

Extreme terrain deformation in an uncontrolled waste disposal plant in Andros Island.

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Abstract

Uncontrolled waste disposal plants besides the environmental impact intensively alter the morphology setting of the sites and sometimes raise serious hazard issues. When developed in anthropogenic cavities (e.g. old quarries) they are considered as part of the restoration procedure and, excluding the environmental impact, they cause bearable alterations to the already damaged relief. On the contrary, when installed in natural cavities (e.g. stream valleys) their impact multiplies and, besides the terrain alteration, issues related with the impact on the hydrographic network and the stability of the waste disposal plant's slopes raise. The current study aims to investigate the factors that mostly influenced the manifestation of a failure, an extreme terrain deformation that occurred after an intense rainfall episode at an uncontrolled waste disposal plant in the island of Andros, Greece.

Key words: Uncontrolled waste disposal plant, extreme rainfall, terrain deformation, Andros Island.

1. Introduction

Distinctive geomorphologic changes have been recorded either as a consequence of human activities or as a consequence of extreme natural events, such as heavy rainfall and seismic activity (Burton et al. 1978; Price et al. 2011). Concerning human activities, large scale anthropogenic landscape changes have been recorded after extensive mining activity or urban waste disposal practises (Kerle 2002). These activities could be thought as the main topographic change agents that often lead to the occurrence of extensive catastrophic events. The present study describes such extreme terrain deformations encountered in an uncontrolled waste disposal in the island of Andros, Greece. The current plant has operated for decades using as recipient the natural valley of the nearby stream delimiting the peninsula. A huge slope failure occurred after an extreme rainfall episode, over 70mm, in February of 2011 causing extensive destruction of the site. Massive quantities of waste material (over 35.000 m³) were swept away by the running waters and ended in the adjust stream. The displacement of the waste masses formed very steep slopes at the disposal material cone, forming highly unstable slopes (fig 1a). The extreme flows of the masses were identified by the trace left by the movement along the slope of the stream (fig 1b).



Figure 1 a. View of the newly formed steep slopes, b. View of the waste material flow.

In this context the study involved a detail examination of the geological, hydrogeological and geotechnical conditions over the wider area of the uncontrolled waste disposal plant. Additional, volumetric and spatial analyses of the waste materials were conducted in order to estimate the pre and post-event topographic surface. For the estimation of the volume of waste material, elevation data were extracted using available topographic maps that represented the surface before the beginning of deposition and a recent laser scanning series of data that presented the post-event surface.

2. Study area and data used

2.1 Study area

The waste disposal plant is located in the island of Andros at the Strofilas peninsula and served the needs of residents of the municipalities of Andros, Korthiou, Idrousa, and also local communities over 32 years. Andros is the northernmost island of the Greek Cyclades archipelago, approximately 10 km south east of Euboea, and about 3 km north of Tinos (fig 2).



Figure 2 The study area

Regarding the morphological features of the wider area, there is a significant variation in morphological gradients as a result of the geological structure and tectonic activity along with the erosive action of water. The maximum morphological gradient was estimated to be 82° formed on slopes near the site of failure, while the average morphological gradient is calculated to be 19°. Approximately 70% of the total area of the basin has slopes of less than 20°, while the slope aspect in 60% of the total area is estimated to be of SSW – W direction. The morphology of the basin in which the plant is located is characterized as intense and in places where marble formations cover the surface it forms steep cliffs, almost vertical. The predominance of impermeable shales in conjunction with the intense morphological relief, create favorable conditions for increased surface runoff, especially during periods of heavy rainfall. Generally, Andros is the richest island of the Cyclades in amounts of surface waters. This is due to the amount of rainfall that is greater than other islands of the Cyclades and secondly to the fact that Andros comprise mainly of impermeable crystalline schists (Rozos et al. 2011). Concerning the climate features of the area, the climate is characterized as mild and dry. During the warmer months of June, July, August and September the daily temperatures normally reach an average top of 26C⁰. May and October have an average high temperature of 22C⁰. January is normally the coldest month with an average high temperature of 14C⁰ and average low temperature of 9C⁰. The assessment of the meteorological data that are collected from two stations that are operating since late to 2008, in the nearby island of Kea and Tinos, could not be considered representative of the rain gauge system at inter annual basis. However, the data gave an indication of the rainfall regime. On 14/9/2009, the maximum 24-hour rainfall in the station of Kea reached 130mm, while on the same day no rainfall data have been recorded in the station of Tinos, suggesting the local character of the occurrence of intense rainfall events during the spring and autumn period. On 3th and 4th of February 2011 (the date when the failure occurred) at the station of Kea the rainfall reached 95mm, while at the station of Tinos reordered 59.2mm. It is estimated that during the same period in Andros, particularly in the area of research, the amount of rainfall was much higher (Rozos et al. 2011).

