SUSTAINABILITY OF INNOVATIVE MANAGEMENT PRACTICES
OF GEOTECHNICAL RISK AT DAMANG PIT CUT BACK (DPCB) –
A CASE STUDY AT GOLD FIELDS GHANA, DAMANG MINE

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ABSTRACT

This paper will review some methods used to manage geotechnical risk at Damang Pit Cutback. The pit depth is designed up to 250m with push back on the eastern and western walls of the existed and depleted Railway Cutback (RCB) pit. The geotechnical design was presented by SRK Perth, focussing on the optimisation of the bench face angle which finally evolved with “steep slope strategy”; 24m at 80° and 24m at 75° on the eastern and western walls respectively. The east wall was designed strategically to optimise the proximity of the tailings dam to the final pit crest of the push back. The pit has experienced failure in the weathered profile transgressing through the transitional material into the fresh rock at different location of the east wall since development in July 2005. To ensure stability and to minimise ore loss, the east wall has been redesigned using 70° batter angles and reduced berm width of 4m compared to 80° and 8.5 berm width of 24m bench height.

The paper will also discuss how slope failures to the east wall had been sustained, managed and monitored to enhance production. Emphasis is placed on slope management at Damang which includes the principles of wall control blast, visual inspection, slope depressurisation and the state-of-the-art of slope monitoring using Autoslope automated prism monitoring.

Future slope monitoring is considering the use of 3D Laser and Radar to provide early warning so that evacuation could be effected. The intention is to provide mine personnel the means to identify risk areas during mining activities.

1 Introduction

Abosso Goldfields Limited –Damang Gold Mine is an open pit operation located in the Western Region of Ghana about 120km north of Takoradi and 25km north-east of Tarkwa, with a design capacity ranging from 360-680 tonnes per annum. Generally, the entire Damang area consist of series of ridges and valley and ridges have been divided into series of elongated hills, which rise to about 100m above the surrounding terrain. The average height is about 300m above sea level. The drainage system, which is made up of several channels, becomes more active during rainy season. The principal streams are river Benny, Tamang etc. Damang is in the equatorial climate and experiences average daily temperatures between 24°C to 29°C. There are two major seasons; wet and dry. The wet season exhibits double maxima; from April to July and from October to November. The April to July period is the main rainy season with a break in June. The dry season occurs between late November and March. Approximately 2000mm rainfall is recorded annually.

The Damang operations consist of 25tMPa open pit operations and 2.5tMPa CIL metallurgical plant. The mine is currently operating a cutback on the depleted old
Damang pit and three other satellite pits. Rangers Mineral began exploration in 1989; between 1990 and 1995 the mine, mill and power lines were constructed with the first gold poured in 1997. Gold Fields Ghana took ownership in 2002. Mining began from a single large open pit with a primary orebody in a hydrothermal setting. The life of mine was scheduled to complete in 2004, with subsequent near term gold production from treatment of low grade stockpiles blended with oxide ores from the conglomerate of Kwesie and Lima deposits. The primary challenge the mine suffered was to sustain quality mill feed beyond the scheduled completion of mining from the then RCB pit. The birth of Damang Pit Cutback (DPCB) was realised through the Damang Extension Project (DEP). The DEP programme was initiated in December 2003 to accelerate mineral resource discovery and reserves conversion to predominantly through the evaluation of a number of satellite deposits located within the concession areas. This work successfully brought additional mineral resource and reserves to account from the paleoplacer at Tomento North and Tomento East orebodies, and hydrothermal Amoanda (depleted) and Rex Prospects.

The geotechnical study for the DPCB was carried out by Perth based SRK in December 2004 to access the reliability of the west and east wall cutbacks. The east wall cutback forms a crucial part of the maximum potential for pit development which is the proximity of the western embankment of Tailings Storage Facility. The west cutback increased the volume of available ore to ensure sufficient working width.

