In a table-size mine model simulating the arrangement of rooms and pillars, deposition of fill material is shown in figure 7. As resistance to flow of the slurry develops in one direction, a new channel is formed in another direction along a line of less resistance. Eventually, nearly all mine openings are filled. The lateral extent of the fill is determined largely by the available energy in the system. As the mound of fill material builds outward in the mine, the flow channels between the mound and the mine roof become longer and resistance to flow increases. When this resistance, combined with resistance in the pipe, becomes great enough to reduce the velocity of the slurry below that required to transport the solid particles, transportation of the particles ceases. The particles then settle out, and the passage becomes filled.

The pumped-slurry method of blind flushing has the following advantages over the open gravity-feed method previously used:

1. Great reduction in the number of injection boreholes. A single injection hole serves the purpose of many injection holes in the gravity-feed method.

2. More complete vertical filling of mine openings.

3. More complete areal coverage. Areas inaccessible because of surface improvements can be filled.

4. Less disruption of the community in the form of noise, dust, and traffic interference by drilling operations and trucking of fill material.

Disadvantages to the use of the pumped-slurry method would be apparent under the following conditions:

1. Where it is safe for men to enter the mine and control the backfilling operation.

2. Where the mine voids to be filled are close to the surface with little or no rock strata cover, in which case the slurry water could invade surface areas.

3. Where the amount of mine void to be filled is too small to warrant the cost of acquiring and installing slurry pumping equipment.

PUMPED-SLURRY TEST AT ROCK SPRINGS

The test at Rock Springs in 1970 was carried out in cooperation with the city of Rock Springs, the Department of Housing and Urban Development, and the Bureau of Mines. The Bureau's financial participation in the project to the extent of $55,000 was covered by a contribution contract with the city. The city of Rock Springs entered into a contract with Dowell Division of the Dow Chemical Co. of Tulsa, Okla., to perform the injection operation. The total contract cost of the demonstration was $173,140.

A site adjacent to the Connecticut Avenue-D Street area was selected for the test because it was believed to have a high subsidence potential. Exploratory drilling in conjunction with sonar scanning indicated the mine workings under the site were flooded and included both collapsed areas and open spaces in the coalbed. Open passages usable both for water supply and receiving a large quantity of fill material were identified by the detection equipment.

Injection Operation

The objective of the Rock Springs test project was to place 20,000 cubic yards of sand in underground voids through a single injection hole. This should constitute a convincing demonstration inasmuch as the quantity of fill that could be injected under the existing method of blind flushing was estimated at an average of 100 cubic yards per hole.

It was estimated that 20,000 cubic yards of sand would fill mine voids within an average radius of 210 feet from the injection hole, based on an average 6-foot thickness of the coalbed and 65-percent extraction of the coal. The corresponding surface area overlying the mine openings to be backfilled was calculated to be 3.2 acres.

The material used for backfill was fine sand of wind-blown origin available from a nearby deposit. The sand was screened at the pit to reject particles larger than one-fourth inch in diameter, and pieces of debris. The sand was transported by truck to the injection site and stockpiled.

Water to form the slurry was obtained from the flooded mine by means of two wells located about 325 feet downdip from the injection well. The mine water contained about 13,500 ppm dissolved solids but had no disagreeable odor and was not highly corrosive (3). Two submersible water pumps, each with

