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General Report Session No. 6: Case Histories of Geotechnical Engineering and Rock Engineering

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Case Histories of Geological Engineering and Rock Engineering

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INTRODUCTION

This session on case histories in geotechnical engineering deals with applications in rock materials. The eight papers come from six countries around the world. The papers are varied in nature, including surface slopes and underground openings, support requirements, instrumentation, mathematical modeling, and subsidence. The range of rocks is from very weak to those for which no problems are expected.

SARDAR SAROVAR PROJECT

Two of the papers relate to the Sardar Sarovar Project in India. The project includes an underground hydroelectric power station and associated tunnels. The rock is basalt intruded by dolerite dikes and silts, and is dissected by fractures, faults and shears.

The first paper, by Prakash and Sanganeria, discusses the support requirements for the main cavern, access tunnel, drift tube tunnels, and exit tunnels. In these various locations the types of observed failures were block falls, wedge failures, roof collapse, and water seepage. Support selection was based on rock mass classification systems developed by Barton and by Bieniawski. Support requirements were continually assessed as construction proceeded. Rib support was required on tunnels passing through slaked dolerite dikes and sills having faults and shear zones.

The second paper, by Verman, Jethwa, and Goel, is concerned with wall support in the main cavern, which is 210 m long, 23 m wide and 57 m high. The geologic section is shown in Fig. 1. There is a 1 to 2 m thick shear zone running across the cavern width. Since the cavern was so high (57 m), it was necessary to consider special wall support requirements for this shear zone.

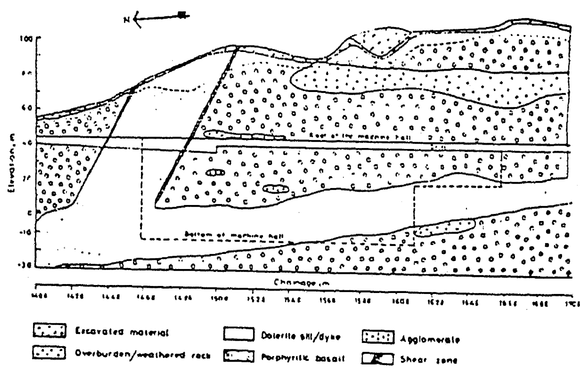

Fig. 1. Geological L-section along the cavern

It was decided to base the wall support design on the roof support requirements for a stable and safe support of the cavern roof.

The roof support requirements were developed using four methods, generally known as Cording, U.S. Corps of Engineers, Hoek and Brown, and Barton methods. Barton's method appeared to be the most reliable in this case. This method was then used with confidence to design the wall support system. The final wall support system consists of 85-mm thick shotcrete, with 10-m long rock bolts tensioned to 10 tons. A square bolt pattern was used, with a 1.6 m spacing near the shear zone and a 1.75 m spacing elsewhere on the walls.

CLASSIFICATION AND TUNNEL DEFORMATION

The paper by Chern, Chang, and Lin relates tunnel deformation to rock mass classification. The site is the western foothills to the southeast of the Taipei basin in Taiwan.

Rocks encountered were sandstone, interbedded sandstone and shale, and tuff. Six support designs were employed, using rock bolts, shotcrete, wire mesh, and steel ribs. Two common rock classification systems were used, the CSIR rock mass rating (RMR) and the NGI-Q system.

Tunnel movements were correlated with rock quality as measured by these two systems. Four measures of tunnel deformation (Fig. 2) were employed. Scatter in the results did not permit finding a relationship between tunnel movement and rock quality defined by the RMR and NGI-Q rock mass classification systems. The wide scatter in the results is believed to be due to variations in geologic structure and in-situ stress conditions between the measurement stations. The author suggests normalizing the uniaxial compressive strength with the in-situ stress to improve the correlation.

