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Slope stabilisation program at West Gully, PT Freeport Indonesia

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Abstract

PT Freeport Indonesia operates a copper-gold mine located in the province of Papua, Indonesia, about 3,500 km east of Jakarta. Current ore production from the project is about 220,000 tonnes per day (tpd) of which about 2.5 ktpd from Big Gossan stope mine, 60 ktpd come from the DOZ block cave and the rest is mined from the Grasberg open pit. Two new underground mines under development are the Grasberg block cave and Deep Mill level zone to ultimately replace surface mine operation.

One of the critical zones for entire mining operation is the mill-processing area. This area is not only dedicated for the processing plant but also is used as access to one of underground waste dump areas. The mill area is surrounded by steep natural slopes and extreme topography which often results in instabilities (debris flows, rockfalls) related to the geological features. West Gully is one of locations at the mill area which requires extensive work to mitigate rockfall hazard which impacts on the operations at the mill. Historical rockfall incidents, geological information, site observation, rockfall simulation, and road access reliability requirement for the future mining operation drive geotechnical recommendations to provide robust rockfall mitigation option. Scaling and meshing of more than 7,000 m^2, constructing two × 8,000 kJ of debris flow barriers, and 8,000 kJ of rock fence for an approximately 700 m high slope was required to reduce rockfall risk to an acceptable level. Those rockfall protections are augmented by 225 m corrugated steel tunnel at the mill level as an additional road protection from potential rockfall events.

Complex geological conditions, steep mountainous topography, average annual rainfall of 5,000 mm, foggy conditions, limited working space and the short distance to the critical facilities created a challenging situation for engineering design, construction, geotechnical monitoring and logistics. This paper outlines the slope stabilisation challenges and unique conditions and also the efforts of the team to reduce and mitigate rockfall hazards to ensure the safety of the workers and future safe production continuity.

1 Introduction

PT Freeport Indonesia operates a copper and gold mining complex in the Erstberg Mining District in the province of Papua, Indonesia. The Erstberg District is located at Sudirman Mountains at elevation from 3,000 to 4,500 m above sea level. The topography is extremely rugged and rainfall in the mine area averages 5,500 mm per year.

Current operations in the district include the Grasberg open pit (160,000 tpd ore), the DOZ panel cave mine (60,000 tpd ore), and the Big Gossan stope mine (2,000 tpd ore). All the ore from the mines has to be processed at the mill-processing facility Mile 74 which is surrounded by steep natural slope and extreme topography with high rainfall (Figure 1). The conditions create a high risk for ground instabilities which can impact critical facilities at the mill.

West Gully is one of the locations above the mill-processing area which requires extensive work to mitigate rockfall hazard (Figure 2). Several rockfall events occurred in the past and two rock fences were constructed. Since the end of July 2011, a number of major rock failures and rockfalls occurred that completely damaged the two existing fences located below the rockfall sources.

Figure 1 Plan view of Mile 74 area, location of critical infrastructures as mill processing plant, maintenance shops, offices, and power plant (LiDAR image taken 2012)

Figure 2 Panoramic view of West Gully slope and mill processing facilities area which is located approximately 700 m vertically below main rockfall source (Photo by P. Warren)

The number of major rockfalls over a short period of time caused serious interruptions to the operation of mill processing facilities, i.e. some rock fragments hit the flocculent and concentrator building; also some hit the main road causing its closure (Figure 3).

Field inspections and evaluations identified potential further instabilities which required immediate and comprehensive implementation of remediation measures. After a geotechnical evaluation it was agreed that the remediation would include: the stabilisation of the main rockfall source (scaling and meshing program for approximately 6,000 m^2), debris flow barrier construction, creation of a rock fence with higher capacity compared with previously constructed fences, a corrugated steel structure tunnel to secure the road, and also roof strengthening for critical buildings.

Figure 3 One of the rockfalls which hit the main road (originated approximately from 500 m above), September 2011

Even though there were no people injured due to rockfalls or slope failure at the Mile 74 area, historical data showed that rockfall incidents impacted mine operations significantly due to main road closure, temporary closure of several mill processing facilities, delays in underground development and production, loss of power (electricity), temporary manpower evacuation, etc.

It became obvious that the hazards associated with rockfalls or slope failures at the Mile 74 area needed to be mitigated to ensure the safety of the workers and the uninterrupted optimum safe production of mill processing and underground development.

2 Geological setting and failure mechanism

The West Gully area is located at the western part of Mile 74 mill processing area. The average slope height is approximately 700 m above the existing infrastructure. This particular area has been identified as a rockfall and debris flow source for several years.