2 Geological Setting

The Damang-Abosso region is located in the southern part of the Ashanti Belt, one of a series of northeast-trending Palaeoproterozoic volcanic belts in southwest Ghana. The volcanic belts each exceed 100km in length and are separated by basins containing fine-grained epiclastic and volcaniclastic lithologies. Lithotypes in the volcanic belts are classified as Upper Birimian whereas those in the intervening sedimentary basins are termed Lower Birimian. In Ghana, the Upper Birimian is traditionally thought to overlie the Lower Birimian. However, Leube et al. (1990) and Eisenlohr and Hirdes (1992) invoke a coeval relationship where the basinal sedimentary sequences comprise distal facies associations deposited between a series of evenly spaced volcanic belts. Tarkwaian rocks include conglomerates, sandstones and subordinate shale, and are spatially restricted to the volcanic belts where they overlie Upper Birimian lithologies (Davis et al., 1994).

The Damang-Abosso region contains Tarkwaian and Upper Birimian lithotypes, with the latter occupying the core of Damang anticline (Fig. 1A). All gold occurrences on the Damang Mining Lease are hosted by Palaeoproterozoic metasedimentary rocks of the Tarkwaian System (Fig. 1B). However, two distinct styles of mineralisation are recognised. Damang, Rex and Amoanda are each characterised by structurally controlled zones of brittle deformation containing mineralised hydrothermal quartz vein arrays. Although host lithologies vary, vein arrays carrying the highest gold grades typically occur in competent quartzite and meta-conglomerate units of the Banket Series (Brabham, 1998). Contrastingly, gold mineralisation at Kweisi-Lima and Tomento occurs exclusively in conglomerate and/or clast-supported pebble metasandstone units of the Tarkwaian Banket Series and is interpreted to be of paleoplacer origin (Sestini, 1973). The auriferous coarse-grained ‘Banket’ units at the Tomento prospect occur on the western limb of a regional F
anticline (Damang Anticline) that can be traced south through the abandoned Abosso mine site (20km) to the Tarkwa gold district (35km; Fig. 1A).

The nature and distribution of host lithologies in the Damang-Abosso region is reasonably well understood from government survey mapping (Fig. 1A). However, a detailed understanding of local structural kinematics and the relationship between regional deformation events and gold mineralization is poorly constrained.

Figure 1: (A) Regional geological setting of major gold operations in the Damang-Abosso area. Mining Lease is outlined in red; adjacent Prospecting Licences are outlined in pink. (B) Location of the Damang Pit and satellite prospect areas on the AGL Mining Lease. Grid coordinates are Ghana National

3 Geotechnical Challenges

Cutback of the west wall was challenged by the Damang fault located within the depleted RCB pit. The Damang fault is a primary structure which is steeply dipping and strikes roughly north-south. The May 2005, SRK report provided a review of the geotechnical implications for mining posed by the fault, a review of mining the west wall and provision of the slope design recommendations. The west wall was cutback by 37m and is proposed to deepen by 250m.

The east wall is mining close to the west embankment of the East Tailings Storage Facility (ETSF). Figure 2 indicates an overview the pit and tailings dam at the located at
the eastern flank of the pit. The mine recognised the potential for mining induced destabilisation of the western embankment which could lead to tailings dam failure. SRK in their December 2004 report, suggested additional geotechnical investigation to be carried out. The investigation provided more clearly defined hydrogeological and geotechnical conditions within the saprolite and oxide layer which forms the East Wall pit crest and also supports ETSF. The investigation also provided a minimum stand-off distance between the East Wall pit crest and ETSF western embankment along the length of the proposed eastern cutback.

Figure 2: Overview the Damang Pit Cutback and Tailings dam looking south

4 Slope Design and Performance

The east wall of the cutback pit is characterized by sequence of sandstone, siltstone and phyllite with dolerite intrusions and several east-west faults is seen to cut across the wall. The bedding planes (reverse structure) steeply dip between 70-80 degrees in a direction ranging from 079-097 degrees to the east. The bedding planes are found to be generally sheared towards the north with continuity >30m and at approximately 2m spacing. Figure 3 shows a cross-section of the east wall of the pit. Originally the slope geometry design for fresh rock formation at the east wall is 80° bench face angle, 24m bench height and berm of 6.5m wide. The entire east wall was later redesigned with batter angle changing to 70° at 24m bench height, 4-5m wide berm basically to reduce the probability of toppling failure. This reduces the overall slope angle from 69.4° to 64.9°.
The west wall is largely formed by sandstone and dolerite intrusions. The weathering profile in the west is not deep compared to the east. The wall design configuration is $75^\circ$ face angle, 24m bench height and 6m berm width. Generally the weathered slopes were mined between $32^\circ$ and $37^\circ$ at bench height between 6-9m. A geotechnical berm of 10m and 13m is also recommended for the east and west wall respectively.

