The Rehabilitation of the Asbestos Mine, Cyprus

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Abstract: The Cyprus Asbestos Mine is situated right in the heart of Troodos forest. Following a continuous operation of 84 years, the mine came to a sudden closure in 1988, leaving behind large volumes of waste tips, a badly designed mine pit and an unacceptable environmental scar to an otherwise heavily forested natural beauty area. The paper describes the efforts made to rehabilitate the area and the various stages of operation involving stabilization of the waste tips, reprofiling of the steep mine slopes, reforestation and revegetation.

1. INTRODUCTION

Cyprus is considered as one of the most ancient sources of asbestos and until recently was one of the most important produces of chrysotile asbestos in Europe. The asbestos mine which is situated in a mining lease covering a surface of 6,5 square kilometers, is of the opencast type, where chrysotile asbestos has been exploited since 1904. Mining operations started on a small scale and involved manual processes of digging and picking. Mining continued with an increasing pace until 1949-1950, when large-scale mechanization was applied for the mining and the beneficiation process, including crushing and milling, screening, fiberising and aspiration. The recovery was 1,4 to 1,6% of the ore milled and the annual production of fibers was ranging from 20.000-40.000 tons. It is estimated that from 1904 until 1988 when the mining activities were terminated, about 130.000.000 tons of rock were mined and about 1.000.000 tons of asbestos fibers were produced. Besides the economic benefits, this long lasting extensive mining activity had serious direct and indirect effects on the environment. The major environmental problems created, are the enormous open pit, the extensive waste tips resting on steep slopes and infilling side valleys (Figs 1 and 2), as well as the pollution with fibers of the soil, the surface water and the downstream dams, with possible consequences on the safety and health of the people. Of serious concern were also the stability of the waste tips which were piled haphazardly in some cases, creating slopes more than 240m high.

The sudden closure of the mine in 1988, left the entire problem not only of the instability of the waste tips, but the overall environmental havoc created by the long mining history, needing badly mitigation measures. The sudden closure, also, did not allow any programmed closing down procedures to be initiated. The rehabilitation works commenced in 1995 with a preliminary appraisal of all issues involved and a course of action was undertaken by a multidisciplinary technical committee, comprising regional planners, foresters, geotechnical engineers and geologists. Emphasis was placed on the stabilization of the waste tips. The downstream slopes of these tips are situated approximately 1 Km upstream of the village of Kato Amiantos. Possible instability of the tips could endanger lives and properties. An ambitious plan was drawn up aiming to stabilize the tip slopes and rehabilitate to the greater possible extent the huge pit area and to reforest the whole area, bringing the site as close as possible to its pristine condition.

