Blasting, fragmentation and wall quality result at West Wanagon slope stability project on Grasberg Mine

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Abstract. West Wanagon Slope Stability (WWSS) Project is part of final slope design of Wanagon OBS in Grasberg District, which provide around 150 Mton of Limestone as rock fill material, slope protection cover, drainage riprap layer and rock drain system. The design will balance operating objective with effective environmental, safety controls, geotechnical stable, adequate drainage with minimum erosion and facilitate revegetation. For past 3 year, PTFI has developed WWSS Geology Rock Model to identify various geology feature to lead blasting pattern and timing design to achieve fragmentation requirement and final slope quality. On 2017, there are 75 vibration monitoring data and give a result of blasting constant $PPV = 137.63 \pm 0.899$. This is based on pattern $7\text{m} \times 8\text{m}$ with timing $62\text{ms} \times 89\text{ms}$ (74%), $49\text{ms} \times 96\text{ms}$ (13%), $62\text{ms} \times 110\text{ms}$ (5%), $46\text{ms} \times 50\text{ms}$ (3%), $46\text{ms} \times 86\text{ms}$ (3%) and other (2%). The result of blasting on slope wall quality using modified – controlled blast evaluation chart (Read and Stacey, 2009) is able to achieve 1. Good Result=69.2%, 2. Geometry Achieved=3.8%, 3. Good Face Condition=23.1% and 4. Unacceptable result=3.9%. The fragmentation has taken at various location and has result that $D_{50}=174\text{mm}$, which meet slope cover requirement with screen to reduce fines content.

Keywords: WWSS, West Wanagon Slope Stability, blasting, fragmentation, final wall quality

1. Introduction
West Wanagon Slope Stability (WWSS) is part of final slope design of Wanagon OBS which begins in 2015 and planned to be completed in 2024. It is located on western of the Wanagon Basin from elevation 4200 m to 3200 m. The objective of this project are providing 150 million ton of limestone material to achieve final slope design that stable against surface erosion or runoff, seismic event and excess pore water pressures.

The final slope design of Wanagon OBS is consisted of WWSS area, which provide limestone material, and Rehandle material (Figure 1). In WWSS area, slope was designed using ISA 43° and BFA 70°. While in the Rehandle material is designed using ISA 21° (2.5H:1V) and BFA 26° (2H:1V). The drainage system on the toe of each catch bench will construct using rock cover with specific criteria based on $D_{50} = 75 \text{mm}$ dan $D_{50} = 150 \text{mm}$ requirement and rock quality requirement. In order to get the material effectively from the ROM, several factor and condition should be determined such as (1) Geological conditions in the form of fault, karst, clay content, RQD, litology; (2) Drilling and blasting design; (3) Fragmentation Result; (4) Wall quality.
2. Geological Condition

Geology model for WWSS was very broad until 2014 and since the beginning of this project on 2015, several drilling holes on elevation 4200 m to 3925 m were added, in order to detail the geology lithology and structures.

In general, the geology rock type in Wanagon Area consist of Limestone system (marbleized, argillaceous and karst), Idenberg#2 intrusion and Wanagon sill, which can be seen on Figure 2. Idenberg intrusion (Tif) is a micro diorite expose with complete sequence of alteration with the country rock. The limestone around Tif strongly altered to white marbleized limestone with low RQD 20-50% and contact polymics breccia also occurs between Tif Intrusion and limestone country rock. Tif Shows fine porphyritic texture with hornblende minerals, Pyrite <1%, Oxide 5-10% near contact breccia, clay 3-5% Limonite clay, and it develops at Idenberg #2 Fault zone.

Based on this geology rock type, geotech engineer is able to determine material suitable for rock cover or deliver to other waste dump. It is also to determine the blasting pattern to meet fragmentation requirement.

Beside geology rock type, geology conducts structural map as seen on Figure 3. This structure will assist geotech engineer to analyze optimum blast pattern and delay time in order to create optimum
energy propagation that have minimal impact to the wall stability. The major structure involve in WWSS is NW, NE and NS direction. This combination of trend may cause planar or wedge failure as seen on Figure 3.

![Figure 3. Structural Mapping and Failure Potential Identification](image)

### 3. Drilling and Blasting Design

In the beginning of exposing WWSS on elevation 4200 m to 4000 m, the blast pattern was 7 m x 8 m in most of the area and applying maximum 800-900 kg of ANFO and iKon. With experience gain on its blasting result since 2015 to 2016, geotech engineer reviews all of previous blast design based on geology rock type, major structure involved, number of holes, maximum peak particle velocity and frequency; blast damage evaluation, slope achievement and fragmentation.