2.2 Geological settings

Andros Island belongs to the so-called "crystalline Attiko-Cycladiki Mass" constructed almost entirely from metamorphic rocks, with complete lack of sedimentary rocks except of course of the compact or loose Quaternary formations. The crystalline mass is mainly composed from schists, marbles and some basic igneous rocks, while acidic rocks that cover some parts of the island are thought to be meta-tectonic appendages. According to Papanikolaou (1978) the study area (waste disposal site) is part of the geotectonic section of "Gerakonias" which involves the marbles of Messarias, the schists of Gerakonias and the marbles of Palaiokastrou. In more detail, the marbles that are present in the area (fig 3) are characterized as gray to dark-gray marbles, fine-medium stratified with moderate to extreme fragmentation.

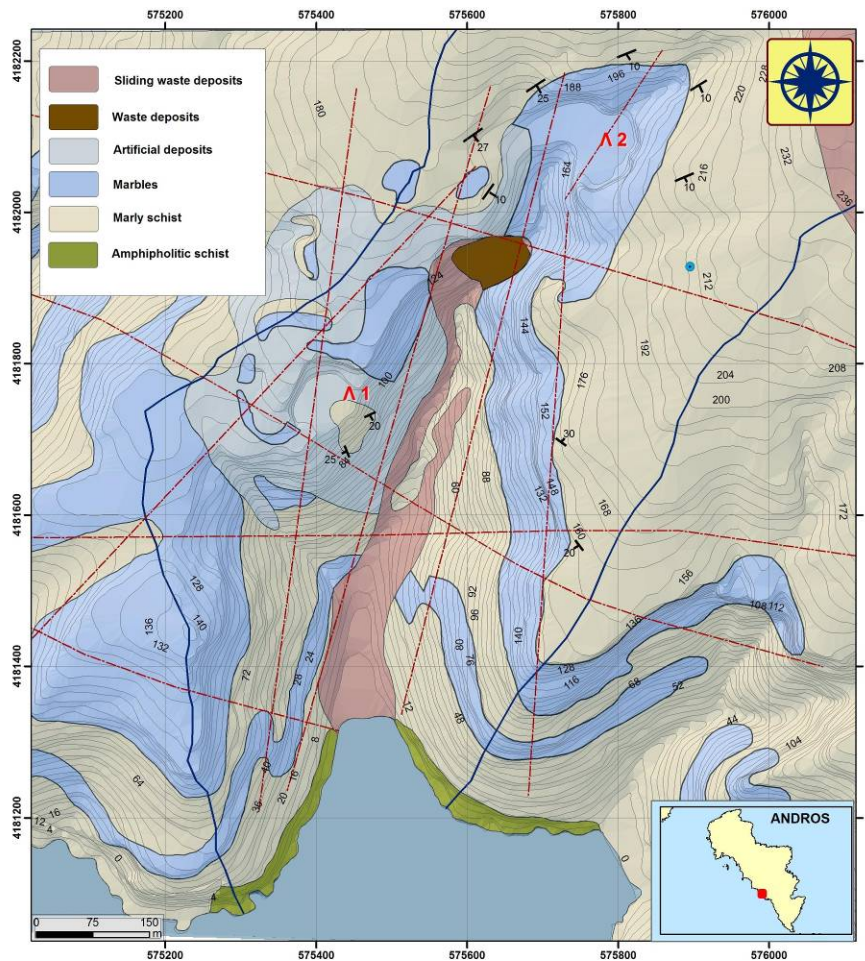


Figure 3 Geological Map

There are three (3) main discontinuity systems usually filled with calcite material although mica schist of varying thickness (up to 50cm) can also be found. In places, the marbles masses have been subject of intensive karstification resulting in enhance secondary permeability. However, the limited water infiltration in the marble formations is responsible for the water volumes to be discharged diffusely along the contact with the underlying shale layers. The marly schist formations are characterized as gray to gray – green schist with thin intercalations of quartz material. Locally thin marble intercalations are present along with layers of amphibolite schists. These formations cover most of the valley formed downstream. They appear to as massive formations