The potential source of material comes from an area of approximately 6,000 m^2 that consists of a combination of limestone, sandstone, and shale rock type. The joints and bedding structures are dipping into the slope with the Wanagon Fault intersecting this area, and with a combination of intense jointing which creates mechanisms for potential slides and toppling failures (Figure 4).

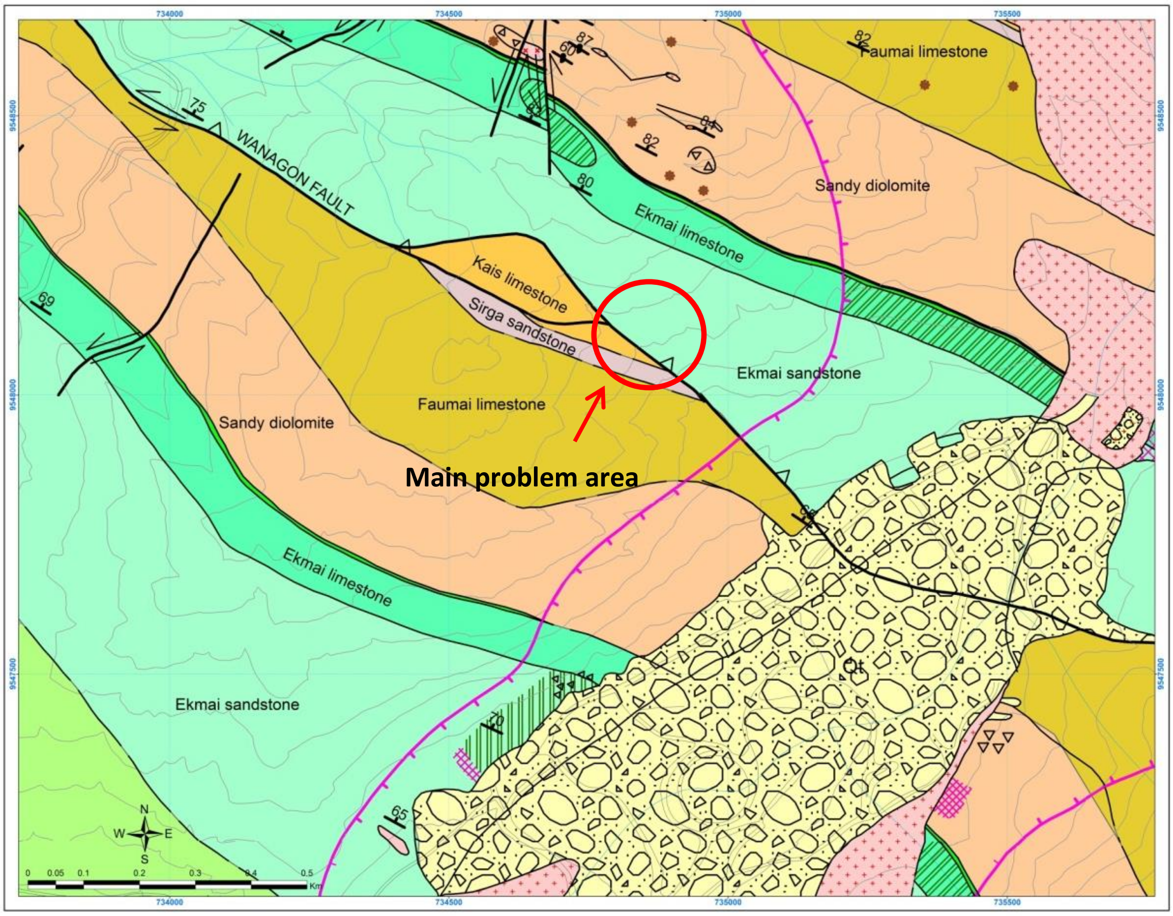

Figure 4 Regional geological map – the West Gully area consists of Kais limestone (Tk1); Sirga sandstone and shale (Ts); and Faumai limestone (Tf); the main structure is a Wanagon Fault with intense jointing and bedding

Referring to the geological setting and historical failures or rockfall events, there are several potential failures mechanisms which can occur in this particular area:

1. Slope unravelling or debris slide; small rocks or material detach from the original rock mass and become accumulated some distance from the toe. It is associated with the weathering process caused by surface water erosion. It is more likely to happen during or after significant rainfall and surface erosion plays a significant role in this type of failure (Varnes, 1978).
2. Wedge failure; the existing joints and bedding planes which intersect each other and dip to the lower area create potential wedge or block geometry which can detach from the original rock mass. Both water from the ground and rainfall can accelerate the wedge type failure (Hoek and Bray, 1981).
3. Toppling failure generally occurs when bigger blocks are sitting on the inclined slope or inclined plane. Again the water from both groundwater and rainfall reduces the shear strength between the block and original rock mass, also adding more weight to the block as well as triggering toppling failure (Hoek and Bray, 1981).
4. In general, the combination of these types of failures are most likely to happen during an actual failure event since the area consists of different types of rocks and vegetation occurring along the 700 m high slope.

