# Case study on the use of high hybrid MSE walls in mine industry

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ABSTRACT: One of the leading sectors for the Turkish economy is the mining industry. Most of the mines in Turkey are in mountainous terrain so large terraces are required to house facilities which process the extracted ore. Because of the level differences, these large terraces can often be constructed most economically using high mechanically stabilized earth (MSE) walls. Two (2) "hybrid" MSE walls, 20m and 14m in height for the grinding and crusher areas, respectively, were constructed for a gold mine in Erzincan, Turkey. The MSE structures supporting these terraces were designed with a modular system consisting of a gabion box at the front with an integrated tail of double twist steel wire mesh acting as the secondary reinforcement, and high strength geogrids as the main reinforcement. The availability of crushed rock for the gabion baskets and the capability of the wall system to withstand impact loads from the haul trucks, make this type of MSE wall the most viable solution for the mines. The design of the walls has been carried out using pseudo-static method (limit equilibrium) taking into consideration different loading conditions, including seismic loading with peak ground acceleration, PGA=0.53g. Prior to the installation of the facilities on the grinding area wall and the dump slab on the crusher wall, deflection measurements were taken using a laser beam. The paper addresses the construction of the MSE wall; advantages of using such system for the project are discussed; the basis of the monitoring and the results are introduced.

*Keywords: earthquake, gabion, geocomposite, geogrid, MSE wall, mine industry, monitoring, reinforced soil wall, soil reinforcement*

## 1 INTRODUCTION

Anagold Madencilik (Anagold) operates the Çöpler mine near the village of İliç, Erzincan province, in eastern Turkey. The mine is currently operated as an open pit, heap leach facility (HLF) with associated processing plant for extracting gold from oxide ore. The additional sulfide ore reserves require the construction of a complex processing plant to process and extract gold from the sulfide ore that will extend the life of mine for an additional 22 years and continue to provide benefit to the local community and to Turkey.

As part of the construction of the Sulfide Plant, Anagold commissioned Tekno-Maccaferri to design and build two (2) MSE-walls to support the plant grinding and crusher areas. Due to limited space within the mine license boundary, the Sulfide Plant was situated within the Çöpler valley and designed within a series of engineered terraces.

The plant layout and design were by Wood and the grading plan and geotechnical engineering was developed by Golder Associates (Golder) working in concert with Anagold, Wood, and Tekno-Maccaferri.

Studio Geotecnico Italiano performed independent review of key geotechnical design and construction issues.

## 2 MECHANICALLY STABILIZED EARTH WALL SYSTEM

### 2.1 *Hybrid reinforced soil structure*

The Terramesh® System (TS) is a modular system used for soil reinforcement applications, and is composed of a facing box integrally manufactured with a double twist steel wire mesh which doubles as secondary reinforcement for face stability. The system is the most flexible, detailed and complete reinforced soil system present on the market, and can easily be employed in seismic areas even though the walls are subject to large loads.

For the extension of the mine project, a hybrid reinforced soil system composed of the TS and ParaLink (PL) high strength geogrids, has been adopted for construction of vertical retaining structures. The system is based on the principles of soil reinforcement, where tensile elements (i.e. high strength polymeric geogrids) are introduced into the soil mass to retain the soil vertically, or at steep slope, through the interaction between soil and reinforcing elements. A schematic arrangement showing this hybrid system is shown in Figure 1.

Facing elements are fabricated from double twisted steel wire mesh produced from heavily Galmac (Zn-Al 5% alloy) galvanized and PVC (Polyvinyl Chloride) coated steel wires having diameters from 2.7 - 3.7 mm. The facing section of the unit is formed by connecting the back panel and the diaphragms to the main reinforcement tail that forms rectangular-shaped cells used for infilling stones. PL are geogrids manufactured as planar structures consisting of a mono-axial array of composite geosynthetic strips. High strength strips, used as main tensile element or primary reinforcement, are manufactured from bundles of high molecular weight and high tenacity polyester yarn, coated with a polyethylene sheath. High strength geogrids are formed by uni-axial arrangement of these high strength strips connected to each other at intermittent intervals by transverse polymeric strips of lower strength. It is a durable material engineered to mechanically and chemically resist biological degradation normally found in soils, Özçelik et al., (2014).

