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SESSION 14 — GENERAL REPORT

TUNNELLING

Reporter
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In this General Report I shall discuss the papers in the alphabetical order of authors' surnames in which they appear in the Conference program.

BANG presents a simple "number-crunching" exercise on a simplified model. He uses other authors' (Korbin & Brekke's) model study, which utilized model material having properties not necessarily characteristic of real in-situ materials.

There seems to have been only one finite element analysis performed, and it gave good agreement with the corresponding model test. The conclusion that the developed model is effective seems overstated, and the author states that further comparisons with model studies are necessary to validate his computer program.

The possibility of using this program as a design tool to design spiling reinforcement systems seems remote. The author seems content to use it to study the results of model studies, and the ultimate aim seems to be to develop an elegant computer program, as an intellectual exercise.

SCHMIDT gives a summary of the routine commercial practice of the design of tunnel linings (which he seems to distinguish from the broader concept of the "design of tunnels" i.e. the consideration of the stability of both the tunnel and the surrounding medium). He gives a summary of simple mathematical models, applied to simplified tunnel geometries, in idealized materials under simplified stress states.

It is very much the approach of a commercial consultant designer, who has to submit a "low bid" for the number of hours to be spent on designing a tunnel, using a calculator rather than expensive computation time on a large main-frame computer. Also implied is a minimum of determinations of soil properties, so that "average" soil properties are to be used in the design.

The final section of the paper addresses the problem of the real world - the variability of the properties of earthen materials, and of the ground stress and ground water conditions. SCHMIDT outlines some of the conventions used by American tunnel constructors, and concludes that thousands of tunnels have been successfully constructed almost in spite of the inadequate design procedures. As he says: "tunnel linings only provide a helping hand; most of the tunnel support is provided by the soil itself". This at first seems paradoxical, if one thinks that the task of a tunnel lining is to prevent the ground from failing and filling or obstructing the tunnel. However, SCHMIDT is apparently considering a tunnel as a conduit for transporting fluids or vehicles through the soil. SCHMIDT answers the question posed in his title in an oblique way. It would seem that he says that the simplified theories outlined by him are mostly brandished like talismans by tunnel constructors, who actually build their tunnels according to long-established practices and rules of thumb. The fact that most tunnels do not fail can be taken as implying that the tunnel design theories do work, even if few detailed quantitative predictions made by such theories can be confirmed by in-situ measurements.

SINCLAIR & ANDREWS make use of the term "tunnel" to mean a conduit, like SCHMIDT appears to. They present a computer simulation of "flotation" uplift effects in conduits immersed in saturated soft clay or sand media. This a similar problem to that examined by MOORE & DIGHT in their paper presented to the 3rd Australia - New Zealand Conference on Geomechanics in Wellington in 1980. It is a pity that SINCLAIR & ANDREWS did not refer to this or other previous work in the field, unlike MOORE & DIGHT, who did quote several other previous workers on the same or similar problems.

MOORE & DIGHT used a simple analytical approach, based upon Terzaghi's theory of arching. They backed this up by scale model testing.

SINCLAIR & ANDREWS also start with the analytical approach derived from Terzaghi's theories, but with a somewhat more sophisticated geometry of potential failure paths than considered by MOORE & DIGHT. They then use a recently developed finite difference program to model what appears the configuration of a planned field project, with the aim of testing the validity of the simpler analytical methods.

Presumably this could be done by:

(a) assuming a configuration, and soil properties, which analytical methods would indicate would be just stable;

(b) assuming a configuration, and soil properties, which the analytical methods would indicate would be just unstable;

(c) computer modelling both cases, to verify the analytical methods by observing "elastic" or "failed" movements in the ground.

If SINCLAIR & ANDREWS followed this approach, they did not report it in this paper. They present some interesting displacement vector diagrams, and displacement versus time plots for 2 unstable runs, but do not say what "analytical" Factors Of Safety were calculated for these or other runs. Their Conclusions imply that some such calculations were made, and it would be interesting to see their results.

The overall conclusion is that the simple analytical methods may be used as a first check against uplift failure, but if conditions are critical (presumably when the calculated Factor Of Safety is only slightly above 1.0) more rigorous methods should be used.

SINCLAIR & ANDREWS do not provide any correlations between their calculations and computations and any physical measurements from scale models or prototype conduits. The computer plots appear very convincing, and correlations between them and the behavior of real or model conduits are awaited with interest.

TRUSCOTT & DAVIDSON present an interesting case study of the intentional (i.e. not inadvertent) destruction of a tunnel, a topic almost diametrically opposed to the remainder of this Tunnelling Session 14. There are several points of interest in the paper, with regard to excavation planning, monitoring of vibrations caused by construction equipment, and completion of the excavation.

The points of most interest to tunnellers, however, would include the observation that the tunnel lining, constructed of sandstone blocks, had only irregular contact with surrounding rock, and therefore could provide little, and unreliable, support to the rock. Voids up to half a metre thick and several metres long were found to exist between the lining and the hard rock.