In 2016 to 2017, several delay timing were introduced, vibration was monitored and the quality was assessed. The delay timing that introduce using 7 m x 8 m patter is 62 ms x 89 ms (74%), 49 ms x 96 ms (13%), 62 ms x 110 ms (5%), 46 ms x 50 ms (3%), 46 ms x 86 ms (3%) and other (2%). The blast charged and timing can be seen on Table 1.

| Geology Rock Type | Marbelized * | Marbelized | Karst 5% - 10% | Karst 10% - 15% | Karst >15% |
|-------------------|--------------|------------|----------------|-----------------|----------|
| Location          |              |            |                |                 |          |
| Row-1             | 500          | 450        | 450            | 450             | 350      |
| Row-2             | 650          | 550        | 550            | 550             | 450      |
| Row-3             | 850          | 800        | 800            | 800             | 600      |
| Row-4             | 900          | 850        | 850            | 850             | 750      |
| Row-5             | 900          | 900        | 900            | 900             | 800      |
| Delay Timing (ms) | 62 x 89      | 62 x 89    | 62 x 89        | 62 x 90         | 63 x 90  |
| Blast Pattern     | Echelon      | Echelon    | Echelon        | Echelon         | Echelon  |

Marbelized * = in the area that stable slope is not an issue i.e. pioneering the original rock for push back construction

The blasting vibration is monitored, to evaluate actual PPV and Hz, then compare with predicted analysis and blasting criteria i.e. PPV < 120 ms and freq > 20 Hz. The result of blast vibration then collected to provide site-specific blast constants as shown on Figure 4.
4. Fragmentation

The fragmentation from different blasting pattern, delay timing and rock type has different result. Therefore, it necessary to conduct fragmentation analysis in each of blasting therefore the characteristic of blasting design and rock can be determined for optimum material size following the criteria. The rock criteria for WWSS as seen on Table 2.

Photogrammetry method is used to evaluate fragmentation after blasting is exposed by shovel. From all of the fragmentation analysis, that conducted on various location within WWSS, the result is 1) all of the sampling location, the requirement for D50=75 mm is met, 2) for D50 = 150 mm, 64% of sampling area is met criteria. The result of analysis can be seen on Figure 6 and Table 3. On all of the sampling analysis, it shows that the maximum fines content (size = 1 inch) is 10% and most of the material is higher than criteria. This result is indicating that in order to meet slope cover criteria, grizzly/sieve panel is required to separate fines material and crusher to reduce the material that higher than requirement. Beside that, it show that the blasting design need to be improve to provide optimum material size for slope cover.
### Table 2. Rock Cover Requirement on WWSS

| Design Element                  | Grading Phase Design | Using Updated Parameters/Hyetograph |
|---------------------------------|----------------------|-------------------------------------|
|                                 | Riprap/Rock D_{50} Size (mm) | Channel Width (m) | Riprap Size (mm) | Channel Width (m) |
| LWOBS Rock Cover                | 100                  | N.A.                               | 75               | N.A.               |
| LWOBS Bench Channels            | 150                  | 4.0                                | 75 to 150        | 0 to 4.0           |
| Upper South Channel             | 530                  | 6.5                                | 510              | 6.5                |
| Middle South Channel (Hillside) | 610                  | 8.0                                | 510              | 8.0                |
| Middle South Channel (LWOBS side) | 530              | 6.5                                | 360              | 6.0                |
| Lower South Channel (with Tunnel) | 610              | 6.5                                | 560              | 6.0                |
| Lower South Channel (without Tunnel) | 610              | 15.0                               | 610              | 12.0               |

**Figure 6. Result of Fragmentation on WWSS**
Table 3. The $D_{30}$, $D_{50}$ and $D_{60}$ from Fragmentation Analysis

| Area          | Material Type              | Sample               | $D_{30}$ (mm) | $D_{50}$ (mm) | $D_{60}$ (mm) |
|---------------|----------------------------|----------------------|---------------|---------------|---------------|
| WWSS - 4060L  | DS#02_Sample1_R1           | 31.6                 | 110.91        | 164.2         |
|               | DS#02_Sample2_R1           | 177.16               | 269.81        | 334.23        |
|               | DS#09_R1                   | 62.93                | 145.73        | 181.97        |
|               | DS#19_002                  | 46                   | 116.68        | 158.67        |
|               | DS#19_004                  | 30.45                | 51.66         | 61.99         |
|               | DS#19_005                  | 56.19                | 112.72        | 141.97        |
|               | DS#19_009                  | 49.51                | 102.85        | 132.45        |
|               | Area #1 (7x8)              | 125.24               | 223.06        | 273.40        |
|               | Area #2 (7x8)              | 133.47               | 218.94        | 260.18        |
| WWSS 4015L - 4000L | Area #3 (8x9)              | 169.55               | 279.63        | 326.43        |
|               | Area #4 (7x8)              | 117.18               | 225.14        | 283.48        |
|               | Area #5 (7x8)              | 195.46               | 273.85        | 314.07        |
|               | Sample #02                 | 95.91                | 216.71        | 255.70        |
| WWSS 3940L - 3925L | Sample #04-2               | 44.31                | 116.94        | 153.80        |
|               | Sample #06-1               | 65.39                | 145.86        | 211.79        |
|               | Sample #01                 | 180.43               | 235.42        | 262.09        |
|               | Sample #02                 | 151.19               | 198.54        | 222.44        |
| WWSS 3925L - 3910L | Sample #03                 | 157.74               | 209.51        | 237.20        |
|               | Sample #04                 | 58.09                | 93.37         | 110.18        |

