

Volumetric estimation of coal resources in seam VI for require backfill Materials of Barapukuria coal mine, Dinajpur, Bangladesh

Md. Mostafijul Karim, M. Farhad Howladar

Department of Petroleum & Mining Engineering, Shahjalal University of Science & Technology, Sylhet

Email address:

farhadpme@gmail.com (M. F. Howladar), mostafijpge@yahoo.com (M. Karim)

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Abstract: Through the distinguish software application along with formal calculation method the study represents a volumetric estimation of require backfill Materials of Barapukuria coal mine in north western Bangladesh, the only coal mine of the country under production, which capable of a low recovery with sustaining mining method. The only productive coal seam of the mine, Seam VI is our main focus during the assessment. Different estimation method is applied to investigate the accuracy of calculation and find out the reasons beyond the deflections. Surfer 8.4 exploits two method of interpolation, inverse distance to power, a weighted average interpolator and Kriging, more flexible gridding method, those yields the volume of 169221180.5 cubic meters and 165323770.4 cubic meters respectively. On the contrary Rockworks is estimated the volume through Delaunay Triangulation method as 115,959,398.4 cubic meters whether another estimation which is made by inverse power weighting interpolation on saved stratigraphic model, gives 174,281,203 cubic meters volume, following 185,760,000 cubic meters through geological reserve calculation. After considering the interpolation approach, available data and previous study agreement, the result of inverse distance to power, at both of software's is consider for backfill materials volume estimation. The required volume of backfill materials is 101532708.3 m³ and for 9% and 10% recovery that's are 9137943.747 m³ and 10153270.83 m³ respectively. The daily requirement of backfill is 562 - 636 m³ and the system need to have a daily capacity of 702 – 795 m³.

Keywords: Barapukuria Coal Mine, Backfill, Volume, Interpolation, Grid

1. Introduction

The Barapukuria coal mine is located at 50-km east of the district capital Dinajpur, the northwest part of Bangladesh. According to Geological Survey of Bangladesh (GSB), who discovered the presence of coal reserve in April 1985, the reserve sustains with six layers, among of them 6th seam is most significant as it contain about 90% of the total reserve and the reserve is identified at average depth of 118-509m. The mine has been extracting bituminous coal since 2005 with multi-slice longwall mining method when recovery percentage of this mine is very low.

Mine backfilling with a growing demand emerge in the mining area in recent times. It is considered as a most developing sector at mining aspect due to its significant role in increasing both the ore recovery and life of a mine by providing mine stability. Backfilling has not yet

implemented in Barapukuria coal field. To assess the backfilling in Barapukuria for the first time we estimate require volume of backfill materials though the determination of volume of seam VI which is our main concern. Different software is implemented with different methods for estimation. The study is conducted by Surfer 8.4 (Surface mapping and computing software) (Golden Software, Golden, Colorado, USA) and Rockworks Version 14 (Rockwork Inc. Golden Co, USA). Different estimation method is applied to inspect the accuracy of calculation and then elaborate the reason of deflections. The calculation is based on the different borehole data. Fig. 1 shows the location of boreholes. The data used for volume estimation are 18 borehole logs among them 7 logs (GDHs) are surface drilled borehole and was drilled and recorded by Geological Survey of Bangladesh in 1985-1988 during their exploration process. The rest of the logs (DOBs) recorded by Wardell Armstrong Mining Consultants in 1989-1990 at their feasibility study in the purpose of mining prospect [1].

Both the Software is using the gridding method. After extracting the spatial and thickness data from each borehole, grid files are automatically generated. Then the volume estimation is done for each cell by using different approach of interpolation and integration, in exception Rockwork read

