THE POTENTIAL AND PROSPECTS FOR ALLEVIATING LONGWALL-MINING CONCERNS THROUGH THE USE OF BACKSTOWING[1]

Michael J. Sanzotti, and Susan B. Bealko, and Christopher J. Bise[2]

Abstract: This study examined the potential for controlling longwall-induced subsidence by pneumatically backstowing the void created by mining with waste rock, and having the process scheduled as a unit operation of the mining activity. After a review of background literature, interviews with representatives of various mining companies, public-interest groups, and State and Federal regulatory agencies, a case-study evaluation of pneumatic stowing in a southwestern Pennsylvania mine site was conducted. The significant result of this investigation indicates that current stowing technology cannot keep pace with the production potential of U. S. longwall systems. At the case-study mine site, concomitant stowing would reduce subsidence by 50% of that incurred during full longwall caving, but the longwall coal production rate would decrease from 4,000 st per shift in the non-stowing case to 1,500 st in the stowing case. A preliminary cost analysis reveals that pneumatic stowing would add $6 to $10 to the operating cost of producing a ton of coal at the case-study site.

Additional Key Words: longwall mining, subsidence, backstowing, overburden, pneumatic stowing, caving.

Introduction

In recent years, the increasing importance of longwall mining to U.S. underground coal production has been due to its more favorable levels of production, productivity, and safety when compared to room-and-pillar mining. In 1975, for instance, longwall mining accounted for 3.1% of the total underground coal production (Barczak 1992). Since that time, a dramatic increase in longwall production is reflected in the fact that longwall mining currently accounts for 37% of the total U. S. underground output (Merritt 1992).

While the future for longwall mining appears promising, one issue that continues to limit its acceptance is surface subsidence. The underground mining of coal creates a void which, under certain conditions, may result in the collapse and settling of overlying strata into the void. The effects on the overlying strata can propagate up to the surface and cause surface subsidence which, in turn, affects the natural and cultural environments; the resulting severity is primarily dependent upon the magnitude of subsidence. However, the extent to which these effects are experienced by humans is a function of the mine's location relative to various land uses, such as housing or agriculture.

It should be obvious that a mining engineer can exercise control only over the siting and dimensions of the void. With this in mind, the National Coal Board (NCB) conducted extensive empirical studies in England over 25 yrs ago to determine the relationship between the various parameters. The NCB found, among other things, that a relationship existed between the ratio of the void width to the depth of cover and the ratio of the maximum amount of subsidence observed to the seam thickness and that subsidence damage is negligible where the width-to-depth ratio is below 0.25 and can be significant when it exceeds 0.40. If the NCB findings can be extrapolated to U.S. conditions, which is often done, then it is obvious that longwall mining, as practiced under depths of cover less than 1,000 ft with face lengths currently averaging 714 ft (Merritt 1992), is conducted under conditions that will result in surface subsidence.

---

[1]Paper presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29,1994.

[2]Michael J. Sanzotti, Graduate Assistant, Susan B. Bealko, Undergraduate Student, and Christopher J. Bise, Professor of Mining Engineering, The Pennsylvania State Unversity, University Park, PA, USA.

Proceedings America Society of Mining and Reclamation, 1994 pp 384-391
DOI: 10.21000/JASMR94040384

https://doi.org/10.21000/JASMR94040384

One alternative in underground coal mining is to leave coal underground to protect surface structures. This practice is reasonable for room-and-pillar mining, but not for the full-caving longwall method. This leaves backstowing, the act of replacing the mined material with some type of fill material so that the newly created void is packed, as a method to restrict the movement of strata within the mine workings. Backstowing has been used successfully, both here and abroad, to limit subsidence damage in isolated cases. Debate as to its potential for limiting deep-coal-mining-induced damage has generated both information and misinformation. Recent legislation (Pennsylvania House Bills 628, 632, and 2514), testimony (the Pennsylvania Coal Association's testimony regarding H.B. 2514 --- "The Deep Mine Mediation Bill" --- October 9, 1990), and positions taken by groups such as the National Wildlife Federation and the Environmental Policy Institute further underscore the need for clear understanding of the issues and the development of accurate information.

Where stowing is applied successfully in other countries, generally three requirements have been met: (1) It is technically and economically the most desirable alternative for mining the resource, (2) the stowing activities are subsidized by the respective governments, and (3) an abundance of otherwise non-usable material is available for stowing.

