DEEP MINE BACKFILLING AT THE WABASH VALLEY CORRECTIONAL INSTITUTION, CARLISLE, INDIANA[1]

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Abstract: An expansion at the Wabash Valley Correctional Institution (WVCI) required development over abandoned coal mine workings. An extensive geotechnical investigation determined subsidence could occur at the surface. Building the Phase II structures was nevertheless determined economically feasible at least in part due to sharing of facilities and resources with the already existing Phase I Institute. In order to limit the possible subsidence damage to the Phase II structures, raft foundations, mine backfilling, and other structural enhancements were considered. Backfilling of this entirely flooded mine at 300 feet beneath the surface in critical areas was determined to be the most cost-effective for many of the buildings. Each mine area was first contained by strategically placing containment grout in certain entries and cross cuts. Once the barriers were sufficiently constructed, the remaining volume was filled with a flowable infill grout. In the highly rubblized areas, set retarder/plasticizer (calcium lignosulfonate) was used to increase penetration. Once the grouting operation began, the grout movement was monitored in adjacent holes using an electric resistivity probe. After grouting operation was finished, core samples were obtained from verification holes drilled in the backfilled mine areas.

Additional Key Words: Grouting; Mine Backfilling; Mine Grouting; Subsidence Mitigation.

Introduction

The purpose of this project was to significantly reduce or eliminate the mine subsidence potential beneath a number of the Phase II structures at the Wabash Valley Correctional Institution (WVCI), Carlisle, Indiana. From the study conducted by Gennaro G. Marino, Engineering Consultants (GGMEC) in 1993, the Indiana Department of Administration Public Works (DAPW) determined that the mine backfilling was the most cost-effective solution for mine subsidence remediation of certain structures (Marino, 1993). As shown in Figure 1, existing Phase I structures are just north of the Phase II construction. Contrary to Phase I, many of the Phase II structures are undermined (see Figure 1). Therefore, due to the abandoned mine void about 300 feet below the proposed Phase II structures, there is significant potential for mine subsidence. History shows that structures ill prepared to handle mine subsidence perform very poorly and can result in abandonment of the structures (Marino et al, 1982; and Marino and Funkhouser, 1986). In order to limit this possible damage and to ensure the operation of the prison structures, mine backfilling was performed subjacent to a number of critical structures.

Backfilling Plan

The mine areas to be backfilled were determined by creating shadow areas for each building to be supported. The shadow areas were projected to mine level using a draw angle of 15°. Although this angle will not eliminate subsidence completely, it was considered cost-effective as no significant damage is expected as a result of subsidence movements outside these delineated draw zones.

The original plan was to contain entire mine areas, using containment grout, for each of the Mine Areas 1, 2, and 3, respectively. Complete containment was thought necessary in order to avoid significant movement of infill grout out of that particular mine area. Experience in the field proved, however, that this

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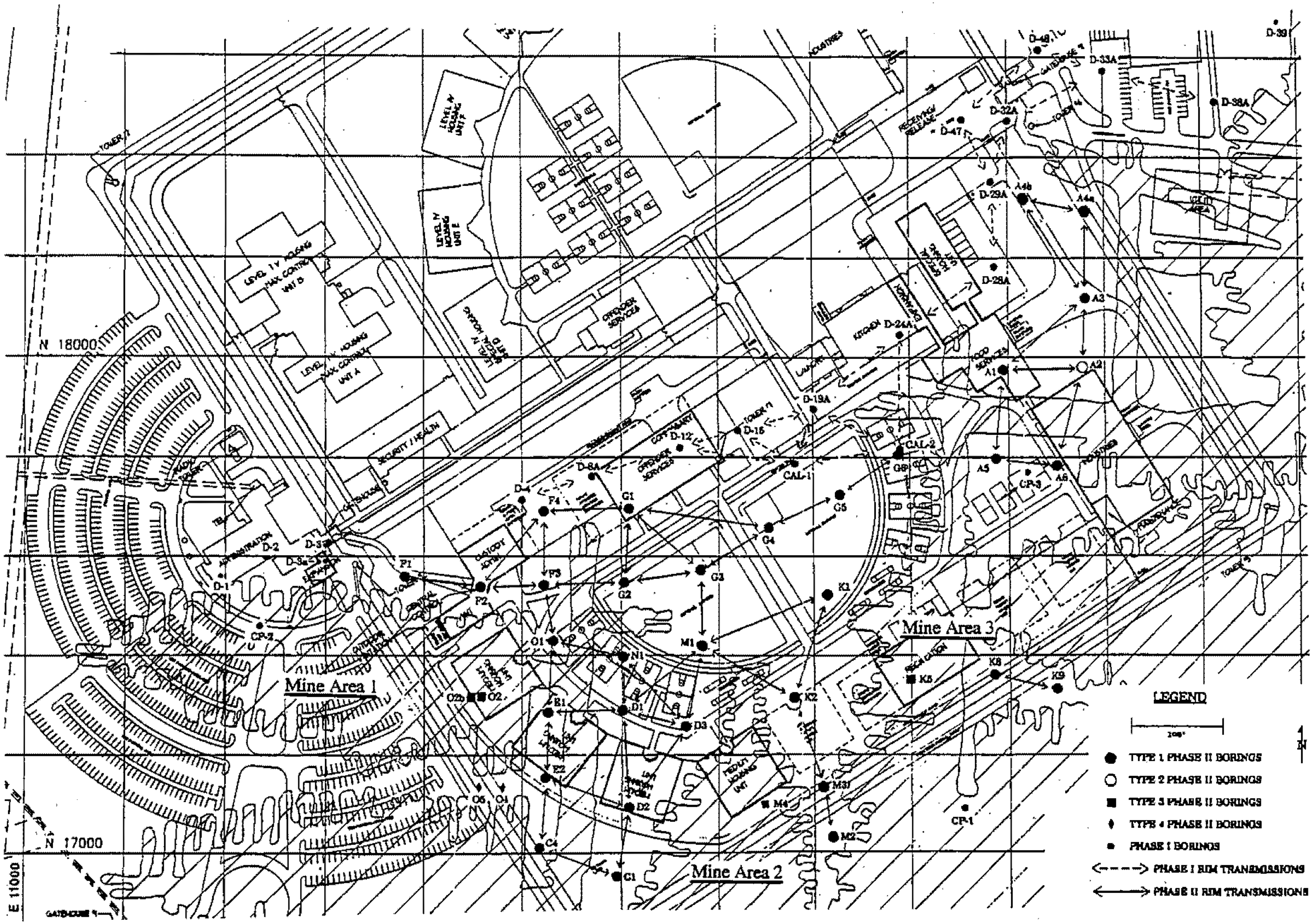