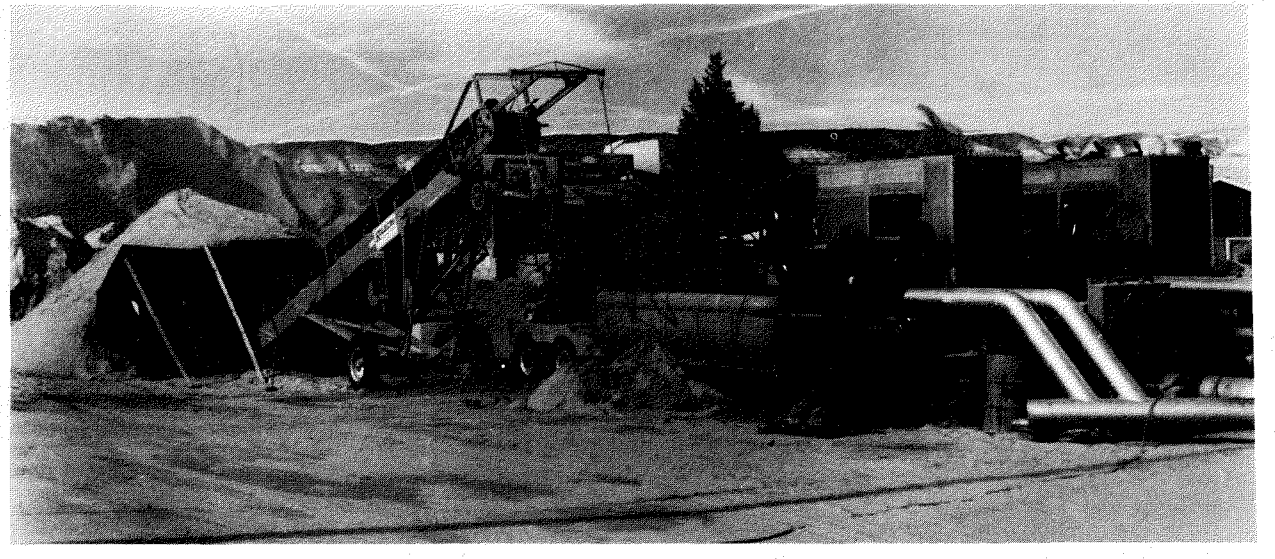

FIGURE 8. - Photograph of the plant site at the first test of the pumped-slurry mine backfilling technique.

capacity of 4,000 gpm, pumped water to the mixing tank. A reserve supply of water for purging the system was maintained in four storage tanks adjacent to the mixing tank. Figure 8 is a view of the plant site, and figure 9 shows the equipment installation in relation to streets.

Water entered the mixing tank at an average rate of 5,500 gpm and mixed with the sand, which was supplied at the rate of 120 cubic yards per hour, to form a slurry. A slurry pump impelled the slurry through the 13-3/8-inch-ID injection pipeline at an average velocity of 17 fps. The injection borehole was cased with 13-3/8-inch-ID pipe to within 5 feet of the mine roof, which was 116 feet below the surface.

