Geophysical Equipment Usage in the Wisconsin Highway Commission Organization

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The use of geophysical equipment by the State Highway Commission of Wisconsin is a relatively recent endeavor. With the exception of a few limited geophysical surveys made prior to World War II using a pioneer model resistivity apparatus, all comprehensive surveys have been made within the past three years.

The geophysical program presently employs one electrical resistivity apparatus and one single-channel refractive seismograph. In general, the combined use of two types of instruments provides more conclusive subsurface information. However, the inherent limitations of either method may restrict the use of one instrument or the other to a certain geological province.

The primary purpose of the geophysical program is to provide maximum subsurface information at the lowest possible cost. Realization of this objective has resulted in a reduction, in certain instances, of the number of hand and machine test borings necessary to supply the required subsurface information.

•GEOPHYSICAL SUBSURFACE exploration methods now in use in the Wisconsin Highway Commission are in an experimental stage with the main objective being to provide a maximum of generalized subsurface information at minimum cost.

The tools used by our geophysical unit are a resistivity apparatus and a single-channel refractive seismic instrument, each of which is a light-weight, self-powered, compact device. These tools are employed primarily to confirm the existence of and depth to bedrock in cut sections, and the probable degree of rippability of the bedrock. Other uses include determining the presence and extent of potential frost heave soils and the location and limits of potential aggregate deposits.

A resistivity device was built according to pioneer BPR plans in 1937 and used intermittently until the program was dropped during World War II. The results of that work are not clear-cut. In some areas results were good, but in others the device was not dependable. Resistivity work was not resumed until 1960, when new equipment was purchased and a full-time geophysical crew began operations on a statewide basis. The findings resulting from their various projects are described in the following report.

It is emphasized that we do not have all the answers by any means, and have much yet to learn. It has been found, however, that the use of these geophysical instruments can yield a large amount of generalized subsoil information, provided that the work is supervised by an experienced geophysicist who is cognizant of the local geology.

Currently, the geophysical unit is under the direction of a graduate geologist. The unit is a subdivision of the Soils Unit, Central Office Materials Section. All geophysical work is conducted by this subdivision on request from individual district offices. The results of the survey are sent directly to the parties requesting the investigation.

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GEOPHYSICAL EQUIPMENT IN USE

In view of the extensive amount of literature available from equipment manufacturers, only a general description of the equipment in use is presented here.

The resistivity apparatus used is a model 274M Michimo from Associated Research, Inc. Figure 1 shows the equipment as set up to take readings. Some of the accessories included are of our own manufacture. Both the Barnes Layer method (1) and the cumulative method (2) of resistivity plotting have been used with nearly equal results. The Barnes method, however, has proved to be more convenient.

Procedures followed in performing resistivity surveys are not completely standardized. Much depends on the geology of the site and the type of information needed. In general, procedures used follow the practices of other states and equipment users who have reported on the subject in miscellaneous publications.

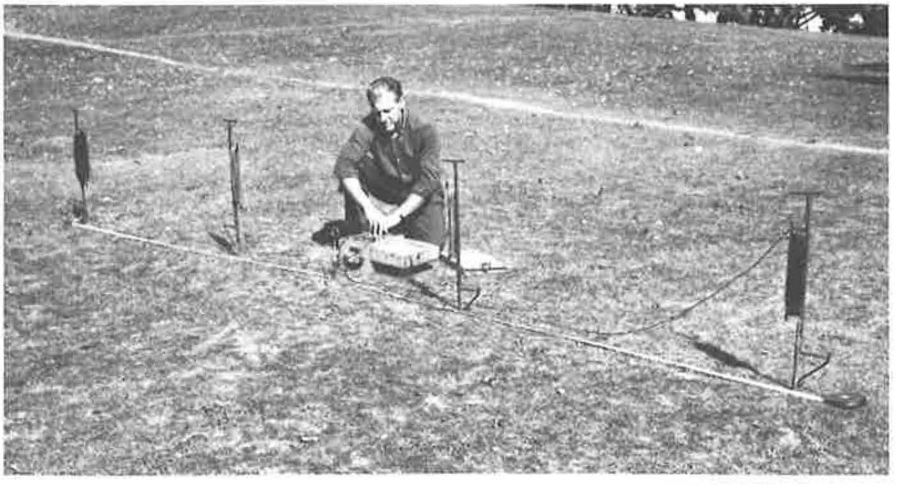

Figure 1. Resistivity instrument as set up to take readings.

