INSTALLATION AND STABILITY OF INVERTED PYRAMID-SHAPED PLUGS FOR CLOSING ABANDONED MINE SHAFTS GALENA, KS DEMONSTRATION PROJECT[1]

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Abstract.-- The Bureau of Mines designed and installed 11 inverted- pyramidal- shaped plugs in a mine closure demonstration project completed in Galena, KS in December 1983. The demonstration project resulted from a study done by the Geological Surveys of Missouri, Kansas, and Oklahoma for the U.S. Bureau of Mines in January 1983. This study identified over 1400 open mine shafts and nearly 500 subsidence collapse features that remained from the original 14,000 shafts sunk in the Tri-State Zinc-Lead Mining District. In Galena, KS, alone over 377 open mine shafts were readily accessible and 150 abandoned mine shafts were within the city limits. Of these, the Bureau of Mines selected 14 abandoned sites for the mine shaft closure demonstration project. During the demonstration project, 11 mine shafts were closed with the inverted pyramid shaped reinforced- concrete plugs, 2 were closed with reinforced concrete caps after backfilling, and one shaft was closed by backfilling only. The stability of the closure devices has been monitored and evaluated over a 3-year period. The results indicate that the Bureau of Mines closure devices are stable and have eliminated hazards associated with open mine shafts in a populated area.

Introduction

The Bureau of Mines operated a shaft closure demonstration project in Galena, KS, in which 14 abandoned mine shafts were closed. The primary purpose of the project, which was part of the Bureau's program for conserving land resources, was to provide alternative methods for closing some of the hundreds of open shafts in the Tri-State area. The project developed from a study to evaluate the hazards of the abandoned zinc-lead district.

The Galena field is in the Tri-State zinc-lead belt district of Kansas- Missouri- Oklahoma, which was one of the largest zinc-lead mining districts in the country. The district produced over 11 million tons of zinc and 2.8 million tons of lead during its 122 years of operation. The total value of the lead and zinc produced in the district from 1850 through 1970, in terms of recoverable metal, was $2,073,200,000. In terms of today's dollars, the value would be in the neighborhood of 20 billion dollars (Stewart 1986, Martin 1946)

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Mining began in the Tri-State district in 1848 with the discovery of ore deposits in Joplin, Mo. The deposits were originally mined for their lead value, but the development of the railroad in the area and the coincidental development of the new milling and smelting techniques for zinc resulted in the area becoming a valuable source of zinc. Zinc production in the district began with the first shipment of concentrates to LaSalle, IL in 1872. Later shipments went to the smelter in Weir City, KS constructed in 1873. By 1875, the Joplin field became the leading zinc producer in the USA. Additional lead-zinc deposits discovered west of Joplin increased mining activity. The Galena, KS, field was discovered in 1877. In 1891, lead mining began in Indian Territory (northeast Oklahoma), near Peoria, and ore discoveries followed near Lincolnville, Miami and Picher. The Commerce, OK, field was discovered in 1905. Large scale mining started in the Miami-Picher, OK, field in 1916. Mining continued in the Missouri portion of the district until 1957 and in the Kansas-Oklahoma portion until 1970.(Dressel et.al. 1986, Fejes et.al 1985, U.S. EPA 1975)

Early mining leases were generally small with many leases being only 100 or 200 ft^2 (Clerc 1907, Hay 1893, Hayworth 1901, Norris 1968, Plyn 1904). The ore was mined by small crews of men using hand tools and simple hoisting devices. Exploration was done by sinking a shaft, generally 50 to 100 ft deep, until ore was found. Exploration continued by drift mining outward from the shaft (Crane 1901). If ore was not encountered, the miner moved to new ground and sank another shaft. The mines were generally developed with little regard to any long-range overall mine plan. If drifts reached 300-ft in length or if ventilation became difficult, additional shafts were sunk. In most cases, the underground mine workings were not mapped.

