Geotechnical Risk Management and Mitigation at Grasberg Open Pit, PT Freeport Indonesia

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Abstract

PT Freeport Indonesia operates Grasberg Open Pit at West Papua Indonesia. Mining of Grasberg pit commenced in 1988 and at the moment pit dimensions are approximately 2.0km by 2.5km with a current depth of 900m. Final planned depth of the pit is 1200m. Grasberg pit advances on average one bench per month with some 16 shovel faces and over 150 haul trucks operating at any time. Overburden material is placed in two main stockpiles located in steep valleys on east and west sides of the pit. Single slopes of the stockpiles are over 400m high. Average material moved daily consists of approximately 150,000t of ore and 600,000t of waste.

Grasberg Open Pit is located in very rugged terrain with extreme elevation changes and at an elevation of over 4000m above sea level. Average precipitation is 4m/year and 10mm/day with storms up to 30mm/hour. There is approximately a few hours each day of good weather while the rest is foggy and misty.

Aggressive mining and adverse weather conditions requires effective geotechnical monitoring systems and controls to ensure safe optimum production. Over the years Grasberg geotechnical group has installed and operates a number of monitoring systems which include: GPS, Extensometers, 5 Total Stations, VWP, Inclinometers, 8 Rainfall stations and 4 GroundProbe radars. There is also a plan to purchase two long range IDS radars. This extensive monitoring network is operated 24/7 from a monitoring room. Based on experience both displacement and rainfall are used as monitoring criteria for the open pit and overburden stockpiles. Detailed action plans are developed for geotechnical “hot spots”, which specify monitoring alarm criteria and actions that have to be taken both by geotechnical and operations depending on the level of the alert. Each action plan is developed taking into consideration pit design, geological and hydrology conditions and mining plan for the area of concern. Action plans and changes to it are communicated to operation and engineering groups on a regular basis.

Implementation of the extensive monitoring system and geotechnical action plans allow Freeport to mitigate geotechnical risk and mine safely the Grasberg pit in very difficult terrain, atmospheric and geological conditions.

1 Introduction

As of December 2010, the Grasberg pit contained 336 million metric tonnes of reserves with an average grade of 0.84 percent copper, 0.92 g/ton of gold, and 1.0 g/ton of silver. The diameter across the top of the Grasberg pit is approximately 4 km and the maximum difference in elevation, top to bottom, is about 1000m (Fig. 1). Total daily material moved is 750 Kton, with 150 Kton/day of ore sent to the mill for processing.
The Grasberg deposit is located in the Ertzberg Mineral District within Sudirman mountain range of West Papua (formerly known as Irian Jaya), Indonesia, at approximately 4 degrees south latitude and 137 degrees longitude.

Grasberg is located within the Papuan fold belt which consists of Palaeozoic and Triassic granite and metamorphic basement rocks overlain by Mesozoic and Cenozoic sedimentary rock. In the Ertzberg district, Plio-Pleistocene quartz and monzodiorite intruded this strata resulting in Cu-Au skarn and porphyry type mineralization. The Grasberg igneous complex is nearly a circular, funnel shaped, diatreme pipe. Overlapping hydrothermal alternation types are roughly concentrically zoned within the diatreme.

The surrounding topography is very rugged and the relief is extreme with elevations ranging from 2900 to 4500m (amsl). As one would expect, anywhere in the equatorial tropics at elevations above 3000m (amsl), weather is unfavourable for mining activities and slope monitoring. Weather consists of short periods of clear weather most mornings followed by heavy rain and fog. Temperature ranges from 1 to 22 degrees Celsius. The average annual rainfall is approximately 4000mm/year (or 10mm/day). Periods of heavy rain of up to 80mm/day and periods of blowing mine dust are both possible. These adverse conditions make geotechnical monitoring and risk management difficult but this are essential to ensure safety of mining operations. Because of these challenging conditions, Grasberg operation is dependent on a variety of deformation monitoring systems and geotechnical risk management systems (action plans). The intent of this paper is to explain how the various monitoring systems are used to manage geotechnical risk and develop mitigation plans to ensure safe and optimum recovery of resources.
2 Grasberg ground and hydrology conditions

Grasberg rocks demonstrate substantial variability in strength, durability, and fracture intensity. As a result slope conditions within the Grasberg pit are highly variable. Within individual rock units there are zones of very poor to very good ground conditions with very different predicted behaviours.