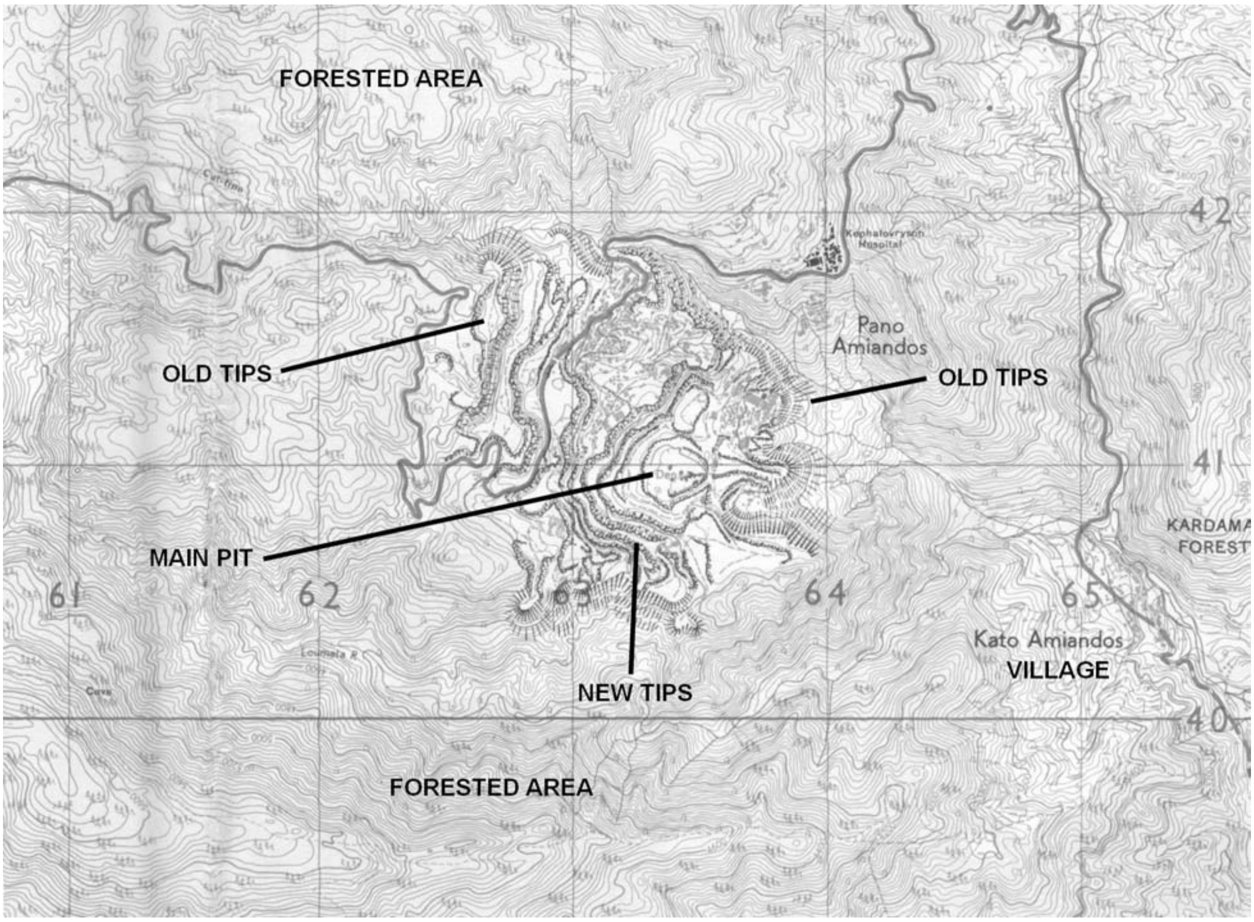

FIGURE 1. Asbestos Mine situated within a mountainous forested area.

2. EARTHWORKS

2.1 Waste tips

The asbestos mine pit is bound by Livadhi valley in the North and the Loumata valley in the South and the two valleys meet about 700-800 m downstream of the mine pit. Mining operations in the early part of the 20th century were of a small scale. Selective open cast mining was carried out by a large labour force and the waste material was tipped in the nearby Livadhi valley at the lowermost part of the slopes. In this way substantial amounts were washed downstream thus making room for more wastes. The tip that was formed during the early years of operation of the mine covers an area of some 35 hectares in plan as shown in fig. 1 and the maximum depth of waste is of the order of 25-30 m.

In the early 50´s the mine was fully mechanized and the use of modern mining equipment changed radically the scale and concept of mining operations. The annual production of rock was of the order of 6 million cubic metres, which after crushing, treatment and fibre extraction it was tipped as a waste. These operations resulted in huge volumes of waste material (known as "old tips") which the steep slopes of the existing dumping areas could not accommodate. In an effort to alleviate the problem, the mining company started to dump the waste material in the nearby Loumata valley. For drainage purposes a 1.3 Km long concrete gallery was built along the valley bottom and wastes were dumped over the gallery infilling the valley. It is estimated

FIGURE 2. Waste tips dumped on steep slopes and side valleys.

that about 60 million cubic metres of waste were dumped in this valley. When maximum heights of the order of 100 m above the gallery were reached, the culvert itself started to show signs of distress and structural failure. Dumping over the culvert was discontinued and only partial dumping in the side slope was allowed. The waste tips in the Loumata valley are known as the "new tips" and they consist of the lower level tip at elevation 1350 and the upper level tip at elevation 1450 m amsl.