In Galena, KS, the mining depths varied from ground surface to 300 feet. The ore was generally confined to thin bedded strata, and ore bodies were usually less than 30 feet thick. But, in some cases, ore zones 80 to 100 feet in thickness were developed. The ore was worked from the upper portion of the ore down to the depth at which water became too much of a problem to continue mining. When pumping facilities were installed, some of these mines were reopened and mining of the thick ore deposits resulted in rooms as much as 100 feet in height. In 1893, Henrich reported that diamond drills were being used for prospecting deeper than 100-ft. By about 1900, the churn drill replaced shaft sinking as the principal exploration tool (Gibson 1972, Plyn 1904).

The use of shafts as a means of exploration and the small lease and subleasing of mining plots resulted in a high density of mining shafts in the area. In preparing a series of reports for the Bureau, the State Geological Surveys of Kansas, Missouri, and Oklahoma located over 1,400 abandoned open mine shafts remaining of the original 14,000+ prospect and mining shafts sunk in the Tri-State district (Luza 1983, McCauley et.al. 1983, McFarland and Brown 1983). Although 90% of the original number of shafts have been closed, the shafts that remain open are constant safety and environmental hazards and limit the use of the land. In the Galena, KS, field alone, 377 open shafts were located within or adjacent to the city limits of Galena. All but 11 of these shafts showed surface enlargement because of cribing removal or failure.

Several methods have been used for closing shafts (Genie Eng. LTD 1983, NCB 1982). In the Tri-State shafts have been closed by backfilling and capped with timber caps, steel plates, concrete slabs, and railroad rail- gratings. However, in some cases the closure device failed and the shaft reopened to again become a safety hazard.

Backfilling was a common method for filling shallow shafts and it is still quite a successful method if done properly with graded material free of degradable trash and in a manner that avoids temporary bridging. Timber caps, rails, and steel plates have been used with varying degrees of success but eventually decay or rust, resulting in an unsafe closure. Although concrete caps have been successful in some instances, there are examples of failed concrete caps in the Galena, KS, area where the caps were improperly reinforced or where washout caused the cap to tip on end. In the Picher, OK, field, at least one company successfully used concrete cubes to close shafts when abandoning the field. The cubes, which were 6-1/2 ft on a side, were constructed on the surface next to the shaft and then rolled into the opening and wedged into place by undercutting and blasting.

Three methods were used for closing abandoned mine shafts during the Bureau's demonstration project described in this report. The newest method, the installation of the inverted pyramid-shaped plug designed by Bureau personnel, is discussed in detail. The results of 3- years of monitoring are also included. Additional details are available (Dressel and Volosin 1985).

SELECTION OF SHAFT SITES

Galena, KS, was picked as a site for demonstrating methods for closing abandoned shafts because of the large number of open shafts that were readily accessible. Before a location was selected for the demonstration, the Bureau contacted the Galena city government to ascertain which areas within the city limits were in the most need of shaft plugging. From the locations the city officials listed, the Bureau selected a site in NE1/4SW1/4 sec. 14, T. 34 S., R. 25 E., at the west end of Front, First, and Second Streets. Virtually all of the open mine shafts in Galena are on privately owned land. A search of the county land records was made to determine the ownership of the lands and the owners were contacted to obtain grants of easement that would permit the Bureau to carry on the demonstration project. Figure 1 shows location of the site and the location of the shafts closed during the demonstration. The breaks in the shaft numbering sequence resulted from changes in the original closure plan, brought about in one case because considerable construction debris had been dumped into the opening, and other cases because the locations were out of the area covered under the grants of easement.

Two of the open shafts selected for plugging are shown in figures 2 and 3. A contract was let in 1982 to obtain the shaft dimensions, assess the conditions of shaft side walls, obtain the elevation of an estimated contact between overburden and solid rock, and the location of underground workings in the shaft vicinity. These measurement were used in preparing the competitive bid specifications for the plug installations reported herein. Another contract was awarded in August 1983, to perform the actual closure demonstration work in which 11 shafts were plugged, 2 were cappped, and 1 was backfilled.