Geologic rock types were reclassified on the basis of expected behaviour into engineering rock types for slope design purposes. Rock type, alternation, intact rock strength, fracture shear strength and RQD are used to differentiate between engineering rock types (refer to Fig. 2).

Grasberg geotechnical risk management has been matched to local ground conditions. On slopes consisting of several engineering rock types, monitoring is necessary within each material and often different monitoring criteria are used for different rock types. The selection of instrumentation and instrument location reflects predicted behaviour.

Figure 2. Geotechnical rock types at the Grasberg pit.

Grasberg dewatering system is an integral part of the overall risk management system. Generally it consists of underground dewatering that utilizes underground drifts to drill upwards dewatering holes to lower regional ground water table in the vicinity of the open pit. Horizontal drill rigs are used to drill horizontal drain holes inside the pit to dewater localized perched water zones. Sub-surface water occurrence is mostly controlled by fractures where major faults play a main role in controlling groundwater movement acting as an impermeable boundary or as a conduit. Pore water pressure vertical downward gradient is observed in most piezometers, showing that water moves vertically around the pit and could create partially saturated/unsaturated conditions due to fractures and permeability characteristics of the aquifer.
3 Grasberg geotechnical risk management - Monitoring strategy

Some degree of slope instability is associated with all economically optimized pit slope designs. Minimization of the adverse effects of slope instability must be accomplished through judicious mine planning, the establishment of operational contingencies and adequate slope monitoring. Monitoring therefore, is the key element in safe, efficient risk management of pit slopes.

Because of the inherent variability of Grasberg rock types, it is necessary to regularly monitor the performance of the pit and waste stockpiles slopes to verify design assumptions. Critical monitoring locations, such as structurally weak zones, heavily loaded zones, or zones with high water pressure are identified and appropriate instrumentation is selected and placed in areas of concern. Locations are selected to provide data as early as possible during excavation. The identification of critical monitoring locations is required to maximize the usefulness of monitoring instrumentation, as it is not practical to indiscriminately blanket the pit and waste stockpiles with instruments.

The objectives of the Grasberg geotechnical risk management and monitoring programs are:

- To help differentiate between normal elastic movements, inconsequential dilation, and incipient slope failure,
- To provide early warning of impending failure so mine plans and operating practices can be modified to minimize impact of slope deformation,
- To provide geotechnical information for analysing slope displacement mechanisms for designing appropriate remedial measures and for optimizing slope design, and
- To establish whether the deformation is responding to remedial measures.

It is assumed that if a sufficient level of understanding of local ground conditions exists and adequate monitoring instrumentation is deployed, there should not be “unexpected” failures. Since slope failures do not occur spontaneously, the dangers of pit and waste stockpile slope failure can be minimized if sufficient layers of monitoring are employed and appropriate response to warning signs and action plans are heeded.

However, the surest way to ensure safe working conditions is rigorous implementation of an appropriate mine design. Geotechnical risk management and slope monitoring cannot fix a defective mine design, nor can it provide warning of impending slope failures unless, fortuitously, instrumentation happens to be of the right type and in the right place.

In general pit slope monitoring programs start off simple and become more sophisticated and complex as conditions demand. Visual monitoring alone is sufficient in some areas until the pit wall expresses one or more signs of potential instability. When signs of incipient failure exists, visual monitoring is supplemented with more frequent accurate wide spread monitoring using more sophisticated equipment.