Figure 1. Plan of Phase II Construction with Borehole Locations, RIM Transmissions, and Outline of Mining.

was not a significant problem. Therefore, to make the grouting operation more efficient, the plan was change for Mine Areas 1 and 2. Instead of containing an entire mine area, only part of the mine area was contained. Mine Areas 1 and 2 were contained using the solid coal on two sides and placing containment grout either in main entry or between two production pillars. Once the mine area was contained at one end using containment grout, infill started from that end of the mine area using the infill grout mix. Grouting generally proceeded across the mine until grout was verified to be at the roof at the other end of the mine area.

Mine Conditions

This project site is undermined by mine workings that exist in the No. 5 Springfield Coal. No other coal seams have been mined at the project site. The mine at the project site was operated by Carlisle Mine Co., and was called Mine 1. The mine began operating in 1905 and was abandoned in 1928. A mine shaft for air ventilation and transportation is located about 800 ft south of the site. There are irregular and regular mining patterns that can be clearly identified on the mine map. The more recently excavated areas are probably the regular sections, whereas irregular geometries were probably mined earlier.

Coal at Carlisle Mine #1 was recovered using double entry method. Based on the mine map, panel entries were generally 15 ft wide with 8-9 ft wide central pillars with 5 to 15 ft cross-cuts at varied spacing. In the high extraction areas the rooms are 25 to 30 ft wide with 8-9 ft wide pillars that are butted adjacent to the entries. Cross-cuts between these production pillars are about 10 ft wide and have varied spacing. The production areas of Mine No. 1 are up to almost 400 ft wide but extend longitudinally up to 800 ft in length. These high extraction areas are found to have extraction rates from 68 to 75%. In a mining report registered at the state, the height of extraction is reported to be 5.2 ft (probably at the shaft location).

As shown in Figure 1, the coal interval between the deep holes drilled at the site was investigated using a cross-hole EM technique (Radio Imaging Method or RIM) to detect mine voids (List, D. F., et al, 1994). Use of this method verified to a large extent the accuracy of the locations of the gross extraction areas. Consequently, the drilling operation for grouting holes was planned assuming the mine map to be correct.

As a result of the drilling related to the backfilling operation, it appears that less mining occurred than indicated in some localized areas of the mine map. Based on drilling results and grout monitoring, the apparent limits to mining have been superimposed onto Figures 2A and 2B. Also, two areas in which RIM surveys indicated the potential that additional mining might be present were not found.

To assess the amount of roof fall across Mine Areas 1, 2, and 3, a comparison was made between holes intersecting the mine void and adjacent holes in the pillar coal. From comparing the difference in depth of the top of the mine void interval and the top of the coal an indication of the amount of roof fall that had occurred can be made. The results from this comparison would in turn also indicate the level of rubblization[3] in the mine void. Based on this comparison, differences in the depths to the top of the void and coal range from 0 to 18 ft. Also, one should note that variations in the void depth can be affected by a number of factors such as: 1) difference in elevations of the ground surface between the void to coal holes, 2) location of the hole within the room, 3) greater induced roof collapse due to the drilling, and 4) inability of the driller to determine top of the void in the softer weathered rocks.

[3]The indication of rubble based on the depth difference neglects any effects from the mining operation. Cave material which had fallen in the mine void during mining operations could have been moved elsewhere and artificially "rubblized" another area.