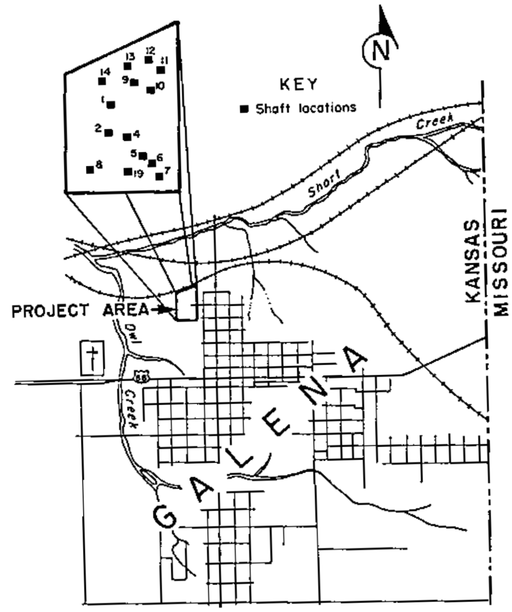

Figure 1.--Project site location.

Figure 2.--Typical shaft showing rotted timber and washout along timbers.

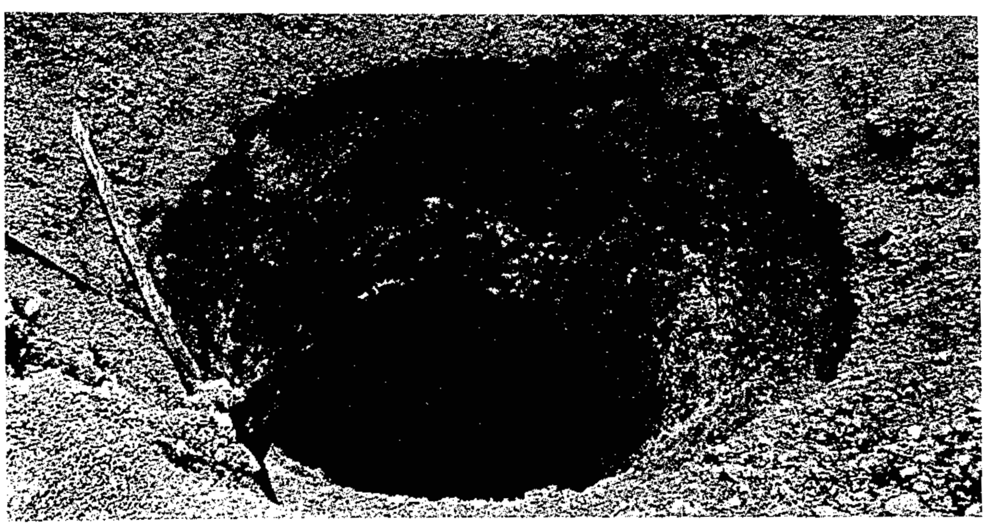

Figure 3.--Typical open shaft showing circular outline in slumping residuum.

DESIGN OF PLUG

An inverted pyramidal design was selected because it fulfilled the following criteria: (1) simplicity of construction, (2) ease of installation, (3) personnel safety during installation, and (4) permanency of the installed closure device. The shafts in this demonstration were roughly square and ranged in size from 4 to 8 ft. The pyramidal plug design was chosen because it was easily adapted to a variety of irregular mine shaft openings with a minimum amount of site preparation. When installed in a shaft, the center of gravity of the inverted pyramid plug could be placed so that the plug would have a tendency to adjust and wedge tighter into the shaft. A lightweight, prefabricated disposable form was designed that required a minimum amount of time to prepare and set in place without having to use heavy construction equipment. The form, complete with concrete reinforcement rods, was constructed in a welding shop away from the demonstration site and installed with a 17-ton crane.

The forms were designed to be totally self-supporting. Once they were set in place they were not anchored to any other structure within the mine shaft. They were constructed in three standard sizes of 8, 10, and 12 ft. The size for a given shaft was selected so that the top of the plug was approximately 4 ft larger on a side than the size of the shaft opening. The reference monument, a 4-inch pipe, long enough to extend above the surface level of the ground after backfilling, was attached to the center of the plug. A sketch of an installed plug is shown in figure 4.

