PRELIMINARY RESULTS OF HYDRAULIC MODEL STUDIES FOR BACKFILLING MINE CAVITIES

Purpose

Surface subsidence is sometimes related to underground mining operations. Mining of solid material such as coal creates voids and when the natural support to the overburden is removed, the overburden weight is redistributed. Although pillars of coal are usually left in the mine to support the roof of the mine cavity, the pillars may not be able to support the redistributed weight of overburden and caving occurs. Caving into the mine void may extend upward through the overburden and cause subsidence at the surface.

Backfilling mine cavities with sand or waste material is a method that has been used to reduce subsidence. Much information is needed to determine the pattern of backfill deposition for the various fill materials and mine cavity conditions. The Bureau of Mines requested the Bureau of Reclamation to perform a hydraulic model study to determine the pattern of deposition for various typical mine conditions.

Summary and Tentative Conclusions

A model of an idealized coal mine was constructed and tested to determine the characteristics of backfilling mine cavities by pumping sand material. The model was constructed and operated to simulate the hydraulic action in the coal mine under the city of Rock Springs, Wyoming, where subsidence due to coal mine cavities has been experienced.

Fine, uniform blow sand with a median size of approximately 0.14 mm from the Rock Springs area was used in the model studies. Similar materials will be used in future backfilling operations for mines in the Rock Springs area.

Sixteen tests were made simulating the following mine cavity conditions:

1. Level floor with cavity submerged
2. Level floor with mine cavity dry
3. Sloping floor with injection hole below the water surface
4. Sloping floor with injection hole above the water surface
5. Corridors between pillars partially blocked and totally blocked
6. Solid walls on one and two adjacent sides of a rectangular section of pillars surrounding the injection hole

The approximate bearing strengths of the backfill material were determined by soils mechanics tests.

Data from the 16 tests lead to the following tentative conclusions which may be modified as additional information is obtained and analyzed:

1. Initial deposition of fine sand backfill material pumped vertically into a level submerged mine cavity takes the shape of a broad ring which builds up to the roof of the mine cavity.

2. The general pattern of deposit in a level submerged mine backfill operation is not dependent on slurry concentration nor on injection pipe velocity. However, a lower pipe velocity will result in a smaller radius of initial deposit ring.

3. Segregation of backfill material occurs in the initial ring when backfilling a level submerged mine cavity. The larger particles deposit near the injection pipe and the finer particles deposit farther from the injection pipe in a radial direction. The particles at the bottom of the deposit ring are larger than the particles at the top of the deposit ring.

4. Fine sand backfill material injected into a submerged mine cavity having a 5° slope deposits in an initial broad-ring pattern almost identical to the deposition pattern in a level submerged mine cavity (see Conclusion 1 above). A solid wall located a short distance from the injection pipe does not prevent slurry from flowing nor backfill from depositing in that direction.

5. Fine sand backfill material pumped into a submerged mine cavity having a 15° slope will deposit in an initial ring around the injection pipe. Backfill material will then be transported and deposited downslope and laterally along breakout paths. As the back pressure builds up from deposits, fine material is transported along breakout paths and deposited in directions of least resistance from the injection pipe.

6. All tests showed that fine sand backfill material will be transported past partial blocks in corridors as deposits build up. Fine sand backfill material will be transported into slack water areas and deposited by circulation of the slurry.

7. Backfill material pumped into a dry mine cavity will develop a deposit with a bed slope which is dependent on a critical tractive force required to move the backfill material at shallow flow depths in an open channel. For the fine sand material obtained from Rock Springs, the bed surface slope of deposit was 0.050 to 0.0625 in a dry mine cavity.

8. When the top of the initial deposit ring reaches the mine ceiling in a submerged mine cavity, back pressure builds up until a breakout channel between the mine ceiling and deposited material is formed. Backfill material is then transported along the channel and deposits in the pool at the end of the channel until back pressure builds up again and a new breakout channel is formed.

The Investigation

Tests With Level Floor

Eleven tests were conducted with backfill material pumped into a mine cavity having a level floor. All tests were conducted with the cavity in a submerged condition, except Test 10 which simulated a dry cavity.