The pit has experienced failure in both the weathered and fresh rock at different location of the east and west wall since development with major failure recorded in the east wall.

![Cross-section of the pit and tailings dam (source: SRK, May 2005)](image)

**Figure 3: Cross-section of the pit and tailings dam (source: SRK, May 2005)**

### 5 Slope Management Plan

Since the east wall was designed strategically to optimise the proximity of the tailings dam to the final pit crest of the push back with the challenges posed by the Damang Fault truncating the west wall, a comprehensive slope management programme (SMP) was introduced to manage geotechnical risk at the Damang Mine. The SMP has been based on assessment of the geotechnical conditions that could lead to pitwall instability. The planned geotechnical management strategies are designed to prevent uncontrolled pitwall failures and thus;

1) Minimise the exposure of operators and equipment to geotechnical hazards;
2) Minimise risk to the ore reserve.

The overall objective of the SMP is to identify potential geotechnical hazards influencing the Damang pits and to propose the risk management procedures to mitigate the risks including monitoring programs and reporting requirements. Given the unprecedented nature of open pit mining the SMP will be reviewed and updated regularly as additional information (due to incomplete geotechnical data) becomes available for analysis. All personnel that enter the pit or who are responsible for personnel that work in the pit are involved in slope management.
6  Slope Failures

Several slope failures were observed in the east wall of the DPCB and reported. The failure began in the weathered profile transgressing through the transitional material into the fresh rock at different location of the east wall since development in July 2005.

6.1  Dealing with failure in oxide slopes

The following geotechnical observations and remedial exercise were considered in dealing with slope failure as mining progress.

6.1.1  Slump on 951mRL

Shallow slumping first developed on the RL 951 berm on 3 April 2006 between 25,700N and 25,875N, at the north eastern corner of the east wall. The slope in the northern part of this zone was seen to be distressing and bulging whereas in the southern section slipped. The main area of slope distress in the NE Corner is shown in Figure 4a and Figure 4b, with the extent indicated by the dashed yellow. The sense of movement is shown by the black arrow. The second unstable area in the Figure 4a (to the south) is one of the slide areas where more significant movement occurred.

![Figure 4: (a) Early stages of batter slumping above RL 951@NE Corner; (b) Slumping of the batter above RL 951 @ NE corner](image)

6.1.2  East Wall Slides

The southern section of the East Wall developed shallow slope failure (slides) in the saprolite material which affected about 20m of batter face. The affected area increased 4 or 5 times before remediation could be implemented. The slides occurred in areas where water seepage has been observed at the base of an alluvial layer at the top of the
highly weathered Huni Sandstone. The influence of the instability was found to increase by omitting a 3m berm (from the design) proposed for the base of the fill layer. The slide affected area is shown in Figure 5a and Figure 5b. The slide debris typically has a low mobility, with the failures taking the form of “stick-slip” movements accelerating following rainfall. The failure surfaces appear to be confined in the upper portion of the slope, within the fill, alluvium and the upper weathered sandstone /siltstone zone.

Figure 5: (a) East Wall Slides on 951mRL berm – Early stages of development (b) East Wall Slide on 951mRL berm showing seepage location and debris

6.1.3 Remedial Action

East Wall remediation involved slope depressurization, batter support using a waste-rock buttress and groundwater drainage. Eight 25m long depressurization drains were installed on the RL951 berm (lined to 18m) reducing the rate of slope deformation.

Stability analysis indicated that a waste rock buttress was required to support the batter face and to raise the slope profile back to design (from the steeper mined slope angle). The preparation for buttress construction is shown in Figure 6a and Figure 6b. A toe drain (initial flow of 200l/min was recognized) was constructed to discharge water from the NE corner towards the pit entrance as in Figure 6c.
Figure 6: (a) Preparation of the RL 951 berm for buttress construction; (b) Preparation of the RL 951 berm with set out for buttress toe (yellow tape) (c) Development of buttress and with construction of RL951 toes drain.