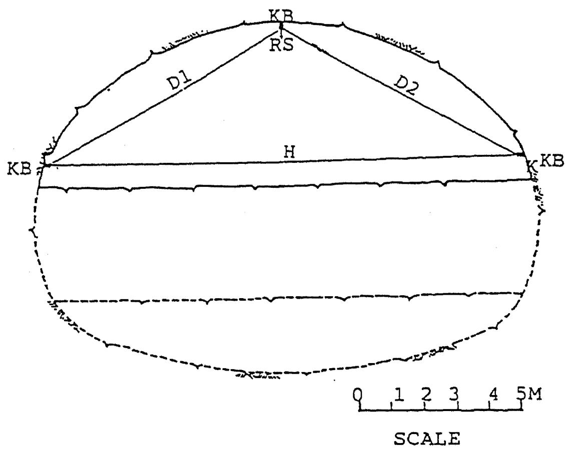

Fig. 2. Typical section of the tunnel

UNDERGROUND INSTRUMENTATION

The authors Yuanyou and Hongweh, from China, have developed a new instrument for measuring the deformations around large diameter tunnels and large openings as are common around underground hydroelectric projects. The new instrument is particularly useful when there is danger of rock falling on the person making the measurement. The concern is that existing instruments require going into unsafe areas to install and read the instruments.

The new instrument is similar to a tape extensometer, except that the tape is replaced by a 1-mm diameter stainless steel wire anchored on one end. The other end is attached to a tension meter in the measuring head (Fig. 3). With a threaded nut, the wire is stretched until a predetermined force is registered on the tension meter. The position of the end of the threaded rod is measured with a micrometer. The reading head of the instrument is located in a safe place. The far-end anchor point is located on the opposite side of the opening, which may be in danger of collapse.

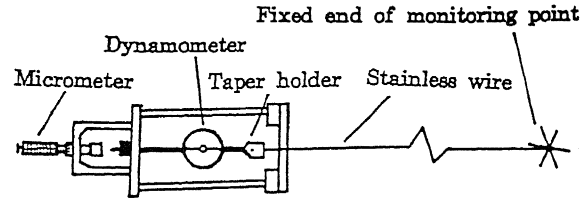

Fig. 3. Sketch map of the improved contraction gauge

Once the instrument is installed, a person does not need to venture across the opening to take a reading as he would with a normal tape extensometer. The value of the new instrument was demonstrated by its use on an underground hydroelectric project. At the site the upper rock stratum is fractured limestone, underlain by shale and siltstone. By using this method, eight different collapse events were successfully predicted.

BOUNDARY ELEMENT ANALYSIS

A boundary element numerical analysis was performed by Makedon on a diversion tunnel in the Platanovrisi dam in Greece. The analyses include stress analysis and stress failure analysis, including structurally controlled failure modes.

The rocks are metamorphic, including gneisses, mica-schists, marbles, and amphibolites, interrupted by granitic formations. The field investigations included aerial photography, detailed mapping of the dam area, petrographic analysis, determining the extent of fracturing at the surface and underground, and determining the degree of weathering and water conditions.

For the stability analysis, the rock was assumed to be elastic and isotropic. The horizontal field stress was assumed to be 1x and 0.33x the vertical field stress six cross sections were analyzed (Fig. 4).

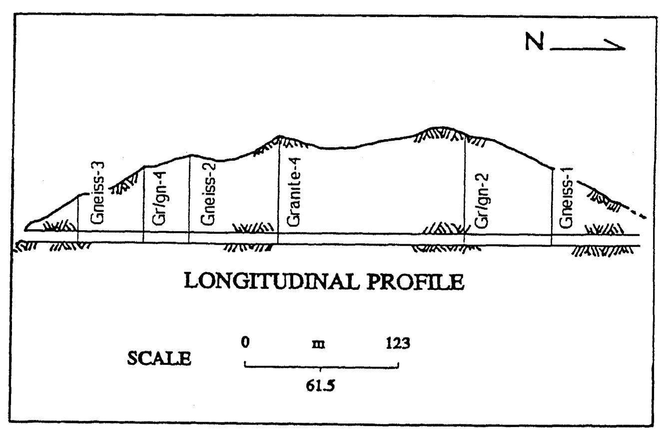

Fig. 4. Longitudinal profile of the Platanovrisi Diversion Tunnel

The primary conclusion is that the Platanovrisi diversion tunnel will encounter optimum geological and tectonic conditions. The rock mass along the tunnel profile is good quality, and the tunnel can be driven with low mechanical disturbance.

