Designations of Excavation Characteristics for Materials Identified in Field Investigations

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This paper describes a system whereby geologic materials could be categorized according to their excavation difficulty during preconstruction field investigations and defines designations of excavation characteristics for each of the types of materials. It is based on the premise that geologic formations, by their very nature, have rippability characteristics that are traceable, and thus predictable, from one locality to the next. The information obtained within right-of-way limits as a part of geologic mapping would be supplemented by numerous closely spaced auger borings. Examples of road and drainage excavation costs in various geologic environments and of costs of field investigations relative to total project costs are given.

In recent years many legal questions about representations of subsurface conditions relative to the design and construction of transportation facilities have arisen. The entire June 1972 issue of the NCHRP Research Results Digest was devoted to the subject (1). In it, the problem was summed up as follows:

> Contractual representations of subsurface conditions to be encountered in highway construction, which prove to be incorrect after the contract has been let and work has begun, frequently become costly burdens on highway construction programs and even serious impediments to the orderly course of planning and development.

As a result of such problems and the growing number of cases that have gone to litigation, government agencies have become more and more reluctant to reveal all that they know about the subsurface at a given site, and plans and specifications that do contain subsurface data are often accompanied by statements disclaiming guarantees of the accuracy of the information that is supplied. The thinking seems to be that the less information that is furnished concerning conditions at a construction site, the less likely is the possibility of being held liable for misrepresentation. However, while disclaimers and policies that disallow or discourage the inclusion of all available subsurface data may be one way of attempting to avoid litigation, nondisclosure, or failure to provide all of the available information, may be just as contestable in court as information that is incorrect.

This paper discusses some of the factors that may have caused the increasing number of legal problems associated with subsurface investigations and offers suggestions as to how they might be resolved or minimized.

ROOT OF THE PROBLEM

Aside from the fact that the states are weakening in their claim of sovereign immunity, there are a number of reasons why misrepresentation suits are increasing. One reason may be traced to the building boom that began soon after World War II and reached its peak in the last 15 years with the construction of the Interstate system. In the rush to prepare projects for contract, there was simply not enough time to investigate the subsurface in the necessary detail. There has also been a tendency to cut short investigations and handle unforeseen problems arising during construction with supplemental agreements, but while supplemental agreements are an expedient way of handling such problems, they usually result in greatly increased costs. They are also rarely to the advantage of the contracting agency in that they must be negotiated from a disadvantageous position.

Furthermore, soil engineering in its fullest definition did not gain significant acceptance by the highway construction industry until about the middle 1960s. Contractors and construction engineers, for the most part, have been inclined to view many aspects of soil engineering as impractical, too theoretical, and a deterrent to the mass production approach to grading operations. Even now, many individuals without training in soil mechanics or engineering geology tend to underestimate the frequently complex nature of the subsurface. In this regard, soil engineers and engineering geologists (geotechnical personnel)—because they are so few in number—have had difficulty in publicizing the virtues of their trades.

Another factor in all this is that subsurface investigations historically have been almost totally design-oriented. Information from such investigations that can be used by construction people is, in most cases, only a

Publication of this paper sponsored by Committees on Earthwork Construction and Exploration and Classification of Earth Materials.

by-product of the design work. This is a failing of the geotechnical personnel who have not geared their investigations to maximize construction information. Nor have they developed a language that can be understood by others. For example, a contractor who is told that he must move 250 000 m^3 (327 000 yd^3) of Bodine cherty silt loam, residuum from the Pennington shale, or even an A-7-6 with a group index of 25 may be no better informed than if he were told nothing at all. This communication problem, on the other hand, may be directly attributable to the role and position of the geotechnical staff in the total department operation, who may be so situated in the structure of the department that they cannot function to their fullest capabilities.

Still another reason is that subsurface investigations, if done correctly, usually require a large inventory of specialized equipment and a staff of technicians to operate it. Subsurface investigations, whether they be for deep mineral or petroleum exploration or for relatively shallow foundation studies, involve difficult, oftentimes complex, and always very dirty work. Furthermore, the work continues year-round. While construction workers may hibernate, so to speak, during the winter months, geotechnicians must continue their work to prepare for the next construction season. People who do this work and are good at it become harder and harder to find.