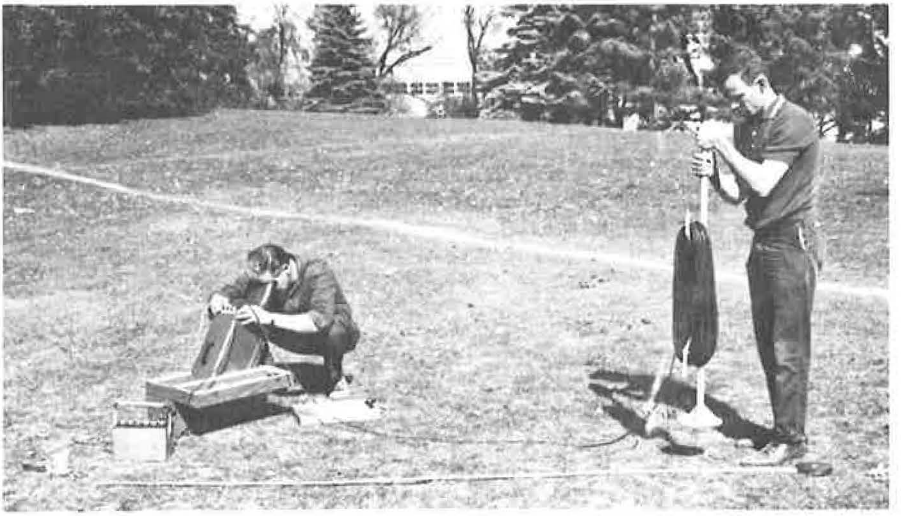

Figure 2. Seismic instrument as set up to take readings.

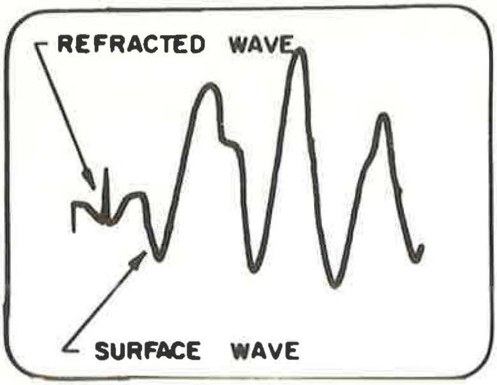

Figure 3. Typical waveform as observed in the oscilloscope of the seismic instrument; the marker is observed in the first trough of the waveform.

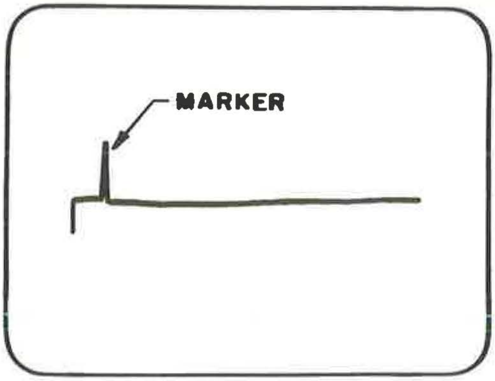

Figure 4. Straight line waveform illustrating the marker.

TABLE 1

MERITS AND LIMITATIONS OF RESISTIVITY AND SEISMIC APPARATUS[1]

Qualification	Resistivity	Seismic
1. Locates bedrock surface	Usually	Yes
2. Distinguishes between hard and soft sandstones	No	Yes
3. Detects soft layers beneath hard layers	Usually	No
4. Is affected by wind, traffic, etc.	No	Yes
5. Is affected by fences, buried cables, and overhead wires	Sometimes	Seldom
6. Differentiates boulder zones from bedrock	Usually	Usually
7. Locates water table		
(a) In soil	With difficulty	Usually
(b) In rock	Yes	Very difficult
8. Aids in determining rippability of bedrock	No	Yes
9. Usable in water saturated areas	Yes	No
10. Usable in frozen ground	Yes	No
11. Operates under wet or damp conditions	Yes	No
12. Locates suitable quarry rock	Possible[2]	Yes[2]
13. Locates suitable gravel deposits	Yes[2]	Sometimes[2]
14. Affected by uneven ground surface and uneven subsurface layers	Yes	Yes
15. Requires experienced operator	Definitely	Definitely

[1]Equipment discussed is Model 274M Michimo Resistivity Apparatus and an early model Terra-Scout seismograph. The limitations discussed herein pertain only to this equipment.
[2]Based on very limited experience.