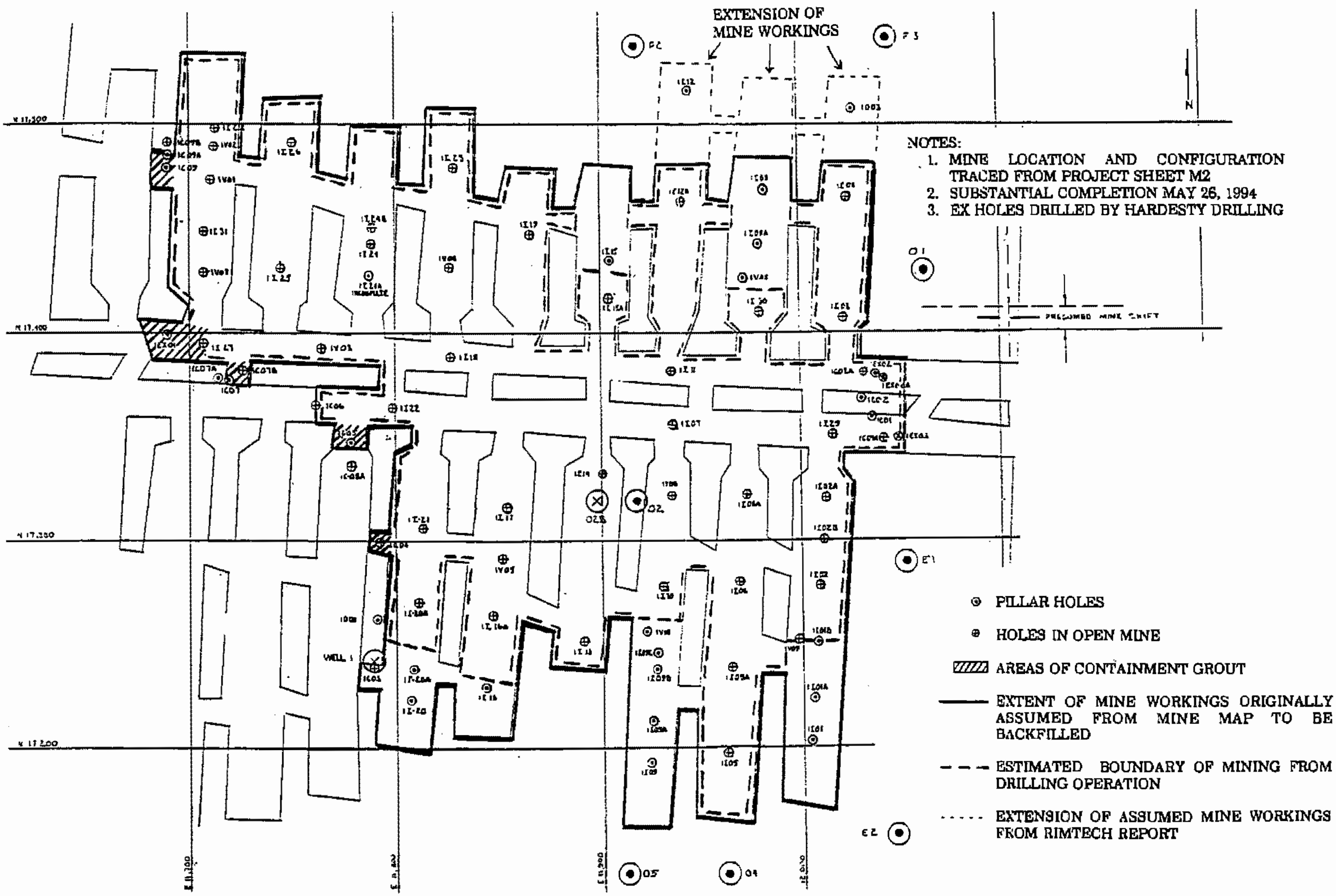
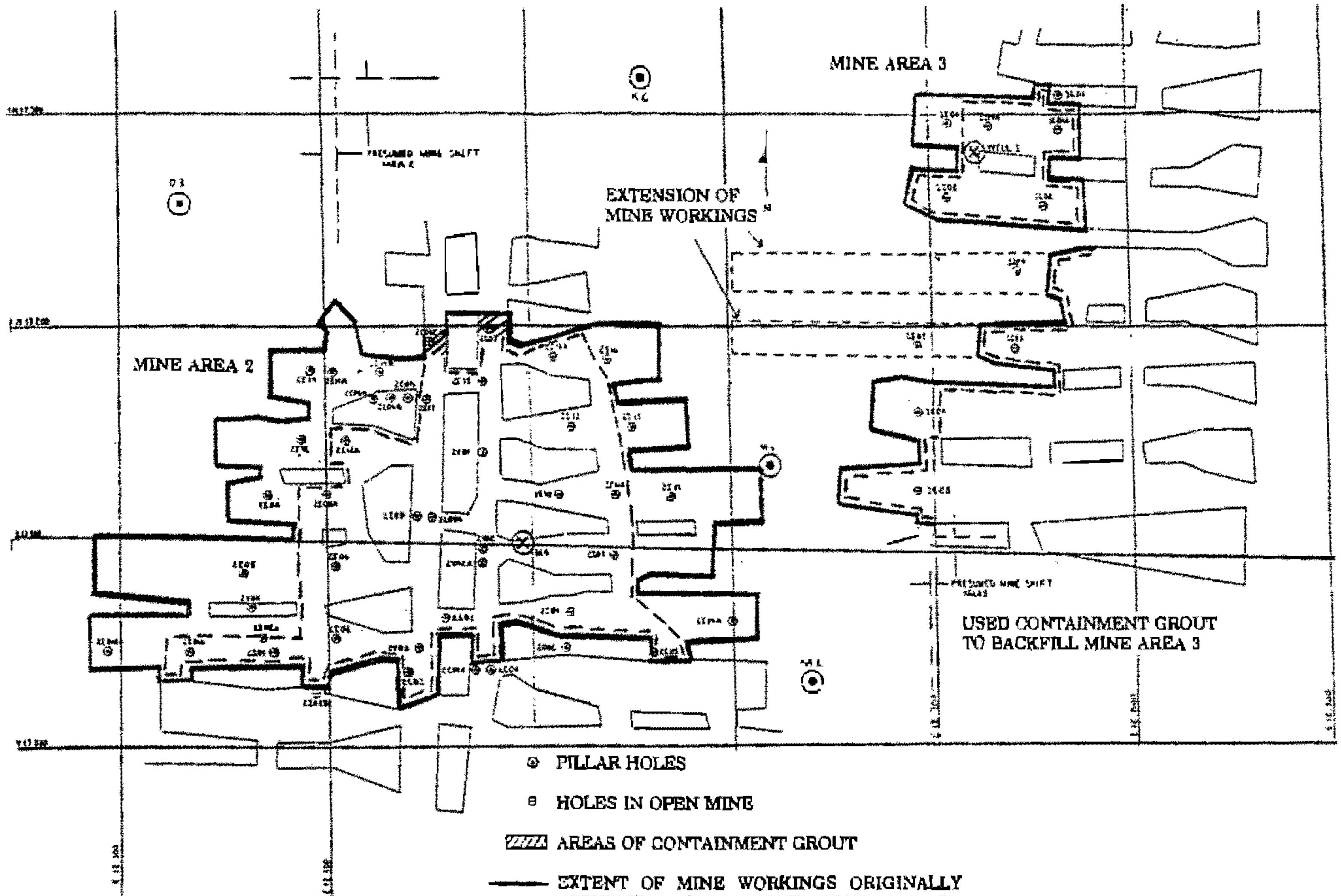


Figure 2A. Mine Work of Mine Area 1.



PILLAR HOLES

HOLES IN OPEN MINE

AREAS OF CONTAINMENT GROUT

EXTENT OF MINE WORKINGS ORIGINALLY ASSUMED FROM MINE MAP TO BE BACKFILLED

ESTIMATED BOUNDARY OF MINING FROM DRILLING OPERATION

EXTENSION OF ASSUMED MINE WORKINGS FROM RIMTECH REPORT

NOTES:
1. MINE LOCATION AND CONFIGURATION TRACED FROM PROJECT SHEET M2
2. SUBSTANTIAL COMPLETION MAY 26, 1994

Figure 2B. Mine Work of Mine Areas 2 and 3.