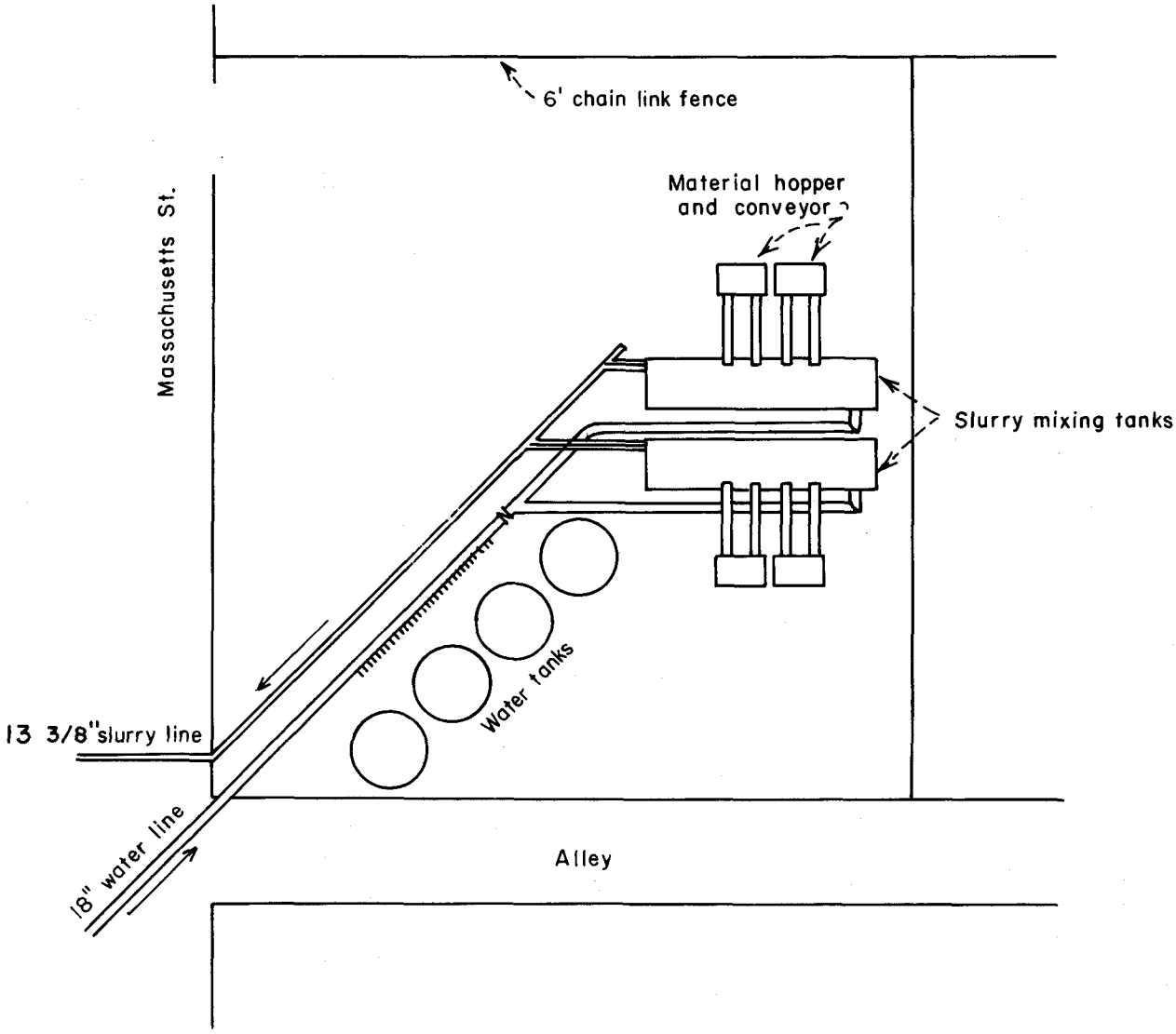

FIGURE 9. - Plan view of installed equipment at the plant site and adjoining streets.

The sand slurry was successfully injected into the mine workings over a 10-day period. Operations were scheduled for 24 hours per day, but actual daily injection time ranged up to a maximum of 21 hours because of electrical and mechanical problems. The solids concentration in the slurry averaged 0.8 pound per gallon of water. No resistance to injection was encountered, and the pressure measurements made at the top of the injection borehole were below atmospheric (vacuum) throughout most of the period.

During the last 12 hours of injection, it was planned to increase the sand concentration and decrease the discharge rate in order to achieve complete filling up to the mine roof. When the flow rate decreased to about 3,000 gpm, however, the sand in the mixing tank was not kept in suspension and the discharge pump became plugged after 19,500 cubic yards of sand had been injected.

Evaluation

The demonstration at Rock Springs proved that the pumped-slurry injection process could successfully emplace approximately 20,000 cubic yards of sand in mine voids from a single injection hole. In fact, there seemed little doubt that more sand could have been emplaced had the initial injection rate been maintained.

Much more difficult to evaluate was the extent (both laterally and vertically) to which the open spaces in the mine had been filled. Prior to the injection operation, four holes had been drilled and cased to be used for observing the results of the filling process. Difficulties were experienced in determining depths to sand fill in these holes, however, because the sampler could not penetrate the sand without churning it into a "quick" condition. Interpretations were further complicated by the probability that the open voids encountered in these drill holes were actually caved spaces above the mine roof rather than rooms at mine level.