The seismic unit in use is an early model Terra-Scout, a portable, single-channel seismograph. An improved model is presently marketed by Soiltest, Inc. Both models employ an oscilloscope to provide a replica of the sound waveform and to assist in timing the sound waves initiated by blows to the earth with a tamper. Figure 2 shows the seismic equipment as set up to take readings. Figure 3 shows a typical waveform as observed in the oscilloscope by the operator. The marker indicated in Figure 4 can be observed in Figure 3 at the first trough of the waveform when the operator has the instrument properly adjusted for a reading.

COMPLEMENTARY USAGE OF RESISTIVITY APPARATUS AND SEISMOGRAPH

In the last two years of operation, Wisconsin's geophysical unit has come to the conclusion that efficient use of available geophysical equipment in a manner to give conclusive subsurface data can be accomplished only when the operator understands the merits and limitations of each instrument. These merits and limitations, in addition to recognition of local geological details by an experienced operator, aid in selecting the instrument best suited for the intended purpose. Table 1 lists the various features of each geophysical method which should be considered in selecting complementary equipment, and indicates some of the advantages of such complementary usage for highway engineering subsurface investigations.

ADVANTAGES IN USING GEOPHYSICAL EQUIPMENT

Savings in cost result when geophysical instruments are employed in a carefully organized program of subsurface exploration in the preliminary stages of highway design. Geophysical methods provide generalized rather than specific information concerning the subsoils as contrasted to information obtained from borings. Geophysical data are usually verified by a few selected borings at each cut, and in this way provide the broad area coverage that could otherwise be obtained only by making many borings at a much higher cost.

Broad areal coverage saves time as well as money. Subsurface information can be obtained much faster by geophysical methods than by conventional methods of power or hand borings, and, in addition, the portability of the equipment permits rapid investigation of large areas.

Geophysical methods can be used to advantage as a preliminary to the planning and organizing of a boring program. Specific boring locations can be selected with greater accuracy by using generalized pictures of subsurface conditions obtained from preliminary work.

To summarize, from the standpoint of cost and speed of operations, geophysical methods far outrank other subsurface investigation methods normally used in our highway planning program.

DISADVANTAGES IN USING GEOPHYSICAL EQUIPMENT

Current policy requires that the geophysicist be thoroughly experienced in operating equipment and in interpreting data inasmuch as years of experience appear to be needed before an operator can interpret with some degree of confidence all of the data all of the time. Therefore, the geophysical instruments should not be used by different survey parties on an intermittent basis. In addition, the operator must have a working knowledge of geology. These limitations may be considered a disadvantage in the use of this type of equipment.

Due partially to Wisconsin's inexperience and partially to the inherent limitations of our geophysical methods and equipment, it is not possible for our geophysicist to interpret with confidence all data obtained. When major subsurface differentials (such as till overlying hard bedrock) are present, the interpretations are easily made and the results are quite dependable. On the other hand, when subsurface differentials are minor or inverted and contain silt pockets, wet layers, irregular weathered zones, or boulders, interpretations are difficult to make and the results rather undependable. Perhaps with added experience, confidence and accuracy will improve.

A disadvantage found occasionally when using geophysical instruments is the disturbing effect of cultural features, independent of geology, on geophysical data. Some of these effects are caused by overhead wires, metal fences, embankments or trenches, buried utilities, and the noises created by traffic and wind. These effects are seldom encountered but they are mentioned because they can interfere with operations, particularly in urban areas.

Finally, problems develop from breakdowns within the equipment itself. As with all electrical and electronic instruments, short circuits and tube failures will occur. Most of the troubles experienced in this respect have been electrical in nature with breakage of the lead wires or contacts common in the resistivity instrument, and slight electrical leakage shorting out the hammer circuit of the seismic instrument. Either of these items can decommission the instruments rather easily, and, although annoying at the time, are considered to be a minor disadvantage in that they seldom interfere with the overall performance of the geophysical unit.

TYPICAL ROAD CUT INVESTIGATION PROCEDURE

In Wisconsin each major road cut on planned highway projects is investigated by one method or another to determine the kind of material within the excavation limits. Most deep cuts are investigated by geophysical means together with a few selected borings. These deep-cut investigations are conducted to confirm the presence or absence of bedrock in the cut so that the excavation bid item can be properly designated. Also, as mentioned earlier, secondary features such as the location of silt pockets or seepage zones may also be investigated.