This study examined the potential for controlling longwall-induced subsidence using backstowing as a unit operation of the mining activity, and is a distinct departure from past studies of after-the-fact stowing under structures to be protected, such as schools and churches. The U. S. Bureau of Mines has, for example, conducted several studies with regard to abandoned anthracite mines in Pennsylvania and in bituminous mines in the Illinois basin (Whaite and Allen 1975; Wade and Conroy 1977). The problem currently faced in Pennsylvania regarding longwall mining is how to limit subsidence while the panel is actively being mined, not after. Thus, this study of the potential for concomitant backstowing during mining focused particular attention on (1) ease of incorporation, (2) potential effectiveness, and (3) anticipated costs.

Case-Study Site Selection and Technical Analysis

To evaluate the technical and economic feasibility of backstowing in southwestern Pennsylvania longwall mines, a stowing system was incorporated into a case-study mine. The mine site selected should be representative of an active longwall mine in southwestern Pennsylvania, and backstowing material should be readily available in the immediate area.

Site Description

The 16,700 acre site is located in eastern Washington County and is characterized by flat-lying to gently dipping sedimentary strata. Geological formations within the area that overlie the Pittsburgh seam at the selected site, from youngest to oldest, are stream alluvium (sand, gravel), the Carmichaels terrace deposits, and the Greene, Washington, Waynesburg, Uniontown and the Pittsburgh Formations.

The Pittsburgh Formation consists of alternating limestone and shale, Sewickley coal, carbonaceous shale, Pittsburgh sandstone, and the Pittsburgh coal, which averages 63 in at the minesite. The strata immediately above the Pittsburgh coal consist of interbedded shale and thin coal, while the strata immediately underlying the coal varies between calcareous shale, limestone, shale, sandy shale, and clay. Mine rock, which includes immediately overlying and underlying strata, may result from materials removed from the mine because of roof falls, floor heaving, excavations for mine water sumps, and other underground operations.

The depth of cover ranges from 80 to 500 ft, with 450 ft being the average depth over the more recently extracted longwall panels. The mining methods practiced in the mine are continuous mining and longwall mining. Continuous miners develop the main and panel entries and may be used for room-and-pillar mining with pillar removal. Three entries are driven for longwall gateroad development, and the width and length of the longwall panels are 600 ft and 6,000 ft, respectively. Production from the longwall is in the range of 4,000 st per shift.

Two refuse disposal areas are at the site: Disposal Area A, which has been in existence for approximately 25 yrs, is completely filled, and Disposal area B, which is currently active, occupies 241 acres. Coarse coal refuse from the preparation plant is loaded into mine refuse rail cars and transported approximately 3 miles overland to the area. There, the refuse is discharged into a hopper, and is deposited within the disposal area in a layer thick enough to support the weight of the equipment hauling and spreading the refuse. The targeted refuse discharge rate from the preparation plant is 4,000 st per day, and the maximum vertical thickness of the refuse pile is 115 ft. To demonstrate the characteristics of the refuse, an effluent water sample was taken from the sedimentation pond that receives runoff water from the refuse area. The samples comply with the limits specified by the Pennsylvania DER as being safe for discharge into the surrounding water system, ensuring that the coal refuse is suitable for reintroduction underground.

At the mine site, subsidence is anticipated over room-and-pillar and longwall mining, but can be planned and controlled with regard to the timing and areal extent. Through the use of field surveys, the subsidence factor observed varied from 0.4 to 0.6. Anticipated effects on the surface may include minor rolls in surface topography and surface tension cracks.

Past experience has revealed that the surface over a longwall panel subsides in a trough-like, gentle depression. It has also been noticed that the major settlement occurs during the first five weeks of mining. Minor structural damages have been observed over the site's longwall workings. The surface over the mine is primarily used for farming and pasture land.

Subsidence Estimation

The subsidence prediction model chosen was first evaluated under conditions without backstowing, and then compared to subsidence profiles with the backstowing operation in place. Strains due to differential settling of the surface were predicted, and the extent to which surface structure damage can be reduced using stowing as a unit operation was estimated.