3 Rockfall analysis and working criteria

3.1 Rockfall analysis and risk mitigation

The rockfall risk at this particular slope is critical to protect the main road and several mill processing plant infrastructures, with the ultimate goal to ensure safety of the workers. From the operation perspective, the stabilisation program is very important to ensure achievement of the underground expansion plan as the main access to the dump for underground overburden is through the main road. Also the mill processing infrastructures are critical for processing ore from both open pit and underground mines.

Required rockfall risk mitigation was determined from field inspection and rockfall analysis undertaken in-house and by a third party (consultant). The back analysis of several actual rockfall events was performed to get more reliable geotechnical parameters for the design of actual rockfall protection.

Rockfall analysis undertaken in-house using both 2D and 3D rockfall computer programs, in order to determine potential rockfall trajectories and to assess the same time effectiveness of the proposed rockfall protection structures, are shown in Figures 5, 6, 7 and 8. Table 1 shows residual risk associated with various proposed mitigation measures resulted from rockfall analysis software.

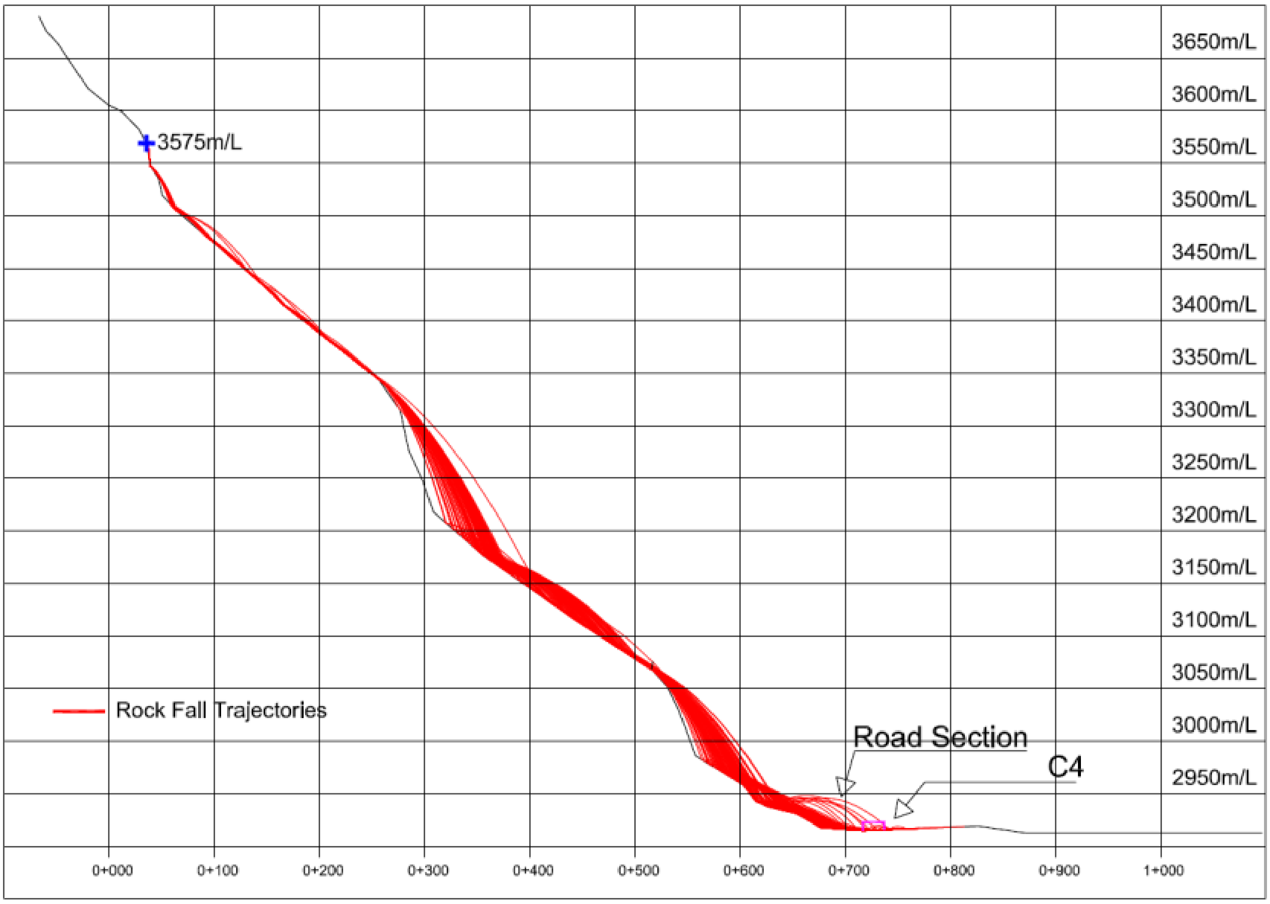

Figure 5 Two-dimensional rockfall analysis results without any protection (Rocscience Inc., 2013)