with good geomechanical behavior and generally considered to be impermeable. Only in zones of intense fragmentation they exhibit increased permeability that results in the development of small springs along the riverbeds of the wider study area. Finally, the amphibolite schist system that covers the research area consists of cloritic, epidotic, amphibolite schist and amphibolite formations. They appear to have intense schistosity, mainly with leafy form, moderate fragmentation and with most discontinuities filled with quartz material. The cloritic shales (characteristic green color) with small quartz intercalations appear with moderate schistosity, local leafy form, slightly to moderately fragmented, while exhibiting low to moderate erosion phenomena.

3. Terrain deformations

As already mentioned the displacement of the waste masses formed very steep slopes at the disposal material cone, forming highly unstable slopes. Serious stability problems in the forehead area of the existing slope failure are most likely to occur during prolonged rainfall or intense seismic activity. The pre-event maximum height of the disposal waste cone reached 30m, while post-event maximum slope in front of the zone of failure approximates 80°.

Figure 4a,b shows the slope angle and slope aspect layers that have been produced utilizing GIS functions from the available laser scanning series of data of the newly formed surface.

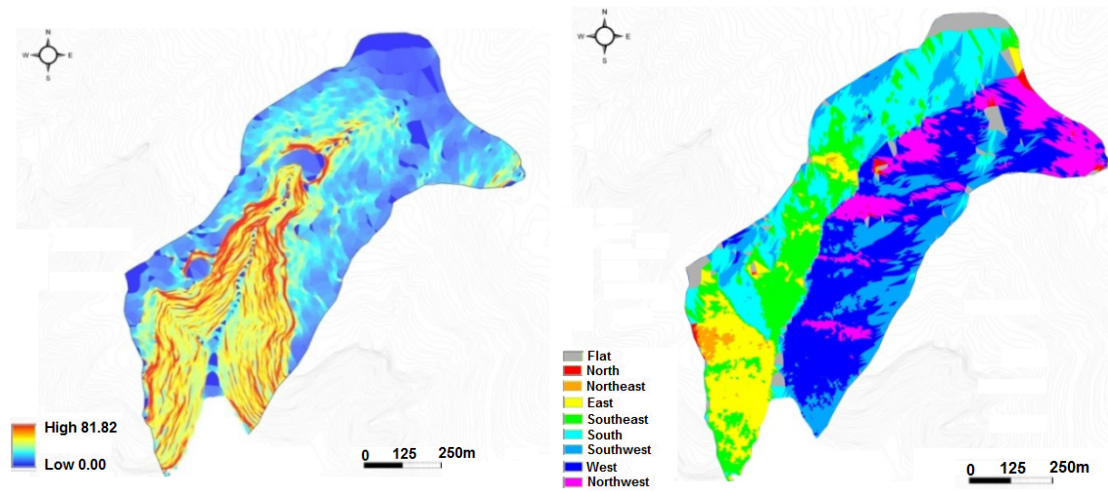


Figure 4 a. the slope angle layer, b. the slope aspect layer

Figure 5 illustrates the morphological changes that occurred in the area of the plant and along the path that the waste material traveled.

