Cerro Santa Rosa tailings dam: Storage capacity increased using a unique mechanically stabilized earth design.

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ABSTRACT: Triton Minera S.A. (TMSA) owns and operates Mina El Limon located in northwestern Nicaragua, approximately 100 km northwest (140 km by road) of Managua, Nicaragua's capital city, and approximately 45 km northeast of Leon. El Limon is an underground gold mine and mill that processes nominally 1,000 tonnes per day of ore through a carbon in pulp recovery plant. Cyanide tailings are deposited in the Cerro Santa Rosa tailings disposal facility; an unlined valley-fill impoundment confined by an earthfill tailings dam. Capacity of the Cerro Santa Rosa tailings impoundment was increased by utilizing a reinforced earth crest raise combined with a rock fill buttress and downstream shell. Plagued by diminishing storage capacity and a short construction season, an innovative application allowed the operators to raise the dam quickly while maintaining an adequate factor-of-safety against slope instability, in a high seismic region. The unique application accommodated a near vertical upstream dam slope, which consequently reduced the fill required to raise the dam, which was historically constructed by conventional downstream methods. Considerable cost savings were realized by the dam owner as a result of a reduced fill volumes and an expedited construction schedule.

1 INTRODUCTION

The first phase of the Cerro Santa Rosa tailings dam was constructed in 1998. Through the years the dam was raised by the downstream method twice, weathered the effects of two hurricanes, and experienced a significant slope failure. In 2003, TMSA. retained Vector Colorado, LLC (VCL) to perform site investigations and engineering design for a final raise of the tailings dam. Geotechnical site investigations began in October 2003 and were completed in early November. In order to meet a very short design/build schedule a unique design application that included a mechanically stabilized earth (MSE) crest raise was developed. The MSE crest raise allowed for a 40% reduction in downstream fill requirements over a conventional downstream raise design. Reduced material handling significantly shortened the construction schedule allowing the Phase IV construction to be completed by beginning of the rainy season in mid-May 2004. Consequently, significant construction cost savings were also realized by the owner.

2 BACKGROUND AND HISTORY

TMSA constructed the Cerro Santa Rosa tailings dam in 1998 to accommodate their tailings storage requirements after their traditional tailings disposal facilities (TDF) (pilas) filled to capacity. A geotechnical investigation and engineering design effort was performed by Laboratoires d'Expertises de Quebec, Ltee (LEQ) in March-April 1998 (LEQ 1998). Subsequent to this study a 15-m high homogeneous (clay) starter dam was constructed to elevation 81.00 m (Phase I). The intent of the starter dam was to provide storage for 1 year until a second raise could be constructed by the downstream method to facilitate additional tailings storage capacity beyond the first year.

In 1998, while the TDF was in use, hurricane Mitch caused the pond water level to rise uncontrollably and the dam overtopped resulting in considerable erosion at the crest and downstream slope of the dam (at the time there was no spillway). Subsequently, in September 1999, LEQ performed additional geotechnical studies and designed a downstream raise consisting of a 50% rock, 50% clay fill with a sand chimney/blanket drain in the downstream shell to crest elevation 86.00 m (Phase II) (LEQ 1999). A spillway consisting of three 80 cm diameter corrugated metal pipes through the dam crest, extending down the downstream slope of the dam and discharging into the pre-dam drainage, was also constructed during Phase II, which was completed the first quarter of 2000.

In early October 2000, during hurricane Keith longitudinal depressions developed on the dam and control points on the dam began to indicate movement. By 10 October major longitudinal and transverse fractures (up to 9 m long and 0.6 m deep) had developed in the dam. The crest reportedly dropped 1.5 m and expansion of the dam slope was observed indicating that a major section of the downstream shell of the dam was moving (Figure 1).

During the dam failure incident, LEQ and Golder Associates (GA) were contacted and brought to site to assist implementing emergency repairs. GA interpreted the failure mechanism as lateral basal sliding on a weak colluvial layer underlying the dam (GA 2000 & 2001). LEQ interpreted the failure mechanism as sliding along the interface of a layer of geotextile between the dam fill and the underlying colluvial clay due to a low interface friction angle (LEQ 2000). The correspondence indicates considerable professional debate between the two consultants regarding the failure mechanism. In-situ field shear testing of the colluvial clay, conducted by VCL in 2003, indicated a significant loss of shear strength upon saturation. Seepage models indicate that the foundation clays beneath the Cerro Santa Rosa tailings dam are indeed saturated (VCL 2004). Therefore, it is probable that the colluvial clay lost shear strength as it saturated, due to seepage from the impoundment. Once the shear strength of the colluvial clay decreased past its critical value a sliding block failure occurred through the clay.