Preliminary Tests Without Pillars

Test 1 was made to determine the adequacy of the slurry tank, propeller-mixer, sand-feed, sand-pump, and piping system. Only a small amount of fine sand material (about 1 cubic yard) was fed into the system during the test. About 10 cubic feet of fine sand material reached the model box, Figure 1. The remainder of the sand settled and remained in the slurry tank during the test.

Test 2 illustrated the deposition pattern for backfill material pumped into a deep submerged mine cavity with no pillars, Figure 2. Slurry was fed at a concentration of approximately 12 percent by weight. Velocity in the injection pipe was approximately 9 feet per second. The angle of repose of the material deposited under water was about 30°. Deposit was in a cone shape with a depression in the top of the cone which was caused by velocity and turbulence of the jet. The maximum height of the deposited material was a considerable distance below the water surface when the test was stopped.

Test 3 was similar to Test 2 except a higher velocity of 16 feet per second was maintained in the injection pipe. Figure 3 shows the pattern of deposition in a simulated submerged cavity for this condition. Velocity from the submerged pipe was high enough to keep the floor free of sand material. A strip of sealing tape on the floor caused nonuniform velocity distribution and consequent nonuniform backfill material distribution.

Test 4 illustrated the deposition pattern as the backfill material deposit reached the water surface in a partially submerged cavity. A rather flat surface (slope 4° to 5°) or shear plane developed at the top of the cone, Figure 4. The depth of flow over this plane was very shallow. The material was transported over the flat, sloping plane according to the tractive force of the water flowing over the plane and the size of fill material, and deposited at an angle of repose on the sides of the cone. Again a typical flow velocity of approximately 16 feet per second was used in the injection pipe.

The first four tests were operated at prototype injection velocities to observe the deposit pattern and determine how the fill material acted under the hydraulic conditions imposed. Thus, radial velocities in the mine cavities for the prototype and the model were similar. Transport velocity is the most important parameter when considering transport of backfill material.

Tests With Pillars, Except FOR Test 7

Test 5 simulated a submerged mine cavity with a roof and pillars confining the flow in the cavity. The fill material deposit in the cavities between the pillars is shown in Figure 5 after the mine roof was removed. Velocity in the injection pipe located at the geometrical center of the pillar arrangement was approximately 16 feet per second. Pillars 40 feet long by 10 feet wide by 6 feet high were constructed in the model at a horizontal scale of 1:24 and a vertical scale of 1:8 giving a vertical distortion of 1 to 3.

This distortion resulted in radial velocities nearly the same as those in the field operation at Rock Springs, Wyoming. The pillars were arranged in a symmetrical pattern to give 60 percent cavity and 40 percent solid pillars in the mine. The test was run until the deposited material nearly reached the ceiling. Back pressure then built up, causing fine sand to break out of the initial ring and deposit outside the pillar area.

Test 6 was similar to Test 5, except four additional pillars (28 total) were installed in four rows, Figure 6. Deposit was similar to Test 5, Figure 7. Sand was added to give approximately 17 percent concentration by weight.

For Test 7, the pillars were removed and the mine roof was placed at a simulated field position 6 feet above the floor. The test was made with the cavity in a submerged condition. A comparison of the deposited fill material for Test 7 with the previous Tests 1 through 4 in which a confining roof was not in place, shows a different pattern on the outside edge of the deposited ring of material, Figure 8. The material in Test 7 was deposited in a scalloped pattern, compared to a smooth, circular pattern in Tests 1 through 4. In Test 7, fill material deposited until the flow area between the top of the sand deposit and the ceiling was nearly closed off. A back pressure then built up, a channel broke out along the top of the sand deposit, and backfill material was transported in this channel until enough material was deposited to form a delta and closed the channel off. The flow then broke out in another channel depositing another delta. This procedure continued, forming a scalloped pattern around the outside edge of the doughnut shaped ring of backfill material.

Tests 8 and 9 were made to show how partially or totally blocked openings in the mine corridors would affect the deposited pattern of backfill material. Figures 9 and 10 show where partially and fully blocked openings are located and how the fine sand backfill material flows to fill the cavities. Even a small flow over a considerable time period will transport fine sand around corners and into cavities that seem to be blocked. As a general rule, if water will flow into an area, fine backfill material transported by the water will be carried in to fill cavities or around corners. Velocity in the injection pipe varied from approximately 14 to 4 feet per second for Test 8 and was steady at 14 feet per second for Test 9. Sand concentration for Test 8 was approximately 30 to 35 percent by weight and for Test 9 approximately 25 percent by weight.