Development of the Grasberg monitoring system started in the early 90’s and evolved over the years as different slope condition were encountered and new sophisticated slope monitoring systems were developed. The current Grasberg monitoring program consists of three levels. Level 1 provides overall surveillance of the slopes and it is designed to help locate areas of potential instability. Level 2 involves detailed monitoring of these potential instabilities and focuses on selected areas of the pit where detailed information is required. Level 3 comprises the monitoring of actual instabilities to help to improve worker and equipment safety through implementation of action plans based on monitoring criteria.

Grasberg’s slope failure potential is too great to rely on single monitoring system due to the fact that it is influenced by pit size, complexity, geotechnical and geologic unknowns, and weather conditions. A wide range of monitoring instrumentation and systems are used at Grasberg including the GroundProbe and IDS slope stability radar, Modular Mining Slope Monitoring System, Leica Geosystems robotic total station prism monitoring system, Orion Monitoring GPS monitoring network, Slope Indicators borehole inclinometers, Geokon and Slope Indicators vibrating wire piezometers and Campbell Scientific weather stations.
The PT Freeport Indonesia (PTFI) slope monitoring program supports pit operations 24hrs/day, 7 days/week, and 365 days/year. Monitoring equipment is installed wherever instability is a concern. Additional instrumentation is installed and monitoring frequency is increased whenever slope instability is detected. Occasionally, instrumentation (mainly prisms and GPS) is installed in non-critical areas to detected normal dilation and rebound, support slope design investigation and provide stable control points. Monitored parameters include both causes and effects. The primary parameter of interest to Grasberg is deformation which is the effect of causes like rainfall, ground water conditions, blasting vibration, etc. By monitoring both cause and effect, a relationship between the two can be developed. Action may be than taken to remedy the undesirable effect by mitigating the cause.

4 State of art monitoring network

4.1 GroundProbe (SSR-X) and IDS (IBIS-M) slope monitoring radars

Early in 2004, PTFI began using a GroundProbe Slope Stability Radar (SSR) to supplement other monitoring systems. The SSR has been shown to be a very useful slope monitoring tool particularly well suited to detect very low magnitude displacements with high precision in all weather conditions.

There are two types of radars available in the market: Real Aperture Radar and Synthetic Aperture Radar. Real-aperture radar (RAR) produces radar images by directing a narrow beam of energy perpendicularly to the slope. Each pixel of area of interest is scanned once during a scan by rotating the dish in horizontal and vertical direction. On the contrary synthetic aperture radar (SAR) produces the radar image by moving the antenna along the acquisition and observing the same area many times during one scan from slightly different angles and then combining the backscattered signal coming from the different points along the path through digital processing. Grasberg Open Pit operates four GroundProbe Slope Stability Radars (SSR/SSRX). These radars are the real-aperture radar (RAR) type and have been used in Grasberg pit since 2004. Weather and working conditions seriously tested the GroundProbe software and hardware design. Over the years many improvements both to hardware and software were done to improve accuracy, monitoring distance and reliability of the radars. As a result current radar availability is above 98% and max monitoring distance is 1200m with accuracy of less than 1mm.

Maintenance of these radars is conducted by on-site technicians with the help of GroundProbe technicians who visit site every quarter. All critical parts are stored in the warehouse, including Radar Electronic Box (REB) and Computer Electronic box (CEB). Maintenance arrangement with GroundProbe was specially tailored for Grasberg conditions and remote location to ensure high availability.

As the size (depth and diameter) of Grasberg increased PTFI was looking for radar that would allow accurate monitoring from a distance greater than 2.5km. An Italian company, IDS, has been working on development on such a device since early 2000. A two months trial of IBIS-M radar was performed at Grasberg in early 2010. The trial was successful and proved that this radar can be used for long range monitoring providing that a number of software improvements are implemented to speed up data processing and provide more reliable atmospheric correction algorithms. Based on the results of the trial and implementation of agreed software improvements PT Freeport Indonesia and parent company Freeport McMoRan Copper and Gold decided to purchase this radar system. Two IBIS-M radar systems are expected to start operating at Grasberg in the second half of 2011. Based on the recent review of the condition of the aging GroundProbe radars it was agreed to replace all four existing radars with new generation SSR-XT radar. One short range radar WAM (wall monitoring system) mounted on light vehicle will be used for monitoring of drilling and mining activities performed close to high walls.

