

Modeling for strength assessment of backfill materials associated with the reduction of surface subsidence at the Barapukuria coalmine area, NW Bangladesh

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Abstract: The Barapukuria coal mine, which is the first underground multi-slice longwall coal mine of the country, is located in northwest part of Bangladesh. The southern part of the Barapukuria coalmine area is a vulnerable zone because of the present underground coal mining activities. Land subsidence due to underground coal mining activities has great potential impacts on the surface and near surface structures. After extraction of the first slice of the Barapukuria coalmine, a massive surface subsidence has been occurred throughout the high productive agricultural landscapes and some public houses were damaged that were very close to the mine plan. This study uses numerical modeling techniques to calculate the mining-induced stress characterization and displacement values around an excavation mine panel. The modeling results were emphasized on the two mechanical parameters- (i) mean stress, and (ii) total displacement values. Calculated values of these two parameters have been used to predict the required strength of backfill materials. The values were estimated before and after the surface subsidence. Modeling results reveal that before backfilling the values of mean stress was ranging from 3.3 to 5.7 MPa, and the value of total displacement (surface subsidence) was about 1.23 m. Subsequent to backfilling, the values of mean stress was ranging from 8.1 to 10.50 MPa, which coincides with the value of the natural stress state. After backfilling, the calculated total displacement or surface subsidence value was about 0.136 m. Four samples of sand and silty sands were collected from Phulchari Gat, Sharishabari Gat, Vhanderbari, Pukuria area of the Jamuna riverbed. Strength of backfill materials (cement: fly ash: sand) was detected by using unconfined compressive strength (UCS) test associated with a curing period of 7, 14, and 28 days.

Keywords: - Mean Stress, Surface Subsidence, Unconfined Compressive Strength (UCS), Backfill Materials

I. INTRODUCTION

Surface subsidence is a very common phenomenon in many underground coal mining areas of the world. Surface subsidence is one of the significant mining-induced visible features of a coalmine that produced after a longwall panel has been extracted [1, 2, 3, 4]. Extraction of coal from underground mines generally leads to subsidence of the overlying land within a period of days to years. Land subsidence can give important clues as to the extent of a mine and its impact on the land [5, 6, 7]. Subsequent to the extraction of first-slice of the Barapukuria coalmine in northwest Bangladesh (Fig.1a), it causes mining-induced surface subsidence (Fig.1b) that eventually causes environmental threats to the agricultural landscapes and its associated structures.

Backfill is one of the modern technologies that are being used to minimize the mining-induced surface subsidence in many countries of the world. Backfill is the term for material that is used to fill voids created by mining activity [8]. Backfill is used for the purposes of some mining engineering functions like- (i) control of ground pressure, (ii) manage of deformation of surrounding rock strata of a mine panel, and (iii) prevention of the ground movement and fracturing of overburden strata. It leads to less deterioration in ground conditions in the mine, improving economic operations and safety. The purpose of the backfill is not to transmit the rock stresses, but to reduce the relaxation of the rock mass so that the rock itself will retain a load carrying capacity

and will improve load shedding to crown pillars and abutments [9, 10]. Therefore, it is reasonable to mention that surface subsidence can be reduced and production of a coal mine can be enhanced by using backfill technology [11].

In the past decades, several methods have been used to predict surface subsidence parameters, including- (i) Graphical Methods, such as the National Coal Board Method used in the U.K, (ii) Profile Function Methods, (iii) Influence Function Methods, (iv) Numerical Modeling Methods, and (v) Empirical Methods [12]. The Permian age Gondwana coal has been mined since 2005 at the Barapukuria area [13, 14, 15, 16], which is located within a high-productive agricultural landscapes associated with densely populated areas in northwest Bangladesh. Mining operation without any backfill technology in the Barapukuria coalmine area causes a massive surface subsidence that damages high-productive agricultural landscapes associated with some public houses. So, the most important query regarding the key point of the present study would be focused on that, is it possible to minimize the surface subsidence by using the backfill technology in Barapukuria? To resolve query, the present study uses finite element numerical modeling method to predict the strength of backfill materials that would be required to minimize the surface subsidence at the Barapukuria coalmine area. The modeling result would be useful to enhance the production optimization and safe operation of the mine. Two major objectives of the present study are-

- to compute the mean stress distribution around a mine excavation panel of the Barapukuria coalmine by using finite element numerical modeling, and
- to predict the unconfined compressive strength (UCS) values of backfill materials that were collected from the different locations of the Jamuna riverbed



Figure 1a. Location of the the Permian age Gondwana coal basins in Bangladesh. Sources of sands and silts at the numerous sand bars on the Jamuna riverbed. Four locations of collected samples are shown in Figure.