In Test 10 a dry mine cavity was simulated, Figure 11. Injection pipe velocity varied from approximately 15 to 8 feet per second. A slight amount of back pressure caused a reduction of discharge and velocity in the injection pipe; however, no adjustment to the discharge was made after the test was started. The sides and an end of one corridor was blocked as shown in Figure 11 before the test was started. The blocked corridor was made so a small amount of water flowed through the end block, Figure 12. The blocked corridor filled with backfill material to about the same depth as the corridors outside of the blocked area. In the dry cavity backfill material is transported and deposited according to open channel sediment transport laws. The bed slope from the top of the cone around the injection pipe to the outside of the cone was 0.050 in the longitudinal corridor direction and 0.0625 in the cross-corridor direction, Figure 13. In a dry cavity a shallow depth of water transports backfill material and the steepness of the resulting bed slope depends on the tractive force required to transport the size of backfill material used.

For Test 14 the height of the model pillars was reduced from 9 inches to 3 inches to represent the 6-foot-high prototype pillars without vertical distortion. This test was conducted to compare the pattern of deposition of backfill material in distorted and undistorted models. The general distribution of backfill material in Test 5 (distorted vertical dimensions test) is very similar to Test 14 (undistorted vertical dimension tests). Velocity in the injection pipe, Test 5, was approximately 16 feet per second and for Test 14 about 10 feet per second. Proportionately for the depth of cavity, more sand was pumped in Test 14 than in Test 5. Test 14 had a simulated wall on two of the four sides. These walls seemed to have very little effect on the initial deposit pattern of backfill material as compared to Test 5 which had no walls on the sides.

For Test 16, vertical height of the model pillars was 0.25 foot (no vertical distortion), and the arrangement of pillars was the same as for previous tests. Distribution of backfill material was very similar to the pattern of deposit in the tests with higher pillars, Figure 15. The velocity of slurry in the injection pipe was approximately 16.5 feet per second. The velocity and turbulence were high enough to clear the floor area below the end of the injection pipe.

Tests With Sloping Floor and Pillars

Tests 11, 12, and 13 were made with the mine cavity floor built on a 15° slope. The water surface in the mine was lower than the injection pipe for Test 11. Backfill material was pumped into the mine cavity on a dry floor and the slurry flowed laterally and downslope along the corridors into the ponded water table below. The deposit pattern is shown in Figure 16.

Test 12 was similar to Test 11, except the water table was above the injection pipe in the 15° sloping mine cavity. The backfill material was injected with a velocity of approximately 8.5 feet per second. Material flowed radially from the injection pipe, filling the cavity downslope and also upslope to the water surface. Figure 17 shows the pattern of deposition.

Test 13 was an exact duplicate of Test 12. Comparing pictures of Figures 17 and 18 shows that the deposit pattern for these two tests was very similar.

For Test 17, the mine cavity was submerged and the floor was on a 5° slope. Velocity of slurry in the injection pipe was about 10 feet per second. Concentration of sand in the slurry was approximately 8 percent. Deposition pattern for Test 17 was very similar to the deposition patterns for Tests 5 and 14, which were made with a level floor and submerged condition, Figure 19. Test 17 had a solid wall at the downslope end of the corridors. For the initial ring of backfill material that deposited up to the ceiling of the mine cavity, the deposit pattern was very nearly symmetrical. The first breakout and channelization occurred in an upslope direction. The distance to the initial ring deposit was slightly smaller in an upslope direction than in a downslope direction, which is the obvious reason for the first breakout in an upslope direction. The gravity component, due to the 5° slope, was very likely a reason for the slightly more deposit downslope than in the upslope direction.

General

All tests with pillars were performed with the injection pipe geometrically centered in a symmetrical pattern of pillars. As a result the pattern of deposition on the level and near-level floor conditions were very nearly symmetrical about the injection pipe. Transport and deposit of the backfill material depend on the flow of slurry material in the mine cavity. Rock falls which block or partially block corridors will affect the radial flow and deposit patterns.

Deposition of backfill material in a field operation depends on the extent of open corridors which may or may not be symmetrical.