The method of subsidence prediction used in the study is applied by many mining companies operating in the case study area. Recent work (Hartman 1992) indicates that the hyperbolic tangent function is applicable in the bituminous coal fields of southwestern Pennsylvania:

$$S(x) = (0.5) ((S_{max}) (1 - \tanh cx/b) \qquad (1)$$

Subsidence surveys over a previously mined panel were obtained from the case-study area, permitting a comparison between anticipated subsidence using the model and actual conditions. The values used in the calculation were S_{max} = 3.45 feet, c = 2.0 (a subsidence constant), x varied between -250 ft to 325 ft, and b = 150 ft.

While estimating the effect of backstowing on surface subsidence, the indicator of the percentage loss in seam thickness after the roof has settled is known as the stowing factor or convergence. For pneumatically stowed faces, a convergence of 50% is common (Munjeri 1987; Reinshagen 1986; Voss 1983). Thus, the prediction model can then be developed for backstowed panels using a seam height of 50% of the original extraction height. A method detailed in the NCB's Subsidence Engineer's Handbook can be used to obtain a new value of S_{max}. It was estimated that a subsidence factor of 0.46 would be experienced at the case-study mine and, using this information, a new maximum subsidence was determined to be 1.73 ft. Then, using this S_{max} in equation 1, a new profile was constructed. Values used for the calculations were similar to the previous calculation, except S_{max} = 1.73 feet.

Accordingly, the maximum subsidence can be reduced by 50% using full-face pneumatic stowing. This alone is not enough information to determine the effectiveness of stowing to alleviate subsidence damage since damage to structures from subsidence is the result of differential horizontal movement which causes a strain (extension, +E;

compression, -E) in the ground surface. Extension is characterized by the opening of joints in brickwork and compression is characterized by the squeezing of openings, such as doors and windows, and the horizontal movement of brickwork (Munjeri 1987).

To analyze the strain experienced as a result of subsidence in the case-study mine, a method of predicting strains was used as outlined in the Subsidence Engineer's Handbook. The predicted maximum strains can then be classified with regard to the extent of damage to be experienced using tables developed and presented in the handbook. Figure 1 presents the complete strain and subsidence profiles, while Table 1 presents the associated damage classification.

Stowing System Layout

The +5 in material will be fed into a hammermill crusher using a front-end loader at the coarse coal refuse site. To achieve the required capacity, two 350-st/h crusher units will be needed to ensure the overall stowing-system efficiency. After the material is crushed to -3 in, it is transported, by means of a belt conveyor, to a 32,000-cu-ft storage silo which will ensure a steady feed of material to the shaft gravity pipe and will also reduce the amount of moisture in the material. A screw conveyor at the silo will allow the material to be fed to the shaft opening at the desired rate.

The infrastructure of a pneumatically stowed mine provides the stowing operation with material and other supplies. The layout incorporated the existing design aspects, and the specific configuration complies with guidelines suggested by Voss (1983). Material from the surface silo will be sent into the mine through a 20-in-diam shaft pipe having a spiral guide to reduce particle breakage on impact at the bottom. Recent designs have used cast steel in the construction of the spirals and are interlocked in such a way that smooth conveying of material down the pipe is realized. Advantages of gravity shaft pipes are high-capacity throughput, small space requirement in the shaft cross-section, and ease of maintenance. A throughput of 1,000 st/h of stowing material can be realized using the various pipe designs.

At the base of the shaft, material will be loaded onto a main belt conveyor for transport to the working section. This belt will be 36 in wide, have a maximum capacity of 700 st/h, and will be driven by a 400-Hp motor (Bise 1986). For the case-study, a length of 10,000 ft was used to simulate the access distances between multiple longwall faces. The main belt will discharge into an underground storage bunker, and the material will then be