Drilling Operation for Grouting

For the backfilling operation, the first stage of the drilling operation was to identify the position of the mine as best as possible (optimumly, say within 10 ft). This was important in order to have the best chance of success in locating the mine features necessary for subsequent grouting. The initial drilling of each mine area to be grouted focused on intersecting the main entries to best orient the mine map to the ground surface and obtain north-south and east-west controls. Drilling was terminated when driller felt comfortable that he was in the mine floor. This typically occurred after drilling 1 ft to 3 ft into the floor. There were many instances where the driller did not hit the mine void as planned. In this situation, another hole was drilled about 5 to 10 ft away from the original hole. This new location was established by examining the mine map and determining the most likely location to intersect each mine void.

An alternative drilling plan would have been to drill injection holes using grid patterns (anywhere from 30 to 60 ft grid) and essentially ignoring the mine map (in other words considering mine map to be invalid). There were two basic reasons why a grid drilling pattern was not used. One, there is a lower probability of intersecting voids when drilling grid holes. The other reason is that a better understanding of the actual mine workings is obtained when drilling in conjunction with the mine map. A better understanding of the actual mine workings results in determining the most optimum sequence of grouting. Also, one can better evaluate grout takes, flow of grout, and identify the areas which may have not been completely grouted. A total of 35,690 LF of containment and infill holes were drilled with a total of 5,659 LF of verification and exploration drilling.

During the drilling operation 62% of success was obtained hitting the voids. This percent of success was affected by several factors such as: 1) the mine map had different shifts relative to the ground surface coordinates for each of the mine areas (Figures 2A and 2B), 2) the mine map represented the extent of mining to be greater than encountered during mine backfilling, and 3) map accuracy dropped off (from the gross extraction areas identified from the earlier exploration) as individual pillars, rooms, and crosscuts were attempted to be located.

Because of the drilling accuracy required to intersect certain mining features at depth a verticality criterion was set. To measure verticality of the borehole, a Magnetic Multi-shot Camera was used to obtain a continuous survey of wells that are not cased and free from magnetic material and/or magnetic geological formations.

At the Carlisle, Indiana site, the camera was run in an open hole on a wire-line or cable using centralizers. During the surveying operation the camera was run on a 1 minute auto-timer, i.e., the camera was set to take a picture of the compass every one minute. Survey calculations were done on-site using a computer program developed by GGMEC. Surveying of each borehole took approximately 30 to 45 minutes.

Grouting Operation

Performance specifications were essentially used for this mine backfilling project. The performance specification basically required that: 1) the in-place infill grout have a 7 days strength of 300 psi with less than 1% shrinkage (including bleed), 2) the in-place containment grout has a 7 day strength of 500 psi with less than 1% shrinkage (including bleed), 3) there is at least 50% grout to roof contact with no more than 3 inch separation present. Here in this specification the shrinkage criterion served two purposes: 1) mitigate the use of unstable grouts, and 2) the amount of solids could not be lower during bidding to lower the unit cost of the grout.

The purpose of grouting operation was to fill up critical mine void areas or significant overburden fractures with a relatively low strength, low shrinkage grout. Most of the grout placed consisted of a mixture of cement, flyash, sand, and water, and a plasticizer/set retarder additive. As noted, a small amount of neat grout was used to start each hole. The grouting operation essentially consisted of a mixing plant (on and off site), steel slick line injection pipes, packers, 970 yd^3/hr concrete pump, and necessary support equipment such as endloaders and storage silos.

Within pumpability parameters, grout-mixes were formulated and tested in the lab. Additionally, to have flexibility in the field, a range of containment and infill mixes were designed containing most importantly different quantities of sand. In order to insure that these grouts met the structural requirements, lab tests were performed on the mixes at both extremes of sand use. All these grout mixes mentioned in Tables 1A and 1B met the lab specifications. For the containment grout mixes the amount of sand per yard ranged from 1,713 to 2,449 lbs. For the infill grout, 0 to 2,387 lbs of sand were considered. Based on the limiting design mixes intermediate mixes were developed by using the various constituent ratios for the limiting mixes. These intermediate mixes were the most used mixes for the grouting operation. Tables 1A and 1B shows the summary of the containment and infill grout mix designs.

The general procedure to pumping the grout mix into the mine voids in Mine Areas 1, 2, and 3 basically involve an on-site mixing plant with occasional use of ready-mix trucks. Once the grout was mixed it was placed into a Schwin Tube concrete pump and pumped through a 3 in. steel slick line and down 3 in. steel injection pipe. A packer was used during the grouting operation in the rubblized area. The use of a packer in each borehole can drive the grouting cost significantly higher. As an alternative to the use of a packer, sand was backfilled around the injection pipe to inhibit grout from coming up to surface. Infill grout was injected until at least 600 psi line pressure was achieved or flow refusal was reached. For containment grout, certain target quantities were set as maximum volumes if refusal or 600 psi was not reached.

Before injecting grout into the mine void the injection line was flushed with water. In addition to lubricating the lines and washing out debris in and around the pipe, the initial pumping of water provided a test of the nearfield conductivity. Only in a few cases did any pressure result, and unless the pipe had been mistakenly set in the floor could any pressure be maintained after a short period of time. Once zero water pressure was maintained, a neat mix (a mixture of only cement, flyash, and water) was injected into the mine. During this operation the bottom tip of injection pipe was kept about 1 to 2 ft above the floor of the mine. After pumping 2 to 5 yd^3 of neat mix with no pressure, the selected infill or containment grout mix was injected into the mine. As the pumping operation continued the line pressure, flow rate, and volume of grout injected were monitored by the use of a multiple pin strip chart recorder. Once pressure reached 200 to 300 psi the injection pipe was lifted 0.5 to 1 ft when possible until pressure went back to zero or close to zero.

In cases where rubble was indicated by the driller, the bottom tip of the injection pipe was kept only 1 ft above the mine floor to get as much penetration into the rubble as possible. Also, in rubblized areas, a packer or sand (to backfill annular hole space) was used to achieve downhole pressure and eliminate the flow of grout up the annular space between the hole and the grout pipe.