6.1.4 Trench drain, Surface drain & sump

A trench drain was installed across the east wall on the pit crest to cut off ground water into the pit. A stage electric submersible pump was provided to keep the water within 1m of drain invert at the sump since periodic pump by the use of the diesel pump does not provide effective dewatering as the electric pump. A lined surface drain was constructed near the crest to intercept runoff flow and divert it to the trench drain sump for pumping. Figure 7 below indicates the lined drain, silt trap and the sump collecting water from the trench drain.
6.2 Rock slope failures

The east wall had suffered several toppling failure in the transitional to fresh rock slopes. Two major of the several failures are described below. Three times failure in the same area of the east wall and the recent ramp failure.

6.2.1 Failure above ramp

The east wall of the Damang cut back suffered a failure in the afternoon of Thursday, February 8, 2007 during a heavy rainfall (31.2mm) which lasted for about two hours. Two failures were observed, one at the north-eastern part and the other in the central part of the wall. Figure 8 gives scenery of the east wall just after the failure occurred. No personnel injury and equipments damages were observed and production was not affected. The north-eastern failure occurred between 25770N and 25800N within a known unstable area characterised by tension crack that developed on the 930mRL berm extended to 936mRL berm northwards. The failure mode was toppling along steeply dipping bedding plane and movement was facilitated by parallel bedding shearing which is weak and friable. The surface of the bedding plane is coated with carbonate and chlorite infill with asperity as smooth undulating and straight from large-scale observation. About 25000 tonnes of failed material was found lying at the toe of the wall (918mRL). Prior to the failure no significant movement was recorded from monitoring prisms located in the vicinity of the failure. The central portion of the wall was affected by a wedge failure affecting a bench height of 24m at a strike of 120m. Ruminant of toppling failure was observed along the steeply dipping bedding structures. The wedge failure involves two discontinuities orienting at 60/242 and
78/322 degrees. Estimated volume of failure material lying at the base of the wall was 31200m$^3$. The toppling failure was due to the dilation of bedding planes and flexure of bedding. The failure zone was barricaded off to warn personnel; the material lying at the floor and wall faces were scaled off under the supervision of Geotechnical personnel.

![Figure 8: A scene of the east wall failure, yellow line indicates extents of failure](image)

### 6.2.2 Ramp failure and wall below

Instability of the wall below the ramp was reported to be kinematically feasible at the time the wall below the ramp ranges from 6-12m high. The report was documented in the February 8, 2007, failure. Toppling failure was reckoned to destabilize the wall. In the early hours of Saturday, 26 2008 at approximately 5:00 GMT, the ramp which is the main access into the pit suffered a large scale failure. Five months prior to the failure, cracks developed on the ramp crest which reduced the width to about 12m wide subjecting the section to about 150m long single lane access. The ramp failure was propagated following the development of new tension cracks observed in the unstable section of north of the existing cracks. Cracks development was observed during visual monitoring on Thursday, 24 2008 and was communicated to personnel during safety and production meetings. Blasting was conducted at the toe of the ramp which probably might caused a change in deformation as observed the following morning (Friday, 25 2008.

The area was however conned off and a give-way signage for vehicles and trucks was positioned to avoid loading and congestion in the area. Generally no alarm readings
were observed from automated slope monitoring equipment during the day. The observed movement graphs at the time of monitoring during the day were moderately constant. Alarms began to show late in the evening (25/01/08) to the early hours of Saturday morning. The movement trends continued to increase until the collapse. Velocities in the range of 180-450mm/day were observed from readings. Approximately 120m long of the ramp had slumped as shown the photograph in Figure 9. Debris of rock fall lying at the toe of the wall on the blasted heave is about 18,000m$^3$. The geologic condition related to the failure is similar to all documented failures.