Figure 1. - Test 1. Pattern of deposit is shown for the first test. Very little backfill material was pumped into the model box. The test was performed to observe the operation of the slurry mixing and pumping system.

Figure 2. - Test 2. Pattern of deposit with a slurry concentration of 12 percent by weight and velocity of approximately 9 feet per second in the injection pipe. Fine sand backfill material was deposited in a simulated submerged mine cavity. Backfill material, deposited in the center of the cone cavity causes very uniform backfill material to deposit at the angle of repose on the outer edge of the cone.

Figure 3. - Test 3. Deposit pattern of backfill material pumped at a concentration of 12 percent by weight and 16 feet per second in the injection pipe. Backfill material is deposited in the submerged mine cavity. Nonuniform pattern of deposit occurs when jet strikes the floor having ridges causing nonsymmetrical velocity pattern in the cone cavity.

Figure 4. - Test 4. Gentle sloping shear surface at the top of deposited cone is the result of holding the water surface at the downslope elevation of the shear plane surface. Outer surface of cone deposit rests at the angle of repose. Velocity in the injection pipe was 16 feet per second. Concentration of backfill material in pipe was 12 percent by weight. About 6 inches of remaining backfill material in cone cavity causes very uniform deposit in the cone.

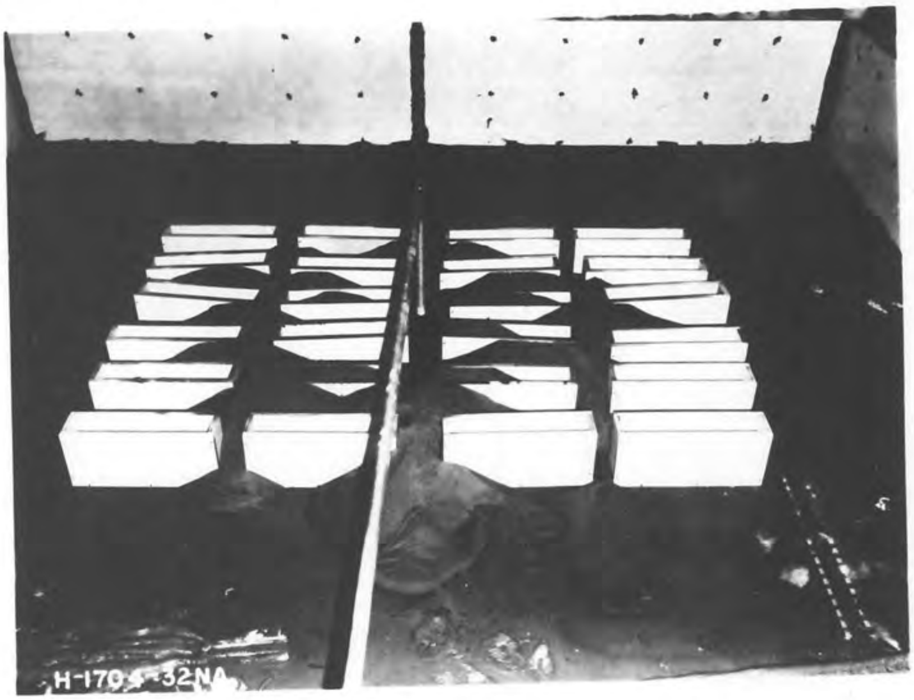

Figure 5. - Test 5. Fine sand backfill material deposits in cavities between the mine pillars. The mine roof was removed after backfill injection test was completed. The mine cavity was submerged for this test. Concentration of backfill material and velocity in injection pipe was 12 percent and 16 feet per second, respectively. The cavity remaining under the injection pipe is a result of the high velocity and continuity transport conditions.