Most of the grout was produced on-site by the contractor. In addition to being more economical than off-site batching, on-site batching allowed the contractor to have direct control of the mix proportions and amount of grout made. The main draw-back to on-site batching, however, is the limited grout production rate due to the size of the plant.

Addition of Admixture in Grout

Water reducing admixture can be used to obtain more flowable, higher slump grout without adding any water to the mix. Also, addition of admixture reduces the water content by approximately 5% to 10%. High-range water reducers reduce water content by 12% to 30% (Kosmatka, S. H. and W. C. Panarose, 1992).

At WVCI mine backfilling project, calcium lignosulfonate as the admixture was used. However, the flyash tended to flash set when the velocity decreased after exiting the injection line. The addition of a set retarding, water reducing admixture increased the initial flowability and delayed the initial set for as much

Table 1A. Containment Grout Mix Designs

WEIGHT

MATERIAL USED	S.G.		#3A mix LBS/C.Y.	#3AB mix* LBS/C.Y.	#3B mix LBS/C.Y.
WATER	1		530	440	392
CEMENT	3.14		407	385	392
FLYASH	2.6		952	715	588
SAND	2.6		1,713	2,201	2,449
		TOTAL	3,602.42	3,742.30	3,820.86
			PCF	PCF	PCF
MIX DENSITY (PCF)			133.42	138.6	141.50
			RATIO BY WT.		
CEMENT/(CEMENT + FLY ASH)			0.299	0.35	0.40
WATER/(CEMENT + FLY ASH)			0.39	0.40	0.40
SAND/(CEMENT + FLY ASH)			1.30	2.00	2.50
GAL WATER/C.Y.			63.60	52.8	47.0

STRENGTH DEVELOPMENT

	PSI	PSI	PSI
4 DAY	1010	-	2250
5 DAY	1170	-	2520
7 DAY			
28 DAY			
SHRINKAGE**	0.50%	-	0.50%

MATERIAL SOURCE INFORMATION

CEMENT	LONE STAR TYPE I
FLY ASH	IPL PETERSBURG CLASS F
SAND	S & G SOUTH PIT #23 SAND

*Having #3A and #3B mix well over the basic requirements, strength tests were not conducted on these results. The #3AB mix was found to perform the best in the field.

**Shrinkage reported includes bleed-settlement as well as shrinkage after set.

Table 1B. Infill Grout Mix Designs

WEIGHT

MATERIAL USED	S.G.	#2 mix LBS/C.Y.	#2B mix LBS/C.Y.	#2A mix LBS/C.Y.
WATER	1	874	516	409
CEMENT	3.14	437	248	193
FLYASH	2.6	1,747	992	771
SAND	2.6	0	1,842	2,387
	TOTAL	3,057.77	3,598	3,760
		PCF	PCF	PCF
MIX DENSITY		113.25	133.25	139.25

	RATIO BY WT.		
CEMENT/(CEMENT + FLY ASH)	0.20	0.20	0.20
WATER/(CEMENT + FLY ASH)	0.40	0.42	0.42
SAND/(CEMENT + FLY ASH)	0.00	1.5	2.5
GAL WATER/C.Y.	104.80	81.9	49.0

STRENGTH DEVELOPMENT

	PSI	PSI	PSI
4 DAY	130	180	140
5 DAY	300	190	210
7 DAY	380	310	300
28 DAY	-	-	
SHRINKAGE*	0.67%	-	0.33%

MATERIAL SOURCE INFORMATION

CEMENT	LONE STAR TYPE I
FLY ASH	IPL PETERSBURG CLASS F
SAND	S & G SOUTH PIT #23 SAND

*Shrinkage reported includes bleed-settlement as well as shrinkage after set.

as 45 minutes. On site tests were conducted to determine the effect of addition of calcium lignosulfonate at varying rates. Figure 3 shows how the flow[4] changed with respect to time with a different percent of admixture. The percents of admixture tested are given in Table 2.

[4]Although the flow measurement is standardly taken using 3" x 6" open ended cylinders, these tests were run with 2" x 4" open ended cylinders for convenience. The flow test is performed by first standing the open-ended cylinder on a flat level surface, filling it with grout, and then lifting the cylinder and allowing the grout to flow freely laterally. The flow measurement is the diameter of spread of grout on the flat level surface.

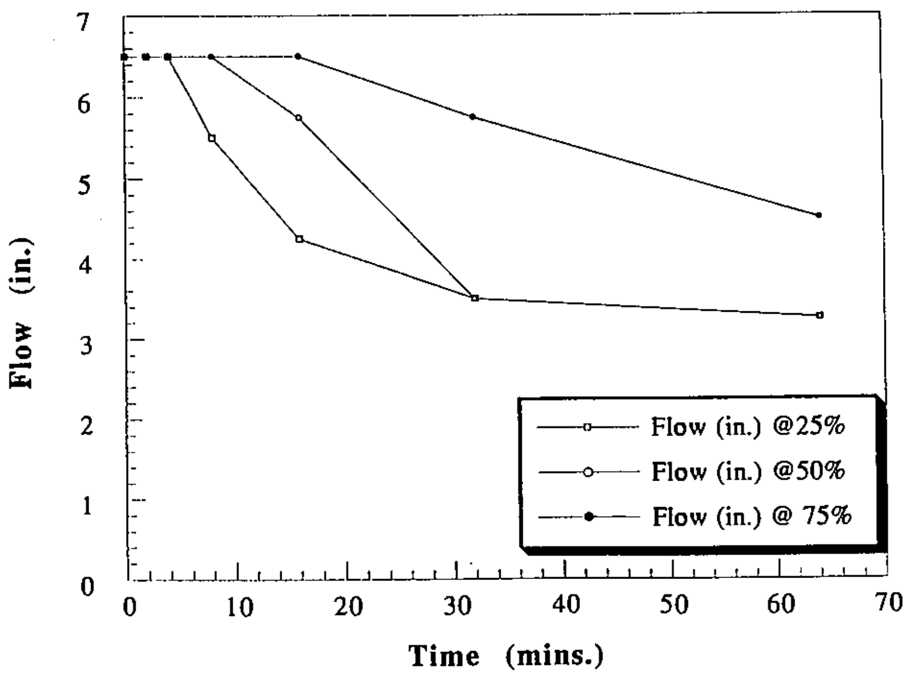


Figure 3. Correlation Between Time and Flow for Different Percent of Admixture Added.

