SHOTCRETE AS AN INTEGRAL PART OF SHAFT CONSTRUCTION

by

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I. GENERAL

Contract A-10a is part of the Rockville Route of the Washington Metropolitan Subway System. The project encompasses 9100 l.f of twin bore tunnels, 19'-2" in diameter, and four fairly evenly-spaced shafts with related cross adits. The shafts vary in diameter from 20' to 26' and their depth ranges from 115' to 165'. The shafts have been sunk through approximately 40 feet of soft ground with 4" x 6" oak lagging and steel sets on 4 foot centers, and the remaining rock section is supported with a 5' x 5' rock bolt pattern and an average thickness of 4" to 6" of shotcrete.

II. GEOLOGY

Geology varies from a light grey quartz diorite to a darker gneissic schist. The top of the rock section is for the most part, a weathered diorite with irregular folliation. The lower section is the gneissic schist which has well defined folliation dipping at 60° to 80°, and jointing near parallel to its schistosity. Joints are either clean or contain re-crystallized feldspar.

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III. CHOICE OF SUPPORT

Our original intent had been to support the shafts with only a 5' x 5' rock bolt pattern. Reports of a cave-in in similar ground, coupled with the expectation that the shafts would remain open for an extended period (2 1/2 to 3 years) contributed to the decision to utilize shotcrete for immediate ground reinforcement, and to avoid deterioration in the period before lining. We sub-contracted the shotcrete work on A-10a, and the sub-contractor using a two-man crew on pot and nozzle did all the work with fill-in help by the miners at each working place.

IV. MULTIPLE SHAFTS

The biggest single problem involved in shotcreting multiple shafts with only one crew is, of course, the correlation of activities. In the case of A-10a, this problem was overcome by scheduling the sinking start-up periods such that only two shafts were in rock section at one time. Shaft #1 was started first and when it was down to bedrock, Shaft #2 was started, and Shaft #3 because it was the deepest was started only two weeks later. By working two shifts per day at Shaft #1, we were able to have it on bottom by the time Shafts #2 and #3 reached rock section. This proved to be the period of highest demand on the shotcrete crew, because Shaft #1 being the starting chamber for the T.B.M. also required servicing. However, we were exceptionally lucky in that really poor ground conditions requiring immediate reinforcement were rarely encountered, and on the occasion that this did happen, we were able to give priority to the site requiring it without delay to another - by skipping a shotcrete application there. Shaft #4 was started just before Shaft #3 was on bottom. Demand on the crew is very obvious in reviewing the records.
Shafts #1 and #4, which were both sunk during periods of no other activity received shotcrete applications every 4 feet, or as often as wished, while Shafts #2 and #3, which were sunk simultaneously, received applications every 8 feet, or perhaps not as often as would have preferred.

V. SHAFT SINKING

Shafts #1, #2, and #3 were excavated by drill and shoot methods, utilizing a job-fabricated jumbo, and sinking hammers. Mucking was carried out with Eimco #630 muckers and crane-hoisted 3 cy. muck boxes. Shaft #4 was excavated in a slightly different manner, utilizing a 6" drill hole drilled from the surface as a burn hole, and mucking was carried out with a satellite arrangement comprised of a backhoe attachment mounted on a muck box filled with concrete. Results were good with both methods.

VI. CYCLE

Typically the shafts were sunk by taking an 8 foot round. A-10a is located in a residential zone and blasting is restricted to specific hours. With a single shift working the mucking operation took the best part of two days, making a total cycle time including shotcrete application on the order of three days. Shotcreting was normally done off the muck pile. But occasionally poor ground conditions or a missed cycle because of pressing duties elsewhere caused it to be done immediately after cleaning bottom and rock bolting.

Normal sequence of shotcreting operations after the swell of the muck pile had been drawn down, included placing the pot at the shaft collar and feeding it directly from a batch truck. Material was fed to the nozzle by carrying a temporary 3" pipe with
Victaulic couplings down with the shaft, so it was only necessary to connect hoses at top and bottom. The nozzle was hand-held, weep pipes were installed to canalize ground water when encountered.

We are fortunate that the Batch Plant is very close by, and material was usually on the wall within 1 1/2 hours of batching. Average duration of the shotcrete operation was 3 1/2 hours, average application rate was 4 cy. per hour. However, crew sizes at the shafts was of the order of 15 to 16 men, and of course, nearly all of these are idled during this period, which is a very critical factor in assessing costs, and obviously why short duration shotcreting is desirable. Calculations based on yards applied versus thickness measured indicate rebound on the shaft walls was in the range of 35% to 40%.

A. Equipment

Equipment used for shotcreting consisted of:

A Meynadier pot with double rotor modification.
2 1/2" Ø hose.
Air pressure of 25 to 30 PSI.
Water pressure boosted by pump to 165 PSI.
Standard 7 sack mix, 7 1/2 when cold weather or ground-water encountered.
Gravel 3/4" nominal crushed.
Additive 1 1/2% sigunit with 2% when wet, dispensed from standard auger feeder.

B. Results

Instrumentation was not installed in the shafts, however, some double position borehole extensometers were located near the brow of the adits after shotcreting, and these have shown no movement to date.
Shafts #1, #2, and #3 do not have shotcrete as a pay item, and hence, were not cored. However, Shaft #4 was cored and strengths in the 2500 PSI range were obtained. We plan to core this shaft again to determine if the strengths have increased appreciably after 9 months.

Shafts #1, #2, and #3 are to be concreted with a 12" thick 3500 PSI lining, while Shaft #4 is to be permanently lined with shotcrete. All four shafts were sunk ahead of schedule.

C. Disadvantages of Shaft Shotcrete

The outstanding disadvantage of using one crew to service multiple working faces is the delay factor. As had been mentioned, inordinate costs are encountered when large crews are idled for long periods and especially on a single shift operation when 4 hours isn't just 1/2 a shift, but 50% of the available production time in a day. In this situation, bad ground could cause considerable delay and cost, by taking the shotcrete crew from a working place scheduled for shotcrete and then being available again at an inopportune time, and finally unavailable when a second opening occurs. As I have mentioned, A-10a was very successful in scheduling the shotcrete work around sinking operations, but had ground conditions been encountered, it would be easy to end up scheduling sinking operations around shotcreting, rather than vice-a-versa.

A double support system of rock bolts and shotcrete can be both a disadvantage and an advantage. Overlapping systems waste both time and money, and with forethought can be avoided. However, when one can not be certain of the exact availability of shotcrete crews, rock bolting becomes a habitual part of the sinking cycle. On the
other hand, since bolting need only take up the period that the ground remains unshotcreted, not as many bolts and wire mesh are required as in a singularly bolted method of shaft sinking. Probably only 40% of the bolts otherwise used need be devoted to slabby or loose material for interim support. Ideally, if the crew is readily available, large blocks might receive minimum bolting and then a shotcrete lining quickly applied to smooth out overbreak, maintaining a minimum thickness, not to break the continuity of lining, to reinforce rock before air slacking loosens it. A circular shaft lends its geometry to this type of reinforcing well, to yield a strongly arched section of lining. It is generally accepted that shotcrete does not "take weight" as does steel, but allows the rock to be bound together in a self-supporting type of lining.

D. Advantages

Of course, the ultimate advantage is support of the shaft, however, some intrinsic gains are made by shotcrete application. Canalization of ground water to weep pipes is efficiently achieved and the shotcrete crust affords a lighter colored surface which reflects light better than country rock, allowing more effective illumination of the working place.

On A10-a, we have maintained an excellent record of safety from falling, sloughed or loosened material, much better than other shafts I have been involved in that were bolted and chain linked, and this is a result of shotcreting anchoring and entrapment of looser material.