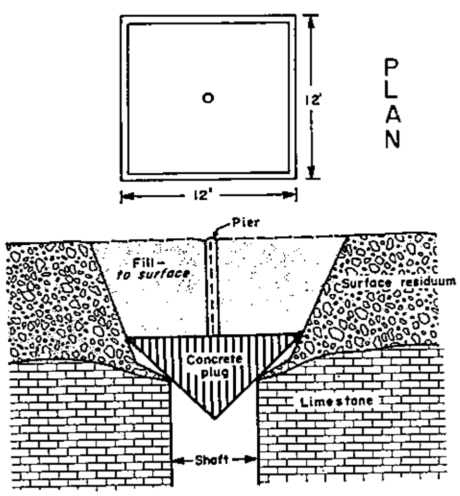

Figure 4.--Installed plug.

Eleven forms were required for the demonstration: 3 were 8-ft by 8-ft, 6 were 10-ft by 10-ft, and 2 were 12-ft by 12-ft. The 8-ft by 8-ft and the 10-ft by 10-ft forms were constructed of 3/16-inch hot-rolled low-carbon steelplate welded at the seams. The 12-ft by 12-ft forms were constructed of 1/4-inch hot rolled low-carbon steel. The external edges of the seams were reinforced by the addition of a fabricated angle, approximately 3-inches on an edge, welded to the seam. This reinforced edge proved very beneficial since much of the weight of the plug rested on the corners before seating. A plate was welded in each corner with an eyelet for attaching cables for easy handling and positioning the forms (fig. 5).

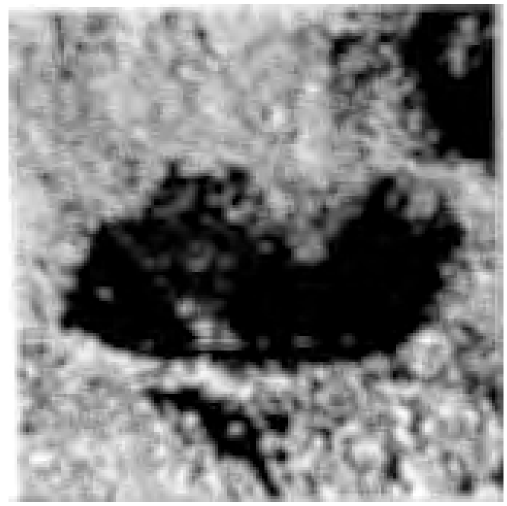

Figure 5.--Eight-ft form showing reinforcing grid.

A horizontal reinforcing rod grid was placed 1-ft from the top in the 8-ft pyramid forms, 1.25-ft from the top in the 10-ft forms, and 1.5-ft from the top in the 12-ft forms. A 12-inch grid spacing was used as shown in figure 5. Grade 60, No. 7 reinforcing bars were used in each instance.

In the 10-ft form, two S4 I-beams with 0.326-inch web thickness approximately 6 ft long, were welded to a 1/4-inch footplate which was welded to the sides of the form. The beams were arranged parallel to each other and spaced approximately equidistant from the parallel side walls and from each other (fig 6).