Table 2. Percent of Calcium Lignosulfonate Used in On-site Test of Grout Admixture.

% Mixture*	Pounds of Admixture Per Yd of Grout Mix Lb.
0.25%	3.10
0.50%	6.20
0.75%	9.30

*Percent of admixture determined from total weight of dry material (i.e., cement and flyash).

From Figure 3, it is clear that lignosulfonate has a significant effect on set time/flow of the grout mix. Furthermore, with the increase in content of admixture in the grout mix, flowability of that grout mix also increase without unstabilizing the grout in the range tested.

Grout Monitoring

To monitor the quality of the grout a number of tests were conducted. The main tests during grouting were: 1) flow tests, 2) shrinkage tests, and 3) water content tests on sand. Also, according to the specification, 4 cylinder samples for every 100 yd^3 or 4 samples per day were prepared for ATEC Associates, Inc. for strength testing. Furthermore, several different measurements were made in the field to monitor the flow of grout during the grouting operation. These include 1) estimated grout quantities for a particular area compared to that pumped, 2) change in resistivity in the holes adjacent to the one being grouted, 3) change in line grout flow with pressure, and 4) return in holes from grouting of an adjacent hole.

Before the grouting operation began, the presence of grout was monitored in holes adjacent to the hole being grouted. This grout monitoring was carried out using resistivity probes. The probe basically consisted of a two prong electrode in which the electrical resistance of the material between electrodes was measured.

The instrumentation consisted of an alternating current voltage source (used to eliminate polarization effects), with a common audio amplifier circuit and a weatstone bridge. When the instrument is attached to the probe through approximately 330 ft of Belden cable, the precision potentiometer is adjusted to obtain a null (dip) on the meter. The resistance can then be read by a counter scale. The device used a series of ranges to measure resistance from 1 ohm to 10 megohms. Since the resistivity of the mine water at the site was found to be very low, sensitivity of the probe was increased by placing heat-shrink tubing on probe from 1 inch above the bottom tip of probe.

Before grouting operation began, a resistivity profile was created of the mine void interval. The reason for creating this resistivity profile in the borehole was to assess a grout movement in and below that hole. An example of the resistivity profile before and after grout movement at the hole is given in Figure 4.

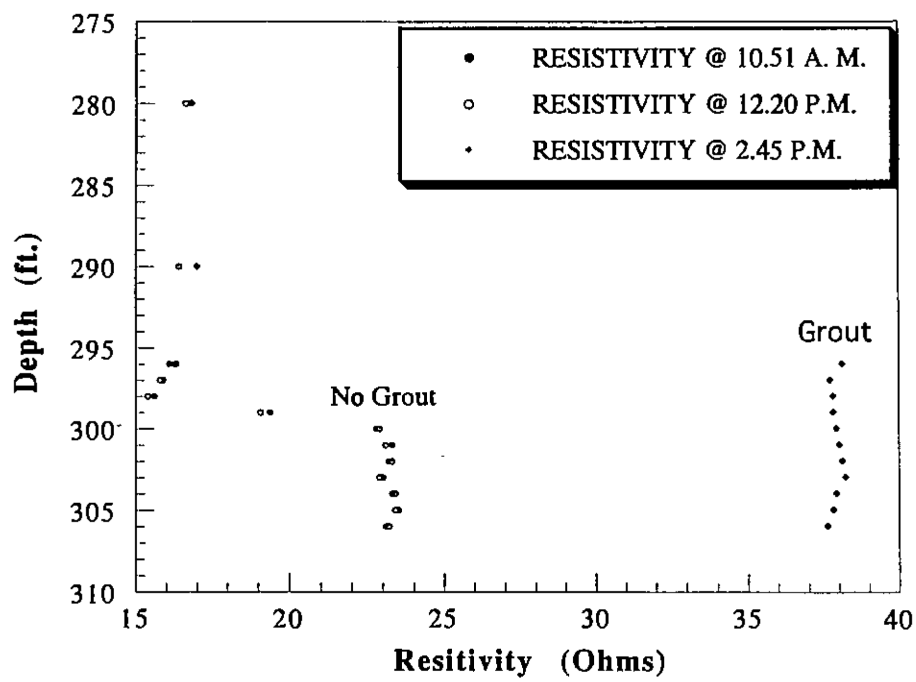


Figure 4. Resistivity Profile Using Electrical Probe (Resistivity Probe).

Many times the detection of grout in a hole from the resistivity probe was confirmed. Confirmation, where return was suspected in a hole, was done by either flushing the hole to the depth of refusal or by redrilling the hole.

Another means of monitoring grout was by evaluating the flowmeter and pressure gage information. During the grouting of a hole a magnetic flowmeter was hooked up to the grout line. This flow meter measured the amount of grout pumped in the hole (yd^3) and grout flow rate (yd^3/hr). Along with the flow meter, pressure gages were also connected to grout line at three different places. One pressure gage was attached to grout line just out of the pump. A second gage was attached in the middle of the line along with the flowmeter and a third gage was attached along the steel sweep. From the grout pressure and the rate at which the grout was being pumped, an evaluation of the grout flow in the mine was made.

Results

A total of 9,559 yd^3 of grout was injected into Mine Areas 1, 2, and 3 and into overburden fractures. The total quantities injected for each mine area are given below in Table 3.

Table 3. Summary of Projected and Injected Containment Plus Infill Grout Quantities for Each of the Mine Areas.

	Projected*, yd^3	Modified Projected**, yd^3	Injected, yd^3	Average Void Height***, ft
Mine Area 1	11,812	9,497	6,478	3.14
Mine Area 2	4,705	2,475	2,130	3.79
Mine Area 3	1,824	1,605	951	2.61

*These void quantities were estimated from using the mine map and the seam height based on the Phase II subsurface investigation.