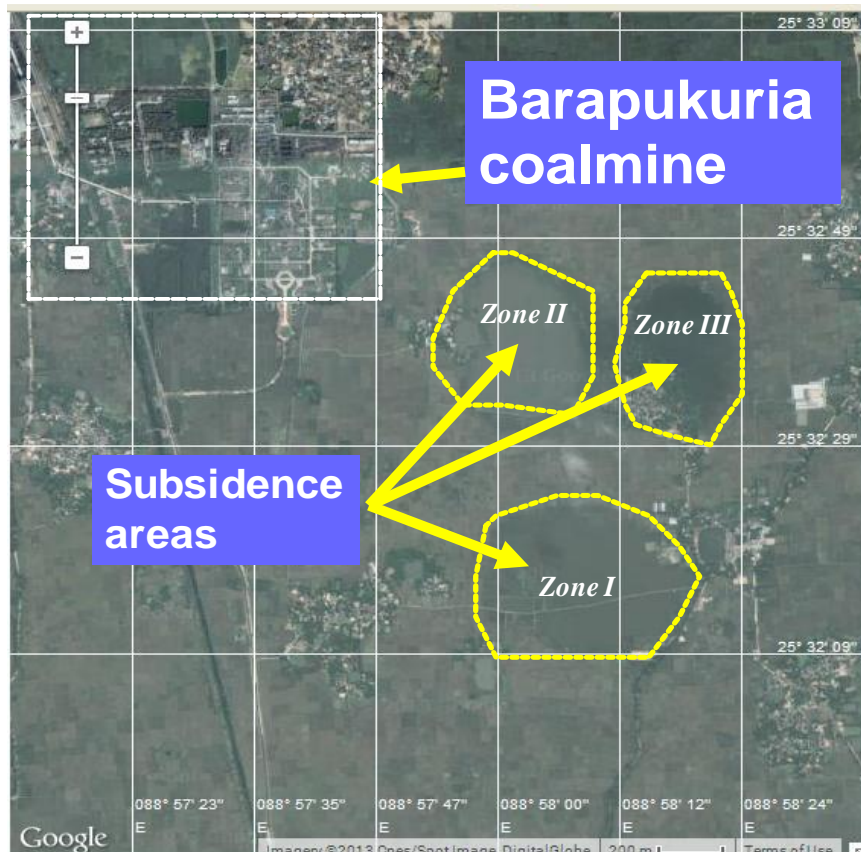


Figure 1b. Area of surface subsidence (about 0.9 to 1.3 m) caused by multi-slice longwall mining method after first slice extraction of coal in the Barapukuria coalmine area, Bangladesh.

II. METHODS AND MATERIALS

2.1. Numerical Modeling

In the present study, a finite element numerical modeling method has been applied to determine the mean stress and total displacement values around an excavation mine panel of the Barapukuria coalmine. Two stages of calculations were carried out. In the first stage, mean stress and displacement values were calculated just before backfilling of the mine goaf area, whereas in the second stage, mean stress and displacement values were computed subsequent to backfilling of the goaf area. The calculated values of mean stress were applied to predict the required strength of backfill materials. Model configuration and boundary conditions are shown in Fig.2. Rock mechanical properties of different geological layers (MCF, UDT, LDT, GUSS, GMSS, Coal seam VI, GLSS) as mentioned in the model are shown in Table 1. For details about the geological and hydrogeological conditions of the Barapukuria coal basin, interested readers are requested to go through the article of Islam and Hayashi, 2008 [13]. The upper surface of the model is free. X axis at the right and left sides of the model is restrained. Y axis is restrained at the bottom of the model.

Table 1: Rock mechanical properties of different geological layers

Material properties	MCF	UDT	LDT	GUSS	GMSS	Seam VI	GLSS	Backfill material
Unit weight (MN/m ³)	0.018	0.022	0.020	0.025	0.025	0.014	0.025	0.015
Young's modulus (MPa)	10000	12650	13500	6500	7555	3239	7860	10
Poisson's ratio	0.15	0.2527	0.20	0.2876	0.3861	0.1929	0.3732	0.21
Tensile strength (MPa)	0.028	0.96	0.47	1.28	1.32	0.007	1.74	0.09
Peak friction angle (deg.)	12	28	15	35	32	15	25	12
Peak cohesion (MPa)	0.085	0.280	0.190	0.440	0.445	0.20	0.440	0.25