2.2 Reprofiling of slopes

The need for reprofiling the slopes of the waste tips was dictated by safety, environmental and other practical reasons. Possible instability of the tip could endanger lives and property in the village of Kato Amiantos which is situated approximately 1 Km downstream of the tips. Thus the primary aim of the reprofiling works was the stabilization of the waste tips. Furthermore, flow of waste materials downstream of the pits could result in serious contamination of the river water and as a consequence, of the reservoir of Kouris dam, further downstream, which is the main water supply reservoir for domestic and irrigation purposes in the southern part of the island. Environmentally the artificial slopes of the wastes contrasted the natural slopes and the general topography of the neighbouring area (fig. 2). Proper reistatement of the environment, essentially required some form of reshaping and reprofiling of the slopes to blend with the rest of the environment.

In deciding this issue it was considered essential that the form of reprofiling would intercept surface water flows thus preventing flow of fibers in the valley streams. Furthermore in view of the alkaline nature of the wastes, which prevents the grow of any form of vegetation, it became apparent that access to lorries would be essential on the new slopes for the transportation of fertile soil, planting and irrigation. Following consultations with the experts of the Forestry Department it was decided that the maximum slope that would facilitate the grow of vegetation would be 2 horizontal : 1 vertical. In addition berms 8 m wide at 15 m elevation intervals, would be required for the planting of trees. A typical profile adopted and implemented at the Loumata valley tips is shown in fig. 3. This slope is the highest man made slope in Cyprus with a total height in excess of 240 m.

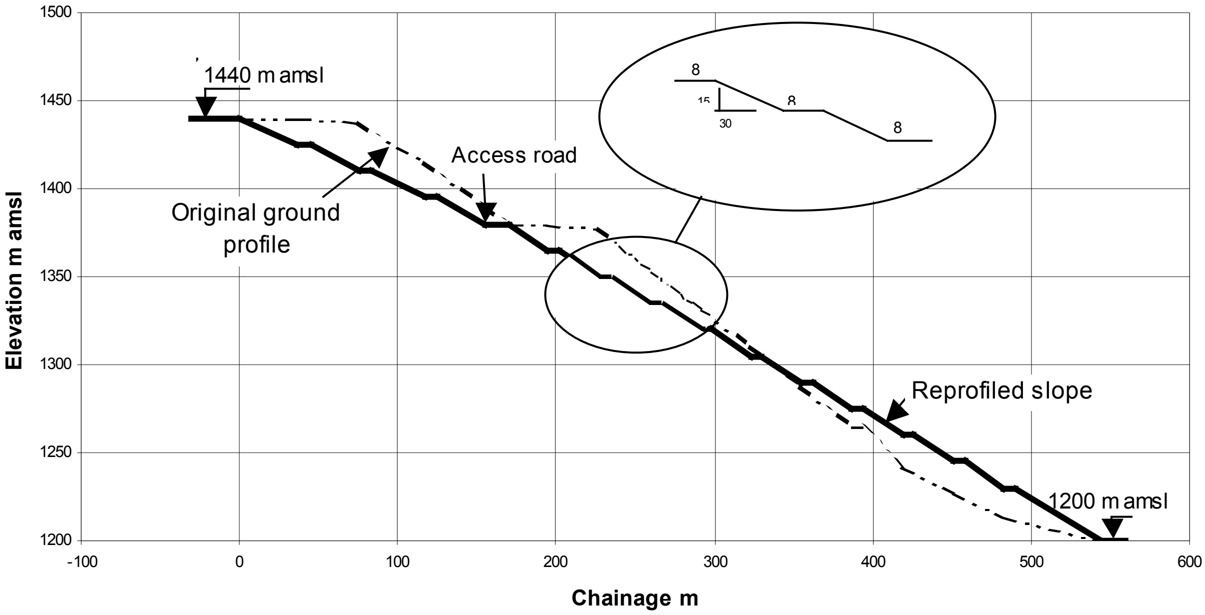

FIGURE 3. Typical profile adopted and implemented at Loumata valley tips.

