced by sedimentary formations driving to Piraeus city.

Taking into account that TBM will be used for underground excavations, the above geological excavation products will adopt soil characteristics. So, circular sliding is expected on the excavation products deposits.

The present paper investigates and suggests the appropriate safety slope geometry of deposits using them for remediation of quarries. The Chamilothoris quarry, which is placed at Koridalos city, near the constructions, is used as an example of proposed geometry application.

Taking into account slope stability of deposits, terraces from 3,5m to 5m height, lower downstairs and higher upstairs, inclined from 30° to 60°, where dips increase from downstairs to upstairs, so as geometry approaches the sliding circle, are proposed to be constructed. Also, enough space, somewhere at the upper stages and downstairs, is indispensable in order to accept the pieces which may fall because of erosion or weathering.

Also, deposits materials with poor mechanical properties are proposed to be placed downstairs, where the slope is formed by small inclinations. Cohesive materials are proposed to be placed upstairs. Excavation products which consists of no cohesive materials, are ought to be placed at the center of quarry, so as they do not influence on slope stability.

Furthermore, drainage layers with dip of 15°, lengthen 15m are also proposed to be put on every terrace.

Keywords; Slope design, Quarry, Piraeus subway, Slope stability, Remediation

1. Introduction

"Chaidari-Piraeus" subway is the under construction line of Athens subway extension driving to Piraeus city. The excavated geological formations consist of metamorphic rocks in Chaidari area, while in Piraeus city the geomaterials consist of sedimentary formations. Taking into account that TBM was used for that underground excavations, the above excavation products adopt soil characteristics (Kymar and Samui, 2006). The present paper investigates the use of deposits for quarries remediation. For this reason, it suggests the appropriate safety slope geometry using Chamilothoris quarry as example.

2. Initial consideration

Taking into account that TBM is used for the subway's excavation, the excavated rock mass is destroyed and soiled. So, the deposits of geological formations of Piraeus subway excavation behave as soil, which means that the potential failures of the formed slopes are circular sliding. Thus, in order to analyze the stability of the slopes (Bishop & Morgenstern, 1960), of the remediated products, the balance of a critical circular sliding surface, which is cut in to a numerous sliding slides with the same width, is examined using Bishop Method (Bishop, 1955).

The geomechanical properties (Craig, 2005) and the percent of the geological formations appearance are showed on table 2.1. The lowest prices of friction angle and cohesion, in addition to average of the prices of dry density are used, so as the conclusions may approach reality.

3. Slopes stability investigation

Table 2.1. Geomechanical properties and percent of geological formations' appearance along Piraeus subway excavation

Geological formation	Type	Percent of total appearance %	c(kPa)	$\phi(^{\circ})$	Dry density (kN/m ³)
Meta-madstone – Clayey schist	AS-PH	14,5	003-50	17-30	19-26
Meta-madstone	AS-SL	3	00-74	20-30	16-26
Meta-madstone – Meta-sandstone	AS-STL	16	004-48	20-30	17-24
Claystone	NG-MS	2	0012-35	20-30	13-24
Marl - madstone	NG-ML	5,5	35-82	25-30	16-23
Meta-sandstone - Schistolite	AS-ST	12,5	00-26	25-40	18-27
Meta-madstone – Clayey schist – Meta-sandstone	AS-PHS	0,5	19-25	17-30	19-24
Serpentinite	OPH	6	20-46	25-45	13-21
Limestone	K	8,5	0-5	>35	
Marl, Marley limestone	NM-MK	9	6-107	25-35	16-22
Silt and siltstone	PT-SM	7	5-214	20-30	15-18
Loose soil	SW	1		15-20	15
Conglomerates	PT-CN	1		20-30	23
Sand	PT-SD	2	18-177	20-30	15-19
Marl, siltstone, claystone	NM-MS	7,5	6-107	25-30	14-22
Sand stone, Claystone	NM-ST	4		20-30	18-23

Eight groups of geological formations are distinguished, in order to investigate the most suitable geometry of the slopes. The minimum geomechanical properties of dry density, cohesion and angle of friction are appeared on table 3.1.

Slope stability is estimated using different slope geometry, taking into account the percent of geological formations appearance and the excavated formations course (Abramson et al, 2002). So, slopes with heights of 24m, 28m, 29m, 32m and 33m are investigated. The dips of terraces are supposed to be the same of all terraces, between 30° and 60° (Berilgen, 2006), or to be different of every terrace between 15° and 90°. The heights of the terraces are supposed to be the same of all terraces 2m, 3m or 4m, or they are different for every terrace from 1,5m to 5m.

The width of the terraces is taking into account from 1m to 6m. Also, the terraces plates are examined as horizontal or inclined.