Figure 1. Slope failure scarp along the Phase II crest of the Cerro Santa Rosa tailings dam

Figure 2. Emergency berm constructed along the downstream face of the Phase II dam following slope failure.

Emergency actions taken in October 2000 to mitigate dam movement consisted of stripping the vegetation and surficial soils downstream of the dam and constructing a blanket drain, a 3.5-m high toe berm, and a “wedge” of fill material atop the berm and against the downstream dam slope (Figure 2). The stabilization berm and “wedge” stopped the active movement of the dam. In addition, inclinometers and piezometers were installed to monitor the performance of the dam. GA made preliminary recommendations for a Phase III dam raise to crest elevation 92 m, which included excavating and removing the weak colluvial layer in the valley downstream of the dam and keying a substantial toe berm into residual bedrock.

In 2001, LEQ performed additional geotechnical investigations (primarily for identifying borrow materials) and engineering analyses in support of a Phase III dam raise (LEQ 2001). LEQ’s final design (Phase III), which raised the dam crest to elevation 89.0 m resembled GA’s recommended geometry. However, LEQ did not specify that the weak colluvial layer in the valley bottom be removed prior to constructing the blanket drain and downstream toe berm. Construction if the Phase III crest raise was completed in 2002 (Figure 3). As-built drawings of Phase III were never developed; however, correspondence with site personnel and geotechnical drilling (VCL 2003) confirmed that the colluvium was not removed prior to construction.

In February 2004 the dam was at an approximate crest elevation of 89 m, the pond elevation was approximately 88.1 m, and the tailings surface was at an approximate elevation 87.9 m. Given a historical tailings surface rate of rise of 2 m/yr only 6 months of operational tailings storage capacity existed with no storage reserve for stormwater retention, (Figure 4). Figure 5 presents a cross-section of the Cerro Santa Rosa Tailings dam and delineates the Phase I clay starter dam and each of the subsequent crest raises.

Figure 3. Cerro Santa Rosa tailings dam following construction of the Phase III downstream crest raise.

3 PHASE IV PROJECT OBJECTIVES

VCL was retained by TMSA to design the Phase IV Cerro Santa Rosa Tailings Dam crest raise. The aim of the design process was to maximize storage capacity within the impoundment and to minimize both construction costs and time. VCL conducted geotechnical investigations, reviewed past hydrological designs, and performed engineering design analysis. It was concluded from these efforts that the Cerro Santa Rosa tailings dam could be effectively raised from 89 to 95 m. Raising the crest of the dam beyond 95 m was deemed to be cost prohibitive due to topographic constraints.

Figure 4. Condition of the Cerro Santa Rosa TDF in March 2004.

4 PHASE IV DESIGN CONSIDERATIONS

The seasons in the northwestern region of Nicaragua may be delineated by precipitation, or the lack thereof, with the rainy season extending from mid May to mid November. VCL was instructed to commence work in October with construction of the Phase IV raise to be completed prior to the beginning of the rainy season. This schedule resulted in a seven month period to conduct geotechnical field investigations, perform engineering design, and construct the Phase IV crest raise.

VCL conducted geotechnical site investigations from 14 to 17 October and 27 October to 03 November 2003. The investigations included excavating 16 test pits, drilling 5 boreholes, installing 4 piezometers, in-situ soil testing and collecting soil samples for laboratory testing.