2.3 Liquefaction

The possibility of flow slides produced by liquefaction of the wastes in the vicinity of the downstream slope was for many years considered as the greatest potential risk for the village of Kato Amiantos. Liquefaction occurs under conditions of full saturation when the materials are subject to cycling loading such as in the case of a serious earthquake. Investigations carried out 1980 at the old and new tips have shown that there is little risk of liquefaction occurring, not only because of the presence of drainage conditions in the two valleys, which would prevent saturation of the wastes, but also because the grading of the waste material varies enormously with most of it falling in the well graded gravely sand category. In places the material contains significant amounts of gravel size material cobbles and even boulders. In accordance with Tsuchida (1970) the most liquefiable soils are uniformly graded fine sands and silts and the asbestos tips under study do not seem to fall in this category. Standard penetration test carried out in a number of boreholes excavated for investigation purposes have shown high SPT N values. In accordance with the Empirical Correlations based on standard penetration resistance proposed by Seed et al. (1984) for an earthquake of magnitude 7,5 liquefaction is not possible.

2.4 Slope stability analyses

The stability of the downstream slope of the tip was examined for two critical loading conditions i.e. static loading and earthquake loading. Drained triaxial test carried out on the fine fraction of waste material have shown a significant loss of strength with increasing confining pressure, a phenomenon which is usually associated with dense rockfill where particle breakage occurs at high stress levels. In carrying out the stability analysis for static loading conditions in the Loumata valley it was assumed that total collapse of the culvert would raise the water table by 20 m above the level of the culvert. Based on the results of the triaxial testing it has conservatively been assumed that the cohesion was zero and the angle of shearing resistance 35 degrees. Stability analyses were performed for a number of reprofiled slopes at the old and new tips areas. At the new tips, for a large number of circular slip surfaces, the minimum factor of safety was found to be 1.32. Factors of safety of 1.3 also were calculated at the slopes of the old waste tips. This shows that the reprofiling solution gives a factor of safety within acceptable ranges and creates a stable slope.

For earthquake loading conditions, pheudostatic stability analyses were performed using a horizontal earthquake coefficient of 0,15g which was considered to be equivalent to an earthquake of intensity IX on the Modified Mercalli scale that has an estimated return period of 180 years at the site. Although the calculated stability factors of safety have no real practical meaning, these were found to be above one for nearly all the slopes. An alternative approach adopted was to calculate the displacements likely to occur by the earthquake shaking when the ground is accelerating towards the face of the embankment. The total displacement is made up of a number of small increaments of movement depending on the number of cycles in the earthquake, as proposed by Newmark (1965). For design earthquakes with a sinusoidal acceleration with a peak value of 0,33 g and a frequency of 2Hz, the total displacements varied between 0,5 and 3,0 m and these are acceptable for the waste tips under consideration.

2.5 Earthworks contracts

The stabilization and reprofiling works formed an enormous task not only because of the huge volumes of material involved but also because of the ragged environment and the difficult winter weather conditions. Government instructions were initially to stabilize the waste tips only, as safety was given top priority. The early positive results achieved, gradually started to switch emphasis to the environmental issue which, after completion of most of the reprofiling works, has became the dominant issue. The current aim of the project is to reprofile the entire lease area disturbed by the mining activities and render it suitable for reforestation.

Due to budgetary and other practical reasons but also due to initial lack of confidence in achieving the required result it was decided to perform the work under medium size contracts addressed mainly to medium size earthworks contractors who traditionally offer more competitive prices. Seven contracts have been completed till now, representing about 70% of the total earthwork. The location of these contracts is shown diagrammatically in fig. 4. The first two contracts carried out for the stabilization of the new tip involved the removal and placement of some 1.8 million cubic metres of waste material (see fig. 5 & 6). The third contract involved the reprofiling of some 450.000 m^3 of material in the old tip area.