After completion of the injection project, the Bureau of Mines instituted an evaluation program based on the drilling of 36 additional holes. In figure 10, the heavy line encloses the distribution of fill as determined by the evaluation team on the basis of all available subsurface data. The circle represents the area with a radius of 210 feet from the injection hole that was the planned area of fill distribution. The actual area backfilled in the mine was 2.8 acres as compared with the predetermined area of 3.2 acres. Restriction of fill to the west is believed to have been caused by human-engineered obstructions (air stoppings) for ventilation control that were not shown on the mine map.

Evidence as to vertical completeness of the fill was the most difficult to collect. In the two holes closest to the injection hole, at distances of about 60 and 100 feet, mine voids were completely filled. In other holes, the degree of vertical filling was hard to interpret, in part because the original mine roof had caved, extending the opening upward from 7 to 10 feet, and the caved material formed mounds on the original mine floor. In some drill holes, sand was found interbedded with caved rubble; in others, the sand was in the

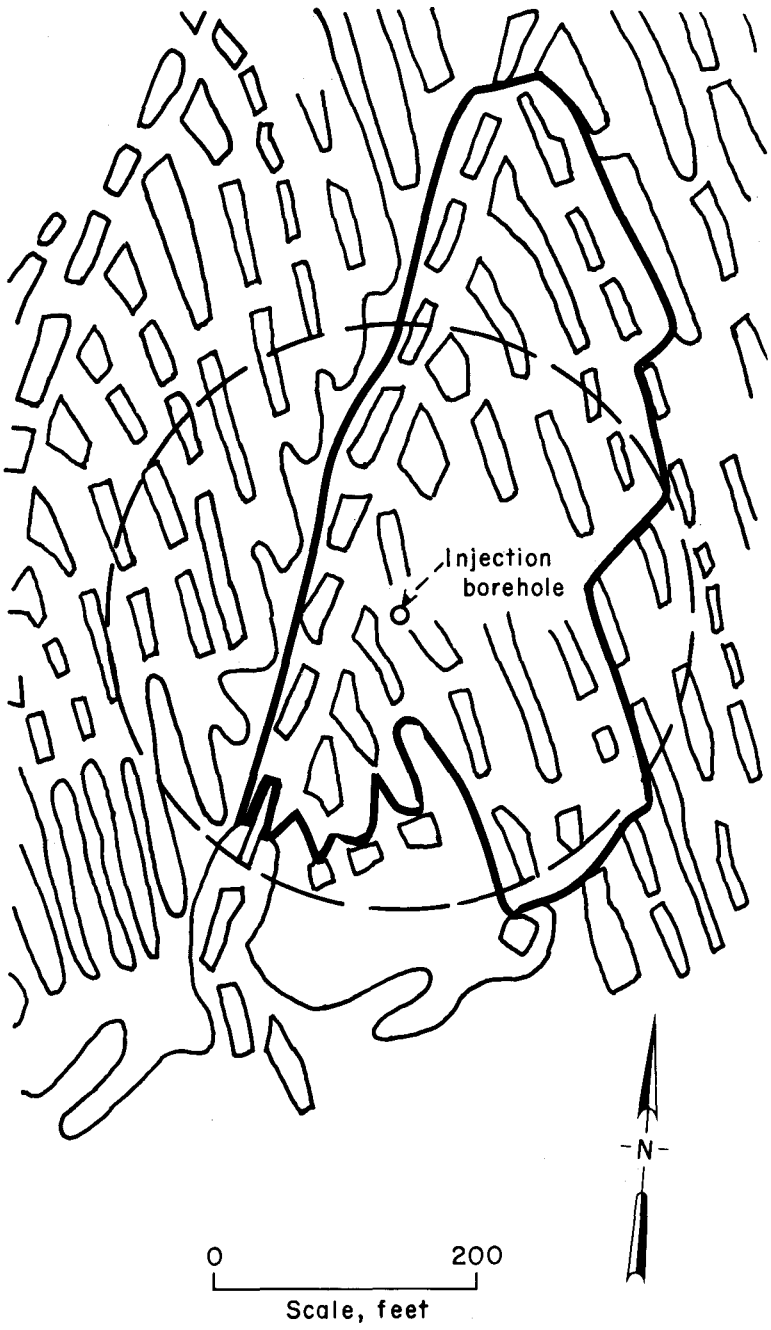

FIGURE 10. - Map of mine workings at the site of the first demonstration project in Rock Springs, Wyo., showing pattern of sand deposition in the mine voids. Dashed circle shows area of planned backfill.

caved space above the rubble. In a few holes, sand was blown up the hole when the drill encountered a cavity, indicating air pockets trapped at the top of the caved spaces. In a hydraulic filling operation, such air-filled voids would remain unfilled.

The relative density of the fill was found to decrease from the injection point. Tests by the Wyoming Highway Department indicated average in-place density of about 127 pounds per cubic foot with relative density values ranging from 36 to 81 percent. This range included mixtures of sand and shale rubble (14).

The degree of subsidence control effected by this project is difficult to evaluate. The emplaced fill in such a relatively small area of the mine would not be expected to completely prevent subsidence throughout the area because of apparent decreasing height and density of the fill away from the injection hole. Any further subsidence that might take place in peripheral areas, however, would tend to be somewhat less than in comparable areas that had not been backfilled. The process was considered to hold sufficient promise to justify further experimentation.

Cost

The cost of the demonstration project, including