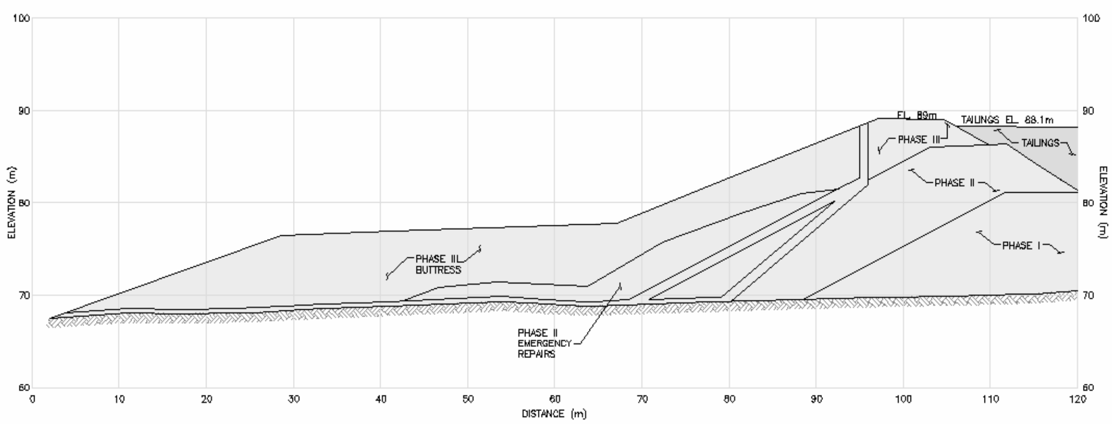

Figure 5. Typical Section of the Cerro Santa Rosa tailings dam showing each phase of development.

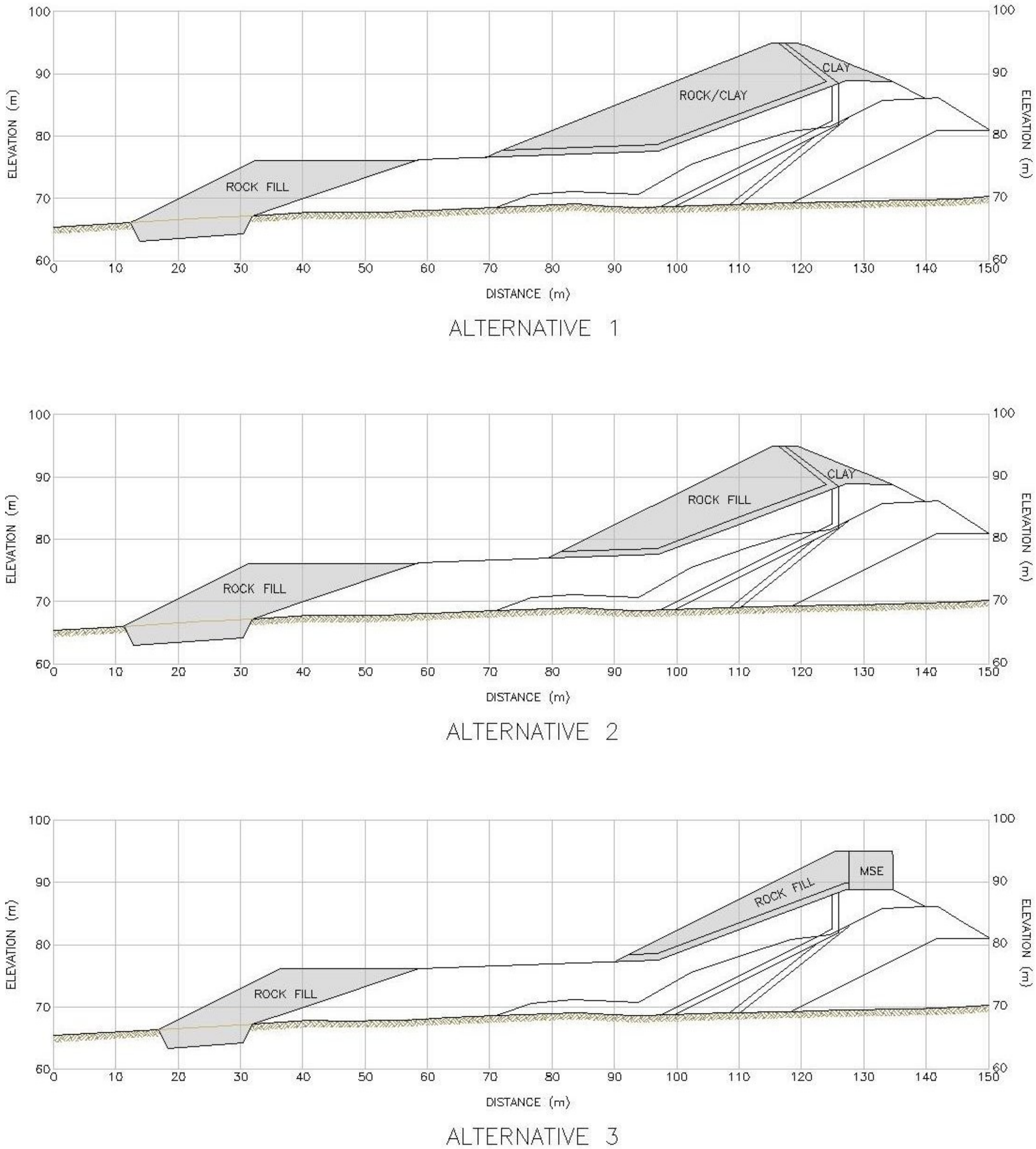

Figure 6. Typical sections for the Cerro Santa Rosa Phase IV crest raise design alternatives.