Subsurface investigations—to borrow terms from the medical profession—involve both diagnosis and prognosis. But since geotechnical engineering is not as precise, exacting, and predictable a science as medicine, a great deal more interpretation is required. This, then, is the root of the problem as well as the key to its solution. For, if wrong interpretations or no interpretations at all have created an increase in misrepresentation and nondisclosure cases, correct interpretations should result in a decrease in such cases.

IMPROVING COMMUNICATIONS

Part of the solution to the problem may be the development of a language or a method of depicting subsurface materials and conditions that is both design and construction oriented.

In this period of soaring construction and maintenance costs, it is more and more important that the contractor have as much advance information as possible about the soil and rock materials and the conditions at a construction site. This applies not only to highways but also to all types of civil engineering projects such as airfields, dams, canals, buildings, and reservoirs. For bidding purposes, as well as for scheduling and equipment selection, the contractor must be aware of any excavation and grading problems that may be peculiar to the conditions or materials at a particular site. It is incumbent upon the contracting agency to furnish such information, for, after all, how can a design be conceived and be considered safe and feasible to build, without knowledge of the subsurface? Such information, if adequate for the design, will in most cases be adequate for construction. There are times, however, when the area to be excavated may need more thorough exploration with conventional augering equipment, to further delineate variances that may affect the kinds of equipment and the time involved in the excavation process itself. It may be necessary to express or present this information in a different manner. While the designer may be interested in shear strengths and bearing values, the contractor may be more interested in moisture contents and rippability characteristics.

NEED FOR ACCURATE GEOLOGIC INFORMATION

It is not always possible to precisely determine excavation characteristics from subsurface investigations alone, but such investigations, coupled with experience in construction in various geologic environments, can be used to evolve fairly accurate interpretations. Geologic formations, by definition, have characteristics that are consistent from one location to another. These include strata thickness, color, structure, grain size, texture, topographic expression, associated soil types, and weathering characteristics. It is logical to assume that a given type of formation would also have similar excavation characteristics that would be predictable from one site to another. This, then, is a major premise in the applicability of the excavation designations proposed in this paper, for, in addition to a thorough auger-boring program, the geology of an area must be known if its subsurface is to be properly and accurately interpreted for construction purposes.

It is no doubt possible to develop an approximately quantitative approach to the classification of materials that is based on a gauged drilling resistance that could be correlated to the measured ability of that same material to be moved by various types and sizes of earth-moving equipment. There are so many variables in a scheme such as this, however, that it would probably be unreliable. The best approach seems to be a simple qualitative system in which numbers are assigned, based on field investigation and past observations as to the relative ease or difficulty of excavation of the various materials that constitute the particular geologic formation. Such a scheme includes only the materials; it does not include other factors such as terrain conditions and the type or deneseness of the vegetative cover. (If desired, these factors could be assigned values that would be added exponentially or in some other manner to the primary excavation difficulty value.)

In devising such a system it is necessary to begin by thinking in terms of the extremes in excavation situations, while at the same time considering the equipment and methods available for use in such excavations. In highway construction, the simplest major excavation is that which can be accomplished with a self-loading scraper. Relatively dry, loosely compacted silts and sands are the easiest and simplest materials to excavate. At the other extreme are the various types of solid rock that require blasting for removal: Unweathered granites and limestones are in this category. On a scale of 1 to 10, the dry silt and sand condition would be assigned a value of 1, and the granite and limestone, the essentially solid rock condition, would be assigned a rating of 10. The main problem, of course, is in deciding on the numerous combinations of materials and conditions that make up the eight other values between. Nevertheless, the following is an example of how a classification system of this type might be set up.

Excavation Index	Degree of Excavation Difficulty	Examples
1	May be easily scraped	Relatively dry sand or silt; some clays
2	May be scraped or bladed	Moist gravel, sand or silt; most clays
3	May be easily bladed or may be scraped with difficulty	Moist clay with minor—less than 25 percent—small disseminated rock particles; some highly weathered