SLOPE MONITORING

The paper by Ruigeng, Yuanyou, and Wenxing considers monitoring a slope in very weak rock during construction. The slope is in a gully below the Qingjiang hydroelectric plant. The profile of the slope and the locations of instrumentation are shown in Fig. 5. The slope height is approximately 50 m above the floor of the gully. The rock is soft and weak shale and sandstone, which is jointed.

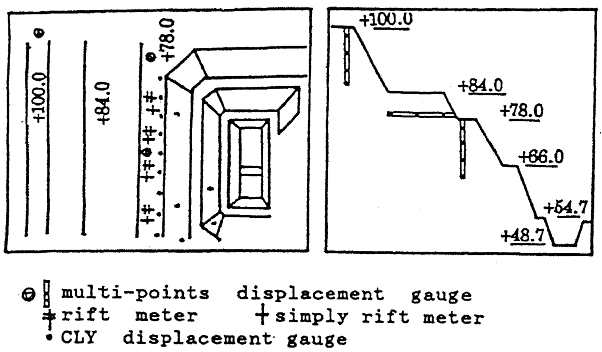

Fig. 5. Sketch map of slope's plan, section and instruments installed

The stability of the slope was monitored during construction. Instrumentation consisted of vertical and horizontal multi-point extensometers, and rift meters (Fig. 5). The results showed that quick cutting and quick erecting are extremely helpful in maintaining a stable slope during construction.

Monitoring results were used to make sure that the slope was not in an acceleration state when the concrete hydroelectric structures were erected. There was a factor of safety less than 1.0 during some phases of slope construction. During the creep phase, concrete placed at the bottom of the slope was very effective in improving stability.

SURFACE SUBSIDENCE

The paper by Nguyen, Braham, and Durup considers the surface subsidence over a series of solution mined salt cavities in the Tersanne field in France.

The overburden is primarily clay and other soft rocks. The salt bed is 1000 m thick and is underlain by a rigid sandstone bed. The salt cavities are 1500 m deep and 150 m below the clay cover. Solution mining which created the cavities ceased in 1983 with 14 cavities over an area of 3 km^2. Surface subsidence has been monitored over an area of 15 km^2 for the last 10 years. Underground cavity closure was also measured. The maximum rate of subsidence is approximately 1 cm per year.

The two-layer problem (Fig. 6) was solved by the finite element method. The two layers were contrasting in that the clay cover was assumed to be soft elastic material, and the salt was assumed to be a viscous mass.

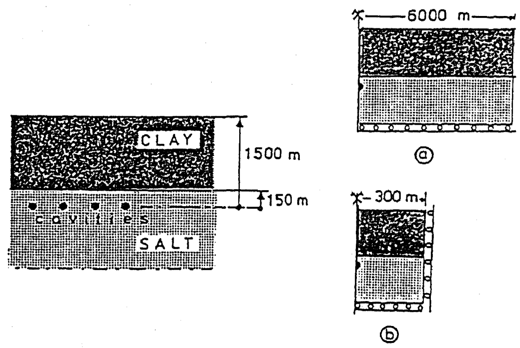

Fig. 6. Simplified two-layered medium
a) single cavity
b) unit cell for an infinite cavity array

The finite element problem was solved in two stages. First, a global calculation gave good precision for the zone surrounding the cavity, including the interface trough between the salt and the clay. Second, the displacements of the interface determined in stage one were prescribed on the bottom of the clay layer, which is presumed to be elastic.

The parametric study showed that for the clay cover layer, Young's modulus is the most influential parameter. Overall, the properties of the clay layer are of secondary importance to those of the underlying rock salt. The field measurements showed a 60% volume loss (subsidence to cavity) which was explained primarily as being due to the compressibility of the host rock and to the initial stress state.

FOUNDATIONS ON SWELLING ROCK

Problems with building foundations on swelling rock were discussed by El-Sohby and Bahr. The site is on a college campus in a newly developed area northeast of Cairo, Egypt. Urbanization and construction on normal alluvial deposits sometimes results in structural failure. The topography is undulant, with 35 m relief at the campus site.

The materials at the surface are marine and terrestrial sediments. Also at the foundation horizon are medium to hard laminated silty clayey shale, sandy silty clay, and medium to hard clayey sandy shale. The clayey shales have low water contents and medium to high swelling potentials.