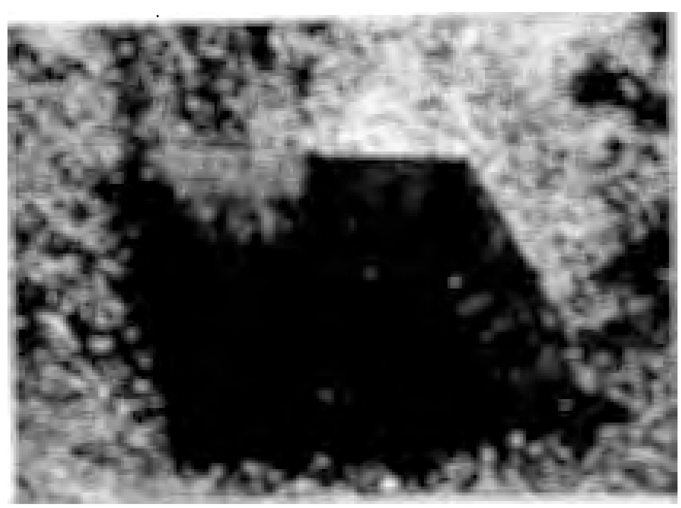

Figure 6.--Ten-ft form showing I-beam position and reinforcing grid.

To brace the side walls of the 12-ft form, two S4 1-beams, approximately 8 ft long with a 0.326-inch web thickness, were welded to the form at right angles to each other. The ends of these beams were welded to a 1/2-inch plate at least 1 ft^2, which in turn was welded to a second 1/2-inch plate at least 1 ft^2, previously welded to the inside of the form approximately 2-ft from the top (fig. 7).

Vertical reinforcing bars were placed 6 inches from each of the sloping sides of the pyramidal form (fig. 7). They were spaced 1-ft apart at the top of the form and tapered down to a few inches near the bottom. The top end of the rebars extended to within 6 inches of the top of the form. A spacer was welded approximately 1-ft from the top of each form to hold the rods 6 inches from the side walls.

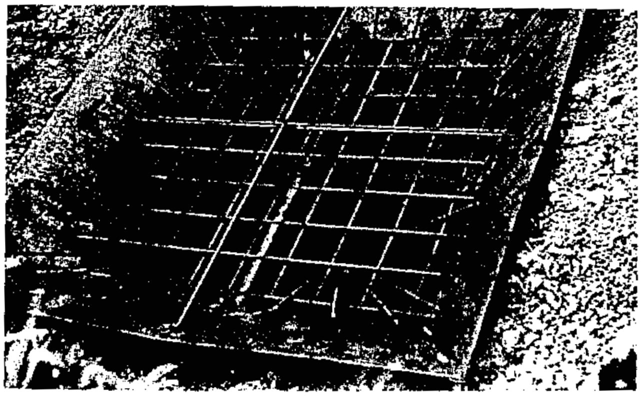

Figure 7.--Twelve-ft form showing I-beams and position of reinforcing bars.

Material requirements per plug are tabulated in table 1.

Table 1.--Material requirements per plug.

	Approximate shaft size		
	4-ft	6-ft	8-ft
Pyramid form size ...ft..	8x8x4	10x10x5	12x12x6
Metal preform........ft^2.	[1]90.51	[1]141.2	[2]203.6
Weight of metal form..lb.	693	1,083	2,079
Estimated rebars per shaft:			
Linear ft............	327	495	698
Weight...........lb..	660	1,020	1,420
I-beam:			
Length...........ft..	0	12	16
Weight...........lb..	0	89	118
Edge angle:			
Length...........ft..	27.7	34.6	41.6
Weight...........lb..	260	325	391
Total weight of steel.lb.	1,613	2,517	4,008
Concrete............yd^3.	3.2	6.2	10.7

[1]3/16-inch cold-rolled, low-carbon steel plate.
[2]1/4- inch cold-rolled, low-carbon steel plate.

INSTALLATION OF PYRAMIDAL- SHAPED PLUGS

A minimum of site preparation was required to prepare the shafts for plugging. The contractor used an Extenda-Hoe backhoe to remove sufficient material from around the surface of each open shaft to provide a roughly level contact of the disposable form with the interface between the surface residuum and the bedrock. The edges of the shaft at the interface were trimmed to allow the center of gravity of the form to be set below the interface elevation and to have a suitable bearing surface for setting the forms. Trimming was done with a jackhammer attached to the backhoe.

The pre-fabricated forms were delivered to the site on a flatbed trailer and were unloaded from the truck and placed directly in the hole using a 17-ton crane (fig. 8). In several cases, additional sidewall trimming using the backhoe and/or jackhammer was required to obtain a level postion for the forms.