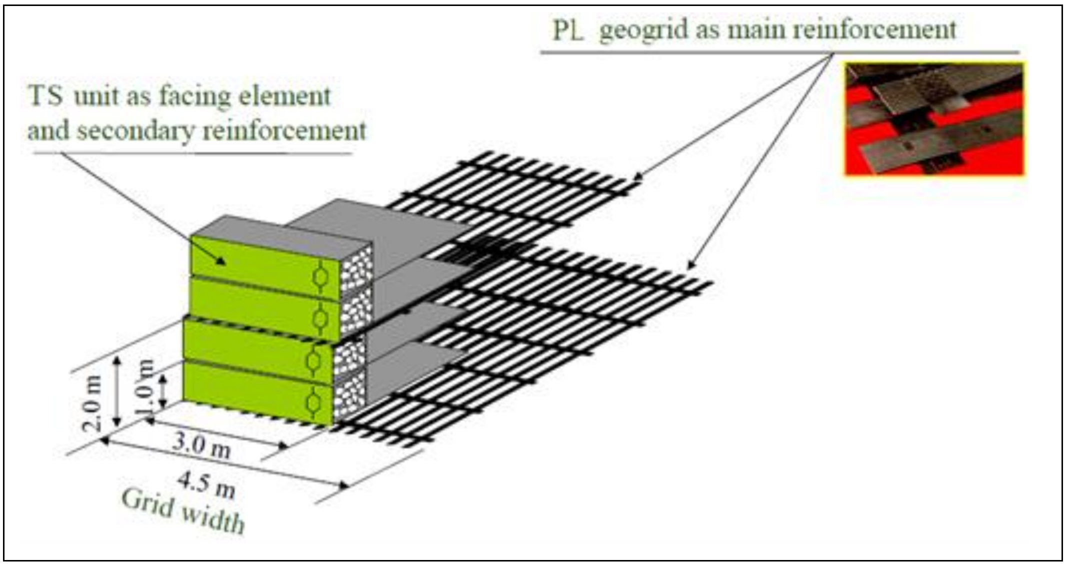

Figure 1. Schematic arrangement showing combinations of TS and PL reinforcement, Özçelik et al., (2014)

### 2.2 *Specific advantages of MSE walls in mines*

In addition to other considerations common to all applications, where applicable, the use of MSE walls in the mining industry offers specific advantages compared to other types of walls, as follows:

- use of “waste” rock for both facing and backfill, with benefits in terms of economy and environmental impact (minimum use of primary resources, reuse of secondary resources);
- minimize import of materials - mine sites are often remote;
- flexibility of structure, which is tolerant to differential settlement, making it suitable for construction over variable ground conditions;

- flexibility in construction, with no constraint on speed of construction from concrete strength and curing etc.;
- simple site operations, some of which is suitable for unskilled labor, facilitating community relations.

### 2.3 *Geological and geotechnical data*

The grinding and crusher area MSE walls are situated on the east and west sides of the Sulfide Processing Plant within the Çöpler Creek valley. During initial mining operations, the original Çöpler Creek valley was partially filled in an uncontrolled manner up to 40 to 50 meters from the base of the valley with coarse mine waste rock. Bedrock, consisting of the Munzur limestone, is present and exposed at the surface and present at shallow depths on the edges of the valley.

In the grinding wall area, the existing ground consisted of some shallow alluvium and uncontrolled fill materials to depths of less than five (5) meters above bedrock in the center of the wall foundation with bedrock exposed on either edge of the wall foundation. All fill materials below the grinding area wall were over-excavated and replaced with structural fill.

