allowed the contractor to lay the pipeline on an existing pedestrian foot bridge, a less expensive and more convenient procedure than providing a supporting trestle (fig. 27). While the pipeline could have followed the ground in and out of the deep ravine, the number of vertical bends required would not only have increased the cost but also have added greatly to the friction head.

On one occasion an accumulation of entrained air in the mine cavity exhausted with high velocity through injection borehole B-6 back through the open-ended pipeline at the pumping plant site. Although no damage resulted from the air discharge, it was concluded that in future projects a pressure release valve should be installed in the pipeline at the top of all the injection boreholes to avoid similar occurrences.

When pumping through boreholes B-5 into rather shallow mine workings that were believed to be isolated from the main part of the mine, water was reported seeping to the surface near the pumping plant site. This water was determined to be the mine water that was being used for the backfilling operation, and therefore pumping was stopped in borehole B-5 prior to the planned completion.

In September, after the 350,000 tons of sand had been injected under the critical areas, it was noted that the mine voids, particularly in the north part of area 11, were accepting the sand slurry easily at less than atmospheric pressure. It was decided, therefore, to continue injection under the highly vulnerable downtown area until funds available to the Bureau were exhausted. This amounted to an additional $150,024.14, bringing the total cost of project work to $1,195,027.14. On October 12 the slurry pumping operation was completed, with a total of 397,464 tons of fill material having been injected into the old mine workings throughout an area of about 90 acres.

A total of $29,959.00 was paid to the firm of Johnson-Fermelia and Crank, Inc., for providing the necessary onsite management and monitoring services, bringing the total cost of the project to $1,224,986.14, or $3.08 per ton. This compares with the $3.54 per ton cost of the previous or second large-scale demonstration project and $5.07 per ton for the first project.

The demobilization of the operation, including cleanup and restoration of all project work areas, was conducted in accordance with the contract specifications. Restoration of the borrow pit was completed in accordance with the stipulations set forth by the Bureau of Land Management and included seeding of the borrow area in fall 1976 and a verification inspection of the satisfactory growth after one complete growing season in spring 1978.

CONCLUSIONS

In positioning injection boreholes for the critical areas in the three large-scale projects, Bureau engineers assumed that the slurried backfill material would be distributed in the flooded mine workings more or less in equal distances from the points of injection. For dry mine voids, the injection boreholes were placed at higher levels in the workings to be filled. These assumptions were apparently realistic, according to observations from

32 monitor boreholes in the first project and from 20 monitor holes in the second project. Similar phenomena were noted during this period at the initial project in Scranton (22) and in the laboratory model studies (appendix). The movement of fill material, therefore, having become predictable in the pumped-slurry process, monitoring for the third project was limited to those boreholes that were later used for injection. The estimated extent of the backfilled areas in the three projects, about 178 acres, was consistent with the estimated volume of void space in the mined beds and with the quantity of fill material that was injected.

Of the methods of hydraulic backfilling formerly used, controlled flushing (see section of "Hydraulic Backfilling Methods") also results in well-filled mine openings because confinement is provided by bulkheads, fill placement is directed by hand into designated spaces, and the daily progress can be inspected. Controlled flushing and the pumped-slurry method are not generally competitive, however, because controlled flushing is limited to accessible mine workings. The alternative method of backfilling inaccessible mine openings, known as gravity blind flushing (see section on "Hydraulic Backfilling Methods") does not involve pumping of slurry and results in incomplete filling, both laterally and vertically. Of the methods of hydraulic backfilling now known, therefore, the pumped-slurry technique (actually another form of blind flushing), provides the most complete filling of mine workings that are flooded or otherwise inaccessible.

The pumped-slurry method proved successful under the following conditions encountered in the three large-scale projects:

Depth of mine workings to be filled, between 30 and 293 feet below the surface;

Dip angle of workings, for the most part less than 6°;

Mine workings relatively unobstructed by caving of overlying strata;

Average depth of alluvium, 35 feet;

Minimum rock cover, 5 feet;

Particle size of screened sandfill material, minus 1/4-inch ranging up to minus 2-inch;

Specific gravity of sand particles, 2.6;

Bulk density (dry), 100 pcf; and

Water available in large quantities.

Although the sand emplaced by the pumped-slurry process does not totally refill the space formerly occupied by the coal, it does support the remaining pillars and reduces the amount of breakage that otherwise would occur in the overlying strata. This lessens the chance that such disturbances might

eventually reach the surface and cause subsidence. There have been no reports of subsidence affecting surface areas overlying the backfilled areas. This included the Kerback-Belmont area where subsidence incidents had been continuing.

Further use of the technique in different areas will define the range of conditions under which it is feasible. Modifications may extend the range of favorable conditions. The depth range for which the new method may be feasible has not yet been defined. At shallow depth, material injected under pressure may rise to the surface rather than being confined to the mine level, especially in areas where overlying strata are fractured. The vertical completeness of fill in mines that are well above water level needs to be determined. The optimum size range of solids for efficient transport will be defined by future experimentation.

The actual injection operations in the gravity blind flushing method require extensive drilling operations to provide injection boreholes and continues truck traffic through city streets to bring fill material to injection boreholes. Similar disturbances, but to a lesser degree, are created when the controlled method is used. At the injection borehole, personnel are working in the street to direct the solids and water down the borehole. In the pumped-slurry method, street disturbance within the project area is limited to the drilling of an occasional borehole and the installation, maintenance, and removal of the distribution pipeline. During the second and third projects, the sand stockpiles, slurry mixing plants and pumps, as well as parts of the pipelines, were situated on the right of way of the Union Pacific Railroad. While strategically located with respect to the injection boreholes, the noise and dust associated with the operation of the plants was isolated from most dwellings. In the first project the slurry mixing plant and pumps were located at the borrow pit, approximately 2 miles from the built-up area, and had minimal impact upon the environment. During the 3-year period the three projects were implemented, the slurry moved quietly through the built-up areas in pipelines, many of which were buried. Aside from the drilling of boreholes and the installation and removal of pipelines, the only work required during the injection periods was cleaning the streets after infrequent pipeline leakage and on a few occasions where slurry rose to the surface in uncapped or improperly sealed monitoring boreholes.

Cost comparisons of the different methods of backfilling are difficult to make because the total number of projects span an inflationary period of rapidly rising costs. Moreover, subsurface conditions vary in the number of coalbeds to be filled, their depth, the thickness mined, and the percentage of coal left as pillars. Of four subsidence control projects in the Anthracite region backfilled entirely or mainly by the controlled flushing method between 1963 and 1968, the cost per cubic yard or per ton of solids injected ranged from $1.84 to $2.38. On the average, a cubic yard of anthracite refuse weighs 1 short ton. For two blind flushing projects in 1965 and 1967, the costs were $2.46 per ton--a cost that is extremely high when the limited effectiveness of the gravity blind flushing method is considered. In four projects between 1966 and 1969 in which controlled and blind flushing methods were combined, the overall cost per ton ranged from $3.64 to $6.76.

The cost of the first large-scale test of the pumped-slurry method (at Scranton in 1972-73), in which about 451,000 cubic yards of crushed refuse was injected, was $2,165,915--a unit cost of $4.80 per ton. At Rock Springs, where crushing cost was not included, costs per ton varied from $5.07 in the first project (only 152,467 tons), and $3.54 in the second (348,427 tons), to $3.08 per ton in the third project (397,464 tons). Absence of monitor boreholes and reuse of some equipment undoubtedly account for part of the lower unit cost of the third project.