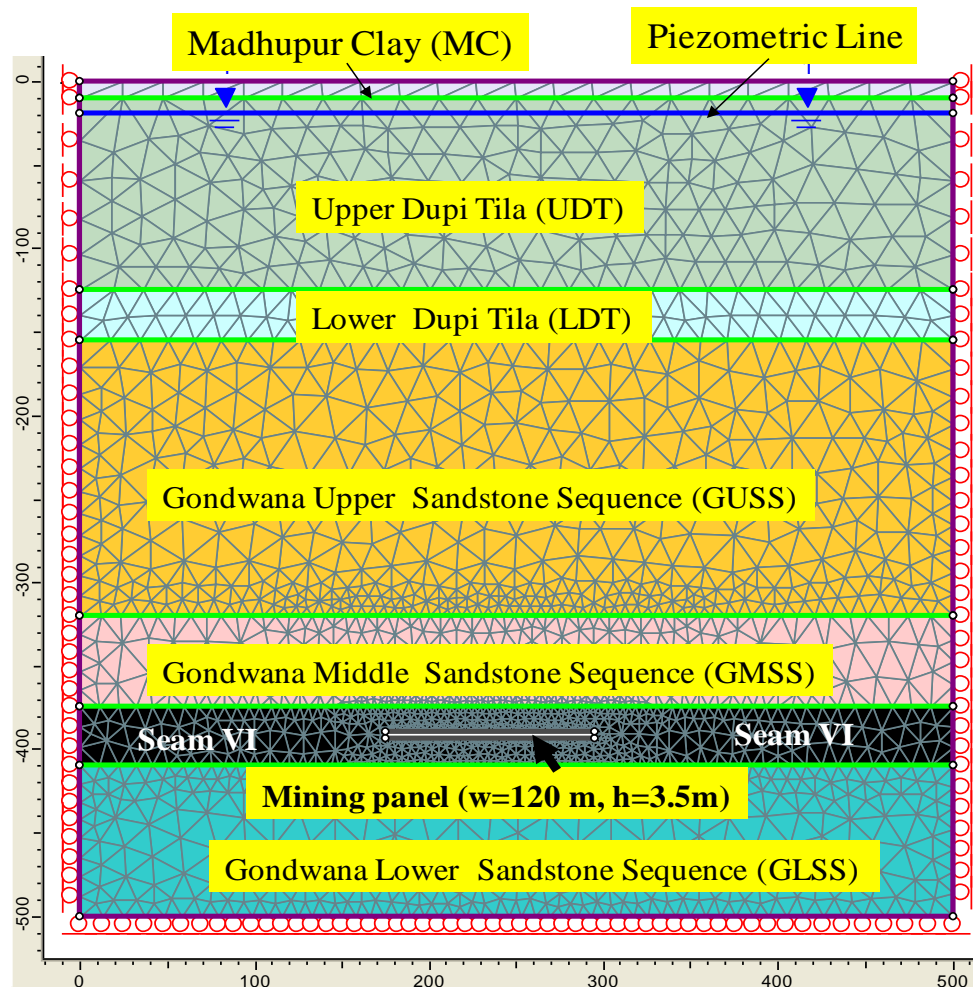


Figure 2. FE numerical model mesh and boundary conditions.

2.2. Modeling Results

Results of the numerical modeling are illustrated in Figs.3 and 4. The modeling results are presented in terms of two mechanical parameters as follows.

- distribution contours of mean stress (MPa) before backfilling (Fig.3a)
- distribution contours of mean stress (MPa) after backfilling (Fig.3b)
- distribution contours of total displacement (m) or subsidence before backfilling (Fig.4a)
- distribution contours of total displacement (m) or subsidence after backfilling (Fig.4b)

Before backfilling, the mean stress at the upper and lower part of the mine excavation panel was about 3.3 MPa. The value increased gradually up to 5.7 MPa towards the upper part of the model up to about 250 m depth (Fig.3a). Then the value decreased gradually towards the upper surface of the model. However, at the upper left and right sides of the excavation panel, the mean stress was ranging from 8.1 to 10.50 MPa. After backfilling, the mean stress around the excavation zone was about 8.5 MPa. However, at the upper left and right sides of the excavation panel, the mean stress was ranging from 8.4 to 9.4 MPa (Fig.3b). This means, the strength of backfill materials almost coincide with the natural strength of rock strata.