**These void quantities were backcalculated by using the mine map modified by extraction limits found from drilling data obtained during the mine backfilling operation (see Figures 2A and 2B).

***The average void heights were determined by taking the injected grout quantity and dividing by the modified projected mine void area.

Also, the amount of grout (both infill and containment) injected into each hole ranged from 7 to 865 yd^3 with an average of 245 yd^3 per void hole. Of course, this average does not include holes which were grouted from an adjacent hole and therefore could not then be injected into.

Although there were a few exceptions, there was a definite pattern to the grout flow from the start of injection to refusal of the hole. Figure 5 depicts the general trend of the actual strip chart records showing the rate of flow and pressure with time, illustrating the various stages of grout injection. In the first stage grout was injected with zero line pressure. Many times, because of the 300 ft drop into the mine, a vacuum pressure was audible in the sweep. In fact, zero to only very nominal could be achieved even at pumping rates of over 60 yd^3/hr using the selected grout mixes. The second stage of grouting would consist of extended cyclic behavior over time where grout pressures would increase to 250 to 400 psi and then drop down to very nominal pressures. During these low pressure periods, the line pressure may be slightly dependent on the flow rate. During the third stage of grouting there was relatively little drop off in pressure and the line would eventually refuse off. Line refusal was called at about 600 psi line pressure although it appeared that once this level of pressure had developed during stage three only significantly greater pressures would get the hole to continue to take grout. This third stage of grout injection was usually relatively short compared to the previous two stages.

Verification holes were placed where incomplete grouting was the most likely. This was based on mainly distribution of grout takes for each hole, the nature of the mine works, and grout communication between holes. There were 10 verification holes drilled in Mine Area 1, 5 verification holes drilled in Mine Area 2, and 1 verification hole drilled in Mine Area 3. These holes are located on Figure 2A and 2B. A

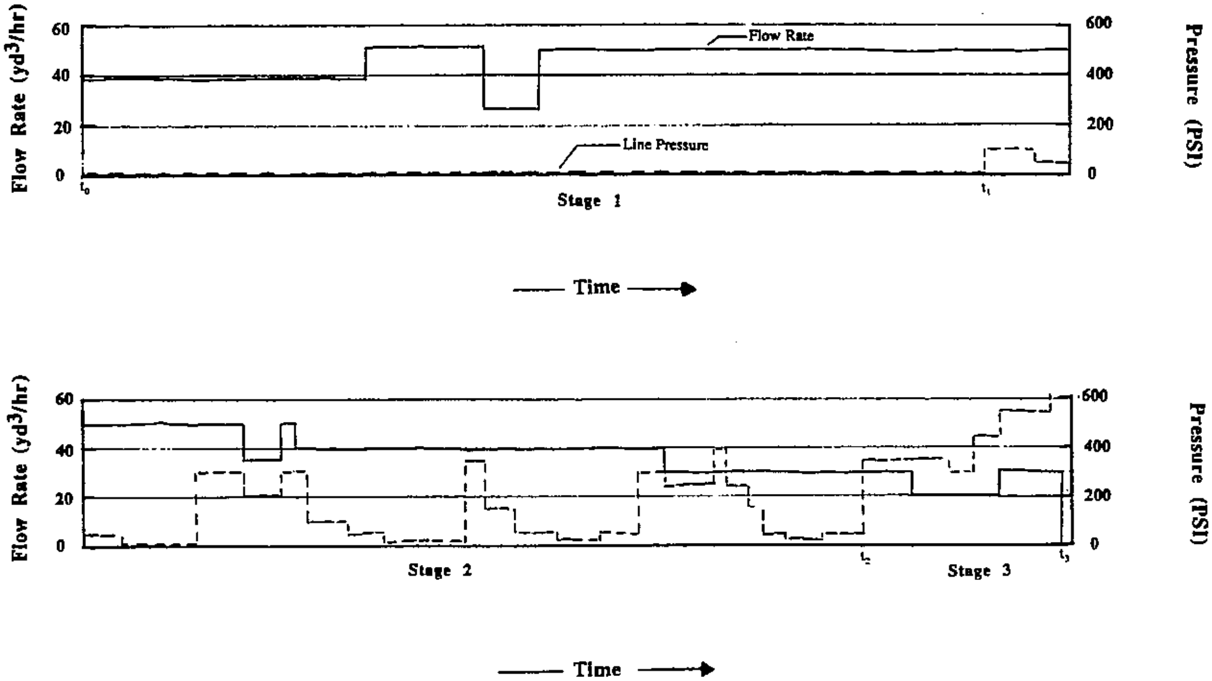


Figure 5. Illustration of the General Behavior of Flow Rate and Line Pressure With Time Showing the Three Grouting Stages.

certain procedure was followed while drilling this verification holes. The driller was directed to start flushing these holes after every 2 ft of drilling from the depth of 285 ft. Once this was accomplished the drilling operation was stopped 2-3 ft above the roof and then mine interval was cored using a 3 inch diameter split core-barrel. A minimum of 7 days of curing time was given for the in-place grout to set before coring. The coring operation was observed by GGMEC, and the driller was requested to report any voids encountered, any rod drops, or any loss of air circulation during coring process. Generally close to 10 ft was cored which included the mine interval.

In Mine Area 1 significantly less grout was recovered from coring, but no indications of voids were apparent during coring. In all of the verification holes rubble was encountered in the mine void mixed with various percentages of grout. Evidently, this rubble, being mainly of small block size, was pushed and compacted by the flowing grout. Compared to Mine Area 1, in Mine Areas 2 and 3 very good recovery of the in-place grout was achieved in many cases. Also, the core samples and the absence of any indications of voids during coring indicates good grout contact to the roof. Each of the verification holes where any substantial voids were suspected (e.g., significant core loss or rubble) were checked by injecting water under about 600 psi with the use of packer into the mine interval. In call cases water pressures were maintained for approximately 15 minutes without any measurable flow into the hole. Therefore these grouted compacted rubble zones were considered tight and secondary grouting was not necessary through these holes.