all the extras associated with a first-time application, was $9.00 per cubic yard ($6.75 per ton) broken down as follows:

Project planning.....	$0.158
Investigation of mine openings.....	.542
Preparation of wells and manifolds.....	2.350
Fill material and handling.....	2.832
Injection.....	2.818
Site restoration and reporting.....	.300
Total cost per cubic yard.....	9.000

These costs reflect the demonstration of the process only and do not include the preceding site studies or the subsequent evaluation program. The cost per acre, about $62,500, is excessive, of course, and reflects the disadvantage of applying the method wherever only a relatively few mine voids are to be backfilled. The success of the test, however, which proved that 19,500 cubic yards of sand could be inserted into mine voids through a single borehole, promised invaluable aid to mining communities, fully justifying the cost of the experiment.

Reports

The Department of Housing and Urban Development, in cooperation with the city of Rock Springs, Wyo., arranged with Candeub, Fleissig and Associates, Consultants, Newark, N. J., to make a study of the demonstration project and a comprehensive report on the backfilling technique and its possible application in other mining areas of the Nation (3).

After the demonstration, the city of Rock Springs initiated a broad study of its overall community needs under the Community Renewal Program with assistance from the Department of Housing and Urban Development. This study has led to the establishment of priorities not only for subsidence control, but also for the treatment and renewal of other sources of deterioration and blight (19).

A comprehensive study of the general geology and underground mining in the Rock Springs area, in conjunction with the Community Renewal Program for the city, was made for the purpose of determining the economic feasibility of backfilling the mined-out areas. The report was made by the firm of Johnson-Fermelia & Crank, Inc., Consulting Engineers and Land Surveyors, Rock Springs, Wyo., and was completed March 1, 1972 (9). Two recommendations are included in the report: (1) That an extensive exploratory drilling program be conducted in various parts of Rock Springs to verify existing mine map data; and (2) that Federal funding be obtained for a large-scale mine backfilling project under the Belmont-Kerback area to assess the effectiveness of the process in arresting the continuing subsidence in that area.

FIRST LARGE-SCALE TEST

Scranton, Pa., was selected by the Bureau as the locale for the full-scale pumped-slurry demonstration project in 1972-73 because of its subsidence history and the active local interest in subsidence control. Population