Before backfilling, total displacement or computed surface subsidence was about 1.23 m (Fig.4a). It is reasonable to mention that the computed result in the present study almost coincides with the measured field data at the Barapukuria coalmine area. The measured data was ranging from 0.90 to 1.3 m, approximately. The computed result shows that subsequent to backfilling, total displacement or surface subsidence would be about 0.136 m (Fig.4b).

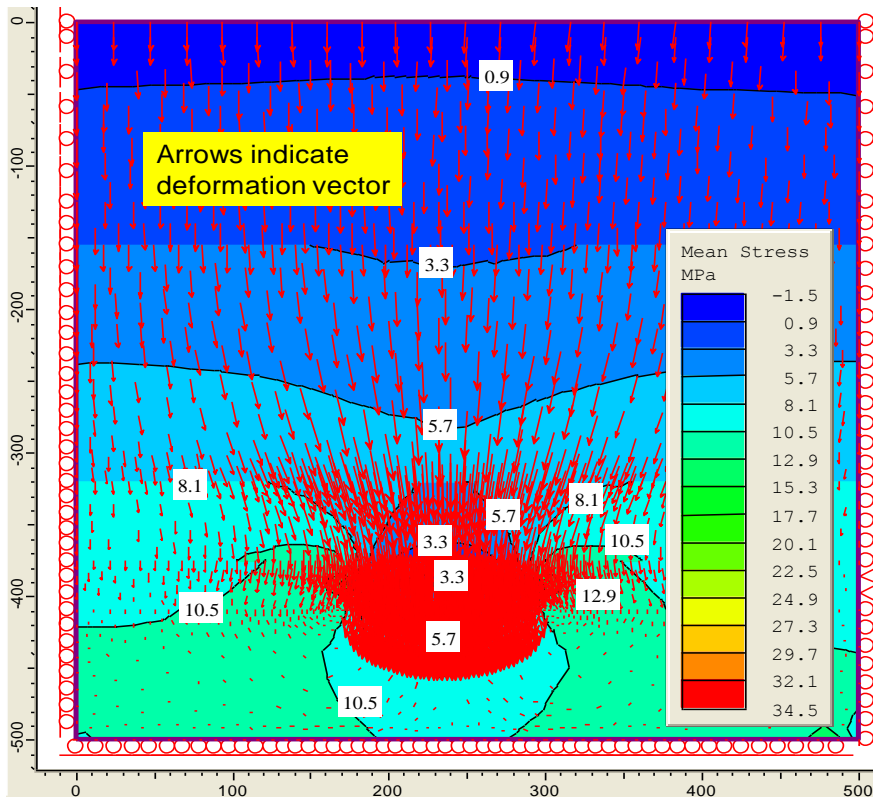


Figure 3a. Distribution contours of mean stress (MPa) before backfilling.