Selective core samples were sent to the laboratory for strength testing. In-place compressive strengths of the containment and infill grout exceeded the specification requirements of 500 psi and 300 psi of containment and infill grout respectively. In fact, the average strengths of the tested containment and infill cores is 2,476 and 1,581 psi respectively with no sample below the required values.

Also, 2" x 4" cylinders taken periodically before the grout enters the hopper of the grout pump were tested for strength. These test results, per specifications, are back-up checks to the in-place strength test in case adequate grout samples could not be recovered during coring. The specifications called for the above values to be achieved in 7 days breaks. The average cylinder strength for the containment grout was 1,525 psi with a standard deviation of 475 psi, and for the infill grout cylinder the strength averaged 512 psi with a standard deviation of 245 psi at 7 days.

Conclusions

Beneath proposed prison facilities in Carlisle, Indiana at a depth of 300 ft was an abandoned coal mine which was evaluated to have subsidence potential. Such subsidence would cause major structural damage to the proposed Phase II prison facilities of the Wabash Valley Correctional Institution. In order to limit the possible subsidence damage and to ensure safe operation, mine backfilling was performed in mine areas labeled Mine Areas 1, 2, and 3 which were subjacent to critical Phase II structures.

Based on drilling information collected, Mine Area 1 contains more roof cave than Mine Area 2. Mine Area 3 appears to have had the most fall but this area was small in comparison to the other two areas. The effect of the additional amount of rubble seemed nominal, however, as there was no substantial change in the grouting operation from Mine Areas 1, 2, and 3.

During the grouting operation each mine area was first contained by strategically placing containment grout in certain entries and crosscuts. Once the mine areas were significantly contained, it was pumped with infill grout (which was lower in cost and more flowable than containment grout). Infill grouting generally proceeded across the mine with each injection hole grouted to refusal. In some highly rubblized areas, set retarder/plasticizer (calcium lignosulfonate) was used in the grout to increase penetration.

Once the grout operation began, the grout movement was monitored in adjacent holes by using electric resistivity probes. Most of the holes were pumped to refusal, necessitating multiple shifts. After the grouting operation was finished, core samples of the grouted zones were obtained for the verification. The results obtained from verification process showed the success of the operation.

At the completion, 9,559 yd^3 of grout was injected and 41,349 LF of drilling was performed. By implementing this backfilling procedure, the potential subsidence at certain Phase II structures was suppressed at Carlisle, Indiana Prison site.

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EARTHEN STRUCTURES IN MINING AREAS[1]

Kazimierz Kłosek[2]

Abstract: The problem of lowered load capacity and stability of transportation and hydrotechnical earthen structures exposed to mining-induced influence is discussed.
Results of the author`s model invesigation and site measurements are demonstrated, together with theoretical analysis of the phenomenon of plastic zones development in the mining subsoil.
Extensive influence of horizontal strains in mining areas on the resistance properties of the soil is evidenced. The author`s proposal is to strengthen the load capacity of the subgrade and stability of earthen structures by the application of geosynthetics.

Additional Key Words: Load Capacity-Stability; Earthen Structures; Mining Deformations.

Introduction

Due to underground mining activities land subsidence "W" and its slope "T" increase, which, in turn, results in substantial deformation of elongated earthen structures such as: embankments, transportation cross-drifts, reservoir and water- course dikes.
The need to maintain the functional utility of earthen structures
compels periodical rectification of their body grade line, which is illustrated in Fig.1.

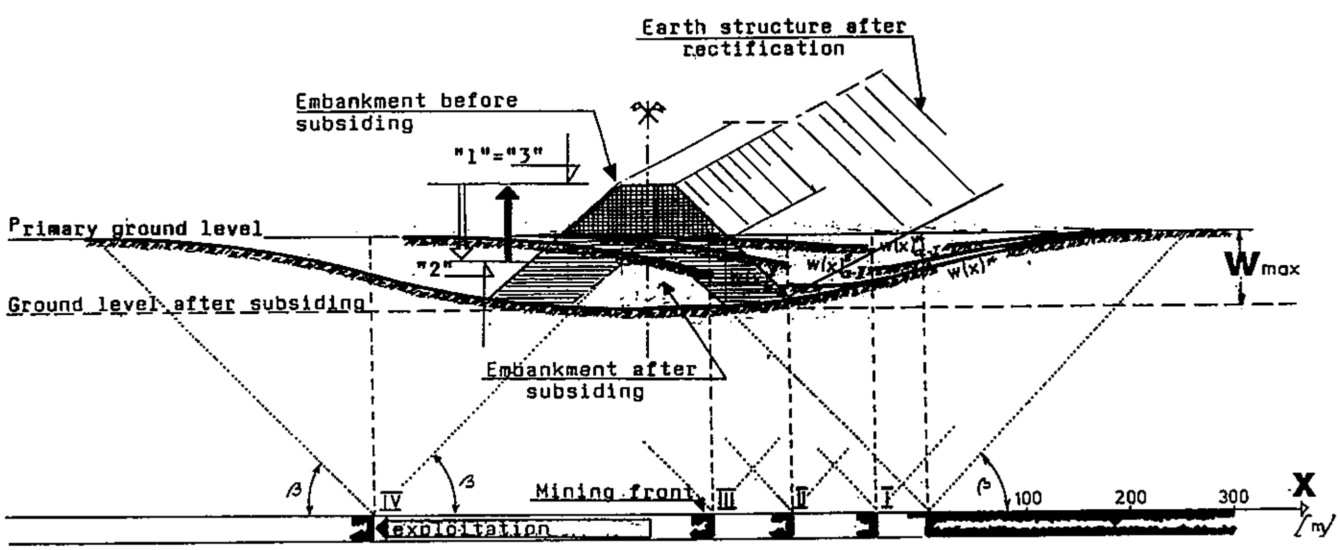

Figure 1. Changing of grade lineas in earthen structures on mining subsidence areas.
"1" - primary (designed) grade line
"2" - permanent grade line,
"3" - ultimate grade line, after rectification.

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