In the crusher area, the depth of the uncontrolled fill ranged from 41 to 47 meters below the crusher and MSE wall foundations. Over-excavation and replacement of this fill material was impractical due to the presence of an adjacent stormwater pond, therefore a mitigation plan, consisting of a pre-load and ground wetting procedure to limit potential future settlement of the crusher and MSE wall, was developed. The pre-load consisted of additional mine waste materials placed over the footprint of the crusher area with pre-wetting applied using a drip irrigation system similar to that applied to the ore heap in the mine’s heap leach facility. The pre-load, which was in-place for approximately seven (7) months resulted in measured settlement ranging from 1.3 to 1.4 meter, much of which occurred in the first few months after the pre-load and ground wetting were initiated. Post-construction deformation monitoring of the walls was performed and is discussed in Section 4. Monitoring is on-going.

### 2.4 *Seismicity*

The project seismic design parameters were obtained primarily through a Probabilistic Seismic Hazard Assessment (PSHA) performed by Fugro-Sial in July 2012. The PSHA study contains a detailed seismotectonic model that characterizes the various sources of seismicity affecting the project area. The PSHA incorporated data from all potential seismic sources within 500 km of the site, which included 13 active plate margins and 25 planar fault sources.

The acceleration response spectra were estimated for three different seismic events (the 1-in-144 year, 1-in-475 year, and 1-in-2475 year events). Two (2) of these events are typically considered in the design of earthen structures, including MSE walls and tailings dams. The 1-in-475 year event (i.e., the event with 10-percent probability of exceedance in 50 years) is commonly referred to as the Operating Basis Earthquake (OBE) and was defined as having a peak ground acceleration for bedrock ($PGA_{rock}$) of 0.30g, associated with a magnitude M7.0 event. For long-term evaluations (i.e., after closure), or for critical structures, the Maximum Design Earthquake (MDE), or 1-in-2,475 year (2-percent probability of exceedance in 50 years) is typically considered. This event was defined as having a $PGA_{rock}$ of 0.53g, and is associated with a magnitude M7.5 event.

The PSHA shows that the maximum ground motions for the site are associated with the Divrigi, Malatya North, and North Anatolian Faults, which are located within 7 to 65 km of the site.

### 2.5 *Project site and characteristics of the walls*

As shown in Figure 2, a total of two (2) walls were planned which characteristics are described below.

#### 2.5.1 *Grinding area wall*

The grinding area wall is a 195m long mostly straight wall, with a 3m dogleg with a maximum height of 19.50m. A 5.70(w) x 3.30(h) utility culvert is located approximately 4m from the top of the fill, in approximately the middle of the wall. In order to prevent interference between wall and culvert construction, a recess area was created using gabion baskets which enabled the continuation of the wall construction while preventing the wall backfill from entering the culvert area. A general live load of 30kPa was used in static analysis of the wall.

### 2.5.2 *Crusher wall*

The crusher wall is 100m long and has a form of "Z" shape. The maximum height of the crusher wall is 14m. A concrete slab located approximately in the middle on top of the wall was constructed to allow haul trucks to dump ore into the sizer. The slab section was designed using rear and front axle loads of 145kN and 115kN, respectively, for the dump truck, with a 90kN/m horizontal load. A general live load of 30kPa was used in static analysis for the rest of the wall.