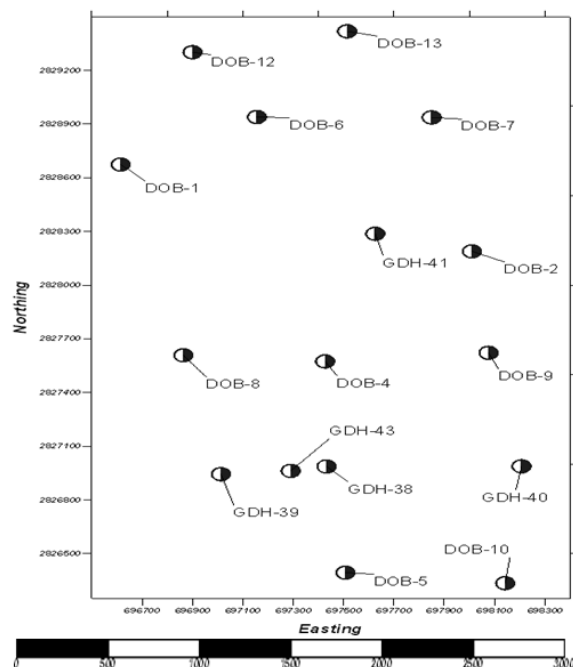


Fig 1: Location of 18 boreholes, those used in volume estimation (Surfer 9)

an existing stratigraphic solid model and computes volume of each rock or soil type whether Surfer uses classical numerical integration algorithms to ensure the accuracy. A formal calculation is made by Geological Reserve Calculation Method after Boki (1967) equation. Through a detailed discussion about every derived result, the estimated volume is determined after available data types, quantity and calculation methodology consideration.

2.1. Geological Existence of Coal in Barapukuria Coals Mine

The Barapukuria coal mine is located at the northwest part of Bangladesh, between longitude $88^{\circ}56'36''\text{E}$ – $88^{\circ}59'02''\text{E}$, and latitude $25^{\circ}34'40''\text{N}$ – $25^{\circ}31'28''\text{N}$ with an approximately 5 km^2 basin area. The basin host the Permian aged coal belongs to Gondwana Group. Within the basin area the surface elevation is 30 to 32 m above mean sea level. The coalfield consists of six seams; those are marked as I to VI, of which the lower seam VI is being mined. The coal basin is categorized an asymmetrical faulted syncline with an approximately N-S axis. The coal bearing Gondwana formation rests on the Precambrian Basement complex. The structural sequence of the basin, with a varying thickness of maximum 390m, is divided into four formations named as Madhupur clay, Dupi Tila formation; separated as upper and lower Dupi Tila and only ground water containing formation, Gondwana Group and Pre-Cambrian Basement complex.

dominant lithological components of the sequence are continental arenaceous sediments, with subordinate siltstones, shales. (Wardell Armstrong, 1991, Islam and Hayasi, 2008)[1, 11]

Figure 2 represents two dimensional Strip logs of four boreholes among the 18; those are used in volumetric calculation. Seam-I is only present in one borehole (GDH-40). Seam II and IV seem to be the most horizontally and their thickness differs between 2.5 to 15m. Seam III and V are laterally variable and discontinuous. Among the all seam VI is the thickest and laterally continuous in the basin whether its thickness varies from 22m to 42m. Seam VI contains most of coal reserve of the mine. Sandstone exists as roof and floor of coal layer although a thin mudstone horizon is frequently present as the immediate roof. The coal