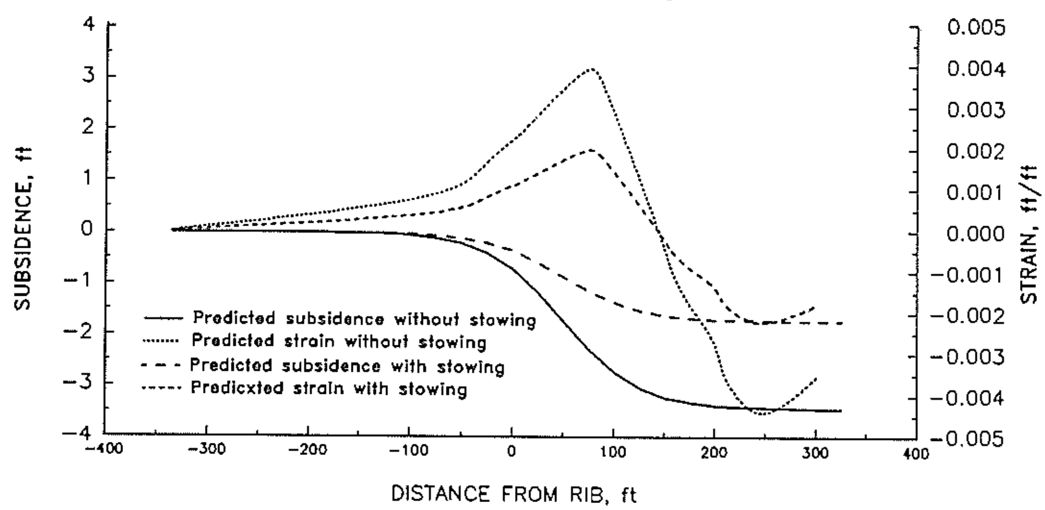

Figure 1. Graph showing predicted subsidence profile and predicted strain profile without pneumatic stowing compared with predicted subsidence profile and predicted strain profile with pneumatic stowing

Table 1. Results from strain calculations and the associated damage classification for a 100-ft-long structure located over the panel being mined.

Subsidence control	Maximum extension (+E)	Maximum compression (-E)	Damage classification (from NCB)
With pneumatic stowing (full-face).	+0.00195 ft/ft	-0.00221 ft/ft	Class I to II: Hair cracks in plaster, no visible cracks on the exterior, to doors and windows sticking slightly, Repairs to decoration probably necessary.
Without pneumatic stowing (caving).	+0.00390 ft/ft	-0.00441 ft/ft	Class IV. service pipes disrupted and door frames distorted, floors sloping noticeably.

supplied to the stowing machine by a second conveyor similar to the longwall stage loader and conveyor unit utilized in the coal haulage operation.

Once the stowing material is delivered to the section, it is ejected using a stowing machine with a rated output capacity of 9,800 cu ft/h. The stowing machine discharges material to a 9-in-diam roadway line consisting of lengths of rigid pipe and a hydraulic telescoping section, all lined with cast basalt. From the roadway line, the material flows through a 90° bend into the face stowing line which is suspended from rear cantilevers on the longwall shield supports. Each 15-ft pipe section is coupled with specialized couplings and a discharge unit is incorporated (every 25 to 30 ft). There are basically two different discharging methods used in pneumatic stowing, the lateral discharge and the mechanized front-end discharge. In this study, the mechanized front-end discharge is used because it is a newer development and is reported to obtain a better and more unrestricted placement of stowing material in the void. As the cut advances, the face pipe is displaced toward the gob by hydraulic rams and is left suspended from the supports in such a way that it does not interfere with the next stowing section.

As previously mentioned, the average production from the existing caving longwall face is approximately 4,000 st per shift. With concomitant backstowing, the ability to pack the newly created void will become the factor affecting coal production since, within a given time period, the amount of coal mined must be balanced with the ability to fill the void created by mining that coal. For example, if 6 h of production time is available per shift and the stowing system is designed using a stowing machine that has a discharge rate of 9,800 cu ft/h, the amount of void that can be created and fully stowed per shift is approximately 37,500 cu ft. At current longwall mining rates and optimistic backstowing performance, the production from the longwall face after implementing backstowing would drop to about 1,500 st/shift or 4,500 st per day. Although a stowing machine exists which will stow material at a rate of 12,300 cu ft/h, the lower capacity machines are more common, primarily due to compressed-air requirements (Rauer and Voss 1983; Reinshagen 1986; Voss 1987).

Case-Study Economic Analysis

The economic analysis section consists of a capital cost estimation, an operating cost estimation, additional labor considerations for the stowing operation, and a cash flow analysis to incorporate all of these factors, including the production loss, into the economic impact of implementing such a system in an existing longwall mine.

Capital Cost Estimation

The capital costs needed for the stowing installation total $12,546,624, which consist of surface equipment ($1,302,480), infrastructure equipment ($5,430,500), and stowing equipment ($5,813,644). It was assumed that the mine already owns a front-end loader to do the job of loading the refuse into the crusher. As indicated earlier, the materials-handling system used for this case-study was dictated by the inherent features of the chosen site. Also, in an effort to use the most economical methods, waste drop pipes in the shaft and belt haulage in the mains were chosen. Obviously, other methods could be used and should be evaluated according to established site-by-site criteria. The equipment listed represents the minimum requirements for stowing one longwall face.