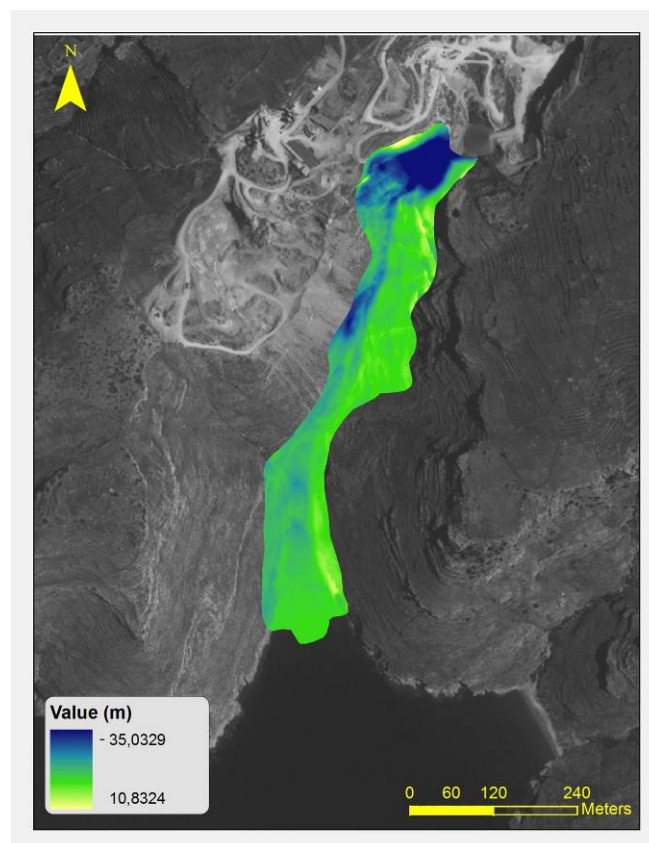


Figure 5 Terrain deformations

4. Volumetric and spatial analyses of the waste material

Estimates regarding the spatial distribution and volume of the waste material were performed by using survey data and data from the on-site mapping process. The waste load can be divided into three (3) volumes the first of which contains the volume of waste that have been preserved in the original repository. The size of the repository was calculated to be 5000m²

with an average thickness of 12m and a volume of 60000m³. The second volume contains the scraps that have been scattered along the riverbed after the failure. The waste is spread in an area that is approximately equal to 36.000m² with an average thickness of 0.8 - 1m and a volume of 29000 - 36000m³. The third volume consists of waste deposited on the beach and in the sea. Assuming an average depth of 2 to 3m the third volume of waste is estimated to be from 11000 to 16500m³. In conclusion, the total volume of waste that had to be managed was estimated to be from 100000 up to 112500 m³.

5. Results and Discussion

From the conducted analysis it is obvious that there is an absolute need of implementing mitigation measures since there is an increased possibility of a new failure to occur, especially in areas of very steep slopes. The proposed measures, altering the post failure morphology and establishing a secure site, involved:

- Construction of a retaining wall within the stream in order to allow secure configuration of the volume of waste repository.
- Lowering the deposition cone and safely transport the waste masses in place that will be formed after the construction of the retaining wall. The masses behind the wall should be formed with a slope less or equal to 1:3.
- Removal of the waste masses from the seaside.
- Topping the waste repository with specific soil layers and geosynthetics.