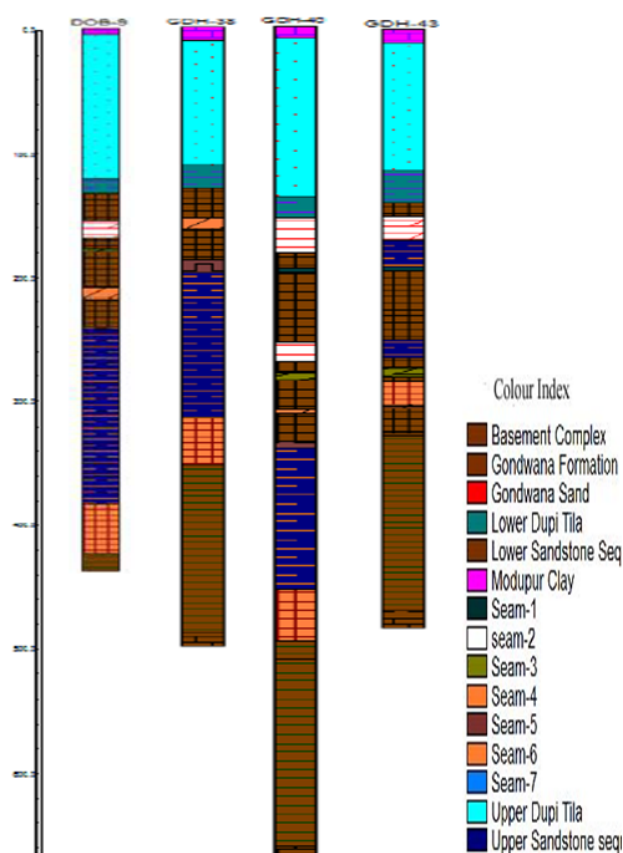


Fig 2: 2D Strip log of Different Borehole (By RockWorks/15).

Resources were formed in cold environments and deposited in association with lacustrine conditions (Wardell Armstrong, 1991; Bakr et al., 1996, Islam and Hayasi, 2008) [1, 2, 11]. Seam VI roof is consist of of 15 m to 140 m of relatively homogeneous and massive pale grey to white, medium to coarse-grained sandstones, gritstone, and conglomerates and strongly kaolinized, forming a white clay matrix which significantly lessens the primary permeability. The floor sandstone below the seam VI is different in composition from the above Gondwana sequence and dominantly consists of an interbedded sequence of sandstone, siltstone, and mudstone. Fluvatile sandstone and interbedded sandstone or siltstone sequences also repeatedly

found with infrequent thin and discontinuous coal (Wardell Armstrong, 1991, Islam and Hayasi, 2008) [1, 11]. Figure 3 Illustrates a three dimensional model that represents the three-dimensional view of the strip logs of all enabled Boreholes.

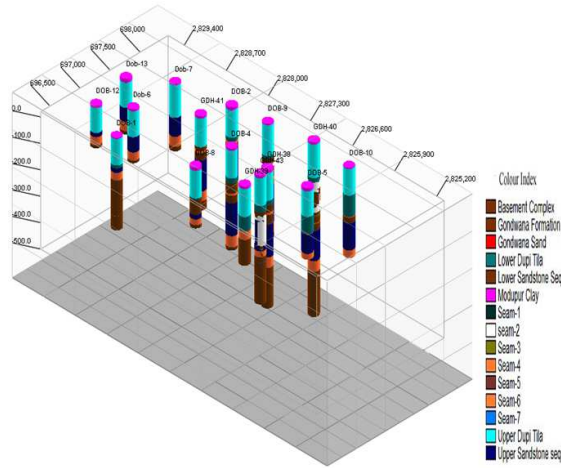


Fig 3: 3D Model that represents the three-dimensional view of the strip logs of all enabled Boreholes (By RockWorks/15)

2.2. Role of Backfill in Coal Mine

Backfill refers to any waste material that is placed into voids mined underground for the purposes of either disposal or to perform some engineering function. Backfilling of coal mines in the past has been primarily restricted to abandoned mines (Bloomfield, 1984) [3]. The purpose of the backfill is not to transmit the rock stresses, but to reduce the relaxation of the rock mass so the rock itself will retain a load carrying capacity and will improve load shedding to crown pillars and abutments (Barret et al., 1978) [4]. Research and in situ testing have shown that fill cannot rigidly support the total weight of overburden and acts only as a secondary support system (Cai, 1983) [5]. According to Brady and Brown (1985) backfill works as a support medium in three ways [6]. By imposing a kinematic constraint on the displacement of key pieces in a stope boundary, Secondly, both pseudo-continuous and rigid body displacements of stope wall rock, Finally, as a global support element in the mine structure. Materials used as mine backfill or components of a fill mass are of five types (J. Palarski 1994, Tony Grice 1998, Thomas et al 1979) [7, 8, 9] as run-of-mill concentrator tailings, used with a cementing agent to form paste fill, deslimed mill or concentrator tailings, or sandfill, natural sands, aggregates, development mullock and similar coarse, cohesionless media, cementing agents of various types. In the case of Barapukuria Coal mine the available backfill materials are Sand, Mine Tailing, Fly Ash and Cement. Volumetric estimation of the mineable area of the coalfield will reveal the require backfill materials volume and it will also play a rule in determination of the suitable backfill method which typically depends on available Backfill materials.