Excavation Index	Degree of Excavation Difficulty	Examples
		shales; some organic materials
4	May be bladed with difficulty	Clay with moderate to heavy—25 to 50 percent—small disseminated rock particles, or with minor pinnacle and/or boulder content; some moderately weathered shales; colluvium with minor boulder content; sanitary landfill material; alluvial boulders
5	May be bladed with great difficulty; or may be easily ripped, dredged, or draglined	Clay with heavy disseminated to some bedded chert; slightly weathered shale; talus or colluvium with heavy boulder content; saturated clay, silt, sand, or gravel
6	May be ripped with some difficulty	Very slightly weathered shale; thin and slabby, disjointed limestones and siltstones; saprolite (rotten igneous or metamorphic materials)
7	Rippable with great difficulty	Thin-bedded chert with clay seams; thin-bedded limestone or siltstone with interbedded shale
8	Requires blasting (up to 25 percent)	Weathered granite, slate, and other igneous or metamorphic rocks; friable sandstone; medium- to thick-bedded limestone with cutters, or disjointed with clay or shale seams; soils with rock pinnacles or large boulders
9	Requires blasting (25 to 50 percent)	Hard shale; thin- to medium-bedded sandstone, siltstone or limestone with interbedded shale; soils with numerous rock pinnacles or large boulders
10	Requires blasting (greater than 50 percent)	Thin- to thick-bedded sandstone, siltstone, and limestone; granite, slate, and other well-indurated or fresh igneous, metamorphic, and sedimentary rocks

Each state or agency would have to prepare, more or less by trial and adjustment, its own criteria for the materials and conditions that would fall into each category of excavation difficulty. These categories would then be incorporated into the profiles and sections that are normally used to depict subsurface conditions (Figure 1). At some later time it might even be possible to standardize such a system, at least on a regional basis, so that contractors who work on projects in those areas could develop a more confident and consistent approach to bidding.

The creation and successful application of a classification system such as this will depend on the position, role, staffing, and overall competency of the geotechnical units responsible for field investigations. Correct interpretations will depend on a great deal of field work on the part of the professionals in the organization. Not only must the soils engineers and the engineering geologists be on hand during the drilling and sampling program, but they must also be constantly observing ongoing grading operations on nearby projects, noting and comparing the construction methods used and the excavation efforts required in the various geologic formations that occur in the area. They must also spend considerable time on the project once it has been let to contract to check the accuracy of their interpretations and to make adjustments and refinements in the system.

UNIT COSTS VERSUS SITE GEOLOGY

Many things go into establishing a bid price: the proximity, type, size, and location of the project, the number of projects being worked by the bidder, the specialty areas of the bidder, and the degree of competition are all important, but a principal factor, though it may not be consciously defined as such, is the site geology. This involves such things as the rock and associated soil types, the extent of weathering, the terrain and drainage conditions, and the structure (faulting, jointing, and direction and angle of dip of the strata). All of these are directly related to the ease or difficulty of excavation of the site and, thus, to the grading and drainage costs.

In Tennessee, as in most other states, the geologic structure may vary considerably over a given area, but, at least on a small scale, certain broad assumptions and predictions can be made about the excavation characteristics of the materials present in a given area. For example, Tennessee is divided into six major physiographic provinces; that is, there are six regions with their own distinct patterns of geologic structure, relief features or landforms, and climatic conditions. These are, from east to west, the Unaka Mountains, the Valley and Ridge, the Cumberland Plateau, the Highland Rim, the Central Basin, and the Coastal Plain as shown in Figure 2 (2). The Highland Rim, the Central Basin, and the Coastal Plain are often further subdivided, but for the purposes of this paper only the major divisions will be considered. The most complex province physiographically, as well as geologically, is the Unaka Mountains province. The least complex is the Coastal Plain. As might be expected, highway construction costs in the Coastal Plain province are significantly less than those in the mountainous province. Some relationships of physiographic areas, probable excavation indexes, and excavation costs for recent projects are indicated below.

Area	Excavation Index Range	Recent Costs ($/m^3)
Coastal Plain	1 to 5	0.84 to 1.33
Highland Rim	3.5 to 6	1.64
Central Basin and edges of Cumberland Plateau	3 to 9	2.22
Cumberland Plateau	6 to 7.5	2.03
Valley and Ridge	4 to 7	1.44
Unaka Mountains	5 to 10	2.62

This kind of correlation could be used as a reference for creating a classification system based on the excavation difficulty of specific geologic formations.

The next step would involve the collection of information about individual projects in each province according to the geologic formations that are traversed. This involves detailed surface mapping along the alignment, a detailed subsurface investigation program, and a comparison of the materials and conditions found along the alignment with those of nearby projects that traverse the same geologic formations that are traversed. This involves detailed surface mapping along the alignment, a detailed subsurface investigation program, and a comparison of the materials and conditions found along the alignment with those of nearby projects that traverse the same geologic formations. The subsurface investigation should be accomplished primarily with power augers. In some cases, geophysical methods may be used but only

Figure 1. Schematic of boring pattern in plan and profile.