4. The most suitable geometry

Taking into account the above factors, that increase slope stability, the most suitable geometry of slope's design for quarry's remediation using ground materials of Piraeus subway excavation, is succeeded by;

- Terraces from 3,5m to 5m high, lower downstairs and higher upstairs
- Terraces inclined from 30° to 60°, where dips increase from downstairs to upstairs
- Creation of a wider level spot at the second terrace, under the foot of the slope, inclined 15°, increasing the restrained forces and forming a safe surface for accepting the material, which may fall from upstairs because of weathering or erosion.
- The sixth terrace, under the foot of the slope, is 6m wide, so as it can accept the upper weathered material.
- Terraces are preferred to be 4m wide, so as they may retain weathering material.
- Geometry approaches the sliding circle.
- Deposition of materials with poor mechanical properties downstairs, where the slope is formed by small inclinations.
- Deposition of cohesive materials with best mechanical properties upstairs.

5. Example of application on Chamilothis quarry's remediation

The Chamilothis quarry is placed at Koridallos area of Attica department. The location is near the construction works of Piraeus subway, so the quarry may be suitable for excavation material deposition (Fig.5.1).

Taking into account the above investigation of slope geometry and material deposition, the remediation of quarry can be achieved by eight terraces, which the height will be from 3,5m to 10m – increasing the slope angles from 30°, downstairs to 60°, upstairs. Near

Geological group	$\gamma(\text{KN/m}^3)$	$c(\text{KN/m}^2)$	$\phi(^{\circ})$
1	22	3	17
2	20	0	20
3	20	4	20
4	18	12	20
5	19	35	25
6	22	0	25
7	17	20	25
8	21	19	17

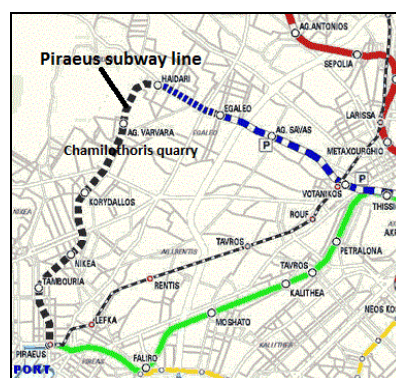


Fig.5.1. Location of Chamilothis quarry

the foot of the slope, the inclination of the second terrace will be 15° , so as the restrain powers will be enhanced, and it can also be a safe "plate" that can accept the eroded material or the pieces may fall from superior terraces.

The width of the terraces is chosen to be

4m for the following two reasons; the first one is the acceptability of the weathered material and the second one is the preservation of enough space for coming ways. In order the quarry's geometry approaches the sliding circle; the width of the fifth terrace is chosen to be 2,5m. Finally, the width of the sixth terrace is better to be 6m, so it can increase the stability, being a plate, which can accept the weathered material from the above terraces.

As the deposition of materials concerns, the materials with poor mechanical properties is proposed to be placed downstairs, where the dips of terraces are small, and cohesive materials are

proposed to be placed upstairs, where the terraces are sheer. So, materials of group 1, like meta-madstone or clayey schist, with cohesion more than 3kPa, friction angle more than 17° and apparent weight of 22kN/m^3 , can be deposited at the bottom of the quarry. Under the materials of group 1, materials of group 3, like meta-madstone or meta-sandstone, with cohesion more than 4kPa, friction angle more than 20° and apparent weight of 20kN/m^3 are proposed to be placed. On the middle of the slope, material of group 4, like clayey stone, with cohesion more than 12kPa, friction angle more than 20° and apparent weight of 18kN/m^3 , can be placed. Just above this formation, it can be deposited cohesive materials of group 5, like marl or mudstone, with cohesion more than 35kPa, friction angle more than 25° and apparent weight of 19kN/m^3 . Finally, on the upper terraces, materials of lower mechanical properties than the previous group can be placed, which cohesion may be at least 20kPa, the friction angle may be at least 25° and the apparent weight may be about 17kN/m^3 . These properties are described by material of group seven, like serpendinite (Fig.5.2). Materials of group 8 will be excavated far away from Chamilothis quarry, so they did not considered on our predictions.

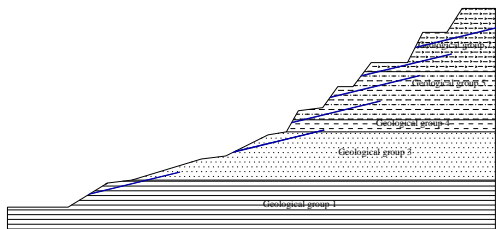


Fig .5.2. Deposition design and draining beddings arrangement for slope with height of 33m

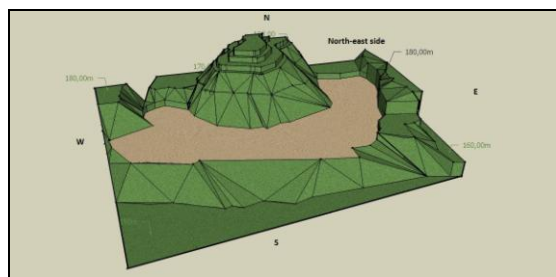


Fig .5.3. Chamilithori's quarry

Non cohesive materials, of groups 2 and 6, are not proposed to be placed on the external slopes, but they can be placed at the center of the quarry, between the slopes, so as their low mechanical properties don't influence slope stability.