![Figure 9: A view looking south of the toppling failure on the ramp surface](image)

7 Ramp Design Change

The percentage of slope failure at the east wall was found to be unacceptable by management; the stability of the wall above and below the ramp was investigated and led to redesign of the ramp access such that the east wall was completely avoided. Several options were considered before the ramp was relocated to west wall. After the ramp failure the following mitigation strategy were carried out to continue mining while investigations continued:

1. A no-go zone area was marked out below the failure (Figure 10 indicates pit designs before and after failure). A 3m windrow constructed along the no-go line to enable pit operations to continue, whilst providing protection for personnel and equipment moving past the failure zone.
2. Construction of buttress, by tipping waste rock over the face of the failure, working from safe ground north and/or south of the actual failure.
3. A geotechnical emergency response procedure was proposed for all personnel involved in the pit operation.
Figure 10: (a) Old pit design indicating ramp at the east wall; (b) New pit design indicating ramp at the west wall

8 Monitoring

Slope monitoring programme at the Damang encompasses the use of prisms, tension cracks pins (extensometers), visual inspection of berms and piezometers to monitor slope face displacements and ground water levels behind the slope. Many of the slope failures and displacements at the DPCB were driven by surface and ground water entering and eroding the slopes.

- The existing east and west walls have over 80 monitoring prisms installed to monitor unstable and near stable area. Monitoring started by the conventional approach where data are collected by surveyors, however the mine commissioned the use of an automatic prism monitoring equipment (Autoslope) provided by SOFTROCK Solutions

- A total of seven piezometers (3 at west wall and 4 at east wall) have been installed and recorded on a monthly basis. The piezometers were used to establish baseline groundwater profiles to assess pit wall depressurisation and in-pit dewatering

- Weekly berm walk over surveys are conducted on accessible berms and benches. However daily walk around surveys are carried out before shift; following mining activities under unstable batters a procedure is followed before activities commence as per guidelines in the DCB Geotechnical Risk Assessment (SRK, May 2006)
• The inspections record changes in batter stability and the presence of groundwater seepage and erosion. Areas where the stability has changed is studied and installed with additional monitoring instrumentation where deemed necessary

• The results of the inspections are reviewed with the results of the piezometers and prism monitoring to assess stability level. The results are reviewed with the Mine Manager on a weekly basis and communicated to all personnel

• 3D laser monitoring equipment had been commissioned for trial to augment Autoslope in other to increase the reliability of monitoring. Equipment purchase will base on the outcome and the confidence that will be obtained

• The Mining Superintendent ensures that blast vibration levels are routinely monitored and managed, to minimise the impact of dynamic loading on wall stability

• The Mine Surveyor ensures that all final batter toe positions are surveyed and reconciled against design, prior to designing the blast for the next (lower) batter. Any re-designs due to local failures, toes, etc. are geotechnically assessed prior to implementation.

• A monthly geotechnical report summarising all monitoring results and any failures or other geotechnical issues is produced by the Geotechnical Engineer and circulated to the Principal Geotechnical Engineer (Perth), Mining Manager, Chief Mining Engineer, Pit Superintendent and Mine Surveyor

10 Risk Management

As part of measures undertaken to control safe drilling near the pit high walls, a Job Safety Assessment (JSA) was made using the AGL risk assessment index. A documented procedure had been drafted for mining activities under unstable batters. During drilling and blast, load and haul, grade control drilling activities, the following procedures are always in place for safe execution of job:

• A JSA is completed by working personnel before the commencement of any job within the area.
• Geotechnical Engineer to inspect the area before work commences.
• Presence of geotechnical personnel is required as work progresses using a two way radio as a communication tool for mining personnel.
• Mining operations is not carried out in such areas during night shift unless otherwise pre-arranged.
• The mining contractor’s drill and blast superintendent in collaboration with Unit manager for production are also required to assess the area before work commences.
• A limited exposure of personnel and equipment, at most two drill rigs is used in such areas; however a third rig is deemed necessary where wall control blast (presplit holes) are required

A rockfall hazard sign post is erected at unstable ground and below batters to warn personnel.
11 Conclusions

The Geotechnical Slope Management Plan forms an integral part of the Damang Cutback mining operation. This has been the evolution of geotechnical safety culture which has been developed to educate the workforce on geotechnical hazards during end of month safety meetings and daily tools box meeting. Geotechnical data collection and analyses is an ongoing process with the emphasis to produce quality control in terms of slope development. As part of management plan to improve the slope failure risk management at the mine, plans are been considered to purchase the 3D Laser monitoring after the trial period to augment Autoslope. Management had also considered the use of Slope Stability Radar (SSR) slope monitoring system from Reutech Slope Stability.

12 References