INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

Investigating Residual Metamorphics for Tunnels

Investigation des Roches Décomposées Metamorphiques pour Faire un Tunnel

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SYNOPSIS Deeply weathered metamorphic rocks underlie many U. S. cities. The transition zone between residual soils and rock often occurs at the depths where subway tunnels must be located. Adequate technical description of the highly variable transitional materials requires not only the traditional approaches of soil and rock mechanics but also qualitative descriptions in which the behavior of the material under the action of excavating tools is judged and described.

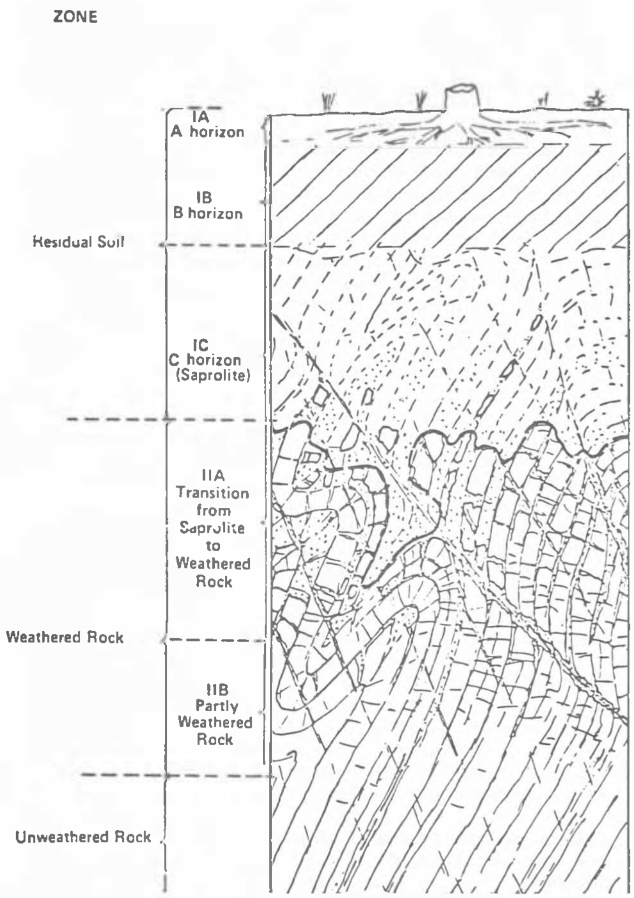
INTRODUCTION

The eastern seaboard of the United States is largely underlain by pre-Cambrian metamorphic rocks once exposed to a long period of weathering. In many areas coastal plain deposits consisting of Cretaceous sediments blanket the weathered rocks. A thin mantle of more recent materials may be found near the surface.

In the northerly part of the coastal area glaciation has removed surficial material including the products of rock weathering of the pre-Cambrian metamorphics. To the south, however, the Cretaceous is often underlain by a complete weathering profile consisting of residual soils, a transition zone of variably weathered materials with soil-like properties, and finally rock exhibiting slight to negligible signs of weathering.

Many cities are located on the Fall Line, a zone marked by waterfalls and rapids where the coastal plain sediments lap onto the basement rocks. The power that could be developed at the Fall Line encouraged the establishment of mills and factories around which the cities grew. Today beneath these cities the transition zone of weathered materials is often found precisely at those depths most suitable for the construction of subway systems and large interceptor sewers. Consequently, recent subway systems in Washington DC, Atlanta, and Baltimore have been constructed at least partly within the transition zone.

The properties of residual soils and transitional materials have been investigated over a period of years with respect to the design and construction of foundations (Sowers 1963). Suitable techniques have been developed for dealing with foundation problems in spite of the inherent variability of the materials. Tunneling, however, has raised an additional problem: how to describe and characterize the materials, particularly of the transition zone, so as to convey to designers and potential constructors of large tunnels a proper conception of the behavior of the materials that



after Deere and Patton, 1971

Fig. 1 Weathering Profile for Metamorphic Rocks will be encountered. Resolution of the problem suggests that qualitative descriptions of the materials may be as necessary as quantitative measurement of their physical properties. This situation arises principally from the variable nature of the transitional materials.