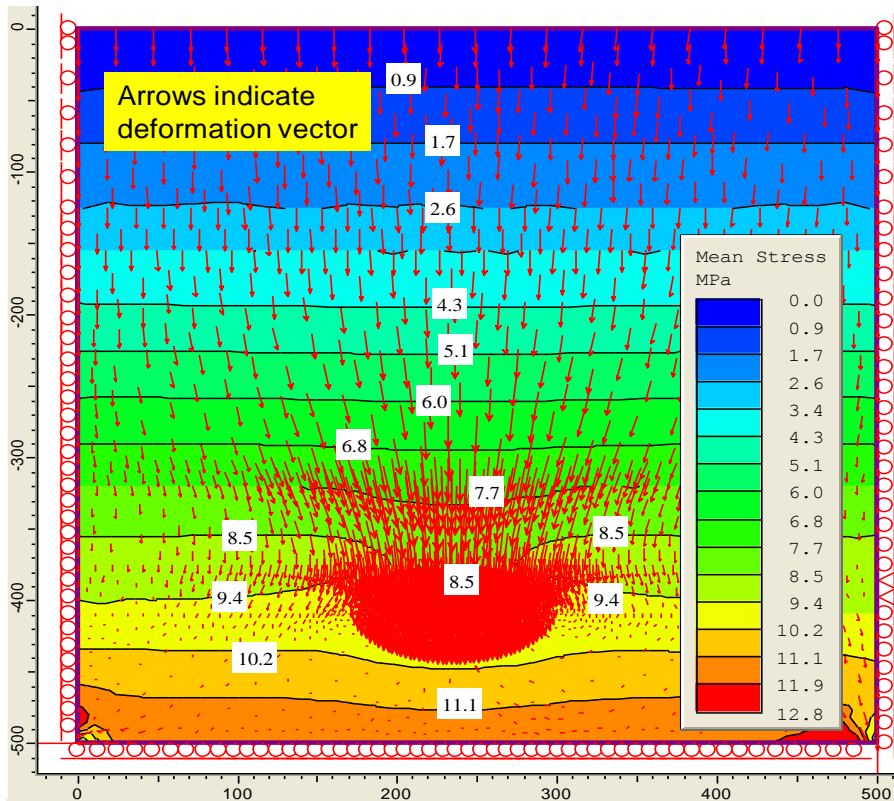


Figure 3b. Distribution contours of mean stress (MPa) after backfilling

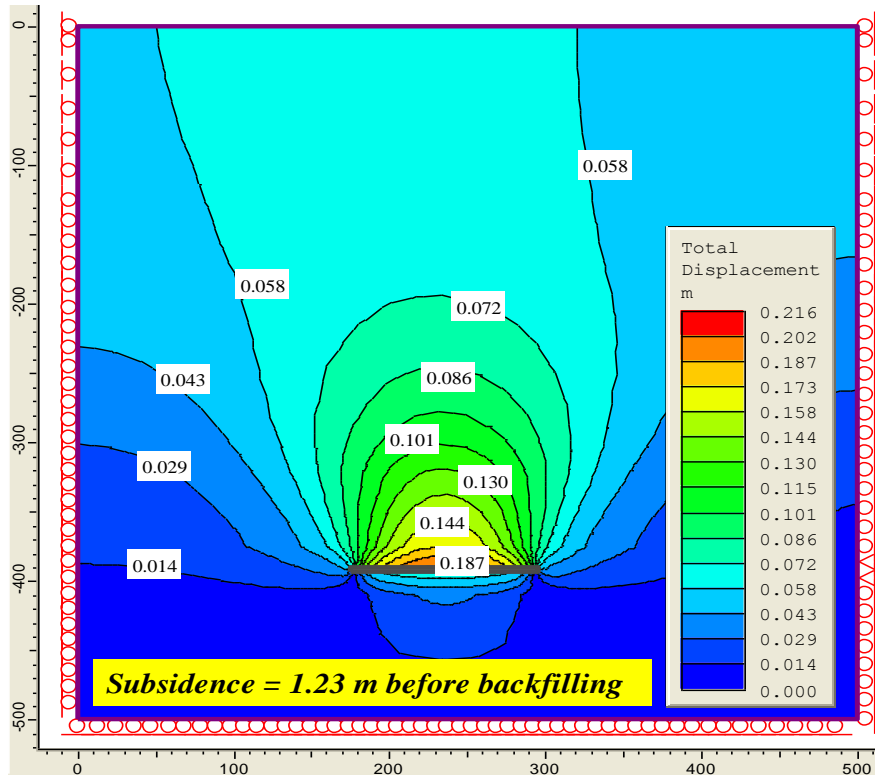


Figure 4a. Distribution contours of total displacement (m) before backfilling

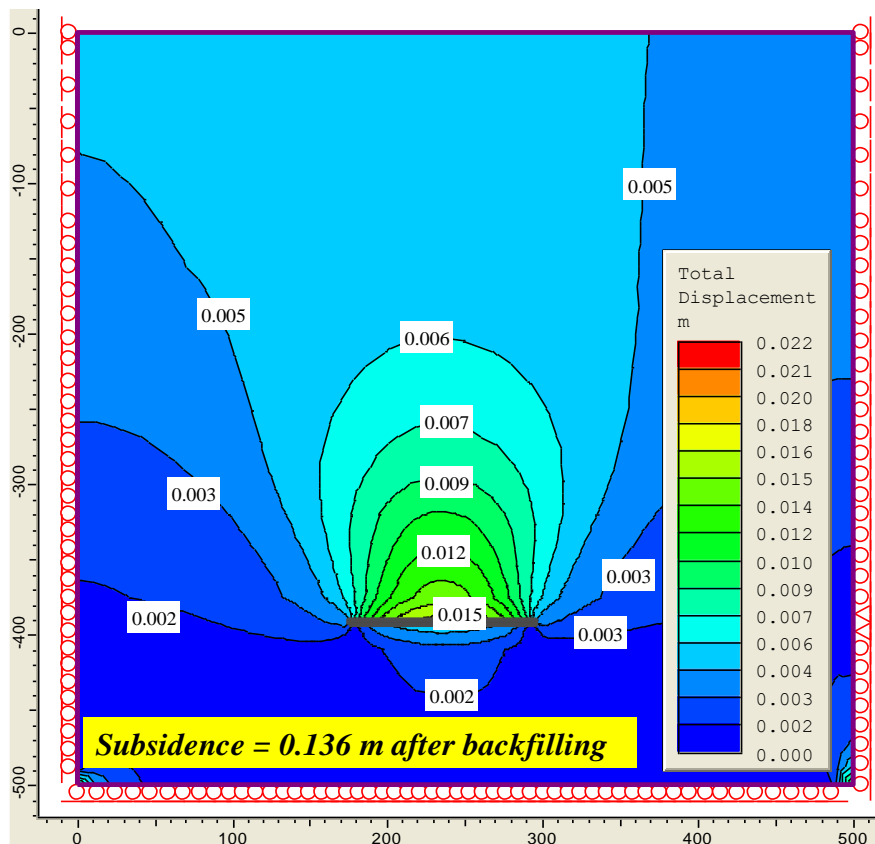


Figure 4b. Distribution contours of total displacement (m) after backfilling

2.3. Test of strength of behavior of backfill materials

Four samples of backfill material, like sands and silty sands were collected from the different parts of the Jamuna riverbed, which is the widest riverbed of the country having numerous sand bars (as shown in Fig.1a) with huge amounts of deposits. The following laboratory procedures were carried out to verify the strength behaviors of backfill materials.

- Collected samples were dried in the air and sunlight first and then the sieving analyses were carried out by using ASTM standard sieves. The grain size distributions curves are presented in Fig.5, which was prepared by using semi-log graphical plots.
- Some cubes with a size of 25mm×25mm×25mm (Fig.6) were made using the riverbed sands, fly-ash and Portland cement with different ratio.
- Unconfined compressive strength (UCS) test of cubes with different ratio of materials were carried out to determine the required strength of backfill material with a curing period of 7, 14 and 28 days. The test results are shown in Table 2.

2.3.1. Grain size distribution curves

The grain size distribution curves of collected samples are shown in Fig.5. Distribution curves show that the values of co-efficient of uniformity were ranging from 1.15 to 1.76, which indicates a poorly graded uniform soil. Usually, a poorly graded soil having a coefficient of uniformity of 2 or less [17].

