Optimization of Slope Angle and Its Seismic Stability: A Case Study for the Proposed Open Pit Coalmine in Phulbari, NW Bangladesh

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Abstract: The present study reflects upon the results of substantial program of two-dimensional Finite Element Method (FEM) numerical analyses of the open pit that links to slope angle optimization associated with the safety factor of the pit slope of a coal mine in Bangladesh. In the present analyses, two types of models have been presented. The first model estimates safety factor without seismic effect on the overall pit slope of the model; the second model incorporates safety factor with seismic stability of the model. The calculated optimum slope angle of the first model is 31° with a rational safety factor of 1.51, prior to the seismic effect. However, the value is reduced to 0.93, 0.82, and 0.72, after we applies the seismic effect in the second model with M6, M6.5, and M7, respectively. Finally, our modeling results emphasize that for the case of the proposed Phulbari coalmine, there is extremely high prospect for causing massive slope failure along the optimum pit slope angle with 31° if the mine area felt seismic shaking, like the Sikkim (in northern India) earthquake with M6.9 on September 18, 2011.

Keywords: Open pit coalmine; Optimum slope angle; Safety factor; Seismic stability

Introduction

Over the past several decades, there has been inadequate development in the computer aided analyzes of slope angle optimization in an open pit coalmine. Slope angle optimization is, in fact, a challenging issue in the mining world. It has been observed that small changes in the overall pit slope angle (OPSA) have significant influence on the overall economy of the mining operation. The decrease of the OPSA, increases the land requisition that enhances striping ratio throughout the life of a mine. An ideal design of slope angle could be able to predict where and under what circumstances a failure surface/zone can develop (Ning et al. 2011). Reviews of literature reveal that the application of numerical analyzes method for the study of slope angle optimization and the seismic stability analyses in open pit mine has become only relatively common in recent years (Stacey et al. 2003; Zhang et al. 2010; Daftaribesheli et al. 2011; Li et al. 2011).

Analyses and assessment of the stability of slopes are the most important aspects in open pit extraction of coal. In order to evaluate the stability of a mine slope, the geological factor, the geometrical and the geo-mechanical characteristics of slope should be examined first (Koner and Chakravarty 2010). Then, stability of mine slope should be evaluated from the seismic point of view, if the mine area is located very close to the high seismically active zones (Islam and Shinjo 2009a). Earthquakes affect rock slopes in two distinct ways. The first one is the immediate detachment of rock from a slope face and the second involves the earthquake-induced opening of fissures and rock fracturing that may result in rock dislodgements in
Scholarly opinion reveals that during the early feasibility studies for a proposed open pit mine, like in the Phulbari coal basin of the northwestern Bangladesh, an estimate of safe slope angle is required for the calculation of coal to waste ratios and for the preliminary pit layouts (Hustrulid and Kuchta 2006). In addition, seismic stability of pit slope is also required because it plays a vital role in the safe operation of a coalmine.

This study tries to evaluate the slope angle optimization and then to assess the earthquake-induced stability of the pit slope based on the finite element method (FEM) numerical simulation. The article focuses on the calculation of the maximum safety factor that leads to recognize the optimum slope angle. Two major objectives are:

- To calculate the optimum slope angle based on the material properties of the different rock strata of the Phulbari coal deposit, and
- To estimate the safety factor of pit slope associated with earthquake effect. The seismic shaking intensity would be applied here in terms of horizontal peak ground acceleration (PGA).

1 Geology of the Phulbari Coal Deposit

The Permian age Gondwana coal is found in 13 basins of the northwestern part of Bangladesh. All coal basins show a high subsiding graben-basin and a thick sedimentary content. The Phulbari coal deposit (Figure 1) is one of the largest Gondwana coal deposits of the country. Two major coal-bearing seams developed in the deposit that took place in a shallow marsh-swamp-lake complex which sometimes occurred under shallow lacustrine environment. Also the Barapukuria, the Phulbari coal basin is an intracratonic rift basin, where the coal seam thickness runs from 9 m to 42 m. The coal seams are overlayed by a 150 m to 350 m thick sedimentary deposit. The two seams dip towards east to northeast and normal faulting at the coal deposit has led to formation of steeply dipping coal seams. The coals have a low sulphur and ash content and they are highly volatile B bituminous rank. The vertical stratigraphic position is over 350 m of continuous low ash coal (Faruque et al. 2011).

1.1 Stratigraphy

The coal-bearing rocks of the Phulbari deposit consists of repeating sequences of sandstone, siltstone, mudstone and freshwater shale, clay and coal. Theses rocks have a total thickness of about 350 m that overlie the basement complex (Figure 2a and 2b). In 1997, a reconnaissance study of the coal in the deposit was first conducted by Broken Hill Proprietary (BHP) Billiton, an Australia-based company. The first mapping of the geology and coal deposits was prepared by GHD (2004) (Faruque et al. 2011). The coal-bearing sequences in the Barapukuria and Phulbari are found within the Gondwana Group of sequence. The coal contains abundant methane gas, which has been a problem for the mines in the Barapukuria area since the early 2005 at the 1110 mining panel (Islam and Shinjo 2009a). The strata of the Phulbari coal-bearing formation are similar to that of Barapukuria. The stratigraphic sequences of the Phulbari coal deposit is divided into four formations based on age and lithology:

- Madhupur clay from the recent Holocene era,
- A water-bearing Dupi Tila aquifer of Late Miocene-Middle Pliocene age,
- Permian coal-bearing Gondwana Group rock sequences, and
- Precambrian Achaean basement complex.

![Figure 1](image-url) Location of the Phulbari coal deposit in NW Bangladesh (after Faruque et al. 2011)