Contracts 4,5,6 & 7 were performed within or adjacent to the mine pit and they involved earthworks (excavation and placement) in intact rock, crushed rock from the mining operations

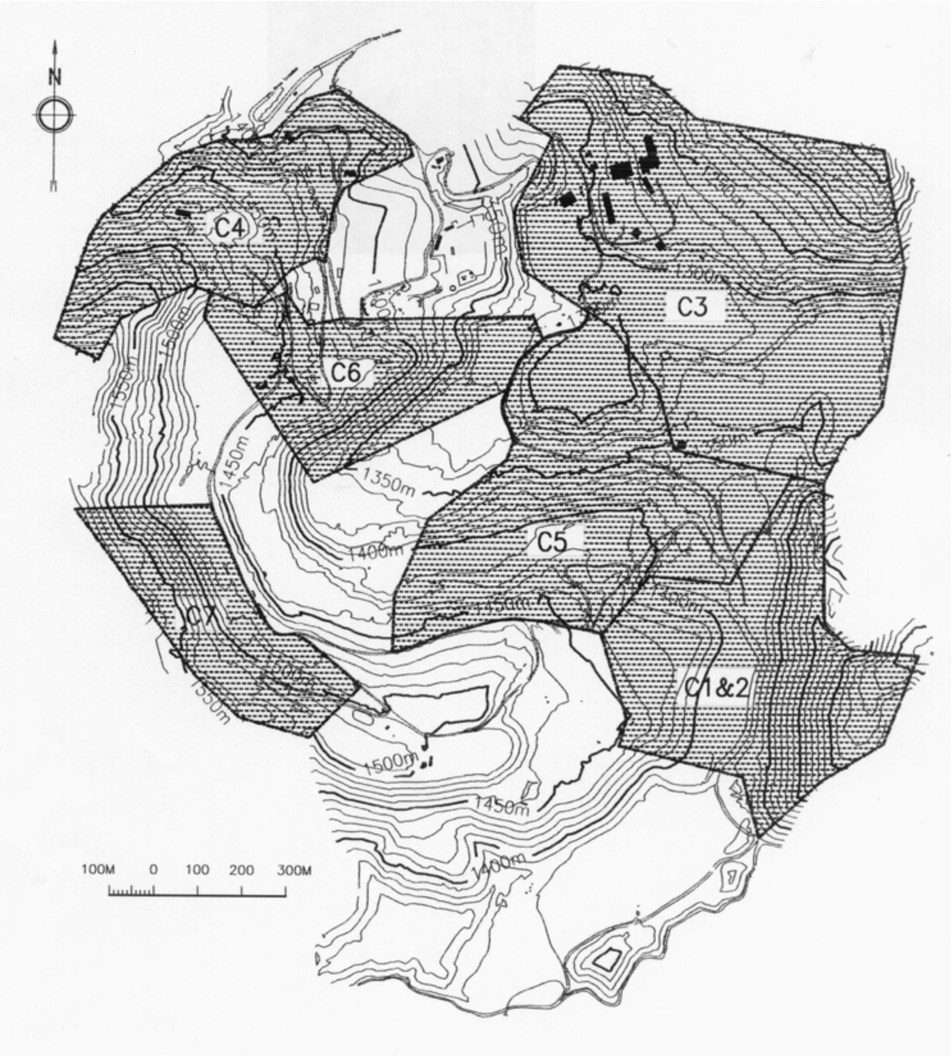

FIGURE 4. Earthworks contracts executed to date (shaded).

FIGURE 5. Stabilization of the Loumata valley tips.

FIGURE 6. Stabilization of the Loumata valley tips.

and waste material. All contracts completed todate involved the excavation and placement of some 3.6 million cubic metres of material, at a total cost of some 1.7 million Cyprus pounds (appr. 2.9 million Euros). Earthworks commenced in 1996 with a target to complete all works in the mine area within a decade. It is anticipated that the set time target will be achieved.