In summary Grasberg radar monitoring will consist of three systems:

- Two IBIS-M radars will placed on the top of final walls for long range, long term monitoring
- Four SSR-XT will be deployed for medium range monitoring of areas already showing signs of instability.
4.2 Robotic Total Station

The “backbone” of Grasberg slope monitoring program is a network of reflecting prisms (currently over 800 are deployed) and robotic total stations (5). The prism network enables continuous displacement monitoring (weather permitting) of the pit slopes.

Robotic Total Station (RTS) is an automated device that is used to read at regular intervals the prisms targets placed at the area of interest. By doing periodic or continuous target reading, displacement of the slope can be identified. Horizontal and vertical movement is measured to sub millimetre accuracy, allowing deformation in three directions to be established together with the movement vector, which is critical for the understanding of slope movement characteristics. Five RTS’s are deployed at Grasberg. The most advance total station from Leica is used (TM30) in combination with Leica GeoMos software. To protect the RTS instruments from the adverse effects of weather stable sheltered base stations have been fabricated to house RTS instruments. This total station has extreme distance and accuracy capability to track target movement direction using the ATR method. Prisms database data is analysed using additional software from CNI (Call & Nicholas, Inc.): PrismsDB, PrismsMon and Microsoft Excel with macro are used for reporting. Prisms displacement data can be presented in EDM (Electronic Distance Measurement, prisms distance change to Total Station) or in 3D displacement.

Prism monitoring provides the most accurate 3D deformation measurement but its reliability is limited by the frequent fog conditions occurring at Grasberg pit and also by physical difficulties of installing prisms in unstable areas in a safe manner.

4.4 GPS

In 2004 Grasberg Geotechnical and Orion Monitoring Company completed the installation of the GPS monitoring network at Grasberg. A non expensive single frequency GPS receiver and InteTrak software are used. GPS reference station is located at the top of Dispatch Ridge (Fig. 1) with all GPS monitoring stations located within 3km from this reference point. By using static processing with data recording every 15 minutes good results can be obtained when GPS is located on an open wide area such as at the flat dump areas. During data processing automatic or manual refinement is performed by removing incorrect results and then three dimensional displacement data can be calculated with high accuracy.

GPS units are mainly deployed outside off active mining areas such as old overburden stockpiles, final pit walls and, subsidence area to monitor long term displacements and deformation. Recently GPS units have been proven to be useful in monitoring of active overburden stockpiles providing 3D displacement data required for alert trigger and stability analysis.

4.5 Wire extensometer or Slope Monitoring System (SMS)

SMS manufactured by Modular Mining Systems was one of the first monitoring systems used at Grasberg to monitor displacements at the pit and waste stockpiles. Recently SMS have been replaced by Slideminders manufactured by Call & Nicholas.

The SMS or Slideminder is a wire extensometer that transmits total displacements via radio to a computer in the monitoring room for further processing. They are mainly used to monitor unstable areas at the pit or waste stockpiles where visible movement already occurred. Wire extensometers are introduced when prism, radar measurements or visual observations detect a potentially unstable zone. The monitor is erected on stable ground behind cracks and the wire is pulled out to a pin set in unstable ground. Automated alarms can be activated if excessive movement or velocity is recorded. Movement criteria which are used for triggering different levels of alarms have been established to suit local overburden and pit slope conditions.
4.6 Rainfall monitoring

Campbell Scientific weather stations have been installed at Grasberg and surrounding areas. Eight stations are in operation covering 2.5x2.5 km² with five of them installed inside the pit. Rainfall data is recorded by each station every 15min and data can be accessed using a web application. A Microsoft Excel macro was also developed to analyse raw rainfall data which is then used to assess alert levels based on rainfall criteria. Rainfall intensity is an integral part of geotechnical hazard management as it is used in action plans to set alarm criteria.