To select the location of the retaining wall it was necessary to satisfy three (3) conditions: First of all, the retaining wall must be founded on the bedrock. Secondly, the retaining wall should be founded in a place with no debris material since if present the construction of its foundation may cause instability problems and finally the retaining wall should be founded in a place upstream to avoid taking additional measures for potential runoff problems. According to these, the optimum position for the foundation of the retaining wall was located approximately 150m from the shoreline, with 4m height and foundation width 3m. Note that, addition 1.5 - 2m of height will be needed for coating materials that will cover the surface. The retaining wall should be manufactured with galvanized gabion to prevent their oxidation. To test the stability of the proposed retaining wall several runs have been executed using the computational package Larix a program for geotechnical analyses based on classic methods (fig 6).

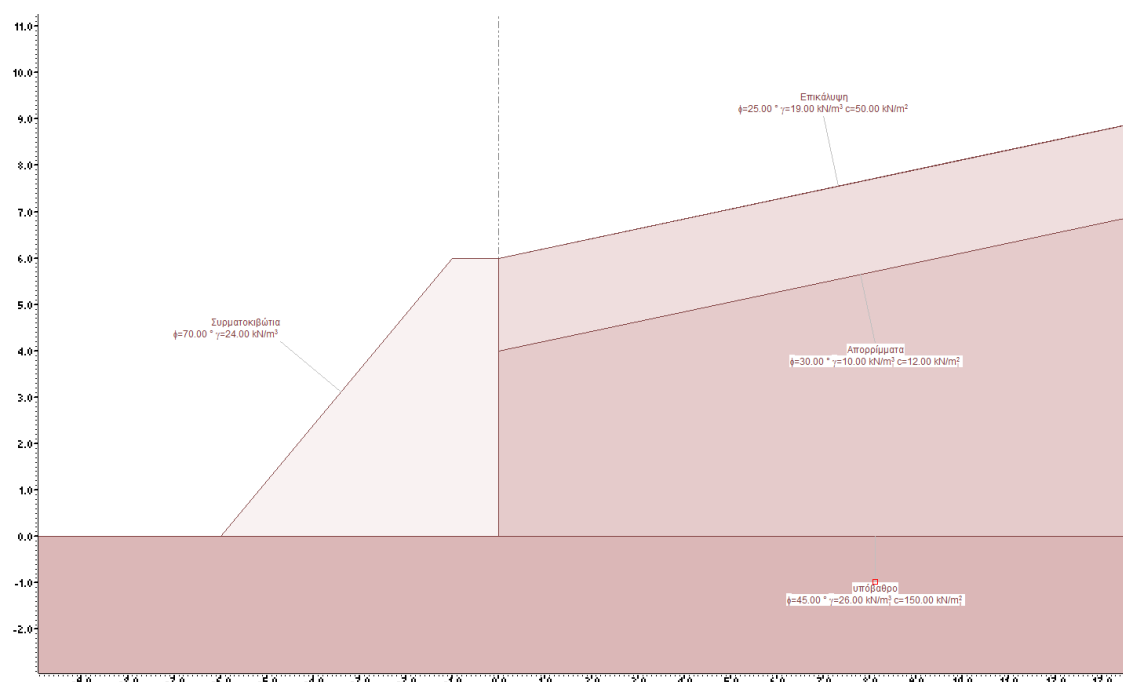


Figure 6 The geometry of the retaining wall resolved using the computational package Larix.

Larix estimates the safety factor for sliding by formulating the global equilibrium forces acting on a slice according to the well known methods of Janbu (Janbu 1954; Janbu et al. 1956; Janbu 1957) and Krey (Krey 1936). The analyses were carried out using both, Janbu and Krey methods, taking into account the worst height scenario (6m) and the most conservative mechanical parameters (Tab 1).