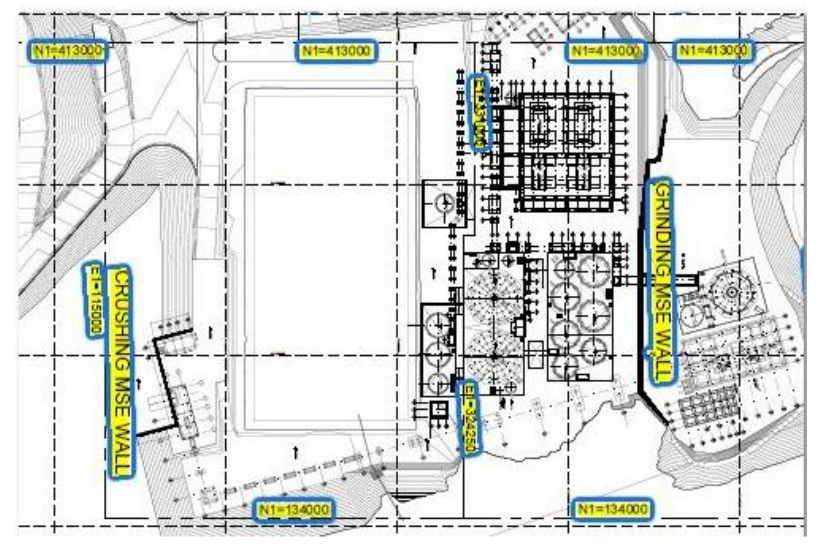

Figure 2. Plan view of the grinding area and the crusher walls

## 3 CONSTRUCTION TECHNIQUE

### 3.1 *Foundation preparation and geogrid installation*

The foundation subgrade at the base of each of the MSE walls consisted of a 76mm minus well-graded structural fill. In the crusher area, 1 meter of structural fill was placed after removal of the preload. The subgrade area for TS and geogrids were leveled and graded to the elevations required by the project construction drawings. The PL geogrids were laid starting from the outer line of the wall and were unrolled perpendicular to the wall alignment. The 4.5 m wide PL rolls were cut to the design length required for the first layer and adjusted for the consecutive layers based on the guidelines by Özçelik et al., (2014).

### 3.2 *TS unit installation*

The TS units were first opened and unfolded. The facing section of the units were then assembled individually by erecting the back, ends, and diaphragms, ensuring that all panels were in the correct position, and the tops of all sides were aligned. The four (4) corners of the facing box were then connected to the outside wall facing first, followed by the internal diaphragms. All connections were made using steel lacing rings. The TS units were then placed along the outer line of the wall facing previously marked on the foundation level. The units were placed on top of the PL with the gabion portion forming the facing of the wall (Figure-3). The TS units were connected to the adjacent units along the vertical and top + bottom edges of their contact surfaces using steel lacing rings. Even though the strength of the steel wire is relatively weak compared to the high strength polyester fibers forming the geogrid, the integrity of the facing created by connecting all units together, increases the flexibility of the system especially under seismic forces. Geogrids acting as the main reinforcement, shall be resisting and carrying the seismic forces with friction and arching, leaving a little to the tail of the TS unit acting as the secondary reinforcement. This is one of the reasons that TS system has been widely used in a refinery construction based in an earthquake sensitive area (Özçelik et al. – 2014, Tanyu et al.-2016)

### 3.3 *Filling the gabion basket with stones*

Rock for filling the TS was produced by crushing and screening select limestone mine waste rock. Selected rock was hard, angular to round, and durable such that it would not lose its integrity on exposure to water or weathering during the life of the structure. The rocks ranged from 100 mm to 200 mm. Dimensional control of gabion rock is essential, since undersize stones could fall from the wall face and pose a safety hazard to future plant operation, while oversize stone would impair correct filling. After initial difficulties, quality and productivity of gabion rock was significantly improved using screens ("grizzlies") for the two (2) limiting sizes. Oversize rock was then mechanically broken down to size, while undersize rock was used in other applications.

To obtain a good appearance of the TS facing, the use of wooden formworks was selected. The use of the formwork provided an aesthetic post-construction appearance. After the placement of a layer of rock in the cell, the rocks were adjusted by hand to minimize voids and achieve maximum density. Rocks in the outer face of the TS unit were carefully hand placed to give a neat, flat, and compact appearance. A non-woven geotextile was installed at the back face of the TS unit (Figure-3).