4.7 Subsurface monitoring system

4.7.1 Inclinometers

Slope Indicators borehole inclinometer is used to monitor subsurface lateral deformation especially to detect deep seated failures. A 70mm diameter PVC pipe with grooves is inserted into a vertical borehole and deformations in two directions are surveyed by drawing the probe upwards from the bottom of the casing to the top. They are mainly installed where surface movement has been detected by other instrumentation and geological conditions behind the pit slope indicate possibility of a deep seated failure.

4.7.2 Piezometers

Standpipe and vibrating wire piezometers (VWP) are used to measure water levels and pore water pressures beneath the pit walls and waste stockpiles slopes. They are frequently used to monitor effectiveness of drainage measures. Readings are obtained with a portable readout or a data logger. Nested vibrating wire piezometers are used in heterogeneous rocks to measure pore pressure in different rock units.

Pore water pressure has a very well established influence on slope stability. Measuring ground water levels and/or water pressures is therefore an important part of the geotechnical hazard management system.

4.8 Monitoring room operation 24/7

Data from field slope monitoring devices is sent through radio or WIFI to control computers installed in a server room with power back-up batteries to ensure uninterrupted operation of the monitoring system. Data collection and processing is done on these computers using latest versions of software.

Displaying of slope monitoring results is done remotely from the monitoring room. One geotechnical engineer and one technician are in the monitoring room 24/7. Two computers are used with 4 displays for each computer. One computer is used to view Slope Stability Radar data from 4 units and data from each unit is displayed on separate monitor. The other computer is used to display robotic total station, GPS, rainfall and extensometer data also on separate monitors for each type of instrumentation.

The engineers and technicians are present in monitoring room for 24/7 to monitor all monitoring system and to take action as specified in the action plan. Action taken depends on the level of alert and specifics of the area involved. Hotspot Action Plans are explained in detail in posters displayed in the monitoring room to remind operators of what needs to be done in case of an alarm.

Senior engineers can access monitoring data remotely 24/7 from their laptops, which allows them to analyse data and provide support to the monitoring room when required. This ensures that data is watched and analysed 24/7 so no important changes in data patterns are missed.
Mitigation of geotechnical risks at Grasberg Pit and overburden stockpiles

Over the years Grasberg Geotechnical Group have developed geotechnical risks mitigation systems based on a detailed understanding of geology, hydrogeology and, mechanical behaviour of different types of rocks. Alarm criteria based on integrated monitoring systems were also developed in the process. All of the above are utilized in development of action plans for potentially unstable areas of the pit and overburden stockpiles which provide guidelines for both engineering and operation groups on how to react to geotechnical emergency situation. A geotechnically sound pit wall design is the most effective mitigation measure. A quarterly review process of mine design ensures that the latest geological and geotechnical data are included in pit wall design and mine plans.
The backbone of the geotechnical risk mitigation process is an integrated monitoring system. Radars are the main monitoring tools which are used in Grasberg for direct monitoring of unstable areas and for triggering alarms if the specified monitoring criteria are exceeded. Prisms are installed all over the pit surface with regular patterns at 100m horizontal intervals and vertically every two double benches. Prisms are mainly used to detect initial slope movement and also to provide detail 3D movement data for geotechnical analysis. GPS units are installed in areas where more accurate results and movement direction are required. Prisms and GPS are also used to verify movement recorded by radar. Extensometers and inclinometers are installed in unstable areas for surface and below surface deformation monitoring.