Table 1 – The mechanical values of the materials (Rozos et al. 2011)

Description	Parameters			Polygon points					
	ϕ [$^{\circ}$]	γ [kN/m 3]	c [kN/m 3]	Points	x(m)	y(m)	Points	x(m)	y(m)
Gabions	70.00	24.00	0.00	1	-20.00	0.00	2	-6.00	0
				3	-1.00	6.00	4	0.00	6.00
				5	10.00	8.12	6	20.00	10.24
Coating	25.00	19.00	50.00	1	-20.00	-20.00	2	-7.00	0
				3	0.00	0.00	4	0.00	6.00
				5	20.00	20.00	6		
Waste material	30.00	10.00	12.00	1	-20.00	-20.00	2	0.00	0.00
				3	0.00	0.00	4	10.00	6.12
				5	20.00	20.00	6		
Bed rock	45.00	26.00	150.00	1	-20.00	-20.00	2	20.0	0

The outcomes of the analysis indicated that the proposed retaining wall will not exhibit any stability problems and is safe. The minimal safety factors were estimated to be 3.9 for the Janbu method and 4.2 for the Krey method (fig 7 – 8).

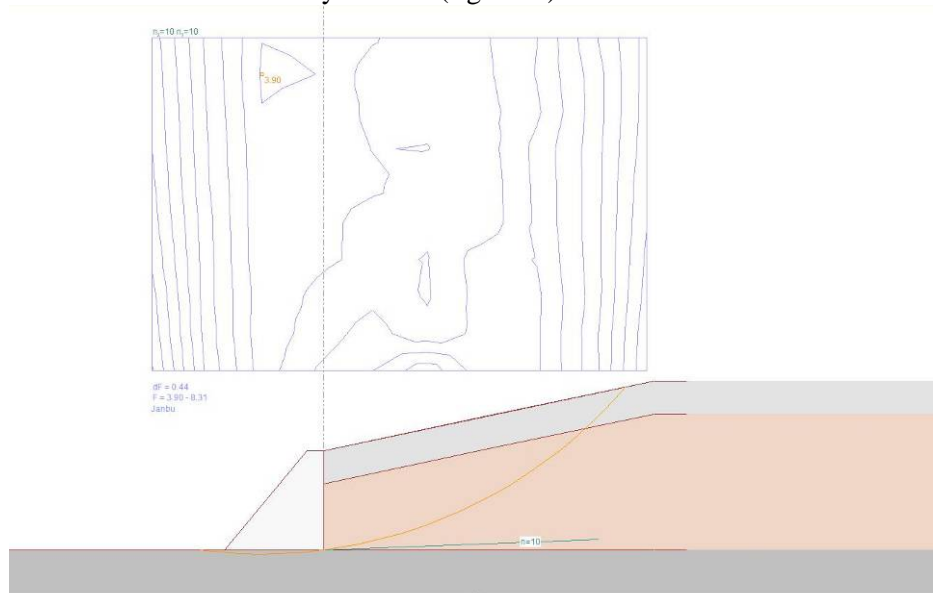


Figure 7 The results of stability analysis implementing Janbu method.



Figure 8 The results of stability analysis implementing Krey method.

In order to eliminate any risk and to avoid another failure the remodeling of the entire volume of waste is necessary by creating a new repository with gentle slopes. More specifically, it is suggested to safely transport the waste masses along the riverbed and form new slopes less or equal to 1:3. Figure 9 and 10 illustrate the suggested new surface along with four (4) surface profiles that show the post – event surface of the waste volume and the new suggested surface.