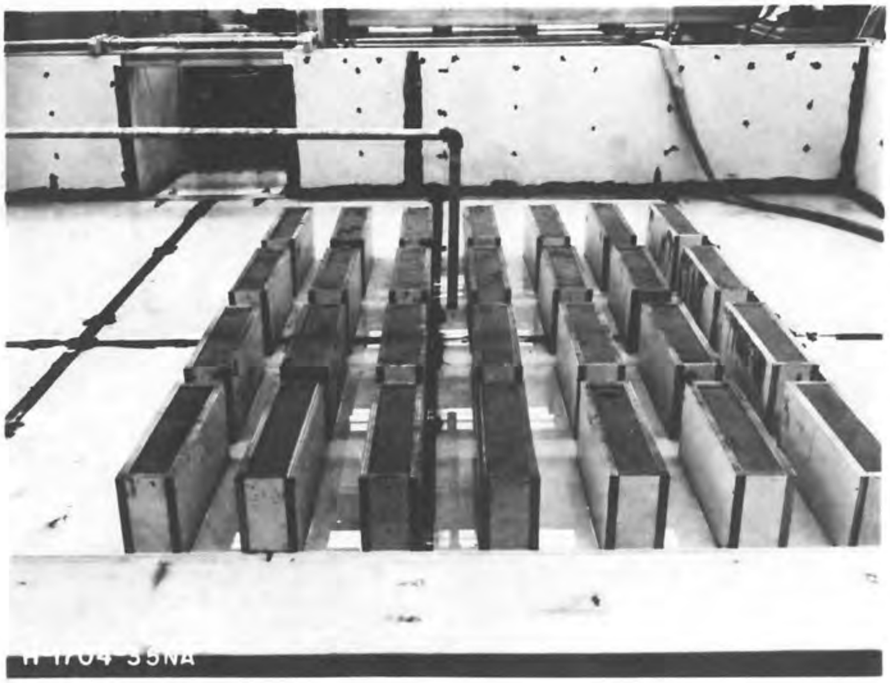

Figure 6. - Test 6. Seven rows of four pillars each were arranged in a symmetrical pattern to give 60 percent cavity and 40 percent solid pillars in the mine before Test 6 was started. In future tests, eight rows of four pillars each were used. Forty feet long by 10 feet wide by 6 feet high pillars are represented in the model by 1.667 feet long by 0.417 foot wide by 0.75 foot high. The horizontal scale was 1:24 and the vertical scale was 1:8. In some tests, vertical and horizontal scales were both 1:24.

Figure 7. - Test 6. Deposit pattern of backfill material is shown for Test 6 after mine roof was raised. Test was conducted having a concentration of about 16 percent backfill material injected into the mine cavity at a velocity of approximately 15 feet per second. The mine cavity was submerged. As slurry pumping continues, breakouts occur along paths of least resistance to cause backfill deposits to extend out beyond the pillar area.

Figure 8. - Test 7. The contours simulate 1-foot intervals, 0-6 feet, in prototype mine cavity. The test was conducted with no pillars and with the mine roof held 6 feet above the mine floor. The scalloped pattern of deposit results from breakouts as deposited backfill material causes back pressure in the center cavity and in the injection pipe and pumping system. Injection pipe velocity was 14.5 feet per second and slurry concentration was 16 percent.

Figure 9. - Test 8. Deposition pattern is shown for Test 8. Corridors are partially blocked and fully blocked at points indicated. Backfill material deposits in the cavity areas adjacent to blocks in corridors. Apparently a small amount of circulation is all that is needed to carry fine backfill material into dead end cavities. Velocity in the injection pipe varied from 13 to 4 feet per second. Slurry concentration was about 35 percent by weight. Corridor block designations are: U 1/2 indicates upper 1/2 of corridor is blocked; L 1/2 indicates lower 1/2 of corridor is blocked; full indicates full corridor is blocked.