Figure 3. Various stages of the construction

## 3.4 *Backfilling*

The structural fill behind the walls consisted of the 76mm minus well-graded structural fill produced by crushing and screening the available limestone waste rock. The structural fill was carefully placed in lifts extending to the end of TS units design reinforcement length and compacted using a smooth drum vibrating roller. The construction team, including Anagold, Golder and Tekno-Maccaferri, implemented a detailed quality assurance plan for the project.

Following geogrid placement and gabion basket installation, the earthworks contractor, Çiftay A.Ş., (Çiftay) placed, moisture conditioned, and compacted the 76mm minus Structural Fill, (Figure-3). Care was taken to ensure that the installed TS units were not disturbed during placement and grading of the first lift of structural fill.

Structural fill was transported from the stockpile in end dump haul trucks and dumped adjacent to the exposed TS units. Çiftay placed the structural fill vertically onto the TS unit tails and PL geogrids from a low height using a Caterpillar (CAT) 980H rubber tired front-end loader. A ground spotter observed the operation to ensure that the TS units and PL geogrids were not displaced, and that the loader did not inadvertently travel onto the exposed PL geogrids.

Following placement of structural fill, the first lift was graded into an approximately 30cm thick loose lift using the rubber tired loader. In subsequent lifts, structural fill was transported from the stockpile in end dump haul trucks, dumped and graded into approximately 30cm thick loose lifts using a CAT 14H motor grader. The placed and graded structural fill material was compacted using a minimum of six (6) passes by CAT CR76XT smooth drum vibratory roller, as determined during a test pad construction. The material was moisture conditioned as required to facilitate compaction to the project requirements. The roller was not permitted to move in a direction perpendicular to the face of the wall. Pushing of structural fill material directly towards the TS units, particularly in the area immediately behind the units, was not permitted. During compaction, the movement and operation of CR76XT compactor whilst in vibrating mode was not be permitted closer than 1.0m from the rear face of the TS unit. Compaction of the 1.0m zone immediately behind the TS units was carried out progressively in layers by the CR76XT compactor whilst in static mode (non-vibrating) and by use of smaller vibratory plate compactors at internal corners.

### 3.5 *Drainage*

Drainage is one of the key factors in the design of an MSE retaining wall. The friction between the reinforcing element (geogrid) and the fill is the primary mechanism for the transfer of loads to the foundation soil. Therefore, proper and adequate measures must be taken to keep water away from the reinforced fill. In a study by Koerner et al., (2011), 51 of the 82 cases evaluated failed due to improper drainage. Drainage of the grinding area MSE wall was accomplished using a geosynthetic drainage composite installed between the reinforced backfill and the existing slope. This also served to provide separation between the existing slope and the reinforced backfill.

The geocomposite was manufactured by thermal bonding an extruded monofilament (GMA) polypropylene drainage core with two (2) filtering nonwoven geotextiles (Figure 4). The material is characterized by a three dimensional “W” shaped configuration, as longitudinal parallel channels. The geocomposite was laid flat on the slope and wrapped around a perforated drainage pipe which extended out from the rear of the reinforced fill, where it was connected to a perforated drainage pipe and subsequently to a solid pipe that was directed to a selected location to promote drainage away from the base of the wall.

The geocomposite was installed at the back of the reinforced fill of the crusher wall (Figure 4) on the reshaped slopes and part of the slopes of the grinding wall. Due to the steep slopes in portions of the grinding area wall alignment, a coarse free-draining gravel material was used in lieu of geocomposite.