WEATHERING PROFILE IN METAMORPHIC ROCKS

The significance of the weathering profile with respect to engineering activities was brought forcefully to the attention of engineering geologists in connection with deeply weathered granite in Hong Kong (Ruxton and Berry, 1957). In their masterful paper on slope stability in residual soils, Deere and Patton (1971) described the typical weathering profile for metamorphic rocks and classified the profile into three principal zones, Fig. 1. They pointed out that the transition zone, IIa, lying between the saprolite above and the partly weathered rock below, is the seat of many engineering problems largely because it is characterized by a great range in the physical properties of its components. According to Deere and Patton, these components "vary from soil-like materials to rock-like corestones. Corestones make up 10 to 95 percent by volume of the transition zone. The weathering has taken place more rapidly along the pre-existing joints and faults and along lithologic units that are more susceptible to weathering. The soil between the corestones is a medium to coarse sand which can be relatively clean, or silty and micaceous. This zone is commonly very permeable and water losses are often noted by drillers . . ." Deere and Patton define corestone as the ". . . term used to describe an unweathered or partially weathered rock core or remnant of a former larger joint-bounded block of weathered rock". Difficulties in tunneling are obviously related to the size of the corestones with respect to the size of the tunnel, the resistance of the corestones themselves, and the strength and pattern of occurrence of the weaker materials between the corestones. These weaker materials may or may not possess at least a trace of cohesion.

Deere and Patton's diagram, Fig. 1, suggests that corestones are likely to be more or less equidimensional. Subsequently, in describing conditions along the Glenmont Route of the Washington DC Metro System, Patton (1974) recognized that the shape of the unweathered or slightly weathered elements in weathered metamorphic rocks might tend to be lenticular as a result of the banding of the parent rocks, and also as a consequence of dikes and other elongate features. He described these elements as "harder pockets or bands of more rock-like materials".

Although all natural deposits are variable to greater or less degrees, a specific physical property can usually be characterized adequately by its mean value and some statistical measure of the variation from the mean. In the transition zone, however, the variability itself becomes, with respect to tunneling, a significant if not the most significant property. This fact should be taken into consideration in any program of exploration for tunneling, and should be reflected in the documents prepared for information of the bidders.

ADEQUATE DESCRIPTION FOR TUNNELING

Unfortunately, contract documents for tunnels, at least in the United States, have traditionally contained only two bid items for tunnel excavation: earth (or soil), and rock. This simplistic view has led to many misunderstandings and much litigation. Once a contractor has committed himself to a method of tunneling and to his tools for excavating, whether for soil or rock, changes are costly. Mixed faces, wherein unquestioned soil overlies unquestioned rock, have justly earned a reputation for difficulty and high cost. Yet, tunneling in the transition zone of rock weathering, where the materials are in fact neither soil nor rock, is potentially more fraught with uncertainties. Hence, it becomes even more important and difficult to describe the material at a given site. The prospective bidder needs to know what equipment he can expect to use to excavate the materials, and what the support requirements will be. Should he use a shield? If he uses a shield, can it be pushed ahead of the face or must an excavation be made into which the shield can be advanced? What will be the most efficient means of excavating? Will blasting be required? Will predrainage, grouting, or compressed air be required? Would a slurry-faced or balanced-pressure machine be feasible?

For materials possessing at least a trace of cohesion, a useful indicator of tunneling methods and difficulties is often the unconfined compressive strength. In the transition zone, the unconfined compressive strength would indeed be useful if maps could be prepared showing in detail the variation of strength over entire successive faces of the advancing heading. One could then determine the location and dimensions of the hardest materials, judge whether they would interfere with advancing a shield, and select effective excavating tools. One could also determine the strength and distribution of the weakest, soil-like, constituents, judge the tools necessary to excavate them, and most importantly judge whether excavation of the soft materials would permit overlying hard blocks or elements to fall or to be pried into the heading. Even though the rock-like elements, such as corestones or bands, might appear too hard for excavation with earth equipment, it might prove unnecessary to attack them directly. Thus, the compressive strength (or the lack of any cohesion) of the weaker materials surrounding the blocks might be at least as significant as the strength of the hard blocks themselves. The dimensions of the blocks relative to the size of the heading would be key factors in governing whether excavation could proceed by attacking the soil-like materials, undermining the larger blocks, and allowing them to come into the heading.

