Optimization and slope stability coal mine with dewatering system using limit equilibrium method

I Iswandaru*, N F Isniarno and R F Hirnawan
Prokram Studi Teknik Pertambangan, Fakultas Teknik, Universitas Islam Bandung, Jl. Tamansari No.1 Bandung 40116
*iiswandaru@unisba.ac.id

Abstract. Mining activities related to excavation or landfill will always face problems with slopes, both in the form of a working slope and a final slope. The slopes must be analyzed for stability to prevent landslide hazards because they involve work safety, equipment safety, and smooth production. PT. XYZ is a coal mining company located in the Lilin river, South Sumatra, planning to optimize and stabilize the final slope to a depth of 120 m. Geotechnical drilling has been carried out as many as 3 points with a total depth of 270 m and 80 samples of rock and soil testing. The results of optimization and slope stability conditions at PT. XYZ can be conducted by dewatering at each elevation to obtain optimal slope conditions at PT. XYZ can be done up to elevation of -130 meters above sea level with a depth of 142 meters with an angle of 35° with the condition of the ground water level must be maintained at the halfway point of the slope (GWL Chart No. 3). Under water saturated conditions (GWL Chart No. 5) at the same elevation the permissible angle is only 25° with a final slope height of 136 m.

1. Introduction
Excavation or landfill will always face problems with slopes, both in the form of a working slope and a final slope. The slopes must be analyzed for stability to prevent the danger of landslide in the future, because it involves work safety, security of equipment and property, and smooth production. Therefore, an analysis of slope stability is an important part of preventing disruption of production and fatal disasters, so as a control tool of the design process is monitoring and carrying out steps to stabilize the potential slope. The design of the slope of a coal mine opening greatly determines the economics of the mining project as measured by the value of the Stripping Ratio (SR) which is the ratio of waste excavated to coal that can be mined. On the other hand, the maximum overall slope which can be made in the context of obtaining a small SR and the safety of the slope stability is guaranteed, highly dependent on the geotechnical properties and conditions of the rock mass of the mine opening slope. PT. XYZ which is located in the Sungai Lilin area of South Sumatra to optimize and stabilize the final slope to a depth of ± 130 m for optimal slope stability for any reduction in mining elevation and dewatering efforts to keep the slope dry by lowering ground water levels. Geotechnical drilling has been carried out as many as 3 points with a total depth of 270 m and 80 samples of rock and soil testing. Slope modeling uses the boundary balance method, the right method to be used on sedimentary rock characters.
2. Method research and result

2.1. Limit equilibrium method

The Limit Equilibrium Method is a very popular method for use in the analysis of translational and rotational slip type slope stability. Slope stability conditions in the boundary equilibrium method are expressed in the safety factor index which is calculated using force equilibrium, moment equilibrium, or using both conditions. The equilibrium method applied in this study is the Bishop method, because this method ignores the shear forces between slices and assumes that the normal force is sufficient to define the forces between the slices [1].

\[ F = \frac{1}{\Sigma W \cdot \sin \alpha} \sum \left( C' b + W \left( 1 - ru \right) \tan \phi \right) \left( \frac{\text{sec} \alpha}{(\tan \alpha \cdot \tan \phi)} \right) \]

Note:
- \( F \) : Safety factor
- \( W \) : Weight of the slice
- \( C \) : Cohesion
- \( \alpha \) : Slope
- \( b \) : Width of the slice
- \( u \) : Pore water pressure
- \( \phi \) : Inner sliding angle

2.2. Factors affecting slope stability

Factors that affect the stability or slope failure can be grouped into 5 main factors, namely:

- Slope geometry, i.e. height and slope.
- Physical -mechanical properties.
- Physical properties that increase slope stability are weight, porosity and air composition. Compressive strength, tensile strength, shear strength, cohesion and internal shear angle represent mechanical properties that also affect slope stability.
- General orientation of the discontinuity structure. The slope structure which greatly affects the stability of the slope is fault fields, bedding and fractures. This stone structure is a weak fields and at the same time as a place of air seepage making it easy to landslide.
- Factors outside the slope system, in the form of external loads and or vibrations (earthquakes and mine blasting).
- The existence of ground water in the rock slope mass.
2.3. Stability criteria
Slope stability, which is expressed by the Factor of Safety FoS, is the ratio of shear strength of rock mass that can be mobilized to hold the slope from landslides with shear stress acting on the landslide field due to its gravity to drive the slope to landslides. Theoretically SF > 1.0 is stable and SF < 1.0 is a landslide and precisely SF = 1.0 is a critical condition. Based on KEPMEN ESDM No. 1827 [3].

| Slope Type | Failure Impact | FoS min       |
|------------|----------------|---------------|
| Single     | Low, Medium    | 1.1           |
|            | Low            | 1.15-1.2      |
| Inter-ramp | Medium         | 1.2           |
|            | High           | 1.2-1.3       |
|            | Low            | 1.2-1.3       |
| Overall    | Medium         | 1.3           |
|            | High           | 1.5           |

2.4. Result
Geotechnical drilling was carried out at 3 points with a total depth of up to 270 m, the number of samples carried out for testing physical and mechanical properties amounted to 80 samples consisting of Claystone and Sandstone rocks. In figure 1, the cross section of the geological model of coal has several seams with a relatively thick thickness of up to 5 meters with a slope of 30°.
The physical properties tested were natural and saturated density, the mechanical properties were tested by direct shear to get the cohesion value and the friction angle in the rock. Test results from 80 samples of physical and mechanical properties were then carried out by simple statistical analysis by finding the minimum, maximum, average, and median values of Tables 2 & 3). The median value of claystone and sandstone rocks is used as a reference as input parameters for the overall slope modeling.