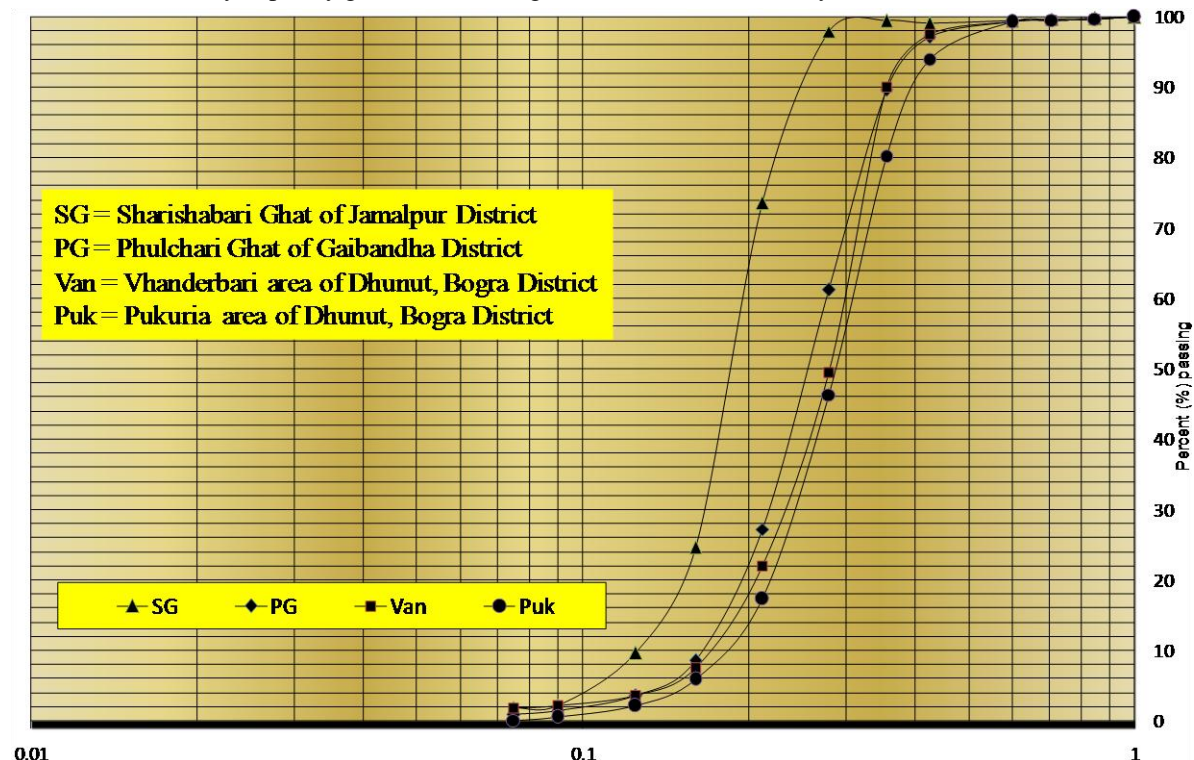


Figure 5. The grain size distribution curves of collected samples

2.3.2. UCS test results

The UCS test were carried out by taking into consideration of four samples of sands and silts that were collected from Phulchari Gat, Sharishabari Gat, Vhanderbari, and Pukuria area of the Jamuna riverbed (Fig. 1a). For the case of Phulchari Gat sample, the material ratio of 3:2:6 (cement: fly ash: sand), respectively, provided a result 3.30, 3.85, 5.0 MPa, respectively after a curing period of 7, 14, 28 days. If the considerable material ratio was 3:2:8 (cement: fly ash: sand), the strength values were 2.92, 3.50 and 4.38 MPa, respectively; after a curing period of 7, 14, 28 days. For the case of Vhanderbari sample, the ratio of 3:2:6 (cement: fly ash: sand) provides a series of strength values of about 3.64, 4.40, 5.50 MPa, respectively, after a curing period of 7, 14, 28 days. If the considerable material ratio was 3:2:8 (cement: fly ash: sand), the strength values were 4.10, 4.96 and 6.20 MPa respectively, after a curing period of 7, 14, 28 days. For the case of Sharishabari Gat sample, the ratio of 3:2:6 (cement: fly ash: sand) provided a series of strength values of 3.06, 3.68, 4.60 MPa respectively, after a curing period of 7, 14, 28 days. If the considerable material ratio is 3:2:8 (cement: fly ash: sand), the tested strength values were 2.72, 3.20 and 3.96 MPa, respectively, after a curing period of 7, 14, 28 days. For the case of Pukuria sample with a ratio of 3:2:6 (cement: fly ash: sand) provided a series of strength of 4.67, 5.60, 7.00

MPa respectively, after a curing period of 7, 14, 28 days. If the considerable material ratio was 3:2:8 (cement: fly ash: sand), the tested strength were 4.45, 5.34 and 6.67 MPa, respectively, after a curing period of 7, 14, 28 days. Unconfined compressive strength (UCS) test values with a curing period of different samples are shown in Table 2.

Table 2: Unconfined compressive strength (UCS) test values with a curing period of 7, 14 and 28 days.

Samples collected from the Jamuna Riverbed (Fig.1)		Cement: Fly ash: Sand	Curing period and Unconfined Compressive Strength (MPa)		
Sample No	Locations		7 days	14 days	28 days
Sample-1	Phulchari Gat	1:0:8	0.38	0.48	1.03
Sample-2	Vhanderbari	1:0:8	0.53	0.43	1.06
Sample-3	Sharishabari Gat	1:0:8	0.32	0.40	0.87
Sample-4	Pukuria	1:0:8	0.46	0.58	1.00
Sample-1	Phulchari Gat	1:2:8	0.66	0.80	1.00
Sample-2	Vhanderbari	1:2:8	0.64	0.78	0.99
Sample-3	Sharishabari Gat	1:2:8	0.64	0.78	0.98
Sample-4	Pukuria	1:2:8	1.34	1.60	2.00
Sample-1	Phulchari Gat	1:2:6	1.30	1.56	1.96
Sample-2	Vhanderbari	1:2:6	1.32	1.59	1.98
Sample-3	Sharishabari Gat	1:2:6	1.34	1.58	1.97
Sample-4	Pukuria	1:2:6	1.37	1.65	2.06
Sample-1	Phulchari Gat	3:2:8	2.92	3.51	4.38
Sample-2	Vhanderbari	3:2:8	3.10	4.96	6.20
Sample-3	Sharishabari Gat	3:2:8	2.72	3.20	3.96
Sample-4	Pukuria	3:2:8	4.45	5.34	6.67
Sample-1	Phulchari Gat	3:2:6	3.30	3.85	5.00
Sample-2	Vhanderbari	3:2:6	3.64	4.40	5.50
Sample-3	Sharishabari Gat	3:2:6	3.06	3.68	4.60
Sample-4	Pukuria	3:2:6	4.67	5.60	7.00



Figure 6. Some samples of backfill material with different ratio of cement: fly ash: sand

2.3.3. Cost analysis of backfill materials

The cost analysis of backfill materials includes cost of samples, transport and labor costs. Bangladesh Railway (BR) wagon and/or Truck would be required to transport sands from the dumping grounds that should be located at the western bank of Jamuna River. The cost analysis of backfill material is shown in Table 3.