Table 1. Required Construction Quantities

Alternative	Rock (m^3)	Sand (m^3)	Clay (m^3)	Geogrid (m^2)	Geotextile (m^2)	Excavation (m^3)	Total Material Handling (m^3)
1	117,000	12,000	35,400	NA	13,900	10,700	175,100
2	122,700	13,900	9,800	NA	13,900	10,300	156,700
3	76,400	8,700	11,400	21,000	15,400	7,800	104,300

Following the geotechnical site investigations, preliminary design of the tailings dam raise was begun. Three options for raising the crest of the dam were investigated. These options included:

1. A conventional downstream earthfill raise of the embankment using a clay/rock mix for the downstream shell, clay for an upstream impermeable zone, and sand to extend a chimney drain.
2. A downstream raise similar to Alternative 1 except that the downstream shell is constructed entirely of rock and a blanket drain of sand and geotextile is placed beneath the downstream shell.
3. A MSE (clay reinforced with a geogrid and geotextile) wall used to raise the dam crest combined with a downstream shell of rock and a blanket drain of sand and geotextile beneath the downstream shell.

All three alternatives required a buttress and a keyway constructed at the toe of the existing dam to alleviate the potential for basal sliding and assure that adequate factors of safety for slope stability were maintained (Figure 6).

Each of the alternatives had pros and cons. Alternatives 1 and 2 were conventional downstream raises, being fairly simple to construct and requiring little technical knowledge on behalf of the Central American contractor. However, they also required more material handling and construction time. Alternative 3 required technical knowledge to construct the MSE portion of the raise as well as the additional material cost of the geogrid. In addition, some lead time was foreseen to obtain the geogrid required. However, Alternative 3 required less material handling and had the potential for a faster construction period than Alternatives 1 and 2.

Based on conceptual design models that met, or exceeded, stability design criteria, the following material quantities were required for each of the alternatives presented (Table 1).

Sufficient deposits of rock, sand, and clay were identified near the impoundment during the site investigations to construct the embankment by any of the alternatives. However, given the short time frame available for construction, Alternative 3 was recommended as the design of choice as it required only 60 % of the total material handling when compared to Alternative 1. Therefore, construction costs would be significantly lower using a MSE wall crest raise when compared to that of a standard downstream crest raise. VCL recommended that TMSA consider raising the Cerro Santa Rosa tailings dam by constructing the MSE wall design option.

On 14 January 2004, TMSA completed an in-house cost comparison of the three alternatives presented and authorized VCL to proceed with the Phase IV crest raise using the MSE wall method. However, rather than raising the crest the full 6 m to elevation 95 m, it was requested that the design be staged and include a 3-m raise in 2004, followed by a final 3-m raise in 2005. This staged method of

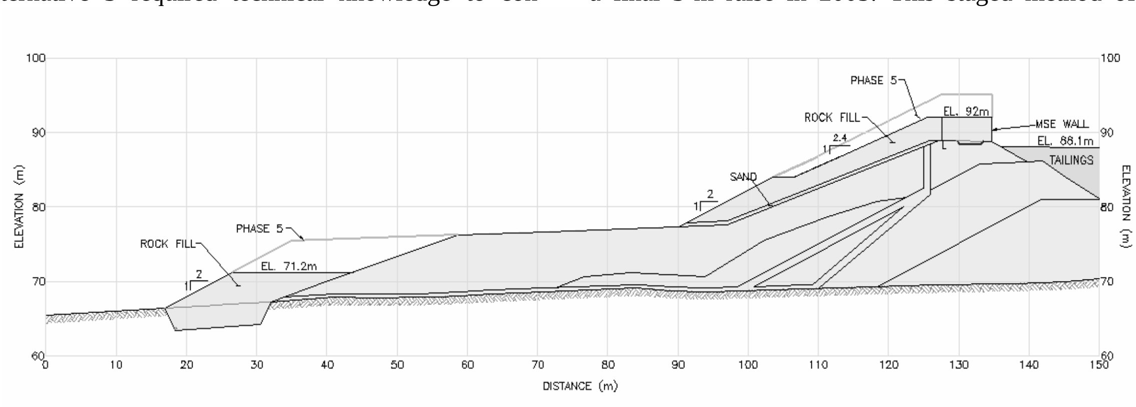

Figure 7. Typical section for the staged Cerro Santa Rosa Phase IV crest raise design.