In order to estimate the safety factor of the slopes of the quarry, 411 sliding cases are investigated for every slope. Taking into account the proposed geometry and deposition, the radius of critical circle on unsaturated conditions is calculated 66,286m and the safety factor 1,112 (Siddique et al, 2005) (Fig.5.4). Actually, the safety factors of the most critical sliding circles are up to 1,4, although there are some cases where the safety factor is higher than 1,4.

On saturated conditions, circular failure is estimated at the upper part of the first terrace. The radius of the critical sliding circle is calculated 28,2m and the safety factor is 0,017 (Fig.5.5). The safety factors of the most critical sliding circles are up to 1,2, although there are some cases where the safety factor is higher than 1,2. That means sliding may occur, where the load of the slope is increased, because of the presence of the water. Draining beddings inclined 15° , lengthen 15m, on every terrace, can direct the water out of the slope (Fig.5.2).

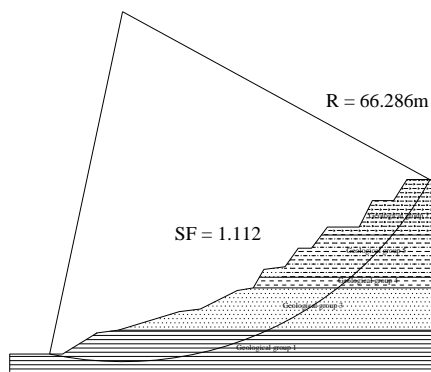


Fig . 5.4. Critical sliding circle of slope with height of 33m on unsaturated conditions

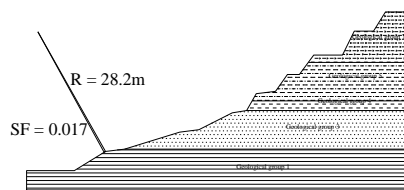


Fig .5.5. Small failure of the slope with height of 33m on saturated conditions

6. Conclusions

Taking into account that TBM is used for the subway's excavation, the excavated rock mass is destroyed and soiled. So, the deposits of geological formations of Piraeus subway excavation behave as soil. That means the failures of the sliding of the slopes, which are formed by excavation materials, are circled. In order to investigate the suitable geometry of slopes stability, eight groups of geological formations, with different mechanical characteristics, were distinguished, according to excavation formations.

Slope stability was estimated using different slope geometry, taking into account the percent of geological formations appearance and the excavated formations course.

The most suitable geometry of slope's design for quarry's remediation using ground materials of Piraeus subway excavation is succeeded by;

- Terraces from 3,5m to 5m height, lower downstairs and higher upstairs

- Terraces inclined from 30° to 60° , where dips increase from downstairs to upstairs
- Designing of enough space somewhere at the upper stages and downstairs, in order to accept the pieces which may fall because of erosion or weathering.
- Geometry approaches the sliding circle.
- Deposition of materials with poor mechanical properties downstairs, where the slope is formed by small inclinations.
- Deposition of cohesive materials with best mechanical properties upstairs.
- Use of cohesive material at the slopes and no cohesive materials at the middle of the quarry

The above investigation is applied on Chamilothis quarry's remediation. The radius of slopes critical circle in unsaturated conditions is calculated 66,286m and the safety factor 1,112. Actually, the safety factors of the most critical sliding circles are between 1,1 and 1,4, although there are some cases, where the safety factor is higher than 1,4.

In saturated conditions, circular failure is estimated at the upper part of the first terrace. The radius of the critical sliding circle is calculated 28,2m and the safety factor is 0,017. The safety factors of the most critical sliding circles are up to 1,2, although there are some cases where the safety factor is higher than 1,2. That means sliding may occur where the load of the slope is increased because of the presence of the water. The sliding may be deterred by draining beddings inclined 15° , lengthen 15 m, on every terrace, which they can direct the water out of the slope.

References

- Abramson, K.W., Lee, T.S., Sharma, S. and Boyce, G.M. (2002) Slope Stability and Stabilization methods. John Wiley & Sons Inc. pp. 712. Nash, 1987
- Berilgen, M. (2006). Investigation of stability of slopes under drawdown conditions, Computers and Geotechnics, Elsevier 2006, www.Elsevier.com
- Bishop, A.W. (1955) "The Use of the Slip Circle in the Stability Analysis of Slopes", Geotechnique, Great Britain, Vol. 5, No. 1, Mar., pp. 7-17
- Bishop, A.W. and Morgenstern, N. (1960) Stability Coefficients for Earth Slopes. Geotechnique. Institution of Civil Engineers, London, Vol. 10, No. 4, Dec., pp. 129-150.
- Craig, R.F. (2005). Craig's soil mechanics. Spon Press, Taylor and Francis Group, London and New York
- Kumar, J. and Samui, P. (2006). Stability Determination for Layered Soil Slopes using the Upper Bound Limit Analysis. Geotechnical and Geological Engineering Journal, Springer Publications, Vol. 24, 1803-1819.
- Siddique, A., Safiullah, A.M.M. and Ansary M.A.(2005). An investigation into embankment failure along a section of a major highway, Proceeding of the 16th International Conference on Soil Mechanics and Geotechnical Engineering, Vol.1-5, 2005, pp.979-983.