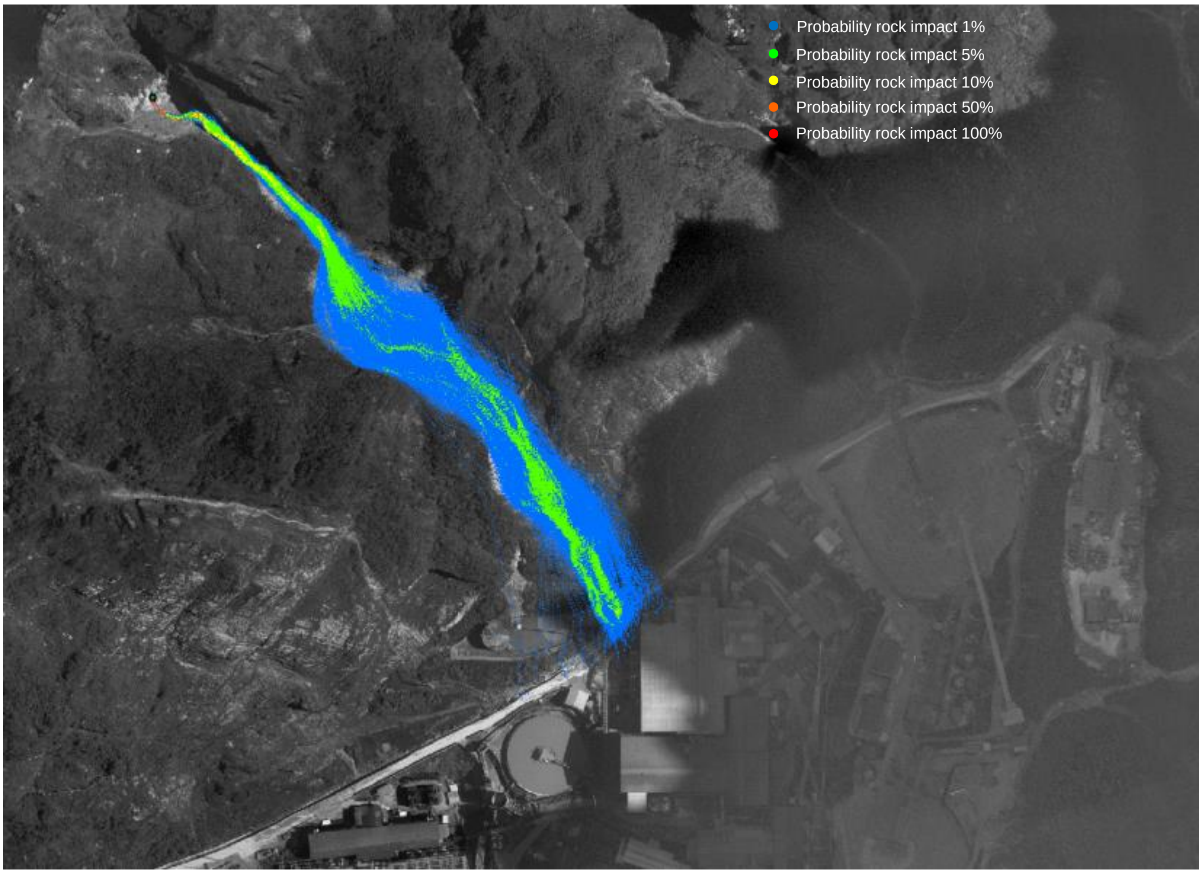

Figure 6 Three-dimensional rockfall analysis results without any protection (FEAT, 2013)