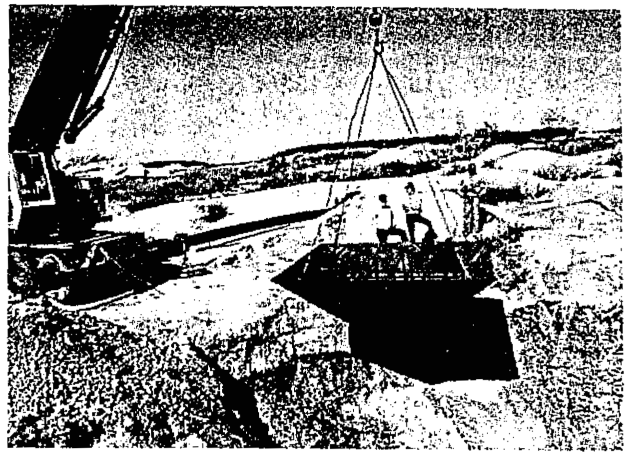

Figure 8.--Lowering 10-ft form into opening.

Class A concrete was delivered to the site from a local batch plant. Just prior to pouring, a reference monument was attached to the center of each plug (fig. 9). The 8-ft forms each required 3.2 yd^3 of concrete, the 10-ft forms 6.2 yd^3, and the 12-ft forms 10.7 yd^3.

After the first three plugs were placed, it was noted that there were gaps between the form and the sidewalls along the edge of the pyramid shaped form. In these areas, reinforcing bars were positioned over the edge of the form and extended to the side of the prepared opening. This was covered with a 2-ft width of expanded metal, and 4 inches of concrete was poured on this expanded metal.

Figure 9.--Ten-ft form showing spider-leg reinforcing over edge of form to support the expanded metal.

Before pouring concrete in the last eight forms, steel reinforcing rod was bent and fastened to the installed horizontal reinforcing grid and extended in spider-leg fashion several feet over the edge of the form (fig. 9). The 2-ft wide expanded metal was positioned over these reinforcing rods, and concrete was poured over this when the form was filled (fig. 10). An additional 1 to 1-1/2 yd^3 of concrete was required for each shaft because of these modifications.

Figure 10.--Ten-ft form filled with concrete.

In the installation of one 12-ft and one 10-ft plug, the center reinforcing bars were left unwelded to the sides of the form to allow the form to bulge along the edges to better fill the gaps. This appeared to be an effective measure.

After a concrete curing period of at least 7 days, the excavated areas were backfilled with waste rock available near the shafts. The backfill at each site was mounded so that the center of the fill was approximately 2 ft above the surrounding ground surface. The 4-inch pipe extending from the center of each plug was trimmed so that it extended 6 inches above the fill; it was filled with concrete and was designed to remain as a marker for evaluation purposes.

INSTALLATION OF SLAB CAPS

In some instances, solid rock exposed at the surface was competent enough so that there was virtually no cratering or shaft enlargement at the surface. In these cases, it was found expedient to trim away loose surface rock and install reinforced concrete slabs. Two mine openings, approximately 4.5-ft by 4.5-ft, were closed by this method during the completion of the project.

The slabs were designed to extend approximately 5-ft over each edge of the open mine shafts. A reinforcing grid of No. 7 rebars was installed. The bars were spaced 1-ft apart at the edges, 1/2 ft apart in the area over the shaft opening, and located 1/2 ft from the bottom of the pad. A monument pipe was attached to the center of each grid, and an 18 inch thick pad of class A concrete was poured. The material requirements for each poured slab are shown in table 2.

Table 2.--Material requirements per slab.

Size of shaft............ft..	4.5x4.5
Dimension of slab.........ft..	15x15x1.5
Number of No. 7 rebars........	46
Total length of rebars....ft..	690
Total weight of rebars....lb..	1,420
Thickness of concrete.....ft..	1.5
Volume of concrete.......yd^3..	12.5

These slabs are of sufficient size and sufficiently reinforced to remain indefinitely without breaking or flipping over in the event of washout under part of the cap. They were also designed to withstand loads from automobile or truck traffic which may occur in the area following closure of the shafts.