5.1 Geotechnical risk mitigation at Grasberg Pit

5.1.1 Integrated slope monitoring at pit bottom

Currently lower parts of pit walls and pit bottom are underlain by Hardzone (GTRCK-6) of Dalam Diorite unit with RQD >70%. This area is cut by two major faults: 1) Mid Grasberg structure zone which is oriented perpendicular to wall (N 250 E/-90), and 2) N340E trending structures dipping -55-60 degrees to the pit. Combination of high RQD rock and intense fracturing result in a number of rock falls generated from the pit walls above pit bottom.

During 2009 there were 5 incidents of rock fall (Fig. 4), often without any warning from radar. The radar alarm was not triggered because of the small size of falling rock when compared with radar resolution and the brittle characteristics of rock fall events.

Figure 4. Recorded rock fall events at pit bottom in 2009.
Detailed evaluation of these events was conducted to find suitable criteria to provide rock fall warning for crews working at the pit bottom. Rainfall intensity has a critical impact on the occurrence of rock falls. Rock falls tend to occur within one hour whenever 24hrs cumulative rainfall is above 20mm on average and rainfall intensity is exceeding 8mm/hr. Deformation recorded by radar during rock fall events was within 1mm range. Based on the above conclusions monitoring criteria for pit bottom were modified by combining rainfall and radar monitoring data. Number of pixels required to trigger alarm was reduced from 32 to 4 pixels that resulted in reduction of scanning time from 7 minutes to 2.5 minutes. Modification of monitoring criteria resulted in the radar being able to record displacements prior to rock fall and to provide early warning. Rock fall analysis and physical rock fall tests were carried out for different sections of the pit bottom to further verify monitoring criteria. Based on the evaluation rock fall events, detailed working and closure criteria were established for different sections of the pit bottom to effectively mitigate risks and allow for safe operation at the pit bottom.

5.1.2 Integrated slope monitoring at Lower Yapen

The Yapen area is located at the south-west corner of the Grasberg pit and has a history of slope instabilities. The Yapen area is located within the GIC (Grasberg Intrusive Complex) in the Dalam Fragmental Rock approximately 180m above the weak HSZ (Heavy Sulphide Zone) contact. Structurally this area is controlled by SE-NW and Mid Grasberg Fault structures that resulted in a highly fractured wide area. Alteration is primarily phyllic and potassic. Pervasive phyllic alteration created weak altered rock with RQD value less than 10% and clay content up to 20% (GTRCK 1-4), (Fig. 2).

Figure 6 shows a picture of the Yapen slope with an outline of the movement area. Yapen area encompasses the south-west corner of PB8E2S and a remediated slope from a PB7S September 2008 failure. During PB8E2 mining frequent small failure events occurred. These failures were remediated three different times by re-sloping the weak material and improving drainage to minimize the impact to this water sensitive material. The intent of the remediation was to stabilize the slope and get back on the planned design.

After remediation was completed the Yapen area was generally stable for a number of months, but as of early March 2010 the radar was recording increased surface deformation especially in the western section of Yapen area. Episodic accelerations due to mining operations (blasting and mining at the toe) and high precipitation events have resulted in continued deformation. Since May 2010, acceleration was observed. (Refer to Figs. 5 and 6). Precipitation events have resulted in continued deformation and expanded surface cracking from the 3535 to the 3715 bench.

In order to mitigate risk, rainfall and displacement rate criteria were developed as working and closure conditions for the impacted area. Working and closure criteria included: four hours moving average radar velocity over specified area (2500m²) and cumulative rainfall for 24, 48, 72 hours. Movement criteria are used for different alert levels and rainfall criteria are used in case of monitoring instrumentation malfunction. Evacuation limits for both orange and red level alarm were established based on run out analysis carried out using 3D DAN computer program. In order to ensure that the mining area is safe to enter after recorded deformation acceleration, re-opening criteria were also set up for radar velocity and rainfall. In this case both (rainfall and deformation acceleration) criteria have to be met before the area of concern is re-opened for mining.