3. Methods of the Study

The calculation is based on the different borehole data. The data used for volume estimation of the seam six are 18 borehole logs among them 7 logs (GDHs) drilled and recorded by Geological Survey of Bangladesh in 1985 and the rest of the logs (DOBs) conducted by Wardell Armstrong

Table 1: Upper and lower surface depth of seam VI with different borehole location. (Wardell Armstrong, 1991, Islam and Hayasi, 2008) [1,11]

ID no	Easting	Northing	Seam Roof(m)	Seam Floor(m)	Thickne ss(m)
DOB-1	696615	2828674	131.8	161.2	29.40
DOB-2	698010	2828189	291.4	328.4	37
DOB-4	697427	2827574	331.15	373.45	42.30
DOB-5	697508	2826394	249.1	271	21.3
DOB-6	697156	2828939	163.35	193.72	30.37
DOB-7	697850	2828937	199.55	237.6	38.05
DOB-8	696864	2827608	195.8	217.43	21.63
DOB-9	698076	2827622	381.62	421.37	39.75
DOB-10	698142	2826335	312.7	341.4	28.70
DOB-12	696900	2829301	118.65	149.49	30.84
DOB-13	697514	2829418	162	198	36
GDH-38	697432	2826987	331.62	371.24	39.62
GDH-39	697013	2826944	170.33	203	32.62
GDH-40	698207	2826988	450.19	491.03	40.84
GDH-41	697626	2828287	285.27	321.56	36.29
GDH-43	697290	2826962	286.82	329.19	42.37

Mining Consultants in 1989-1990 [11]. The study is conducted by Surfer 8.4 (Surface mapping and computing software) (Golden Software, Golden, Colorado, USA), Rockworks Version 14 (Rockwork Inc. Golden Co, USA). Gridding method is common in both applications.

3.1. Gridding Method

In this process initially the borehole logs are converted to a common data format and spatial information are converted to planner earth projection UTM (Universal Transverse Marketer). Then volume calculations are performed on solids defined by an upper and lower surface. The upper and lower surfaces are defined by a grid file or a plane of

constant Z level. Blanked regions on either the upper or the lower surface are excluded from consideration during the volume calculations.

Volume calculations are generated for each grid cell. In areas where the surface is tilted at the top or bottom of a grid cell, surfer approximates the volume of the prism at the top or bottom of the grid cell column. For very coarse grids, the prisms can contain a significant volume. Volume calculations become more accurate as the density of the grid is increased.

Mathematically, the volume under a function $f(x,y)$ is defined by a double integral (Stewart 1995) [10],

$$Volume = \int_{x_{min}}^{x_{max}} \int_{y_{min}}^{y_{max}} f(x,y) dx dy$$

In Surfer, this is computed by first integrating over X (the columns) to get the areas under the individual rows, and then integrating over Y (the rows) to get the final volume. We use two different methods for calculation, Inverse Distance to a Power and Kriging method. The yield volume is in cubic meter units. Then the volume is converted to acre-foot. Finally we get the tons of coal by multiplying the result by conversion factor (tons/acre-foot).

Rockwork uses the Borehole Manager's Stratigraphy-Volume tool to read an existing stratigraphic solid model and compute volume of each rock or soil type. The resulting computations are displayed in the Geological Utilities datasheet. This program assumes an already created solid model that illustrates the distribution of the desired material. This can be created using the Borehole Manager Model tools (Lithology, Stratigraphy). This program also assumes that already created grid model of the surface topography that will be used when modeling. The surface grid model must have the same dimensions and node counts as the X and Y dimensions of the input solid model.

"EZ Volume" reads a column of thickness values from the datasheet and computes volume using a Delaunay

triangulation method. The output is a textual report.

3.2. Geological Reserve Calculation Method

The geological reserves were estimated by the following equation (Boki, 1967).

$$Q = S m \gamma, \text{ tons}$$

Where, m= Average thickness of coal seam (36 m).

γ = Average specific gravity of bituminous coal (1.32 t/m³; GSB, 1992)

$$S = \text{Area of the coal seam (5.16 Km}^2\text{)}$$

4. Results and Discussions

In Surfer volume calculations are performed on solids defined by an upper (Fig. 4) and lower surface (Fig. 5) and the data assigning from the Table 1.