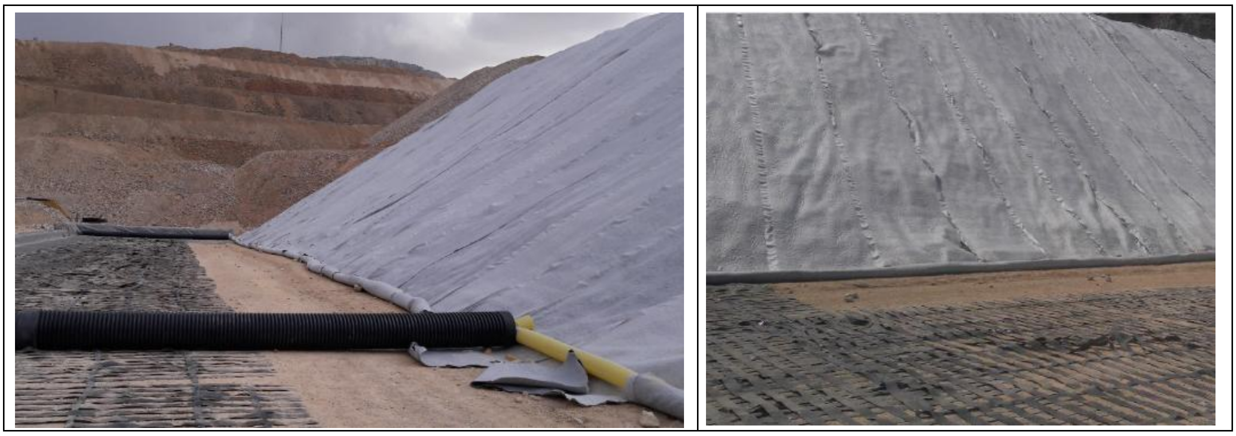

Figure 4. Drainage composite covering the slope of the crusher wall

## 4 MONITORING

Both the grinding and the crusher walls were monitored using survey prisms from January to December 2017, which was the last reading available prior to publication. Four (4) prisms were installed on the crusher wall and six (6) prisms on the grinding wall (Figure-5). In addition, four (4) prisms were installed at mid-height elevation (1070m) on the grinding wall. Some of these prisms became unusable as construction of the Sulfide Processing Plant facilities progressed.

Deformation readings were carried out with Lecia TS09 total station. Coordinate system used is Universal Transfers Merkator $3^0$ (UTM-37) – Datum (ED50) European Datum 1950. First reading was in mid-January 2017. In the beginning, readings were taken daily for the first week then it was monthly, after May it was every other month. Readings are taken at the same hours of the day. Nine out of ten readings in February, March and April, show an apparent rise of the top of both walls. After May, the elevation readings of both walls reduced close to the original values. The grinder wall then showed a small amount of additional settlement, whereas the elevation of the top of the crusher wall remained approximately constant.

After one year into the MSE wall service life, comparison of the profiles exhibited very limited horizontal displacements. Maximum (east-west) outwards horizontal deformation measured after the completion of the crusher wall was 46mm; slight inward or no horizontal movement was measured at the grinder wall. Results show similarity by Isola et al. (2016), who measured horizontal displacements on a similar MSE wall using three-dimensional images. Measured deformations in north-south direction are considered spurious.

The reference benchmark was at the corner of the Heap Leach service pond (Figure-5). One possibility is that the anomalous readings may reflect movement of the benchmark due to changing water levels in the pond, rather than real movement of the wall. Even though the benchmark was secured with a concrete base, this does not reach bedrock. Major superstructure works like: most of the crusher ROM pad foundation concrete, hydro tests performed on tanks, mill erection were all done after June 2017, so it is unlikely that those operations influenced the settlements.

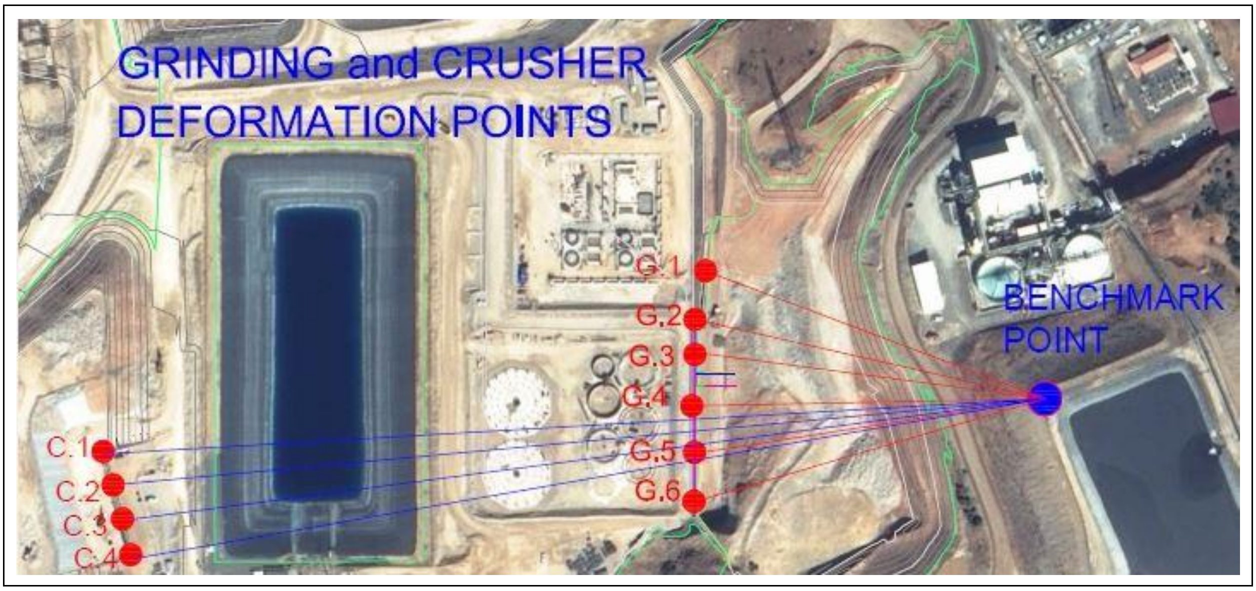

Figure 5. Plan view of the bench mark and the monitoring points on the grinding area and the crusher walls

## 4.1 *Grinding area wall*

Three (C3,C4,C5) out of six prisms were not obstructed and can be measured up to date. As an example, the deformations of points C4 and C5 on the grinding area wall are shown in Figure 6. The measured vertical movement in the grinding area wall has reached a maximum uplift of 33mm and ended at -47mm indicating a rise on the height of the wall. The measured horizontal deformation is null to maximum 25mm inward.

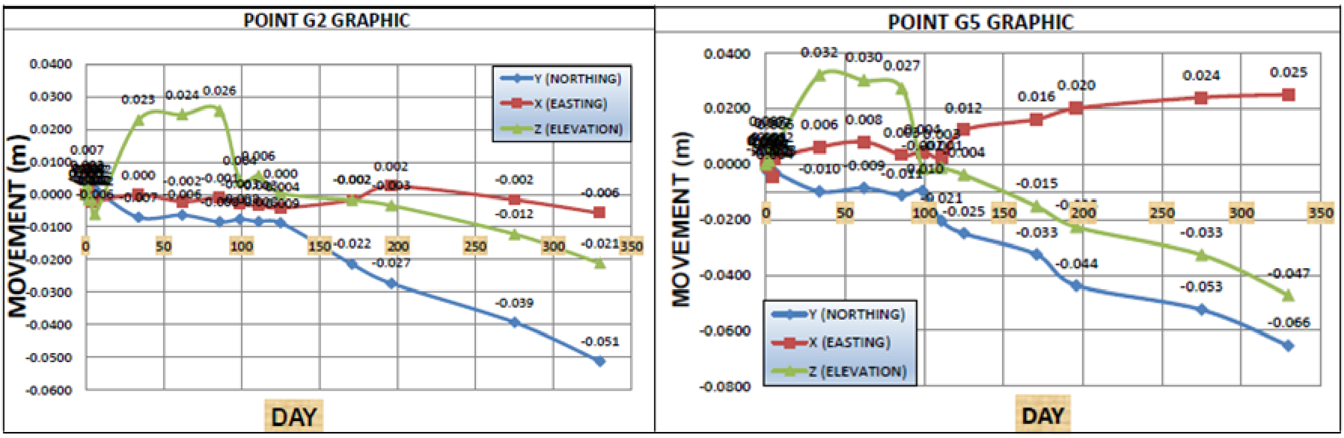

Figure 6. Deformation measurements of the grinding area wall

## 4.2 *Crusher wall*

Two (C3,C4) out of four prisms were not obstructed and can be measured up to date. The deformations of points C3 and C4 on the crusher wall are shown in Figure 7. The measured vertical movement in the crusher wall has reached a maximum uplift of 94mm and ended at 2mm indicating substantially no vertical movement of the top of wall. The measured horizontal deformation reached a maximum 46mm outwards, subsequently reduced to 19 mm.

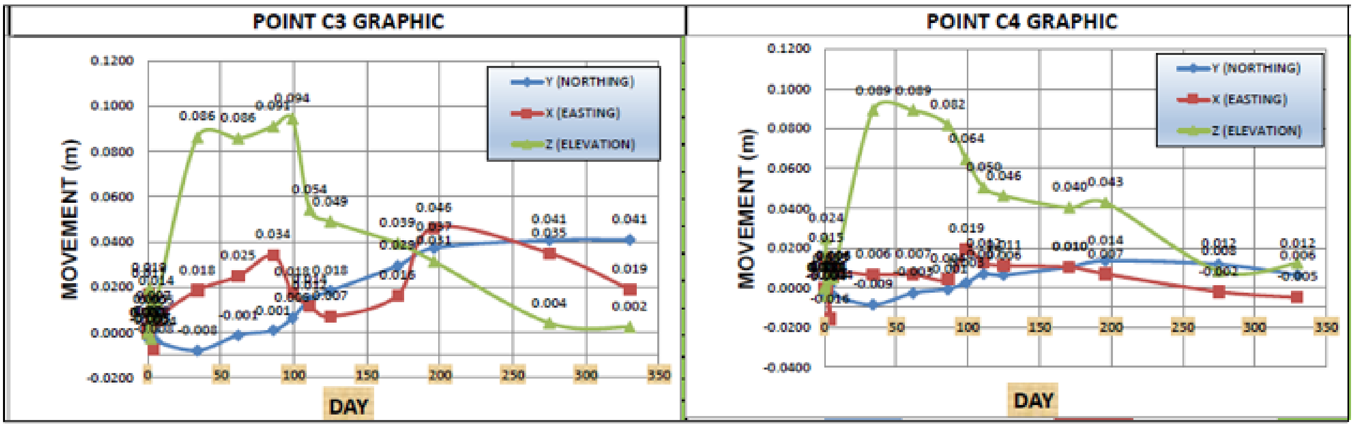

Figure 7. Deformation measurements of the crusher wall

## 5 CONCLUSIONS

1. The most cost effective and practical retaining wall solution utilizing an efficient combination of polymer and steel wire reinforcement behind a rock filled basket facing was selected for the grinding area and the crusher walls of a gold mine in eastern Turkey.
2. The free draining and flexible facia was an ideal choice for this high wall, due to its inherent ability to accommodate settlements and vibrations resulting from the facilities constructed above it.
3. The use of of available limestone waste rock for both facing and backfill, ruled out import materials from quarries with benefits in terms of economy and environmental impact.
4. A drainage geocomposite was used at the back of the reinforced backfill and the existing slope as a separation layer, replacing classical free draining gravel hence saving natural resources.
5. The monitoring of the facing of both grinding area and crusher walls revealed that even after the construction of the main facilities, the maximum deformation at the face is in the range of 46mm.

## ACKNOWLEDGEMENTS

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