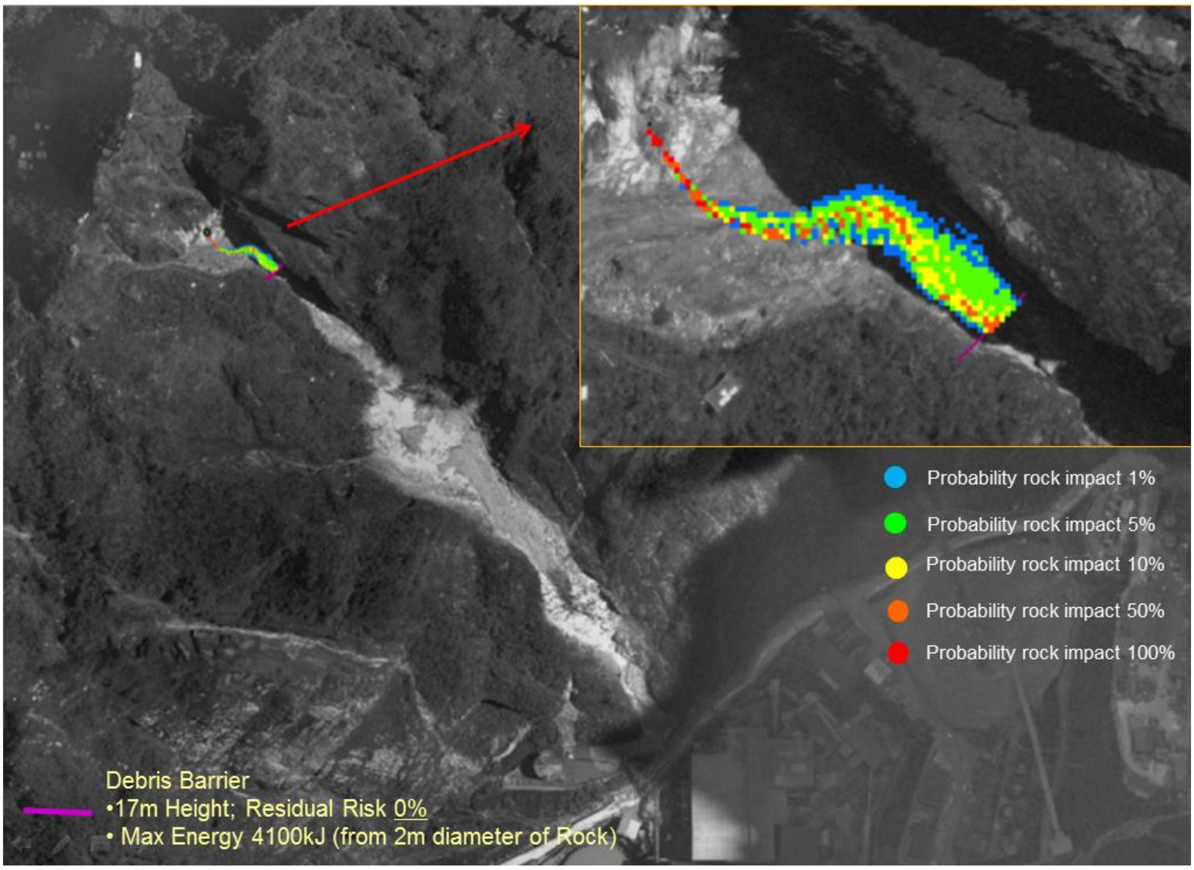

Figure 7 Analysis on debris flow structure effectiveness to capture material (FEAT, 2013)

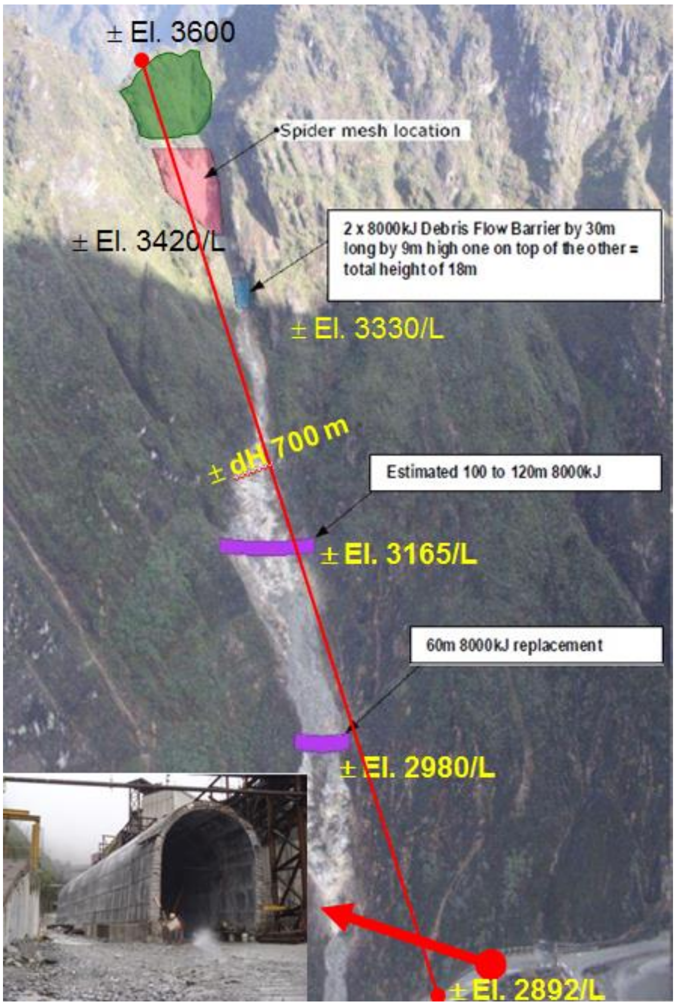

Figure 8 The original proposed rockfall protection and remediation at the West Gully area