The total capital cost is based on the most recent manufacturer's equipment prices and the most recent available literature on issues involving the stowing and mining industries. A $1 million contingency has been added to accommodate any minor construction needed to install the stowing system and any further roof supports required, bringing the total capital required to $13,546,624.

Operating Cost Estimation

The USBM Cost Estimation System Handbook (1987) was used to estimate the operating cost of surface and infrastructure operations. The stowing segment of the operating cost was calculated using a method outlined by Singh and Courtney (1975), due to a lack of published literature and limited information from overseas mine operators and manufacturers. In this method, the operating cost represents the cost of replacement or repair divided by the recommended life of the equipment in tons of stowed material. Results from the calculations are presented in Table 2.

Additional Labor Requirements for Pneumatic Stowing

Sources of labor information in stowing systems are mostly European and data have been modified for U.S. conditions. Surface personnel needed include a front-end loader operator and an operator for the crushing operation. This crusher operator will be able to monitor the material moving to the storage silo and will also be able to detect problems associated with the movement of material to the shaft waste pipe. Maintenance and emergency situations will be somewhat dependent on the existing personnel of the mine; therefore, the estimate is fairly conservative. For the underground segment of the operation, two additional miners will be needed to maintain the waste belt line. In the face area, the longwall crew will be responsible for running the stowing operations.

In all, an additional eight workers will be needed to sustain the stowing operation. This number will be incorporated into the economic analysis to show the impact on the entire operation. Labor cost per day is estimated to be $219 and is based on an average hourly wage for a typical underground crew.

Cost Analysis

In the cost analysis, information for the case-study mine was obtained to simulate the production costs for a longwall mine in southwestern Pennsylvania. The analysis was conducted for a 20-yr mine life incorporating one longwall unit and three continuous miner sections. The economic analysis used a labor schedule, production schedule, operating-cost detail, capital-expenditure detail, and a depreciation schedule. Once the base-case analysis was created, information obtained from the previous capital-cost, operating-cost and labor-requirement sections could be used to analyze the effect of adding a pneumatic stowing operation to the mine. Table 3 summarizes the information obtained in the analysis.

Three cases were studied in the cost analysis. In the Base Case, the production cost of a mine incorporating one full-caving longwall section was analyzed. In Case 1, the various cost items and production impacts for pneumatic stowing were added to the Base Case. In Case 2, an additional longwall section and an additional continuous-miner section were added to the mine to attempt to return to the production levels in the Base Case; further, it was assumed that continuous-miner production could increase to 450 st per miner shift when the machines are less constrained by longwall development.

Table 2. - Summary of operating costs for the pneumatic stowing operation.

Segment of operation	Cost per ton of coal mined
Surface facilities:	
Loading............................	$0.3641
Crushing...........................	0.1019
(Power and materials handling included)	
Infrastructure:	
Shaft pipe.........................	0.0825
Main waste conveyor........	0.1760
Loading conveyor............	0.1163
Stowing operation:	
Stowing machine.............	0.0531
Air compressor................	0.2500
Road pipe.........................	0.0460
90 degree bend................	0.0457
Face pipe..........................	0.1728
Telescoping pipe..............	0.2897
Discharge units................	0.5000
Total Operating Cost....	2.1981

Table 3. Summary of economic analysis for a 20-yr-life longwall operation with and without the incorporation of pneumatic stowing.

Production:	Base case	Case 1	Case 2
Annual...........................st	3,243,000	1,518,000	3,0011,500
Daily.............................st	14,100	6,600	13,050
Days/year.........................	230	230	230
Tons/shift - CM.............st	350	350	450
Tons/shift - LW.............st	4000	1500	1500
Plant recovery...............%	80	80	80
Labor:			
Hourly workers/day(avg)	236	244	296
Absenteeism..................%	12	12	12
Overtime.......................%	15	15	15
Salaried workers/day........	66	66	66
Tons per miner/day..........	46.7	21.3	36.0
Economics:			
Labor cost (hourly + salary)............	$4.69	$10.28	$6.08
Operating cost..................	13.90	16.10	16.10
Total cash cost.................	18.59	26.38	22.18
Total operating cost (includes depreciation)...	20.13	30.64	25.39

Summary and Conclusions

This study has addressed the use of concomitant pneumatic stowing to alleviate the concerns of longwall mining. The use of pneumatic stowing as a subsidence-control measure must rely greatly on the technical and economic feasibility of incorporating the stowing system as an additional unit operation of the existing system. The study included a hypothetical case-study evaluation of pneumatic stowing at a southwestern Pennsylvania mine site to determine its feasibility.