Table 2. Test results and input parameters of the physical and mechanical properties of claystone.

| Criteria | INDEX PROPERTIES | DIRECT SHEAR |
|----------|------------------|--------------|
|          | Natural Density (gr/cm³) | Saturated Density (gr/cm³) | C peak (kg/cm²) | φ peak (°) | C residual (kg/cm²) | φ residual (°) |
| Min      | 1.89  | 2.02  | 0.46 | 12.92 | 0.17 | 3.58 |
| Max      | 2.22  | 2.32  | 4.64 | 29.24 | 0.72 | 8.13 |
| Average  | 2.00  | 2.15  | 1.91 | 21.78 | 0.43 | 5.83 |
| Median   | 1.98  | 2.13  | 1.43 | 23.16 | 0.43 | 5.62 |

Table 3. Test results and input parameters of the physical and mechanical properties of the sandstone.

| Criteria | INDEX PROPERTIES | DIRECT SHEAR |
|----------|------------------|--------------|
|          | Natural Density (gr/cm³) | Saturated Density (gr/cm³) | C peak (kg/cm²) | φ peak (°) | C residual (kg/cm²) | φ residual (°) |
| Min      | 1.95  | 2.12  | 0.20 | 20.82 | 0.06 | 4.85 |
| Max      | 2.04  | 2.21  | 4.31 | 29.35 | 0.94 | 8.28 |
| Average  | 1.99  | 2.16  | 2.62 | 26.17 | 0.57 | 6.52 |
| Median   | 1.99  | 2.15  | 3.25 | 27.36 | 0.62 | 6.54 |

Slope simulation is carried out by referring to the elevation of the mining floor starting at elevation of -30 masl to -130 masl. Slope optimization is carried out for each additional elevation depth of 20 m. Groundwater conditions are simulated using saturated conditions and dewatering conditions no. 3 (can be seen in Figure 1). The results of slope optimization and stabilization can be seen in table 4.
Table 4. Results of slope stability simulation with optimization and dewatering.

| Elevation (E;m) | Depth (Z;m) | Slope Angle (°) | FoS GWL Chart no. 5 | FoS GWL Chart no. 3 |
|----------------|-------------|-----------------|---------------------|---------------------|
|                |             | Ordin ary       | Bishop p            | Janbu r             | Spence r |
| -30            | 27.214      | 50              | 2.787               | 2.67                | 2.697    | 2.868   | 3.07    | 3.026   | 3.089   | 3.477   |
|                | 27.15       | 55              | 2.71                | 2.551               | 2.64     | 2.753   | 2.987   | 2.911   | 3.034   | 3.435   |
|                | 27.089      | 60              | 2.63                | 2.478               | 2.579    | 2.85    | 2.903   | 2.838   | 2.965   | 3.411   |
|                | 48.223      | 50              | 1.807               | 1.708               | 1.682    | 1.712   | 2.016   | 1.995   | 1.982   | 1.999   |
|                | 48.089      | 55              | 1.748               | 1.619               | 1.623    | 1.64    | 1.956   | 1.923   | 1.929   | 1.951   |
| -50            | 47.951      | 60              | 1.687               | 1.428               | 1.365    | 1.436   | 1.848   | 1.741   | 1.799   | 1.79    |
|                | 68.834      | 45              | 1.527               | 1.47                | 1.4      | 1.469   | 1.78    | 1.807   | 1.741   | 1.803   |
|                | 68.815      | 50              | 1.485               | 1.318               | 1.259    | 1.335   | 1.712   | 1.651   | 1.679   | 1.73    |
|                | 68.799      | 55              | 1.381               | 1.168               | 1.076    | 1.176   | 1.528   | 1.469   | 1.508   | 1.51    |
| -70            | 96.173      | 35              | 1.366               | 1.303               | 1.193    | 1.299   | 1.58    | 1.626   | 1.545   | 1.627   |
|                | 93.288      | 40              | 1.288               | 1.209               | 1.077    | 1.207   | 1.493   | 1.515   | 1.435   | 1.51    |
|                | 90.877      | 45              | 1.236               | 1.143               | 1.03     | 1.143   | 1.447   | 1.454   | 1.38     | 1.45    |
|                | 121.992     | 30              | 1.301               | 1.3                  | 1.087    | 1.3     | 1.487   | 1.572   | 1.372   | 1.571   |
| -90            | 120.83      | 35              | 1.228               | 1.155               | 1.039    | 1.153   | 1.428   | 1.463   | 1.365   | 1.461   |
|                | 118.781     | 40              | 1.116               | 1.026               | 0.893    | 1.029   | 1.325   | 1.351   | 1.264   | 1.356   |
|                | 135.557     | 25              | 1.33                | 1.347               | 1.158    | 1.346   | 1.542   | 1.654   | 1.451   | 1.651   |
| -110           | 140.631     | 30              | 1.203               | 1.16                | 1.04     | 1.16    | 1.416   | 1.47    | 1.36     | 1.469   |
|                | 142.323     | 35              | 1.07                | 1.014               | 0.898    | 1.014   | 1.268   | 1.315   | 1.219   | 1.31    |

Note: Slope Recommendation.

3. Conclusion
The results of optimization and stability of the slope by conducting dewatering at each elevation to obtain optimal slope conditions at PT. XYZ can be done up to elevation of -130 meters above sea level with a depth of 142 meters with an angle of 35° with the condition of the ground water level must be maintained at the halfway point of the slope (GWL Chart No. 3). Under water saturated conditions (GWL Chart No. 5) at the same elevation the permissible angle is only 25° with a final slope height of 136 m.

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