Surfer approximates the necessary one-dimensional integrals using three classical numerical integration algorithms: Extended Trapezoidal Rule, Extended Simpson's Rule, and Extended Simpson's 3/8 Rule. The difference in the volume calculations by the three different methods measures the accuracy of the volume calculations. If the three volume calculations are reasonably close together, the true volume is close to these values. If the three values differ somewhat, a new denser grid file should be used before performing the volume calculations again. According to Table 2 we get three values are nearly same so the net volume reported as the average of the three values. We use two different methods. One of them is Inverse Distance to a Power, is a type of deterministic method for multivariate interpolation with a known scattered set of points. The assigned values to unknown points are calculated with a weighted average of the values available at the known points (Shepard, 1968) [12]. The average volume by this method is 169221180.5 cubic meters and the estimated reserve is 271.22 Mt (Table 2).

Table 2: Estimated Volume of Require Backfill Materials of Seam VI by Surfer 8.4: [Here, 1 acre=4046.85642 m³ and 1 m=3.28083333ft, Tons of coal=(acre-foot)*(1976.97 tons/acre-foot)]

Estimation Method	Volume (cubic meter)	Average Volume(m3)	Tons of coal	Require backfill (Mm3)	Require backfill volume(Mm3)	Require backfill
					With 9%	With 10%
Trapezoidal Rule	169221736.096					
Inverse Distance to a Power		169221180.5	271219662.7	101532708	9.14	10.15
Simpson's Rule	169220805.802					
Simpson's 3/8 Rule	169220999.698					
Trapezoidal Rule	165322544.290					
Kriging		165323770.4	264973079.1	99194262.24	8.93	9.92
Simpson's Rule	165324335.236					
Simpson's 3/8 Rule	165324431.864					

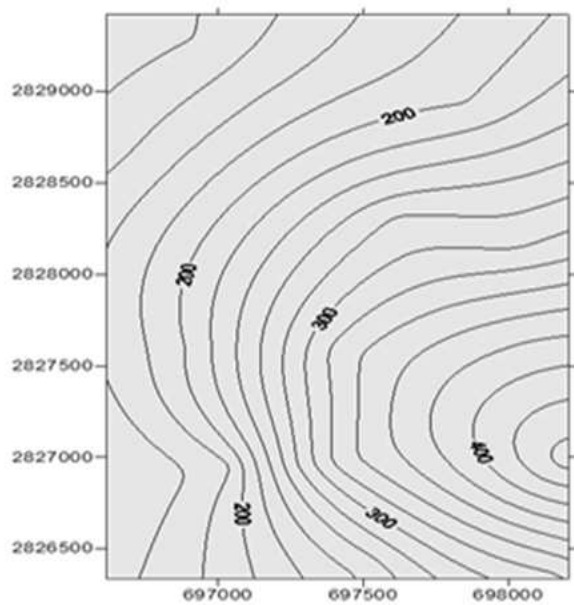


Fig 4: Contour Map of seam roof (Surfer 8.4).

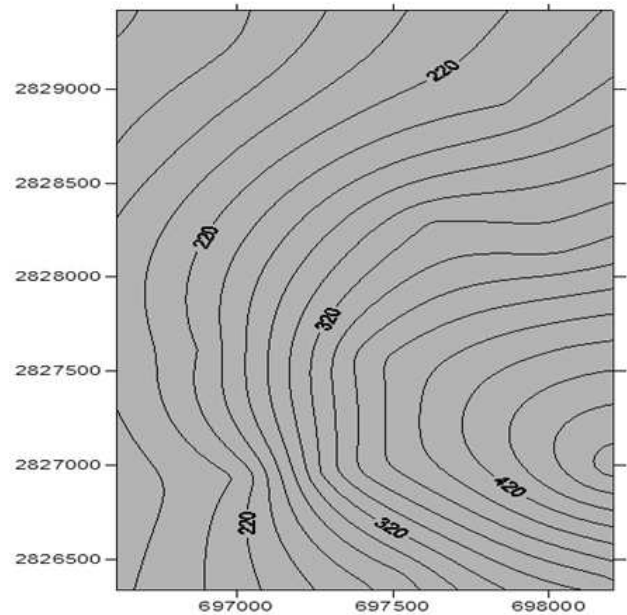


Fig 5: Contour Map of seam Floor (Surfer 8.4).