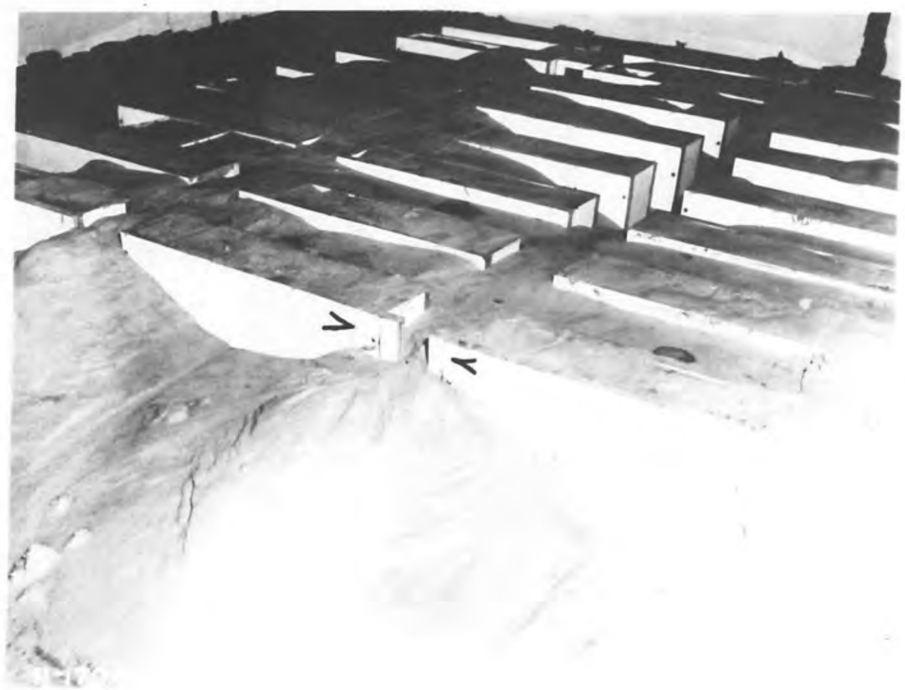

Figure 10. - Test 9. Blocks to reduce flow areas by one-half in the corridors were placed at several locations (see arrows). Deposition of backfill material occurred to about the same height on both sides of the partial blocks. Slurry concentration was approximately 25 percent with velocity in the injection pipe approximately 14 feet per second.

Figure 11. - Test 10. Arrangement of pillars for Test 10. Backfill material was pumped into a dry cavity. Blocks in one corridor were placed at A, B, and C as shown.

Figure 12. - Test 10. Backfill material pumped into a dry cavity deposit causing a slope according to the critical tractive force of the particular material used and the depth of flow transporting the backfill material. Note deposit in corridor that is blocked. A small flow was allowed to pass through blocks. Slurry concentration was 20 percent and injection pipe velocity varied from 15 to 8 feet per second. No roof was used in the dry cavity test.

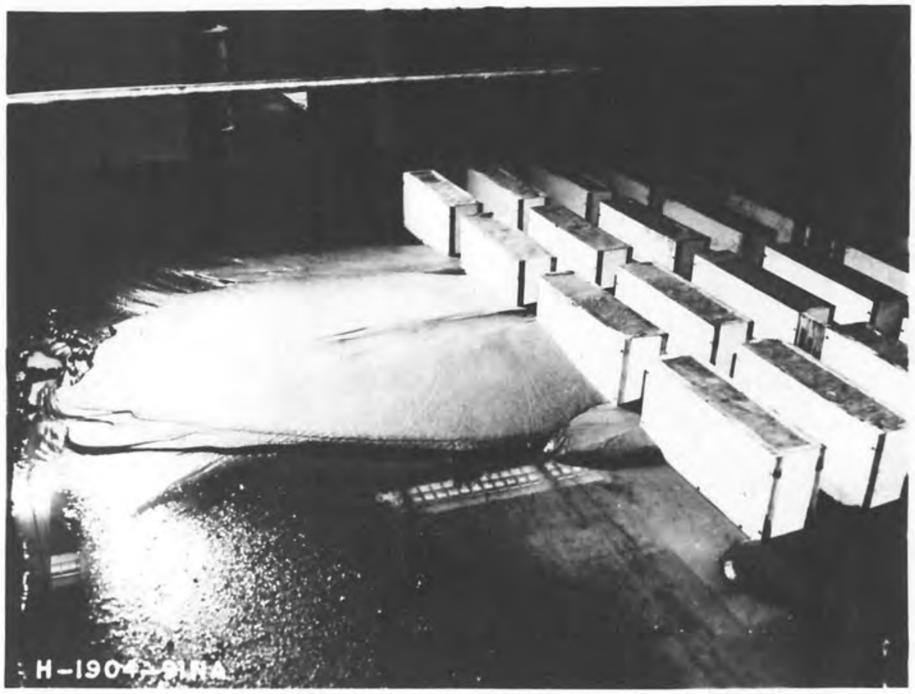

Figure 13. - Test 10. Deposit at edge of pillar area shows slope of deposited backfill material for Test 10 conducted in a dry cavity. Bed slope for longitudinal direction of pillars and corridors was 0.050. Bed slope in transverse direction to pillars was 0.062.