Table 1 Residual risk for each structure protection

Rock Diameter (m)	Residual Risk to Facilities Underneath (%)					
	Without Protection	Debris Barrier	Upper and Lower Rock Fence (RF)	Lower Rock Fence	Tunnel	Lower Rock Fence and Tunnel
1	100%	0%	0.2%	0.7%	0.2%	0%
2	100%	0%	1.5%	2.0%	0.2%	0%
4	100%	Collapsed	Collapsed	Collapsed	1.0%	0%

Note: The residual risk is determined by the cumulative trajectories of rock passing the rock barrier for 1,000 chances; collapsed means that the rock barrier has a lower strength than impact energy from rock of a particular diameter; rock density is 2.5 tonne/m^3.

The proposed rockfall risk remediation at the beginning of project was as follows:

- Scaling and spider meshing installation at main source area which was approximately 6,000 m^2.
- Debris flow barrier (17 m height with 8,000 kJ capacity).
- Rock fence at the upper section (9 m height with 8,000 kJ capacity).
- Rock fence at the lower section (9 m height with 8,000 kJ capacity).
- Corrugated steel/concrete tunnel (9,000 kJ capacity).

3.2 Working criteria

Considering the steep natural slopes, the extreme topography with high rainfall, and the remaining risk of rockfalls, working criteria had to be developed to ensure the safety of workers working on the slope and to protect all activities underneath.

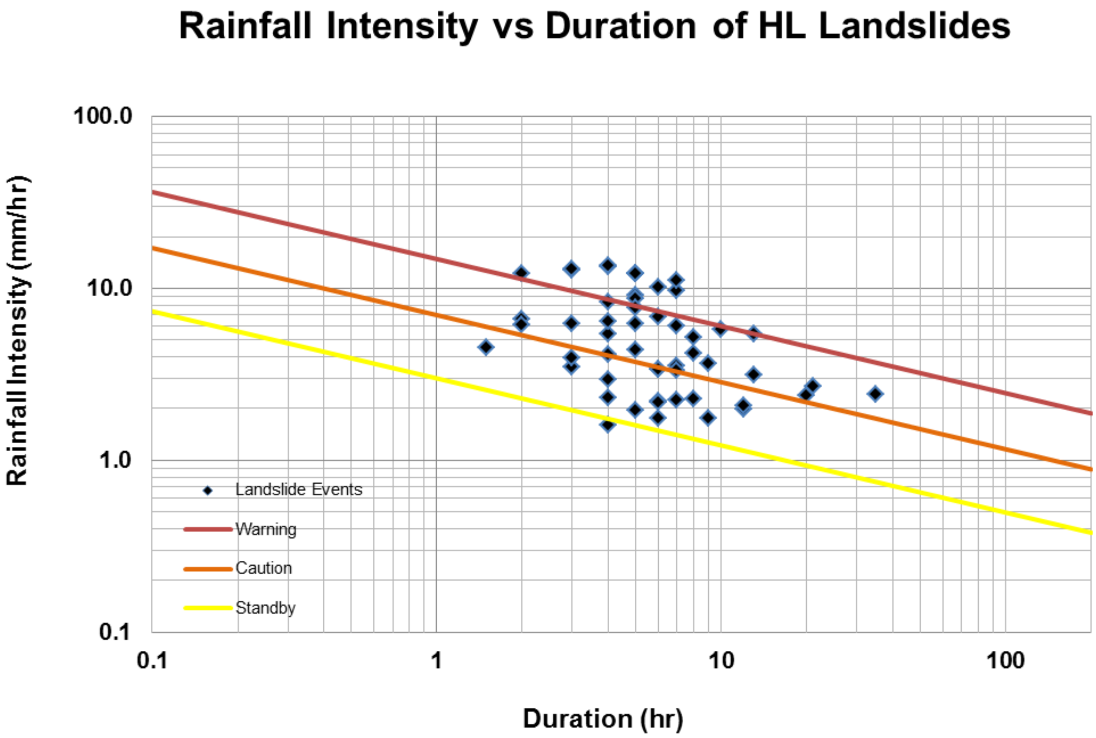

Figure 9 The rainfall intensity – duration control for the highland area PT Freeport Indonesia

It is obvious that rainfall has a significant role in the rockfall events or failures within this area, so its effect needs to be quantified. Referring to Caine (1980), the rainfall intensity – duration control for shallow landslides and the debris flows thresholds for highland areas were developed as practical working criteria. (Figure 9). The critical rainfall threshold is 14 mm/hour and 96 mm/24 hours, and to increase safety lower thresholds were adopted as working criteria, i.e. 12 mm/hour and 30 mm/24 hours.