INSTALLATION OF BACKFILL

In preparing shaft No. 14 for plug installation, the hole was found to be larger than original surface measurement had indicated, and it was difficult to obtain a stable bedrock surface. It became apparent that the alternatives were to either install a 16 ft plug, a 22 ft cap, or completely backfill the hole. Backfilling was chosen. This method, currently the locally accepted way to close a shaft, proved useful to this project in that it provided a reference for evaluating the closing of shafts by either plugging or capping abandoned mine shafts. Approximately 350 yd^3 of backfill were required to close the opening. A 4-inch pipe was placed at the shaft center as a marker for this closure.

DISCUSSION OF CLOSING DEMONSTRATION

A minimum of installation problems were involved and only a few changes were necessary in completing the planned demonstration program. The most serious problem was that no suitable underground maps were available for the demonstration site.

Working around abandoned mines shafts, particularly in areas where the extent of the abandoned underground mine working and the stability of the surface material around the shafts is not known, is potentially hazardous. Most of the abandoned mines are filled or partially filled with water. Water, encountered in all shafts during the mine shaft inspection performed by the contractor, made it difficult to determine if either the actual bottom of the shaft or a temporary bridge had been reached. Some shafts were filled with debris, such as old autos, air conditioners, and/or refrigerators. There was no way to get around or through debris at the bottom of the shafts. No debris was removed during the closure demonstration.

It also became obvious that the shaft dimension measurements made from the surface in these old hand-dug shafts before they were prepared for plugging were not entirely reliable. In several instances, measurements, made after the holes were prepared, required changes in plug size from original specifications. For example, the plug put in open shaft No. 19 was the plug originally constructed for shaft No. 14.

Sufficient waste rock was available on the nearby surface to backfill the openings over the installed plugs; most of the material trimmed from the shaft openings was allowed to fall into the open shafts. In one instance, temporary bridging of a shaft occurred during the trimming operation. This was to be expected because the material was ungraded, but it pointed out the necessity for using graded material when closing small shafts by backfilling.

The project was completed using a minimum amount equipment at the project site. Required equipment was a backhoe, a flatbed truck, a crane, and a concrete delivery truck. Care was taken to strategically locate the equipment around the shaft collar to avoid parking the vehicles above the underground mine workings and no more than two vehicles were at the shaft at anytime. The contractor and suppliers were informed of the possible hazards and proceeded with due caution and regard for personal safety.

The reinforcing rods were welded into position at crosspoints, and the ends were welded to the sides of the forms. This made the forms very rigid. The welding of the reinforcing rod ends at the center of the sides was omitted in several of the forms installed near the end of the demonstration. This enabled the form to bow out when filled with concrete to more nearly take the shape of the opening. However, when this happens, there are no reinforcing bars in the bowed part of the plug. A modified design that allowed the center reinforcing bars to extend through the plug walls might eliminate this problem.

Four plug forms were set in their respective shafts prior to a 7-inch rainfall. As a result, the forms were filled with water and had to be pumped out before the concrete was poured. Small drain holes were left in the last three plugs installed; however, the plugs were filled with concrete before the next rain.

EVALUATION OF CLOSURE DEVICES

After the 14 shafts were closed, the area around each closure device was backfilled to the rough surface elevation of the immediate area. Once this rough grade was established for the demonstration site, a 2-ft mound of fill was formed directly over each shaft and the tops of the reference markers for each shaft were trimmed to approximately 6-inches above the fill material. A local registered land surveyor was hired to establish a horizontal and vertical survey control net within the mine closure demonstration area. The initial elevation of the reference markers and the results of resurveys each year for a 3 year period are shown in Table 3.

Table 3.--Elevation of reference point on each closure device.