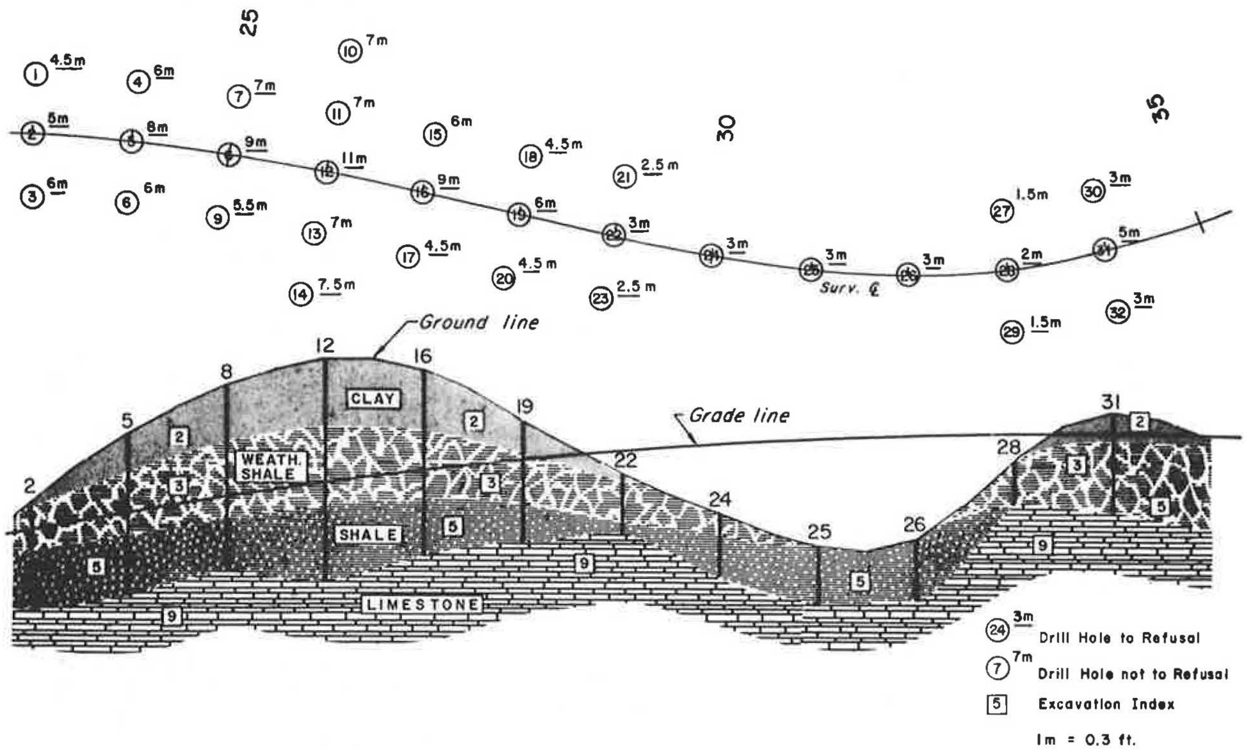
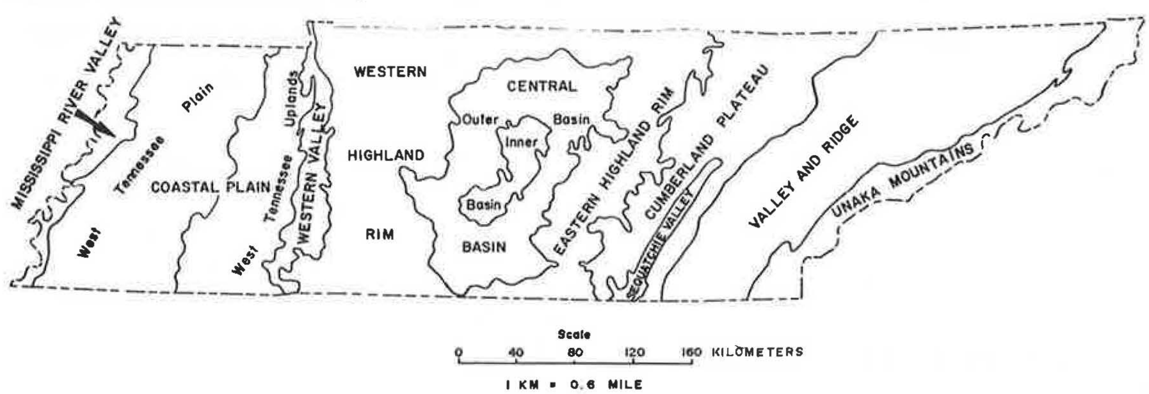