The other criteria adopted were the deformation velocity recorded by radar which was developed based on the experience from the Grasberg open pit, since there was no available data for the mill area and the other criteria were set up using operational judgement (Table 2).

Table 2 West Gully working criteria

No	Criteria	Threshold
1	Rainfall	12 mm/hour or 30 mm/24 hours
2	Radar velocity	3 mm/hour for four contiguous pixels (400 m^2)
3	Acceleration of movement	Determined by engineer
4	Monitoring availability	No monitoring means no activity
5	Other	Determined by engineer/spotter, i.e. dirty water from the slope

4 Preparation and construction challenges

4.1 Preparation and logistics

The project area is not accessible from any existing roads and can be only accessed by helicopter, so it was critical to build the camp with the required facilities to support this project (Figure 10). The camp was built on the opposite site of the ridge and was equipped with a dormitory, kitchen, helipad, material pads, first aid facility, and communication facilities including internet, etc. Without this camp it would not be possible to complete this project.

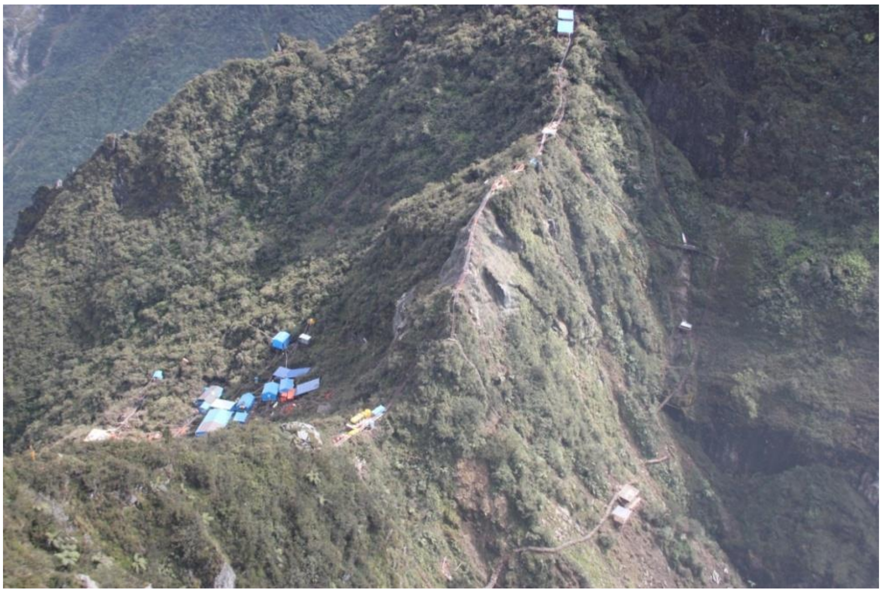

Figure 10 Camp facilities at the other side of West Gully to support the rockfall risk mitigation project

The material pads constructed within the project area guaranteed that the required material were in place when required and were located as close as possible to the particular construction site. The logistic issues were very challenging since all material mobilisation depended on helicopter support and the weather.

A number of walkways were constructed which connected different camp facilities and the camp with material pads and construction sites (Figure 11). The walkways increased safety and made the project more efficient by reducing the mobilisation time for both for people and materials to 15%.

Figure 11 Walkways are a safety initiatives to reduce the risk of accidents and speed up mobilisation time to 15%

4.2 Construction challenges

4.2.1 Geotechnical monitoring

Geotechnical monitoring is critical to provide early warning to workers of instability issues in this area. For this purpose two radars monitoring devices were deployed to monitor the main problem area (Figure 12).

Beside radar monitoring, other devices include prism monitoring which is quite difficult to utilise in fog and rain. Also undertaken was underground microseismic monitoring as this area is close to the Big Gossan stoping mine.