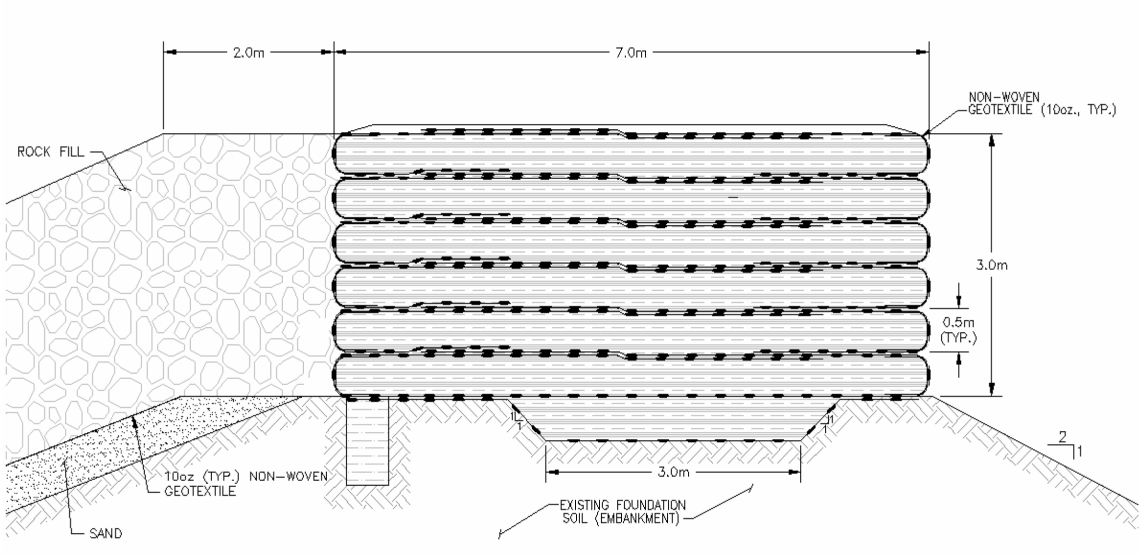

Figure 8. Typical detail of the MSE wall crest raise.

construction would allow the mine to defer capital costs as well as further accelerate the construction of the dam crest raise.

5 PHASE IV DESIGN

The Phase IV crest raise design is a departure from conventional downstream design methods used previously. The design included raising the dam crest by constructing a 3-m MSE wall along the crest, placing a rock fill shell downstream of the crest, and constructing a rock fill keyway and toe berm (Figures 7 & 8). A blanket drain and drainage collection trench was included in the downstream shell. A second drainage collection system was also included in the keyway.

Due to the reduction in the height of the Phase IV crest raise from 6 m to 3 m, the materials required for construction were also reduced by approximately 23% from 104,000 to 80,500 m^3.

The design of the 3-m, Phase IV crest raise was completed in late February 2004 (VCL, 2004). The initial construction schedule called for ordering geosynthetics, stripping, and grubbing the embankment footprint and clay borrow source, and stockpiling rock, gravel, and sand to begin by the last week of February 2004. Construction was scheduled to commence 14 March 2004. It was anticipated that 8 weeks would be required to complete construction. According to the initial schedule, construction would be completed by mid-May, before the onset of the rainy season.

6 PHASE IV CONSTRUCTION

Unforeseen delays are inevitable, particularly in Central America. This project was no exception. Orders for geosynthetics were not placed until 11 March 2004, originally the date they were scheduled to arrive on site. In addition, stockpiling rock and other construction materials did not begin until 10 March 3004. Construction did not begin until 22 March 2004, 1 week later than originally scheduled. An already short construction window was now shorter even before construction began.

Two, 12-hour construction shifts were originally scheduled for Mondays through Saturdays. In order to make up for lost time, a single 12-hour shift was scheduled for Sundays. In addition, rather than complete tasks in series, several tasks were rescheduled to be constructed in parallel. These two significant construction scheduling changes effectively decreased the construction time further in order to complete the construction project by the original completion date.