Decisions of this sort are crucial to determining the kind of equipment and estimating the rate of advance of the proposed tunnel.

Yet, by boring, sampling, and testing, it is economically and practically impossible to develop a sufficiently detailed pattern of the compressive strength of the deposit to permit reaching such decisions. Hence, although boring, sampling, and testing would be necessary to define the general boundaries between the zones and would provide knowledge of the range of compressive strengths, such a program could not provide the necessary information about the pattern of strengths of the materials to be encountered. This pattern, reflecting not only the variations in strength but the approximate dimensions of the rock-like and soil-like elements, must be known in at least a general way before construction.

To provide the necessary information, the quantitative data so characteristic of soil mechanics needs to be supplemented by qualitative descriptions based on visual observations in large test pits, test shafts or nearby excavations, or on references from other nearby projects in essentially the same geology. In many instances the most significant information obtained in the entire exploratory program is the verbal description. Consider, as an example, the description in the contract documents of residual materials on the Baltimore transit system:

"The residual materials were formed through processes of weathering and chemical decomposition of the parent rock formation and usually exist as a gradational weathering profile.

"Those materials which have decomposed to the degree where they have lost their visible remnant rock structure or have been reworked following partial decomposition and have characteristics which suggest relation to the underlying materials are designated Residual Soil (RS). The major or total component of this material is soil-like, although it may contain rock fragments, most of which are friable. This material does not usually exhibit remnant rock structure such as schistosity or relict joints. Standard Penetration Tests in this material may have a wide range of results greater or less than 100 blows per foot.

"Residual material designated as Residual Zone #1 (RZ-1) is considered transitional between Residual Soil and the less decomposed Residual Zone #2. It consists of material derived from the in-situ decomposition of the parent rock with soil-like components and partially weathered and/or fresh rock components. RZ-1 material usually retains some cohesion of the parent rock and exhibits visible remnant rock structure such as schistosity and relict joints. Materials in this zone can normally be sampled with soil sampling techniques. In most, but not all, cases the Standard Penetration Test results are greater than 100 blows per foot.

"In a few cases, RZ-1 material was cored to provide a continuous sample. The material in the RZ-1 zone and its constituents, when the material is disaggregated by hand or using mortar and pestle, are described as soils.

"Residual Zone #2 material is rock-like, being derived by partial decomposition of the parent rock with partially weathered and/or fresh rock components. This material, in-situ, usually retains rock structure and considerable strength of the parent rock. The RZ-2 material is commonly heterogeneous with respect to weathering ranging from decomposition throughout the entire body to partial decomposition throughout the material. This material cannot usually be disaggregated by hand and is described with rock descriptions, notation of soil-like matrix or filler when appropriate, and a notation of the RZ-2 designation. Material in this zone usually requires rock sampling techniques to obtain specimens from boreholes.

"It should be noted that although the residual materials have been categorized by the aforementioned criteria, the transitions between RS, RZ-1, RZ-2 and Rock are frequently not sharp boundaries as may be inferred from the boring logs. Also, one or more zones may not be present above the basement rock at all locations. The interface between RZ-2 and Rock does not imply that decomposition has not occurred below this level. The effects of decomposition are highly variable and the assignment of materials to a specific residual zone is judgmental."

To clarify the distinction between the "soil-like" RZ-1 and the "rock-like" RZ-2, the geotechnical data furnished to the bidders as part of the contract documents contain the following additional comments concerning RZ-1: "Our evaluation . . . indicates that it will tend to act as a very hard, very dense, slightly cohesive to cohesive soil throughout most of the zone and be removable by power hand tools. However, there will be areas of unpredictable but lesser extent of partially weathered and/or fresh rock materials which may require other means of excavation".