The Inverse Distance to a Power gridding method is a weighted average interpolator, and can be either an exact or a smoothing interpolator. Normally, Inverse Distance to a Power behaves as an exact interpolator. On the other hand Kriging method is a geo-statistical estimator that assumes the value of a random field at an unobserved location from samples (Wahba, 1990) [13]. This method yields the volume of 165323770.4 cubic meters and the calculated coal reserve is 264.98 Mt (Table 2).

Kriging is one of the more flexible methods and is useful for gridding almost any type of data set, and this geo-statistical gridding method that has proven useful and popular in many fields. This method produces visually appealing maps from irregularly spaced data. For this reason it produces more accurate result with a large number of data

sets. Here for volume calculation we use only sixteen borehole data (Table 1). So the calculated volume is much lower than it actually has.

With Rockworks we also use two Methods. Initially Volumes are computed using a Delaunay triangulation method in which the samples are connected together in a network of triangles, a sample at each vertex. The volume of each triangle is computed, based on the thicknesses used as Z-values (Fig. 5), and then the total volume added up. This method tends to provide lower estimates of total volume than an orthogonal grid-based calculation. So the calculated volume with this method is lowest compare with others and it is 115,959,398.4 cubic meters when the estimated reserve is 185.85 Mt (Table 3).

Table 3: Estimated Volume of Require Backfill Materials of Seam VI by Rockworks (Version 14):

Estimation Method	Volume (cubic meter)	Tons of coal	Require backfill (Mm ³)	Require backfill volume(Mm ³)	
				With 9%	With 10%
Delaunay Triangulation (EZ value)	115,959,398.4	185854210.5	69575639.04	6.26	6.96
Stratigraphic volumes (Based on solid Model)	174,281,203	279329626.2	104568721.8	9.41	10.46

At the second method Borehole Manager's Stratigraphy-Volume tool reads the saved stratigraphic model (Fig: 6) and compute volume of each layer. The resulting computations are displayed in the Geological Utilities datasheet. The volume of seam VI with this model is 174,281,203 cubic

meters and the calculated coal reserve is 279.33 Mt (Table 3). The model resolutions is 100 that means the number of nodes along the X and Y axes of the grid models is 100, same as along the Z axis for the solid stratigraphic model. The using gridding method is inverse power weighting where the value

assigned to a grid node is a weighted average of either all of the data points or a number of directionally distributed neighbors. So the Inverse-Distance method will not exaggerate its extrapolations beyond the given data points. The range of grid values will be smaller than the data point range: The highest grid value will be less than the maximum data point, and the lowest grid value will be greater than the minimum data point. So it produces a smooth and continuous grid and yields more reliable estimation results.

Furthermore after the Boki, 1997 equation the volume estimates as 185,760,000 cubic meters, correspond the coal reserve of 245.2 Mt, when the average thickness is 36m (as in Table 1), and area is 5.16 Km². The reserve calculated for coal seam VI during the mine feasibility study estimated as 271 Mt by Warderl Armstrong Company. After conversion which gives 169084144.1 m³ volume. The calculation method is unknown. In another calculation the reserve is approximately 300 Mt, resemble to a volume of 187178000 m³, where calculation used polygon method (Islam and Hayashi, 2009) [11]. As we mention earlier with Inverse Distance to a Power, data are weighted during interpolation such that the influence of one point relative to another declines with distance from the grid node and will not exaggerate its extrapolations beyond the given data points, but the polygon method deals with regular