CLOSURE DEVICE In Shaft Number	Survey results showing reference point elevation, ft 12/23/83	10/31/84	9/27/85	11/14/86
8 FT PYRAMID PLUGS				
2	900.59	900.59	900.59	900.59
4	898.46	898.44	898.44	898.44
9	901.98	901.97	901.97	901.97
10 FT PYRAMID PLUGS				
5	890.74	890.74	890.73	890.72
7	897.49	897.47	897.47	897.47
8	887.36	887.35	887.35	887.35
11	901.56	901.54	901.54	901.54
12	897.01	897.01	896.99	896.99
19	890.49	890.47	890.46	890.46
12 FT PYRAMID PLUGS				
6	892.34	892.33	892.33	892.33
10	902.76	902.70	902.70	902.70
15 FT CONCRETE CAP				
1	901.90	901.90	901.90	901.90
13	895.12	895.09	895.08	895.08
BACK-FILLED ONLY				
14	898.21	897.95	[1]caved	[2]caved

[1]Caved 23 ft, estimated 125 yd^3 to reestablish to grade elevation.
[2]Caved 30 ft, estimated 150 yd^3 to reestablish to grade elevation.

All the closure devices remained stable for a period of 12 months (table 3). Subsidence was noticed around shaft No. 14 during a visit to the demonstration area 18 months after completion of the demonstration work. However, no subsidence was noted around any of the other shafts. Inspection of shaft No. 14 a month later and a resurvey of the reference monuments in October 1984 indicated that shaft No. 14 had caved 23 feet. It would require about 125 yd^3 of fill material to reestablish grade. The fill in shaft No. 14 has continued to subside. The survey completed Nov. 1986, indicated that the crater would require about 150 yd^3 of fill to reestablish grade. No appreciable movement of any of the other closure devices has been noted after 3 years of monitoring.

Shaft No. 14 was backfilled to locally established practice. It originally was to be the control reference to determine the success of closing the other 13 shafts. However, its sudden failure probably resulted from the failure of a temporary bridge that developed during the backfilling process or existed prior to backfilling. No effort had been made to remove trash from any of the shafts prior to backfilling or to determine whether there was pre-existing bridging. Nor was a bulkhead established at the base of the shaft to contain the shaft fill material and prevent it from spilling or being washed into the underground mine workings.

CONCLUSIONS

Eleven shafts were closed using the Bureau of Mines designed inverted pyramid-shaped concrete plugs. For comparison with more conventional backfilling, two shafts had a reinforced-concrete cap installed after backfilling and a third was simply backfilled. Initially, all of the three closure methods used in the demonstration project appeared to be effective methods for shaft closure in the Galena, KS, area. Survey data, table 3, compiled over a 3-year period indicate that only the 11 plugs and 2 caps were stable.

For the shallow shafts backfilling is probably a practical way to eliminate safety hazards. Backfilling of deeper shafts can require large amounts of fill material, particularly where large mine openings exist at the base of the shafts. For instance a 90-ft high opening at the base of a shaft can require up to 67,000 yds^3 of fill material to reach the base of the shaft. Further subsidence can continue to be a problem with backfilling.

For any shafts of any depth, either installing concrete caps or pyramid plugs is effective. The method selected depends to a great extent on the cost of labor. For either method, labor is cost intensive, due in part, to the restrictions of a safety harness while working within the abandoned mine shaft's potential collapse zone. The concrete caps required the most time exposure of personnel spent working over a mine shaft and required more concrete than the plugs for closing a given size shaft.

The inverted pyramid plug was the preferred method for closing the shafts in this demonstration project. This method was the easiest closure device to install and could easily be done assembly line fashion for closing a large number of shafts in a relatively short time. The plugs required the least amount of work in the immediate vicinity of a potentially dangerous abandoned mine shaft. The most time intensive installation step was spent in setting up the 17-ton crane, while avoiding locating it over any known underground workings, to safely place the plug forms in the shafts. Most of the labor was spent in fabricating the disposable forms. However, this was performed in a welding shop away from the demonstration site. Evaluation of the closure devices is being continued over a longer period of time to further prove their stability.

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