2.6 Monitoring of movements

Following completion of the stabilization (reprofiling) works at the two main waste tips, it was considered essential to monitor movements both for safety reasons and for better understanding of the mechanical behaviour of the waste material. In extensive monitoring system that involves the measurement of surface and deep seated ground movements and water levels, has been installed. The system includes survey monitoring stations and surface movement markers and inclinometers. Movements recorded todate, indicate that the old tips are prone to small creep type movements which seem to be more pronounced during the wet winter months.

3. REFORESTATION AND OTHER WORKS

Reforestation of the mine lease area is the ultimate aim and forms an integral part of the Asbestos Mine rehabilitation works. This is being planned and executed by the Forestry Department, after consultations with the Technical Committee. The work is performed in stages as follows.

On the level berms trenches 0.8 m deep are opened parallel to each other using a hydraulic excavator. The distance between trenches is about 5 m to allow access of trucks for unloading topsoil. Trenches are filled with topsoil transported from neighbouring areas. The space between trenches is also covered with topsoil approximately 30 cm in thickness. On the slopes, two secondary terraces 1,2 m wide, are prepared and two additional trenches are opened, one at the base of the slope, and a similar one at its top. All surfaces are covered with fertile topsoil. It is estimated that about 4000 cubic meters of topsoil are required for the reforestation of a hectare.

Planting is carried out along trenches and secondary terraces. All other surfaces are sown with a mixture of seeds from different perential plant species. The species used in planting are:

Pinus brutia, Cedrus brevifolla, Rhus coriaria, Robinia pseudoacacia, Cupressus sempervirens, Quercus alnifolla, Arbutus andrachne, Sorbus aria, Juniperus foetidissima, Clematis vitalba, Pistacia terebinthus etc.

The species used in sowing are:

Pinus brutia, Robinia pseudoacacia, Rhus coriaria, Allanthus altissima, Alyssum cypricum, Eschscholzia californica, Alcea roses, Salvia willeana, Pterocephalus multiflorus, Helichrysum, italicum, Cistus cretica, Cistus salvifollus, Phytolacca pruinosa, Vicia tenuifolia etc.

The seeds of plants used both in planting and sowing are collected from plants growing around the mine (similar habitat and rock formation).

Traditional thatching is used for protecting seeds sown on sloped ground from being washed away by rainwater. Ground preparation works are carried out all the year round. Sowing is done from the beginning of September together with thatching. Planting is effected from early October through December. It is estimated that the cost of reforestation of one hectare is around 15000 Cyprus pounds (25000 Euros). The whole reforestation and revegetation effort has so far been proved extremely successful and the encouraging results are already obvious (see fig. 7 & 8).

Reprofiling, stabilizing and revegetating the waste tips is however a small portion of the overall task for a proper rehabilitation of the mine area. With the stabilization of tips nearing completion, the multidisciplinary team working on the overall rehabilitation programme can now move to other particular problems. One of the challenges faced is to find ways to deal with the mine pit itself which is enormous and unfortunately badly designed, leaving high cliffs and scarps. Another issue is the preservation and cleaning of houses and buildings (old fiber mills, office and warehouse as well as beautiful staff houses in the adjacent forested areas).

FIGURE 7. Slopes after reforestation

The ultimate use of the houses and other facilities and the optimum development of the area is the subject of a study currently being carried out by the government, involving environmental and health risk assessment in the mine area itself as well as its broader environment. The scope of the study is to produce a long term master plan that will ensure the completion of the various rehabilitation works and programme, so that environmentally friendly development can be promoted, so that the ultimate purpose of reestablishing the natural beauty of the area is achieved.

FIGURE 8. Asbestos Mine, the new look.

4. CONCLUSIONS

When the idea of rehabilitating the asbestos mine was first conceived in 1995, the task looked enormous if not impossible. There was lack of previous case studies and the initial steps were made with extreme caution. Shortly after the completion of the first earthworks contract and the first reforestation works, it was realized for the first time that the task was not impossible. Contrary to the negative belief that prevailed prior to the commencement of the works it is now apparent that the barren environment of the asbestos mine is likely to improve dramatically in the forthcoming years.

5. REFERENCES:

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