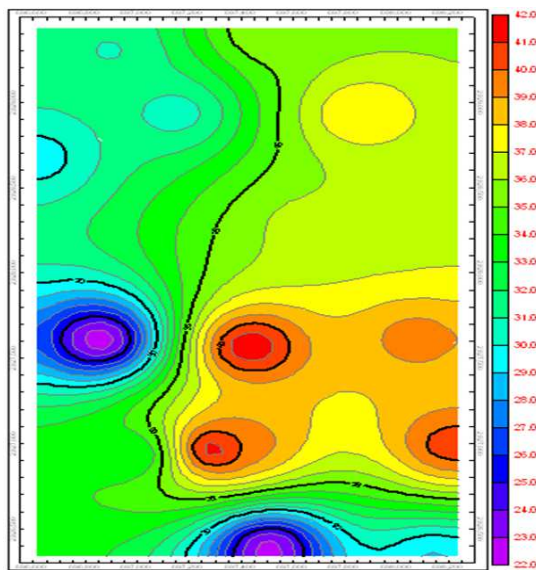


Fig 5: Seam VI thickness in 2-D (Rockwork).

variation of the phenomenon where assumed the point is well surrounded by experimental data and assigning the nearest measure value (Hunter, 2008) [14].

So, it is conspicuous that the calculation by inverse distance to power method in both can be considered as more accurate than others. Moreover it shows good agreements with Warderl Armstrong Company's calculation. According to inverse power weighting method used in surfer results denote that full extraction of seam VI will create 169221180.5m³ void space when with recent recovery percentage creates 15229906.25m³ to 16922118.05m³ void

spaces eventually. This is the important finding to select the backfill materials for the field because the available backfill resources have to have the require volumes. The typical requirement for backfill is approximately 50% of the tonnage mined. It is theoretically about 60%, but all stopes are not completely filled and tertiary stopes may not be filled at all (Ross Gowan). As this rule of thumb the required volume of backfill materials is 101532708.3 m³ and with recovery rate that's 9% and 10% recovery the requirement are 9137943.747m³ and 10153270.83m³ respectively. The daily production of the mine is about 1500-1700 tons of coal per day. If a mine backfills all production stopes to avoid significant delays in ore production, the daily capacity of the backfill system should be at least 1.25 times the average daily mining rate which expressed in terms of volume (Robert Currie). So the daily requirement of backfill is 562 - 636 m³ and the system need to have a daily capacity of 702 - 795 m³.

5. Conclusions

Bangladesh has just planned for coal based power plant to meet its energy crisis when the country cannot utilize its only producing coal mine efficiently, moreover local people

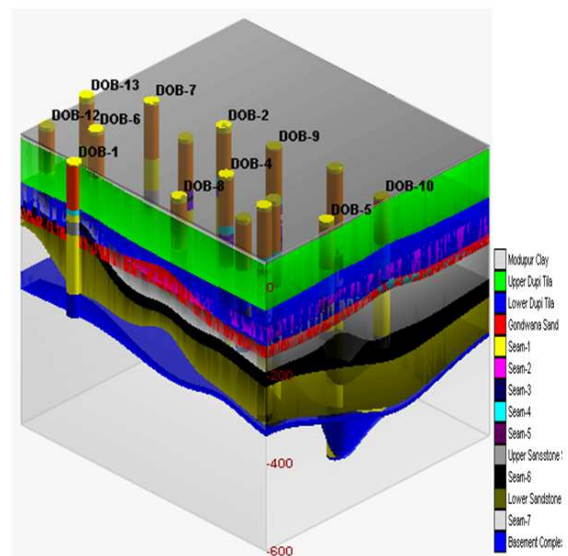


Fig 6: Stratigraphic solid model append with log Colum used in Rockwork during volume Estimation of Seam VI.

raise their voice against the mine activity as the mine induced subsidence is devastating the neighboring residential area. We conducting this study in the aim of the determination of the require volume of backfill along the the estimation of the reserve of the seam VI. That reveals the full extraction of seam VI will create 169221180.5 m³ void space when with recent recovery percentage creates 15229906.25 m³ to 16922118.05 m³ void spaces and required volume of backfill materials is 101532708.3 m³ and for 9% and 10% recovery are 9137943.747 m³ and 10153270.83 m³ respectively. The daily requirement of backfill is 562 - 636 m³ and the system need to have a daily capacity of 702 - 795

m³. Considering these requirement as well as the obtainable materials, sand dominated backfill, either in cemented or uncemented form, in hydraulic placement method can be recommended for Barapukuria coal mine. We also recommend a further study that will characterize the backfill materials and make an assessment of Backfilling of the mine.

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