5. Wall Quality

It is very important to achieve wall quality to achieve safe production, stable slope and mitigate rock fall hazard. In PTFI, the wall quality is determined using 1) Modified – Controlled Blasting Evaluation Chart (Read and Stacey, 2009), 2) 3D Slope Audit, and 3) Shovel digging achievement.

The wall mapping, using modified-controlled blasting evaluation chart, was conducted from elevation 4215 m until 3955 m. The result of mapping on the area is 35.82% good result, 26.37% geometry is achieved but the wall surface condition needs to be considered geometry achieved however face condition need attention, while 19.90% had good surface geometry but unacceptable results, and 17.91% of unacceptable result mapping. The plotted is in Figure 7.

![Figure 7. Plotting Mapping WWSS at Elevation 4215 - 3955](image-url)
From the plotting, focus on wall quality improvement is from the assessment of the wall no 4 (unacceptable result) and No. 3 (good face geometry unacceptable).

The laser scanner is used to conduct 3D Slope Audit to acquire detail wall point cloud, which will evaluation using CAD program. The CAD program will measure the catch bench width (CBW) and bench face angle (BFA) in every 1 m slice, then show its performance statistically. The success criteria for single bench (15m high wall) is defined as CBW target: 7.6 m occurs over 85%. The target CBW value comes from modified Richie formula. The target BFA value is 67° occur over 85%.

The audit slope is carried out at elevation 3970L to 3910L and the result can be seen on Table 4, Figure 8, Table 5 and Figure 9.

### Table 4. Result BFA WWSS

| Elevation                  | 50% BFA Reliability | 80% BFA Reliability | Remark          |
|----------------------------|---------------------|---------------------|-----------------|
| 3970L-3940L double bench   | 58.6                | 55.4                | BFA 62° = 15%   |
| 3970L-3955L                | 55.9                | 53.2                | BFA 62° = 15%   |
| 3955L-3940L East           | 66.0                | 63.0                | BFA 62° = 82%   |
| 3955L-3940L West           | 65.3                | 61.3                | BFA 62° = 73%   |
| 3940L-3925L East           | 60.4                | 56.1                | BFA 62° = 42%   |
| 3940L-3925L West           | 68.5                | 65.0                | BFA 62° = 94%   |
| 3925L-3910 West            | 62.0                | 60.4                | BFA 62° = 67%   |

**Figure 8.** Graph Result BFA WWSS
Table 5. Result CBW WWSS

| Elevation     | 50% CBW Reliability | 80% CBW Reliability | Remark               |
|---------------|----------------------|----------------------|----------------------|
| 3955L         | 10.8                 | 9.2                  | CBW 7.6 m = 90%      |
| 3940L East    | 8.4                  | 6.8                  | CBW 7.6 m = 71%      |
| 3940L West    | 11.6                 | 10.5                 | CBW 7.6 m = 100%     |
| 3925L West    | 11.6                 | 10.5                 | CBW 7.6 m = 100%     |

Figure 9. Graph Result CBW WWSS

In order to assist shovel operator to achieve design, PerfectDig software is used to compare between actual (based on laser scanner) and design. PTFI criteria for success is: 1) offset is not more than 1m and over dug is not more than 0.5m otherwise the pre-split hole will damage. The result is color-based, that easy to understand by operator. In this case, the blue color means over dig and red color means under dig.
## Conclusion

- Good geology information will provide initial information to generate blast design and its relation to stable slope.
- The blast design should be controlled and fine-tune in every blast, in order to meet requirement and keep the wall stable.
• Controlled blasting can be achieved by collecting data from vibration monitoring and blast video. It will give blast engineer good understanding of rock behavior against blast vibration.
• The rock fragmentation analysis on each of blasting is able to determine to success of blasting related to material size requirement. In this case, meet criteria for rock cover.
• The wall quality should be met the criteria in order to perform safe production and stable slope. Each of the wall that not meet the designated quality, it should be stabilized. Failed to meet criteria in the first place, mean that additional cost will add to improve the wall.

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