Three-Dimensional Numerical Modeling of Underground Mining Method at Mae Moh Lignite Mine in Thailand

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ABSTRACT
Mae Moh mine is the largest open-pit lignite mine in Thailand. In this mine, the development of underground mine from final highwall is considered after the surface mining operation is finished. Longwall mining is a common method for extracting coal from various thickness of coal seam. However, due to unfavorable geological conditions such as weak strata and huge final pit slopes, various preliminary studies on the introduction of underground mining systems have been conducted so far. This paper discusses the applicability of longwall mining system and its suitable design by means of three-dimensional numerical modeling: FLAC3D.

KEY WORDS: Coal mining / Longwall mining / Slope stability / Numerical modeling / FLAC3D

1. INTRODUCTION
The Mae Moh mine is located in Mae Moh district, Lampang province, about 630 kilometers north of Bangkok, Thailand. The location of Mae Moh mine is shown in Figure 1. This mine is operated by one of the most well-known Thai state enterprises, EGAT (Electricity Generating Authority of Thailand), and is claimed to be the largest open-pit lignite mine in the Southeast Asia. The total geological and economical lignite reserves of the Mae Moh coal field are approximately 1,140 million tons and 825 million tons, respectively. Its annual lignite production is approximately 12 million tons, which represents 90% of the total coal production in Thailand (2012). All of the lignite produced from the mine is supplied to the 2,400 MW Mae Moh power plant, which is providing 15% of the total electricity demand of Thailand. 347 million tons of lignite has been already produced, and the remaining future reserves are about 478 million tons as of 2010. In the near future, the open-pit operation will be reached to its economical and/or geotechnical limit and underground mine will be developed at the depth of about 500 m from the surface. However, due to the geotechnical issues such as weak mechanical properties of rocks, existence of plenty of faults and extra thickness of coal seams (20-30 m thickness), various studies such as final open-pit stabiility, an applicable underground mining system for Mae Moh mine are being conducted at present. This paper discusses the behavior of pit slope under different extent of rib pillars, size of panels, slope height, and the interaction between open-pit slope and underground working by means of numerical analyses using three-dimensional explicit finite-difference program FLAC3D produced by ITASCA.

2. GEOLOGICAL CONDITIONS
According to the recent studies on sedimentary rocks (e.g. Silaratana et al. 2004, Songtham et al. 2005a,b, Ratanasthien et al. 2008), the Mae Moh basin is bounded mostly by marine Triassic rocks of Lampang Group which are composed of limestone, shale, and sandstone (see Figure 2). EGAT reported that the Tertiary sequences of Mae Moh basin have been divided into three formations; Huai Lang (HL-Fm), Na Khaem (NK-Fm) and Huai King (HK-Fm) formations. HL-Fm mainly consists of red to brownish red semi-consolidated and unconsolidated claystone, siltstone and sand. NK-Fm consists lignite layers and gray to greenish gray claystone and mudstone. Five lignite seams, marked as J, K, Q, R and S seam, are found in NK-Fm. However, the J, R and S seams are considereed as uneconomical seams for extraction due to the poor quality, thickness and depth of seam. Thus, major economical mineable seams are only K and Q seams. The K seam with four sub-divisions is a sequence of black to brownish black, brittle, high calcareous coal interbedded with

Fig.1 Location of Mae Moh lignite mine
soft lignite and light yellowish gray to gray silty claystone, varying from 10 to 30 m in thickness. Q seam with 4 sub-divisions is comprised of black to brownish black to brittle coal with the total thickness varied between 25 to 30 m, interbedded with soft lignite, light brown claystone/silty claystone.

HK-Fm consists of semi-consolidated fine to coarse sandstone, claystone, mudstone and conglomerate with green, yellow, blue and purple in color. The dip of all the strata is dipping approximately 10-12 degrees towards the center of the basin.

Fig. 2 Typical stratigraphy of Mae Moh mine (Courtesy of EGAT)

3. NUMERICAL ANALYSIS

3.1 Description of numerical model

The three-dimensional model (see Figure 3) is composed of two 20 m thick coal seams, marked as K_seam and Q_seam in this figure, 20 m thick interburden, 400 m thick overburden and 80 m thick underburden, respectively. The length and width of the model are 600 m long and 1,100 m, respectively. For the sake of simplicity, multi layers are not considered and the materials except the coal seams are assigned as claystone. The Mohr Coulomb elasto-plastic constitutive material behavior is adopted in this simulation. The mechanical properties of rocks used in this numerical analysis are presented in Table 1. After constructing model, assigning material properties, and defining boundary conditions, the model is loaded by the gravitational force. To allow gravitational stresses to develop within the body, the simulation is stepped to equilibrium. When the unbalanced force ratio falls below the limiting value; 1x10^-5, the run is stopped.