Figure 14. - Test 14. The mine cavity was level for Test 14 and the horizontal and vertical geometrical scale was 1:24. Slurry concentration was 10 percent and the pipe injection velocity was approximately 8.5 feet/sec. Two adjacent sides of the mine cavity were blocked with solid walls. Backfill material moved in all radial directions from the injection pipe. Initial deposit pattern of backfill material was symmetrical around the injection pipe including the directions toward the solid walls.

Figure 15. - Test 16. Test 16 was made with the floor and roof of the mine cavity level. Slurry concentration was 9 percent and the injection pipe velocity was about 16.5 feet per second. A small amount of backfill material was fed into the system to show the initial ring of backfill deposit in the mine cavity with pillars. Deposition pattern is symmetrical around the injection pipe.

Figure 16. - Test 11. Test 11 simulated a mine cavity on a 15° slope. Water surface in the cavity was lower than the floor position under the injection pipe. Slurry would strike the floor and flow downslope into the ponded water. Fine sand backfill material flowed laterally and downslope to fill submerged cavities. Slurry concentration was 24 percent and the injection pipe velocity was about 3 feet per second. The 6-foot-high pillars were represented by a pillar 0.25 foot high in the model. The horizontal and vertical scales were 1:24.

Figure 17. - Test 12. For Test 12, the mine cavity sloped 15° and the water surface in the cavity was higher than the injection pipe. Backfill material deposited beyond the pillars and filled the cavity down slope from the injection pipe. Backfill material also deposited upslope to the water surface elevation. Slurry concentration was high. Velocity in the injection pipe was about 8.6 feet per second.

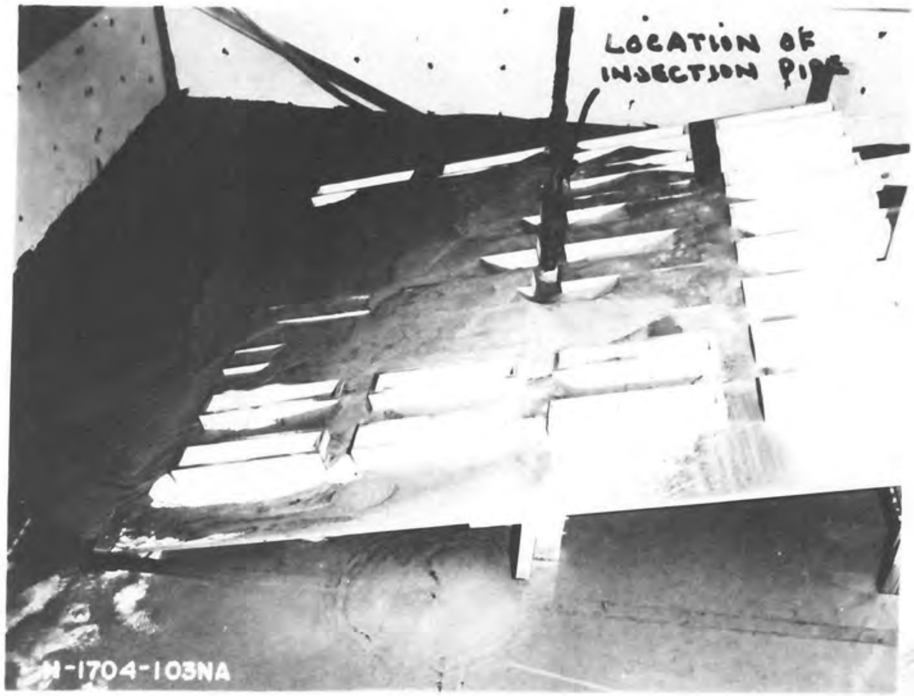

Figure 18. - Test 13. Test 13 was made as a duplicate to Test 12. The slurry concentration was very high and injection pipe velocity was about 8.6 feet per second. Water surface was higher than the injection pipe in both tests. The pattern of backfill deposit, as shown on the figures related to these two tests, are very similar.

Figure 19. - Test 17. The floor and roof of the mine cavity was sloping 5° from the horizontal for Test 17. A solid wall was simulated at the downslope end of the pillars. Slurry concentration was 8 percent and the injection pipe velocity was about 10 feet per second. The mine cavity was submerged. The initial ring deposition pattern was almost symmetrical about the injection pipe. The 5° slope and the solid wall downslope had very little effect on the initial deposition pattern of backfill material.