Monitoring criteria were developed based on historical data, understanding of local geology and response of the rock mass to deformation. This allowed for development of action plans which insured that existing geotechnical risk is mitigated and reduced allowing for effective mining to take place in the area of increased geotechnical risk. Re-sloping of deformed slope and drainage work carried out in second half of 2010 stabilized effectively lower Yapen area and no significant deformation were recorded until now.
5.2 Risk mitigation at overburden stockpiles

On average 600Kton/day of waste material is placed in overburden stockpiles both on the west and east sites of the Grasberg pit. On the west side waste material is placed in very steep valleys using end dumping by trucks and stacker placement. On the east side bottom up construction using trucks over soft foundation is used. Challenges posed by foundation conditions required detail geotechnical monitoring, material specification for different dump conditions and strict control of surface and within dump drainage.

There are three types of overburden stockpiles at the Grasberg area: a. Carstens bottom up construction maximum 45m high lifts relatively stable, b. Middle Wanagon -truck dumped up to 400m high with numerous instabilities recorded, c. Lower Wangon – material placed using boom stacker, infrequent stability problems.

Middle Wanagon overburden stockpile has a height of up to 400m and it is critical that imminent failures are mitigated to ensure safe operation of such high plies. Based on the material placement data and the records of failures that have occurred over the years, it was concluded that daily crest advance rate (CAR) would be the
best tool to manage stockpile stability. Available long term detailed data allowed for development of CAR criteria for different sections of Middle Wanagon stockpile crest. Also, depending on pile height and foundation conditions, material type criteria (i.e. ratio of fine to coarse material) were introduced to further mitigate risk of sudden unexpected failure. Middle Wanagon stockpile crest is over 1000m long and if any section of the crest becomes unstable it is closed for operation, re-sloped and re-opened after no further displacement is recorded.

A typical monitoring device for the stockpile crest is wire line extensometer which has been used at Grasberg for a number of years. A number of failures were not recorded by extensometers as in some locations they could not be placed far enough from the crest without impacting material placement activities. In order to improve monitoring of the stockpile crest GPS units were deployed along the crest and proved to be a very useful device providing accurate 3D displacement data which is used for alarm criteria and also for stability analysis (Fig. 7).

Crest advance rate and, material and deformation criteria together with regular crest maintenance, proved to reduce the number of large failures with only minor slumping occurring since implementation of the overburden stockpiles placement criteria.

Figure 7. 40m vertical drop at Middle Wanagon OBS (June 3, 2010.). Example of GPS monitoring results for Middle Wanagon OBS.

6 Conclusions

Geotechnical risk mitigation is a key element in the safe, efficient management of pit and waste stockpiles slopes. Slope monitoring provides a direct measure of the effectiveness of slope design and its implementation. It can indicate where the design objectives are not being met and facilitate evaluation of possible causes and consequences of the deviation. In some areas visual monitoring alone is sufficient until indications of potential instability are discovered. Whenever safety becomes a concern, sophisticated monitoring instrumentation is deployed and, monitoring criteria and action plans are developed.

Grasberg field instrumentation must be capable of providing continuous, comprehensive coverage under adverse climatic conditions. Unfortunately there is no slope monitoring technique that is generally applicable to all slope monitoring situations. Therefore integrated slope monitoring systems are utilized at Grasberg to deal with changing slope and atmospheric conditions. The use of multiple monitoring techniques helps to overcome limitations of any one device.

The monitored parameters include both causes and effects. The primary parameter of interest in Grasberg is deformation which is effected by causes like rainfall, groundwater conditions, blasting vibrations, etc. By monitoring both cause and effect a relationship can then be developed and monitoring criteria can then be established for a particular section of the pit or overburden stockpile. Actions plans are developed to remedy the...
undesirable effect by mitigating the cause. Geotechnical risk mitigation utilizing integrated monitoring systems and action plans proved to reduce the number and also seriousness of the failures both at the open pit and overburden stockpiles allowing for safe and uninterrupted operation.

7 References