3.2 Modeling procedure, results and discussion

When a coal seam is extra thick, its extraction usually involves dividing the coal block into multi lift/passes. It is well known that the longwall and room-and-pillar are common methods in multi-slice mining practices nowadays. However, in the case of Mae Moh mine where poor geological conditions and weak rock strata exist, an appropriate mining method must be investigated to recover the coal production with full attention to safety. In this paper, the application of multi-slice longwall method is considered and the behavior of the open-pit slope due to longwall mining is discussed.

Tab.1 Material properties used in simulations

<table>
<thead>
<tr>
<th>Materials</th>
<th>Coal</th>
<th>Rocks</th>
</tr>
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<tbody>
<tr>
<td>Density (MN/m³)</td>
<td>0.0143</td>
<td>0.0195</td>
</tr>
<tr>
<td>Young's modulus (MPa)</td>
<td>100</td>
<td>10,000</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>0.4</td>
<td>0.25</td>
</tr>
<tr>
<td>Internal frictional angle (deg)</td>
<td>22.3</td>
<td>25</td>
</tr>
<tr>
<td>Cohesion (MPa)</td>
<td>0.16</td>
<td>1.75</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

In order to investigate the behavior of open-pit slope due to the longwall extraction, the longwall model is created as shown in Figure 4. At first, the excavation of a pair of entries with a dimension of 6 m in width and 3 m in height is drivaged along the roof of the coal seam, and a longwall panel is developed. After that, coal face extraction is started by leaving a rib pillar between the open-pit slope and the longwall panel, and the extraction is advanced forward until the end of the prescribed panel. The length and width of the panel are taken as 300 m and 300 m, respectively.
Fig.4 Details of the longwall model

In the numerical simulations, the different width of the rib pillars, which is the horizontal distance from the pit slope to the longwall panels, in other words, the distance between the pit slope and the underground extraction area, is set and the stability of the pit slope and the ground behavior around the longwall panel are investigated. Firstly, the width of the rib pillar is set at 100 m whereas the vertical distance between the pit floor and the top of the longwall panels/underground extraction area is set at 40 m in the model. Figures 5 (a) and (b) show the failure state and induced displacement contours along the central part of the panel after the longwall extraction. According to these results, the slope displacement is found about 25 cm in average, and failure is developed around the toe of the slope. In this situation, the occurrence of slope instability due to the longwall extraction and the collapse of the mine roof can be expected.

Figures 6(a) and (b) show the failure state and induced displacement contours after extracting the panel where the rib pillar width is extended into 200 m, but the size of panel is unchanged. According to these results, it is found that the slope displacement and extent of failure becomes to be larger and the roof collapse or slope failure are still expected. Figures 7(a) and (b) show the failure state and induced displacement contours after the extraction of the panel with the rib pillar width of 300 m. According to these results, it is found that the impact on the slope stability resulted from the longwall extraction becomes to be small in comparison with that of the previous model. However, as the failure zone around the roof of the panel becomes to be large, the instability of the underground working spaces would be expected.

Next, the effect of the panel size on the behavior of the ground is discussed.

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Figures 8 shows the details of the model where the face length of each panel is 120 m, the width of the barrier pillar between the adjacent panels is 60 m and the width of rib pillar is 100 m. It is also modeled with different width of rib pillars, and investigated the ground behavior in different conditions. Figures 9(a) and (b) show the failure state and induced displacement contours after extracting the panels where the rib pillar width is 200 m. It could be seen from these figures that the failures zone and displacement are relatively small and it seem the distance between the pit slope and the longwall panel is appropriate for the stabilities of the
Figures 10(a) and (b) show the failure states and displacement contours after extracting three slices, respectively. According to these results, the ground displacement at the roof of goaf or the extraction area is found approximately 50 cm whereas the subsidence of slope is 20-30 cm. Although the failure zones around the longwall panels are increased, the pit slope is not largely affected by the longwall extraction and is still stable after the coal seam is fully extracted.

Fig. 7 (a) Failure state and (b) contours of induced displacement after extracting a 300m-panel (face length= 300 m, rib pillar width= 300 m)

Fig. 8 Details of the longwall model (double panels)

Fig. 9 (a) Failure state and (b) contours of induced displacement after extracting double 300m-panels (face length= 120 m, rib pillar width= 200 m)

Fig. 10 (a) Failure state and (b) contours of induced displacement after extracting three slice panels (face length= 120 m, rib pillar width= 200 m)
4. CONCLUSION
According to these results of a series of numerical analyses, it can be concluded that the rib pillar width, or the minimum distance between the open-pit slope and the underground extraction area, of 200 m would be appropriate to lessen the effect of underground mining operation on the stability of the open-pit slope. It can also be found that the application of longwall method is very limited in this mine since the longer the face is, the more failures occur around the pit slope and the mine openings. Thus, the application of shortwall/bord-and-pillar method is recommended rather than that of longwall. However, the panel layouts and barrier pillar design in multi-slice sections must be further investigated.

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