Table 3: Cost analysis of backfill materials

Material Ratio Cement:Fly ash:Sand	Bangladesh Railway wagon		Truck	
	Cost per (1) ³	Cost per (m) ³	Cost per (1) ³	Cost per (m) ³
1:0:8	0.20	\$19.2	0.33	\$32
1:2:6	0.32	\$31.2	0.54	\$52
1:2:8	0.27	\$26.4	0.45	\$44
3:2:6	0.51	\$49.2	0.85	\$82

III. DISCUSSION

Subsidence is a very common phenomenon in many coal mining areas of the world. Most of the subsidence problems are reported to have occurred suddenly and those often remain as serious threats to the subsequent development [18]. From the beginning of commercial production at the Barapukuria coalmine in 2005, the first subsidence was recorded in 2006 in Kalupara and Balarampur villages, which is located above the coal faces 1101 [14]. Subsequently, further subsidence was recorded in other areas during 2008, 2009, 2011 and by the end of 2012. At present, the total affected area of surface subsidence is almost 6.825 hectares that includes 300000 m² in zone-I, 213750 m² in zone-II, and 168750 m² in zone-III (please see in Fig. 1b). High productive agricultural landscapes are affected by surface subsidence that also includes 8 villages in and around the coalmine. Subsidence height was ranging from 0.9 to 1.3 m in respond to extraction of about 3 m coal in the underground. The surface areas affected by water logging for a long period of the year.

Hydraulic sand stowing or backfilling can be a remedial measure to reduce land subsidence. This practice is well developed in many underground mines around the world. However, there has not been taken any backfilling or stowing procedures adopted in Barapukuria mine [15].

The present study emphasizes the strength assessment of backfill material that would be used in the Barapukuria coalmine to reduce the surface subsidence. Numerical modeling of a mine panel geometry associated with two stages of calculation for mean stress and total displacement around- (i) mining-induced goaf area, and (ii) backfilling conditions of that goaf, have been considered here. Subsequent to the extraction of the mine panel, the calculated mean stress and total displacement values around the mine goaf were 3.3 to 5.7 MPa, and 1.23 m, respectively. Subsequent to the backfilling of the goaf area, the computed mean stress and total displacement (subsidence) values around the mine panel were 8.1 to 10.50 MPa, and 0.136 m, respectively.

IV. CONCLUSIONS

The following grounds should be considered for the sustainable development of coalmines Bangladesh in the near future.

- Applied numerical modeling results associated with mean stress and total displacement values in the present study emphasize that the surface subsidence at the Barapukuria coalmine area would be reduced up to 90%, if backfilling technology is applied.
- Unconfined Compressive Strength (UCS) test values (Table 2) and cost analysis (Table 3) of backfill materials reveal that the Jamuna riverbed sands and silts could be used as a cost-effective backfill material for the development of coalmines in Bangladesh.
- Backfilling could be enhanced the production optimization of the Barapukuria coalmine up to 70-80% of the total coal resources (377 Mt).

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authored with 17 scientific articles in different scientific international journals that have been published in Elsevier, Springer and other national and international journals. He has also authored more than 20 popular articles associated with national and international events in the daily newspapers of Bangladesh. He has three years (2001-2004) practical experiences in underground coalmine development in Bangladesh. By means of successive combination of (i) practical experiences in coalmine field, (ii) high ranking research activities in Japan and (iii) teaching experiences, Dr. Islam is the topmost coalmining expert of the country, who has also worked with some renowned experts of the International Mining Consultants of United Kingdom and China University of Mining and Technology (CUMT). The Japanese Government awarded him as a *Monbukagakusho Scholar* since October 2004 to September 2009. Dr. Islam has acquired PhD in coalmining field with a specialization on numerical modeling associated with rock mechanics. He had been nominated for the *'President's Honorary Award-2009'* by the President of the University of the Ryukyus, Okinawa, Japan for his scholarly achievements and contribution to the university and others scientific community. Recently, Dr. Islam has been nominated for the *'Young Scientist Award-2013'* which is organized by *The World Academy of Sciences (TWAS)* of Italy. At present, he is a faculty member in the department of Petroleum and Mining Engineering, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh.