Keynote Address

by

A. A. Mathews*

Five years ago this conference would have been impossible. At that time, the Burnaby Tunnel in Vancouver, B. C., was about the only North American underground project of any magnitude which had successfully used shotcrete as the prime support medium. The Bureau of Reclamation had not written a shotcrete specification for its work, Kirk Fox was just developing a keen interest in the subject, and some of the more progressive mining companies were working on experimental programs. Most designers had never even heard of shotcrete and consequently our tunnel contractors had no incentive to develop an expertise in the field.

I well remember my initiation into the clan. Along with Dr. Vic Dolmage, I was on a consulting panel concerned with the excavation of the Portage Mountain Underground Powerhouse in northern British Columbia. On one of our flights from Vancouver to Hudson Hope, Vic told me of a railroad tunnel in Vancouver which his firm had recently designed. The geology consisted of interbedded shales, sandstones, and conglomerates. Instead of the usual steel supports followed by a concrete lining, the tunnel would be permanently supported by layers of shotcrete, 6-in. thick on the arch and 4-in. on the sidewalls.

---

*President, A. A. Mathews, Inc., Arcadia, California.

I had too much respect for Vic Dolmage to tell him what I thought of such a scheme. So, I decided to just let him find out for himself. Later, during another flight to Hudson Hope, I asked Vic how the tunnel was coming. To my surprise, he reported that the shotcrete support was a success and that good progress was being achieved in driving the tunnel. After that, I simply had to see for myself.

I visited the Burnaby Tunnel later that week upon my return to Vancouver. To my amazement, some 25 ft of essentially finished tunnel was being completed every day. This was a single track railroad tunnel, about 18 ft wide and 28 ft high. With these dimensions, it was possible to use a drill jumbo that would permit a Conway Mucker to work underneath the topdeck.

After blasting, the flyrock and the toe of the muck pile were loaded out. Then the jumbo was moved in and an extension of the upper deck was telescoped over the muck pile to the face. The newly exposed arch was then shotcreted from this platform while the mucking continued underneath. Successive layers of shotcrete in the arch and on the sidewalls were applied later during the drill cycle. Obviously, here was a technique which promised to really advance the state of the art of tunnel construction.

Later, I inspected a subway tunnel under construction in Milano, Italy. The ground was sand and gravel. But by means of making the excavation in small increments followed immediately by shotcrete, the contractor was able to advance the tunnel without the use of a shield or temporary supports.

I visited Stabilator, Inc., in Stockholm and learned how this firm [illegible] equipment and used it successfully on difficult tunnels in Hong Kong. I visited Walter Lang, a manufacturer of shotcrete spraying equipment in Switzerland.

We began collecting technical articles on the design and execution of shotcrete structures. Since most of the work to date had been done in Europe, many of these articles had to be translated from the original German, Italian, or Swedish.

What is it that permits a relatively thin layer of shotcrete to do the work of heavy steel supports and concrete? Certainly, the fact that the additive induces very quick set and high early strength is a factor. Also, the early application of shotcrete helps prevent the start of loosening. If the first fragment is never allowed to fall from the excavated surface, the tunnel will obviously be permanently stable. But there must be more to it than that.

It has long been recognized that some yielding of the excavated tunnel periphery must be allowed if the load on the supports is to be minimized. On the other hand, unless this yielding is controlled, intolerable displacements frequently occur. A layer of shotcrete, rapidly applied to the freshly excavated surface, seems to have the flexibility to yield as required and also has the structural capacity to maintain stability. But the achievement of this objective requires the application, coordination, and control of many elements.

The designer must properly apply the principles of rock mechanics or soils mechanics to the design under consideration. Then he must dimension and schedule the shotcrete and select any complements, such as rock bolts, supplemental supports, or reinforcing. Suitable materials and equipment must be provided. Skilled workers must be found or trained. Quality control must be maintained.

Here in the United States, our failure to satisy all of these requirements simultaneously and promptly has placed us at a cross-roads. In some quarters, shotcrete has been discredited as an effective medium for the design and construction of tunnels. But most of the so-called failures can, in retrospect, be ascribed to deficiencies in one or more of the essential elements noted before.

In California, we have learned the importance of proper control on the job. This was emphasized again in Charleston, South Carolina, along with the necessity for using proper techniques. In Washington, we learned more about the importance of specifications and bidding schedules as well as the necessity for providing suitable equipment and skilled workmen. More appreciation has been developed for the use of rock bolts or light supports to complement the shotcrete.

We know that the shotcrete in a tunnel arch must be tied into a stable foundation. If there is no stable or sound material below the springline, it may be necessary to close the invert. We know that in some types of very blocky ground, the shotcrete may not develop strength rapidly enough to maintain stability. However, the judicious use of supplementary rock bolts may solve the problem.

Light steel supports have been used to complement a shotcrete design for long spans or other severe conditions. But to embed a structural support of fixed dimensions can consume a lot of shotcrete where overbreak is excessive. Also, a rolled structural shape is not the best configuration for embedment. Perhaps a member built up from round bars, as practiced in Europe, would be better.

Remote-controlled equipment for shotcrete application and rock bolt installation has been built. Is such equipment perfected and readily available so that its use may be specified in the interest of safety without unduly handicapping the work?

What type of specification should be written for shotcrete, the method type or the performance type? The method type does not encourage the development of better materials, equipment, and techniques. But the performance type may bewilder the inexperienced contractor and be difficult to administer. How should shotcrete be measured and paid for, so that the contractor is compensated fairly, but also has an incentive to improve performance and minimize rebound?

Many of these problems stem from our mode of contracting for civil projects in this country. The designer prepares the design and writes the specifications. Then the contractor performs the work under the supervision of the engineer. But the engineer can only require the contractor to comply with the plans and specifications. He cannot direct the contractor's work.

Since the behavior of an underground structure depends as much on the construction method and workmanship as it does on the design, the designer is reluctant to utilize an unfamiliar structural element when he has little control over the actual construction. By the same token, the contractor is not likely to welcome a new construction concept when he cannot assess his potential difficulty in meeting the specification requirements.

Some of you can remember when only rivets were used to connect structural steel members. Now, only bolts or weldments are used. But this change was not accepted overnight by the design profession or the construction industry. Years of development and education were necessary.

Today, we in the shotcrete field face a similar challenge. Our manufacturers have to understand the practical problems of the contractor--safety, quality control, equipment availability, compatibility with the tunnel environment and space parameters. Our contractors must be acquainted with available equipment, acceptable operating practices, and materials requirements. They must be prepared to train skilled workmen. Our designers must understand the virtues and limitations of shotcrete. They must know when to incorporate complementary elements in their designs. They must know how to instrument and monitor the work so that it can be used with confidence. Our owners must realize that this is a fledgling industry offering a potential for significant cost and time reductions on a variety of underground work. But in order to realize these benefits, the industry must be supported and nurtured during its development.

It has been well stated that in the evolution of the art of tunnel design, there has been far too much calculation and too little observation. We are tempted to view the tunnel support as a free-standing structure, like a bridge. We then estimate the loads the structure must support and design it accordingly.

For rock tunnels, the load is estimated as being equivalent to a certain thickness of loosened rock overhead, depending on the dimensions of the tunnel and the quality of the rock.

Years ago, that method worked fairly well. If the tunnel required temporary steel support, the steel ribs were usually supporting the ground satisfactorily before the concrete lining could be placed. So, as long as the concrete adequately protected the ribs from damage or corrosion, it was generally satisfactory regardless of its structural capability.

In deep tunnels through poor quality ground, the foregoing rules didn't work. The builder would run into squeezing ground that required re-mining, additional support, and various other expedients. But again, by the time he was ready to place the concrete lining, he had already stabilized the ground.

More recently, the use of rock bolts has, in many cases, eliminated the need for temporary steel supports. Again, when the final concrete lining is placed, the ground is already stable. If the rock bolts have been fully grouted, they can be considered permanent, and all the concrete really has to do is protect the ends of the rock bolts and the rock surface between bolts. And since six or eight inches is about the smallest lining thickness which can be satisfactorily placed behind forms, a highly sophisticated method for designing the lining is unnecessary.

Now, the rules of the game are completely changed. We have a substance which can be applied to the excavated surface immediately after exposure. Frequently, it eliminates the need for any temporary steel supports. In other cases, supplemental rock bolts may be necessary. How can the designer dimension this support system and how can he assure himself that his design is indeed adequate?

The behavior of the excavated opening supported with shotcrete, together perhaps with rockbolts, depends primarily on the in situ rock pressures, the effective physical properties of the rock mass, and the dimensions and physical properties of the shotcrete-rockbolt combination.

Since the relevant effective physical properties of the rock mass depend partly on the size of the tunnel, they cannot be measured in laboratory samples. However, we do have means for measuring some of these properties in situ, and we have means for estimating the value of others. Thus, we can choose parameters for design which, although admittedly inaccurate, at least permit a rational approach to the problem.

We can also calculate the stresses and strains in the structure, or the behavior of the completed tunnel opening, using formulae developed by investigators of rock mechanics theory. The advent of the computer has, in addition, given us more sophisticated solutions, such as the finite element analysis.

But, given inaccurate design parameters and unproven behavior theories, we still need some means to evaluate the performance of our design. Fortunately, we have this capability. We can measure the movements, deflections, and strains in the completed opening and in the surrounding rock. We can measure the pressures on the shotcrete lining, and we can calculate the stresses. This in turn will allow us to reevaluate our original design criteria and its application to our problem.

To summarize, if we are to successfully meet today's challenge to our industry, we must give our designers the benefit of all of the knowledge which can be gained from past studies and continuing observations.

In our competitive society, the success or failure of any product or any process is, in the final analysis, determined in the marketplace. Technically, it may be great to devise a technique whereby a few inches of shotcrete and some rock bolts do the work of heavy steel supports and a thick concrete structure. But if this new technique doesn't reduce the total cost, we cannot justify its use.

Our tunnel builders must devise methods for getting the shotcrete in place with a minimum of lost time to the tunnel progress. This requires detailed planning, especially for smaller tunnels. Materials handling in confined quarters becomes a major problem. Remote-controlled equipment may be dictated for safety or other reasons.

Specifications and bid schedules must be written so as to not unduly favor some particular tunnel technique versus another. The Contractor should have an incentive to use the method which has the best ultimate potential for the Owner.

I am convinced that we need a permanent organization to gather and disseminate information on the design, instrumentation, and construction of underground shotcrete structures--a nonprofit organization, similar to the American Concrete Institute, dedicated to the public service.

Two of our participants, Dick Robbins and Skip Hendron, are members of Standing Subcommittee No. 2 of the U. S. National Committee on Tunneling Technology. Perhaps they could sound out their Subcommittee about getting funding to help organize and launch such an Institute.

This conference is a great way to focus on our problems and to create the kind of interest to solve them. We have a wonderful slate of participants and a tremendous attendance. I'm sure you will all absorb a lot, but I hope this is only the beginning.