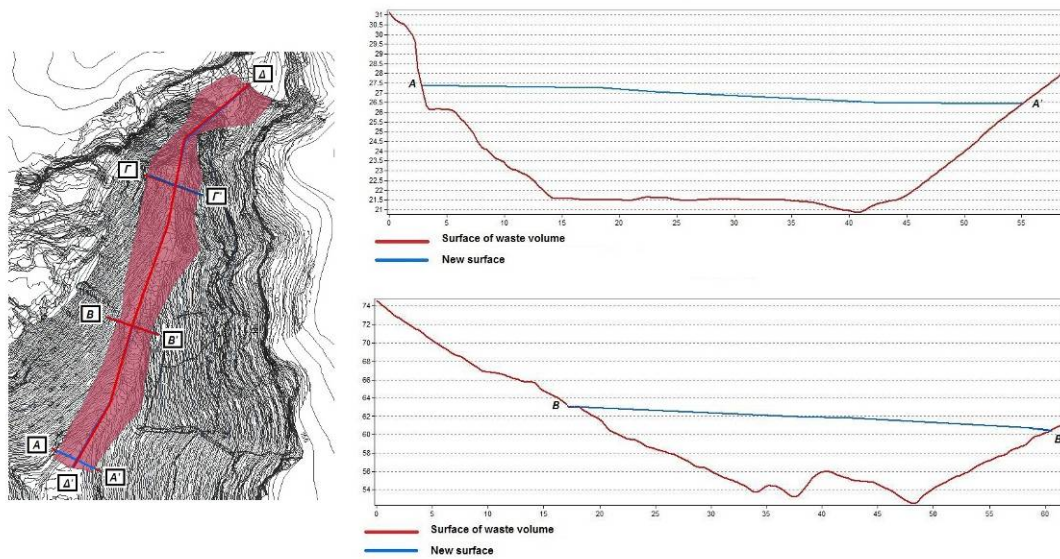


Figure 9 The suggested new surface profiles a –b

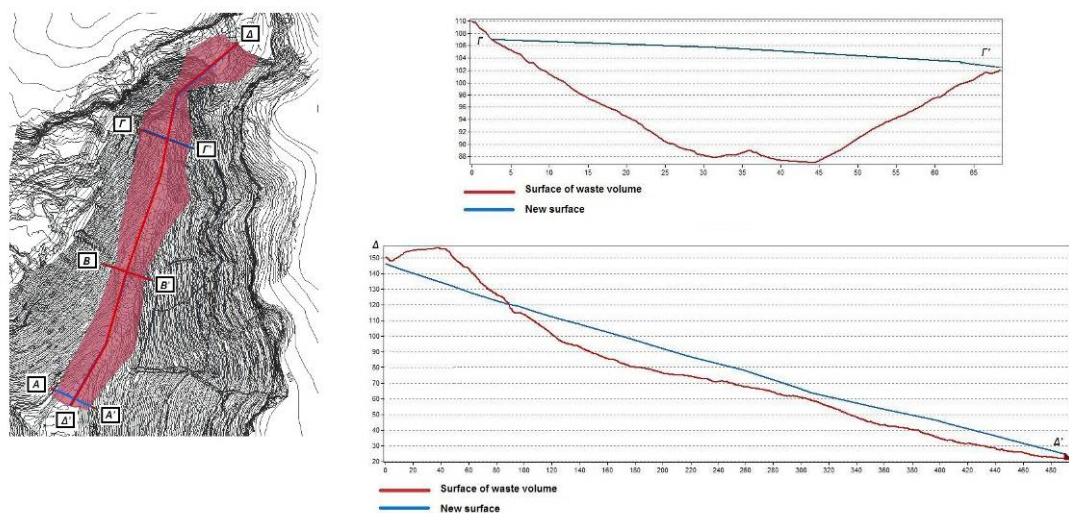


Figure 10 The suggested new surface profiles c –d

5. Conclusions

The uncontrolled waste disposal practice altered dramatically the initial morphological settings of the site by forming a ``disposal material dam`` along the stream. The new unstable structure failed, altering one's again the terrain as well as the coastal zone of the wider site. It is clear that the uncontrolled waste disposal plants, besides the environmental impact, alter intensively and rapidly the morphology setting of the sites, raising at the same time serious hazard issues. The restoration of the site requires major terrain modifications, altering the post failure morphology and an absolute need of implementing mitigation measures for establishing a secure site.

6. References

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