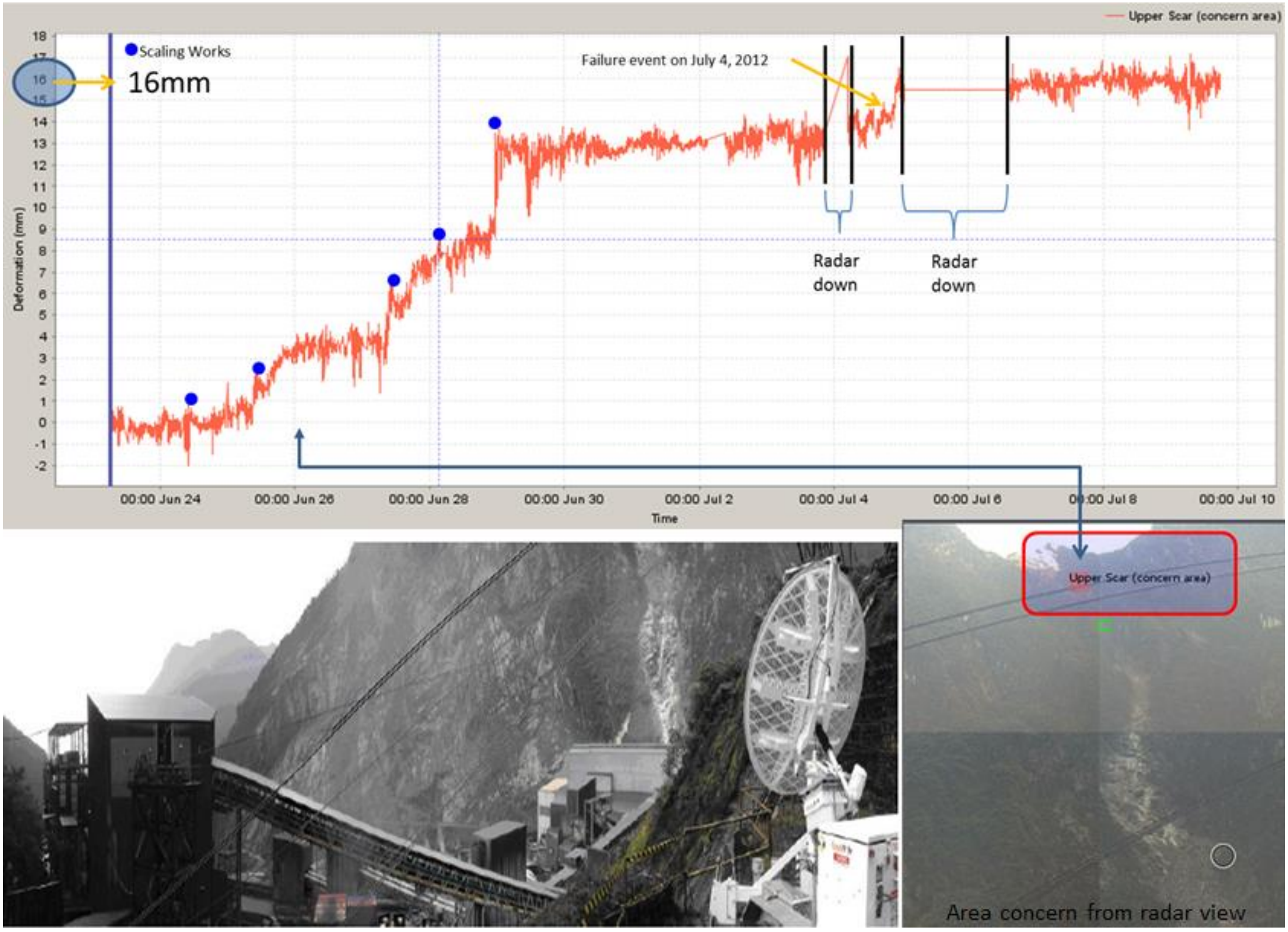

Figure 12 Dedicated radar monitoring to monitor the West Gully slope

4.2.2 Construction phase

Construction started in November 2011, and the main challenge was to construct barriers and install spider mesh in a safe and timely manner. Communication amongst the parties, especially the project owner, contractor and operation groups, which were impacted by this project, was critical to avoid any unnecessary delays. Logistics support and helicopter availability become important keys to the success of the project.

Currently (May 2013), the project is still running and is approximately 80% complete, and no worker has been injured since project commencement despite very difficult work conditions. Ongoing activities are presented in Figures 13 and 14.

Figure 13 Meshing activities at the main problem area (December 2012)

Figure 14 Drilling activities at the main problem area

5 Conclusions

Complex geological conditions, steep mountainous topography, an average annual rainfall of 5,000 mm, foggy conditions, limited working space and short distances to the critical facilities created a challenging situation for engineering design, construction, geotechnical monitoring and logistics.

Securing of the West Gully area was critical to ensure the safety of workers and commuters, and also to avoid interruption to the mining operation, especially for mill processing plant and ensure access to the dump area from underground mines which can affect future mine expansion.

Coordination and communication among all parties was the key to success of this project to ensure project completion in a safe and timely manner.

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