This could be regarded as yet another illustration of the consequences of the old-fashioned approach, still evident in the papers on design of tunnels in soil, that the lining of a conduit exists more to keep the contents in than to keep the surrounding medium out. I have referred earlier to SCHMIDT'S comment that " tunnel linings only provide a helping hand; most of the tunnel support is provided by the soil itself". Such a philosophy sits uneasily with the practice of constructing expensive, continuous tunnel linings inside a cavity, with an irregular, imperfectly defined zone of air- and water-filled voids and/or loose and disturbed ground between the lining and the solid ground. While such a high-integrity, high-cost tunnel lining may be justifiable to keep valuable liquids inside a tunnel, or water out of a tunnel, the good-looking, labour-intensive masonry tunnel linings of past days are now seen as having little value - of not being cost-effective by today's standards.

The concept that the lining has to strengthen and reinforce the rock, by being intimately bonded (almost "welded") to it is an integral part of modern rock tunnelling concepts, such as the New Austrian Tunnelling Method. It does not yet seem to have become axiomatic to all designers of soil and soft ground tunnels.

The two papers by WHITTAKER and his colleagues demonstrate a very different approach to that of SCHMIDT and the other authors dealing with tunnels in soft ground.

WHITE, HASSANI, & WHITTAKER describe another step in the progress from numerically describing the behavior of earthen materials in terms of some theoretical concepts or failure criteria, towards numerically describing them in terms of their actual, observed behavior. This observation may seem trite and obvious (it's virtually a "motherhood" or "flag" statement to prefer the second alternative over the former) but it has been only during the last decade or so that servo-controlled testing machines have permitted the observation of the complete stress/strain behavior, up to and beyond failure, of rocks.

A few tests to destruction have inadvertently occurred in prototype structures in situ, and a small proportion of these has been monitored so that some aspects of the post-failure behavior have been elucidated. The ability to be able to perform statistically significant numbers of tests to destruction, under controlled conditions of confining stress and strain rates, has greatly opened up the ability for geomechanics to be experimental (rather than merely descriptive).

WHITE et al describe their experimental equipment and some test results, and demonstrate the capacity of the work which they have started to significantly improve the validity of calculated closures of tunnels in failing or yielding rocks above the validity of the estimates obtained by using the semi-empirical equation derived by WILSON in 1980.

WHITTAKER, BONSALL & SMITH describe an interesting new method of designing circular tunnels by an approximation method. The method can be regarded as intermediate between the mathematically rigorous (but geologically unreal) closed-form solution for a circular opening in uniform material, acted upon by a hydrostatic stress field, at one extreme, and the finite element approximate solution, which can be made geologically realistic, but which can be too costly, in taking too much computer time per solution, to allow the modelling of many different geomechanical configurations. The finite element method allows completely arbitrary shapes, horizontal to vertical stress field ratio, and distribution of types of materials.

WHITTAKER et al consider the last ability to be the most valuable, and their method treats a circular tunnel in a hydrostatic stress field. It has a flexible ability to cope with many different strata elements, with different failure criteria, and allows the effects of weathering, tunnel size, and support strength to be varied. Their sketches show the distribution of computed stresses and displacements, and the shape of the zone of yielding rock, for a sample demonstration.

Four monitored tunnel cross sections are compared with calculations by the earlier WILSON formula and the new method. The latter is impressively accurate, being an average of -1.4%, or -20 mm in error in its predictions, as compared with errors of -23%, or -226 mm, obtained by using the WILSON method. Both methods, of course, give estimates of closures in real rocks, which would be virtually impossible to obtain by the traditional analytical methods developed two decades or more ago.

I consider that the "rational" approaches demonstrated by WHITTAKER and his colleagues give us leads into the future which are challenging and respectable from both scientific and engineering viewpoints. They show that it will be possible to design tunnels from first principles.

What will be required are:

- adequately discriminatory and reliable geological characterization of the rock mass to be tunnelled through;
- adequate sampling;
- an adequate amount of mechanical testing of samples, using good equipment, such as is now becoming available;
- computation of sufficient typical cross - sections, using realistic geological and geomechanical information.

Using this approach a tunnel may become an adequately engineered structure. It will entail spending more money upon investigation and design - even, shocking to contemplate, sums approaching half as much as is currently spent upon litigation and arbitration to apportion the blame and costs involved in the consequences of the present inadequate investigation and designs.

In contrast, SCHMIDT describes the "conservative" approaches, based upon simplified and therefore largely unrealistic models of material behavior, and a lot of extrapolation of past practices, which it is fair to say have been largely successful - though perhaps more costly and less flexible and efficient than they need have been.

For a deliberately provocative and exaggerated comparison of the 2 approaches consider the following analogy :

A car is being driven along a narrow and twisting road at night. The driver is blessed with excellent hind-sight, in the form of powerful tail lights and a well polished rear vision mirror. Forward illumination is provided by candles, but as time passes the driver is learning to fashion sheets of Alfoil into increasingly efficient reflectors, to throw the candles' light in a beam ahead or toward corners.

Question : As he enters the S-bends should the driver continue to gaze into the rear vision mirror, and extrapolate from past experience (the "conservative" approach) ? Or would he be better served by looking forward to where he will be, and try to improve his lanterns and his foresight (the "rational" approach) ?

I expect that my preference and recommendation are implicit in the loaded way that I have posed the question.