Verbal descriptions of this type may be more meaningful than the results of a series of tests. It would indeed be difficult in the residual materials to which the preceding description applies to select appropriate samples for tests or to determine the most appropriate types of tests. Nevertheless, the formulation of accurate verbal descriptions for some formations requires careful laboratory and field work including tests. When suitable descriptions have been developed, however, they are invaluable in two respects. They are the best means of conveying to all parties an accurate conception of the kinds of materials likely to be encountered, and they define the zones along the tunnel route where quantitative data are needed. In short, such descriptions incorporated in a geologic profile assist the engineer in judging what specific problems may be encountered at different locations, in determining what more specific exploration is required, and in deciding what approaches have the best possibility of giving quantitative data that may be necessary for design or construction.

"The more "soil-like" portion of the transition zone, categorized as RZ-1 in the Baltimore documents, contains much material so weathered that it can be disaggregated by hand. The disaggregated constituents can be subjected to classification tests and classified in accordance with the Unified Classification System.

Commonly, they fall into the ML, CL, SC and SM categories. However, to classify the RZ-1 materials primarily on the basis of the UCS would be misleading because the behavior of the intact weathered materials is radically different from that of its disaggregated constituents. By categorizing the materials first as RZ-1, attention is called to their residual and transitional nature. The UCS designation, added as a supplement, does not then convey an erroneous impression.

As pointed out by Deere and Patton, the transition zone is commonly permeable and water losses are often noted by the drillers. The seat of the permeability is the highly weathered soil-like matrix which often is cohesionless or only feebly cohesive. Even modest seepage through this matrix may render the face unstable by initiating raveling which may develop rapidly into a flow. Control of the seepage is essential. Yet the matrix is highly variable with respect to both geometry and permeability, so that complete dewatering is difficult or impracticable and chemical grouting problematical. Compressed air, on the other hand, has been highly effective in stabilizing the face and minimizing settlement.

Investigation of permeability by tests in drill holes is useful, but inferences concerning seepage and its effects on tunneling are at best uncertain. In both Washington DC and Baltimore, a deep test shaft was excavated to permit description of the materials, to assess the efficacy of predrainage, and to judge the influence of seepage on the materials. The shafts proved to be valuable in the early stages of the projects. As actual tunneling experience was acquired, need to rely on the shaft data diminished.

CONCLUSION

As might be expected, neither the traditional soil-mechanics approach of boring, sampling, and testing, nor the traditional rock-mechanics approach of drilling, coring, and identifying and describing joints and shear zones is fully adequate or appropriate for the truly intermediate or transitional materials ranging from residual soils to partially weathered rock. Techniques must be borrowed from both disciplines. Of equal importance with sampling and testing by soil-mechanics techniques is geological field work in the vicinity to determine patterns of jointing, shearing, and weathering. All data obtained in these fashions should be presented in the bid documents. At least as important, moreover, are qualitative descriptions in which the behavior of the material under the action of excavating tools is judged and described. Verbal descriptions, necessarily involving interpretations, and therefore necessarily subjective, seem nevertheless to be essential ingredients in attempting to portray the significant tunneling features of these materials.

Although both soil mechanics and engineering geology have made great progress in recent decades by virtue of becoming more quantitative, much of value remains in qualitative descriptions.

The essential aspects of the variability of the transition zone can at present be conveyed more successfully through careful descriptions and interpretations than by quantitative data alone.

ACKNOWLEDGMENTS

The verbal descriptions and classification for the Baltimore subway were developed by the Robert B. Balter Co., General Soils Consultant for the project under the guidance of the General Consultants Daniel, Mann, Johnson & Mendenhall/ Kaiser Engineers, and with the assistance of Dr. Tor L. Brekke and the writer. The descriptions and classification are considered to be applicable to the local conditions only, and are not intended as a general model.

REFERENCES

Deere, D U & Patton, F D (1971). Slope stability in residual soils. Proc 4th Panamerican Conf, (1), 87-170, San Juan.

Ruxton, B P & Berry, L (1957). Weathering of granite and associated erosional features in Hong Kong. Bull Geol Soc of Am (68), No 10, 1263-1291.

Patton, F D (1974). Preliminary engineering geology study, Glenmont Route, Sections B009, B010, and B011, Washington, DC Metro System.

Sowers, G F (1963). Engineering properties of residual soils derived from igneous and metamorphic rocks. Proc 2nd Panamerican Conf, (1), 39-62, Sao Paulo.