The foundation was on plain concrete piers 1 to 2 m in diameter and resting on clean sand, after penetrating the clayey layers.

Cracks between structural elements in the building began to appear within a few years after completion of construction in 1968. The degree of crack damage increased with time. The damage is documented by a number of photographs in the paper.

To restore the building, an excavation was made next to the building so that the footings could be examined. It was found that in some places the footings had separated from the top of the underlying concrete piers by as much as 15 mm. Shrinkage of the clayey shales due to moisture deficiency had caused the pier to pull away from the footings. Several laboratory investigations on this type of clayey shale show that it has a high swelling potential. The analysis has shown that the primary problem was not with the original design, but rather the topography allowed water to run and collect around the building and seep down into the clayey shale. The shale then swelled and lost much of its strength, allowing the foundation to become unstable. Over the years, lack of maintenance has also contributed to the problem in the form of water leakage from the drainage and water supply systems.

DISCUSSION QUESTION

In these eight papers, two rock mass classification systems are mentioned, the CSIR rock mass rating and the NGI-Q system. Also, four methods are used to determine underground support requirements, as follows:

a) Cording's method
b) U.S. Corps of Engineers method
c) Hoek and Brown's method
d) Barton's method

Would the authors present, or anyone else present, like to comment on their experiences, good or bad, with any of these systems or methods?

ACKNOWLEDGEMENT

The author of this General Report wishes to acknowledge that the figures contained herein have been taken directly from the respective author's papers.

ADDITIONAL CASE HISTORIES from Vol III
(by Roy E. Hunt)

Five additional papers were included in Volume III, bringing the total papers presented for Session VI of the conference to 13. In Paper 6.17 (L.M. Tyrala) the explorations for a landslide complex in Turkey are described and conclusions regarding its extent are presented. Slide movements and evaluations of risk to a proposed reservoir were not discussed.

Predictions of deformations during excavation of a large cavern in good quality dolomite for a hydro-project in China are presented in paper 6.18 (Yang et al). Roof loads, estimated from Finite Element modeling based on data obtained from a test tunnel, are reported to have obtained good predictions.

A concrete arch dam bearing in fresh granite incorporated a grout curtain and drains in its foundation. During reservoir filling crest displacements were monitored with pendulums. Finite element analyses predicted dam movements in good agreement with those monitored. The project was located in China and presented by Yonglian et al in Paper 6.19.

W. Harsh in Paper 6.20 presented the use of a "mixshield" tunneling machine to excavate a 11.6 m diameter railroad tunnel in the Alps. In soft sedimentary rocks an open face TBM was used to advance the tunnel, and when glacial soil deposits were encountered a closed slurry face was employed on the same machine. Harsh points out the importance of construction procedures to maintain the slurry face and avoid ground collapse when advancing through stratified soils below the groundwater table.

In Paper 6.21, Eswaraiah et al describe the use of grouted rock bolts to support walls and roofs of caverns excavated for a hydro-project in India. Geologic conditions included granite gneiss and schist with dolorite dikes.

SUMMARY and CLOSING REMARKS

It appears that many practitioners are using the Finite Element Method to model deformations and stresses for major works in rock masses including tunnels, caverns and arch dams. The major problem in the application of the FEM is to properly characterize the rock mass quality in terms of stratigraphy and defects, and engineering properties. Information gathered from explorations are very limited.

Most practitioners characterize the rock mass in terms of some rating system with either or both the Geomechanics (CSIR) or the NGI systems being used. Both systems appear to have limitations. The CSIR system considers intact rock strength which can vary from "hard" to "soft" but is not detailed in its characterization of "joint" characteristics and other defects such as residual stresses, whereas the NGI system is detailed in its joint characterization and provides for residual stresses, swelling and squeezing rock but does not provide for intact rock strength and deformation.

What is needed in geologic and rock engineering is an internationally and uniformly accepted rock mass classification and rating system (RMR) that characterizes rock masses as completely as practical and is applicable to foundations and slopes, as well as tunnels. A uniformly accepted RMR will provide the basis for documenting and recording deformation and strength criteria obtained from full and small scale field testing and monitoring which can be applied to problems in similar conditions based on correlations.