Construction of the keyway and toe buttress was completed on 14 April 2004 (Figure 9). Completed in parallel with those activities was the construction of the drainage collection trench along the existing berm. Construction activities then focused on constructing the downstream sand blanket drain and rockfill shell (Figure 10). Construction of the MSE crest raise could not begin since the required geogrid had not arrived on site. However, crest stripping and excavations of the crest key and abutment keys began on 21 April 2004 in anticipation of the arrival of the geogrid.

Figure 9. View of the Phase IV keyway/toe buttress.

Figure 10. Construction of the sand blanket drain and downstream rockfill shell were completed as parallel tasks.

Figure 11. MSE wall construction began on 01 May 2004 with the first lift keyed into the Phase III crest.

The geogrid was delivered to the construction site on the afternoon of 30 April 2004. Construction of the first lift of the MSE wall began on 01 May 2004 (Figure 11), constructed in parallel with the downstream rockfill shell.

MSE wall construction was brought to a halt at an elevation of 91 m due to the onset of the rainy season on 17 May 2004. Over the next week and a half, the remaining meter of MSE wall was constructed, and the Phase IV crest raise construction was officially completed on 27 May 2004 (Figures 12, 13 & 14).

7 CONSTRUCTION COMPARISON

Following the completion of the Phase IV crest raise, TMSA performed a cost comparison of each phase of dam construction. The construction costs (reported in 2004 dollars), storage capacities, and required construction volumes were compared. The results of the cost comparison are presented in Table 2.

Table 2. Cost Comparison

Phase	I	II	III	IV
Crest Elevation	84	86	89	92
Year Completed	1998	2000	2002	2004
Construction Cost ($US)*	782,186	739,843	811,801	601,042
Storage Capacity (m^3)	821,000	238,000	266,000	372,000
Construction Quantity (m^3)	115,400	60,920	180,095	72,198
Capacity Ratio	7.1	3.9	1.5	5.2
Capacity Cost ($\$/m^3$)	1.14	3.50	3.24	1.62
Construction Cost ($\$/m^3$)	8.09	13.67	4.78	8.32

*2004 dollars

This comparison offers insight into the cost saving resulting from the Phase IV design when compared to the previous standard downstream raises. The capacity ratio (storage capacity divided by construction quantities) is significantly higher than either the Phase II or III downstream raises, indicating a more efficient design. As a result, the cost per cubic meter of storage capacity is drastically reduced. In addition, the construction costs are also reduced due to the decreased construction volumes (the Phase III construction cost can not be compared to the other values because TMSA constructed the raise using mine equipment rather than contracted equipment, etc).

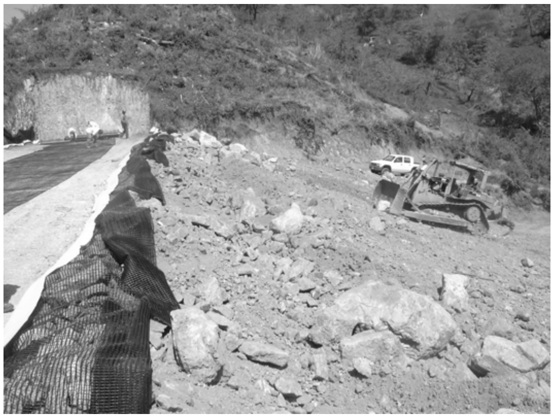

Figure 12. The downstream rockfill shell was raised at the same rate as the MSE wall.

Figure 13. View of the completed Phase IV downstream rockfill shell.

Figure 14. View of the completed Phase IV crest raise, looking downstream.

8 SUMMARY

Through the years since the first phase of the Cerro Santa Rosa dam was constructed in 1998, the dam has been raised by the downstream method twice, weathered the effects of two hurricanes, overtopped once and experienced a significant slope failure. In late summer 2003, TMSA retained VCL to perform site investigations and engineering design for a final raise of the tailings dam. Geotechnical site investigations began in October 2003 and were completed in early November. An alternatives analysis that considered raising the dam in three different ways was completed and it was decided that raising the crest using a MSE wall coupled with a downstream rockfill shell proved to be the most cost efficient and timely method of construction, requiring only 60% of the material handling as compared to a standard downstream raise. Engineering design was completed by late February and construction of the Phase IV crest raise began in March. Although beset by unanticipated schedule delays, the project was completed 9 weeks later on 27 May 2004, a week and a half after the first rains of the season.

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