Figure 2. Generalized physiographic map of Tennessee.



to supplement the borings. The drilling should follow a pattern commensurate with the geology, terrain conditions, right-of-way limits, and proposed roadway gradient (Figure 1). In most cases, borings on 30-m (100-ft) centers will be adequate; however, there are times when 15-m (50-ft) centers or less will be required. This, again, will depend on the geology of the area and the degree of accuracy that is desired. Furthermore, occasional core borings may be required to further delineate variances in materials and conditions at a given site.

Samples for the determination of in-place moisture should be taken periodically by the standard penetration test method (AASHTO T206-74). The number of samples required for this will depend on the depth, width, and length of the interval to be excavated, as well as on the geology of the drilling site. An approximate rule might be to sample every fifth hole along the centerline. This procedure can determine not only the amount of moisture, but also the resistance to penetration by the sampler, which may be useful in developing designations of excavation characteristics for the project.

All of this information could then be depicted graphically in plan and profile (Figure 1), and typical cross sections, as well as detailed sections of the more complex areas, could be developed. The subsurface information displayed in this manner would relieve the contractor of the time-consuming chore of studying the boring and geophysical records and reports to make his or her own determinations of the materials to be excavated.

At first consideration, field investigations in this detail may appear to be too expensive of both time and money. However, the costs of overdesign or the sometimes catastrophic results of underdesign, as well as the construction problems that result from simply not knowing what to expect, make detailed site investigations the most realistic approach.

As a percentage of the total costs involved, the costs of adequate field investigations on most projects are not significant. This is especially the case when auger borings are the principal means of investigating the subsurface. Some typical cost examples are given below.

Example	No. of Holes Drilled	Total Depth Drilled (m)	Drilling Cost ($)	Percentage of Total Project Cost
1	298	915	8 400	0.34
2	309	1525	14 000	0.31
3	272	1186	10 900	0.30

In Tennessee, where almost all subsurface investigations are conducted by state employees, total costs, including all borings, samplings, analyses, and evaluations, rarely exceed 0.75 percent of total project costs, with most ranging between 0.35 and about 0.60 percent.

PREBID SITE INVESTIGATIONS BY CONTRACTORS

There is a trend, at least in Tennessee, toward fewer geotechnical investigations by contractors prior to bidding on highway construction projects. There are several reasons for this. The principal one is that the benefits are no longer considered worth the time, effort, and costs involved if a reasonable amount of information is supplied by the contracting agency. A forthcoming NCHRP synthesis on subsurface investigation practices by highway and transportation departments will indicate that at present only 15 to 25 percent of contractors make a geotechnical investigation prior to bidding. Of those who do so, most do so primarily to determine for themselves the rippability and general nature of the materials to be excavated.

It is logical to assume that most contractors would forgo the effort and expense of prebid subsurface investigations if they were more confident about the information furnished by the contracting agency. It is logical to assume that, the more subsurface information supplied, the more realistic and competitive the bids will be. A contractor would be more confident about bidding on projects for which the subsurface information was depicted in a manner similar to that shown in Figure 1. This should be reflected in road and drainage excavation unit prices: If excavation costs could be reduced as little as 1 to 5 cents/m^3, this would amount to hundreds of thousands or millions of dollars for all projects during a year.

CONCLUSION

Obviously, the more time, effort, and money expended on subsurface investigations, the more information will be gained, and the more information gained, the more appropriate and realistic will be the design. Further, the more information supplied the contractor, the greater will be his confidence and the more realistic will be his bid. This information, however, must be presented in a form that is oriented to construction. A classification system such as that described here would seem to meet this criterion. Such a system should help to close the communications gap that exists between the contractor and geotechnical engineers, and this, in turn, should reduce the number of misrepresentation and nondisclosure cases brought to litigation in the future.

REFERENCES

1. Legal Aspects of Representations as to Subsurface Conditions. NCHRP, Research Results Digest 39, June 1972.
2. Robert A. Miller. The Geologic History of Tennessee. Tennessee Division of Geology, Bulletin No. 74, 1974.