The use of pneumatic stowing in the southwestern Pennsylvania mining district will not completely eliminate surface subsidence caused by longwall mining. For the case-study mine, the maximum subsidence can be reduced to 1.73 ft from 3.45 ft, a 50% reduction. The predicted subsidence profiles are shown in graphical form. To determine the extent to which subsidence is causing damage, the strains associated with the horizontal and vertical displacement were calculated using a method from the NCB. With these strains, a classification of the damage caused can be chosen. Table 1 shows that with stowing, the subsidence damage is reduced from Class IV to between Class I and II.

In the cost analysis of the case-study mine, a Base Case without stowing was compared to the case with stowing (Case 1) and another (Case 2) where production losses due to stowing were accommodated with additional production units. In none of the cases were financing costs, profit margins, taxes on profit, royalties, and cost depletion considered. In addition, stowing material costs and costs to transport stowing materials to the mine site were not considered for Cases 1 and 2.

The significant result of this study indicates that current stowing technology cannot keep pace with the production potential of U. S. longwall systems. The case study indicated that (1) stowing would reduce subsidence by

50% of that incurred during full longwall caving, (2) longwall coal production would decrease, and (3) stowing would add at least $6 to $10 to the operating cost of producing a ton of coal.

Acknowledgments

This project was supported by federal funds from the U.S. Bureau of Mines and the National Mine Land Reclamation Center under Cooperative Agreement CO388026.

Literature Cited

Bise, C. J. 1986. Mining engineering analysis. Society of Mining Engineers, Inc., Littleton, CO.

Bise, C.J., Bhattacherjee, Ashis, Sanzotti, M.J. 1993. The Potential and Prospects for Alleviating Longwall-Mining Concerns Through the Use of Backstowing. Final Report to: National Mine Land Reclamation Center-Eastern Region.

Hartman, H. L. (ed.) 1992. SME mining engineering handbook. Society of Mining Engineers, Inc., Littleton, CO.

Merritt, P.C. 1992. Longwalls having their ups and downs. Coal 97(2): 26-35.

Munjeri, D. 1987. Prevention of subsidence using stowing methods. Colliery Guardian 235(7): 246-247.

National Academy of Sciences/National Academy of Engineering. 1975. "Underground Disposal of Coal Mine Wastes," A report to the National Science Foundation by the Study Committee to Assess the Feasibility of Returning Underground Coal Mine Wastes to the Mined-out Areas. International Standard Book No. 0-309-02324-6. National Academy of Sciences, Washington, D.C., pp 170.

National Coal Board. 1966. Subsidence engineers' handbook. NCB Production Department, London.

Rauer, G. and K. H. Voss. 1983. Pneumatic stowing. Verlag Gluckauf GMBH, Germany.

Reinshagen, K. 1986. Possible developments in stowing. Gluckauf and Translation 122(3): 67-69.

Singh, M. M. and W. J. Courtney. 1975. Feasibility of pneumatic stowing in United States coal mines. Translation of the SME-AIME 258(3): 232-239.

U.S. Bureau of Mines. 1987. Bureau of mines cost estimating handbook (in two parts). Bureau of Mines, IC 9142 and 9143.

Voss, K. H. 1987. Equipment and operation of pneumatically stowed faces. Gluckauf and Translation 123(7): 166-171.

Voss, K. H. 1983. State of development of pneumatic stowing in the hard coal industry of the Federal Republic of Germany. In Proceedings of the International Symposium on Mining with Backfill. (Lulea, Sweden, 1983).

Wade, L. V. and P. J. Conroy. 1977. Rock mechanics study of a longwall panel. SME-AIME Preprint 77-I-391.

Whaite, R. H. and A. S. Allen. 1975. Pumped-slurry backfilling of inaccessible mine workings for subsidence control. Bureau of Mines, IC 8667.