The geophysical phase of cut investigations consists of several parts. Initially, the area under investigation is studied in the office by the geologist, making use of geologic reports and maps, aerial photographs, well logs, and pedologic information to prepare a preliminary geologic report on the site. The geophysicist then lays out the field program, taking into consideration the advantages and limitations of the instruments in relation to local geology and the project requirements.

The field work is not standardized into a routine performance using a grid system or uniform spacing of geophysical soundings, but rather, is performed as the geologic features and project requirements dictate. For instance, when confirmation of the presence or absence of bedrock inproposed cut sections is required in an area of morainal ridge country with no known bedrock occurrences, only a minimum of geophysical work is needed. In an area of similar topography with known exposures and occurrences of bedrock, a more extensive geophysical investigation is necessary not only to determine the presence of bedrock but also to delineate contours of the rock surface.

Whenever possible in the initial stage of a project investigation, the geophysical apparatus should be operated over known subsurface conditions near the project location to provide data with which the project readings can be correlated. The known subsurface conditions may consist of outcrops, road cuts, previous borings, or well records.

A geophysical report including all the seismic and resistivity data, a brief description of the general geology, a summary of design recommendations, and any suggestions for locations of check borings, is prepared for the District Office requesting the survey. The report may be used as an aid in pedologic mapping, in making recommendations to the design section, or in any other specialized use as indicated in the survey request.

Most geophysical investigations in Wisconsin to date have been in proposed road cuts. However, a limited amount of work has included investigations concerning the depth of marsh deposits, the location of potential landslide slippage planes, potential sources of aggregates, sewer trench rock quantities, and dam foundation studies. Some work on the prediction of probable bedrock rippability has been completed, but no conclusive results are available yet.

ACCURACY OF GEOPHYSICAL METHODS

Because our recent geophysical experience dates back only three years, the number of previously investigated sites exposed by construction is quite small. Therefore, opportunities for checks on predicted subsurface conditions have been quite limited. However, on work which has been completed, it has been determined that the presence or absence of bedrock was correctly established in nearly all cases. The actual depth to bedrock was found to be within a few feet of the predicted depth in about 90 percent of the cases. In those instances where the anticipated depth varied by several feet, the rock surface was found to be irregularly weathered and quite uneven. No positive information is on hand to verify the accuracy of geophysical interpretations with regard to secondary features such as ground water elevations or silt zones.

At this time the range of accuracy to be expected from any particular geophysical investigation cannot be stated with confidence, but in general it appears that work accuracy is rather closely connected to the regional geology. By this is meant that certain geologic areas of the state are more conducive to geophysical methods than other areas. It would be expected, therefore, that accuracy will vary with the region investigated. Presently, there is too little data in this field to permit a more informative statement.

COST OF GEOPHYSICAL INVESTIGATIONS

In the early stages of any experimental program, developmental and research costs constitute a considerable proportion of total cost. Considering these expenditures, the cost for geophysical surveys has ranged between $0.50 and $1.50 per foot of depth investigated. Now that many of the preliminary programs are completed, this cost is expected to drop considerably.

CONCLUSIONS

It is emphasized that the statements in this paper are based on a limited amount of experience and must be interpreted in that light. It is encouraging that the use of geophysical methods in Wisconsin has proved rather successful. The cost factor also appears to be improving.

The experience in Wisconsin has shown the importance of obtaining geologic information during the planning of a geophysical exploration program. It has also brought out the merits and limitations of the various types of geophysical equipment presently owned by our department. Needless to say, experienced operators are a primary requirement if valid and economical results are to be obtained.

When properly supervised and intelligently planned, geophysical investigations for highway engineering purposes result in significant cost savings and provide a large amount of useful highway design and construction information.

Discussion

STEPHEN V. THOMPSON, Soiltest Inc.—Geophysical equipment has come into wide use for subsurface soil investigations in recent years. Much work has been done with seismic and resistivity instruments to complement conventional sample boring and test holes. Since relatively few papers have been presented in the technical literature, the authors are to be complimented for presenting information on operating characteristics of the types of instruments frequently used in this type of geophysical work.

The growing acceptance of geophysical investigation techniques has been helped by the relatively low cost of this type of investigation, the speed at which large areas may be covered, and the fact that investigations may be carried on in terrain which may be inaccessible to conventional drilling and sampling equipment.

Information obtained using geophysical methods is best utilized by comparing it with information obtained from actual test borings for correlation and check of the geophysical data. Also, geophysical techniques can help in the intelligent location of the actual test borings.

With use, operators of geophysical subsurface exploration instruments are finding more applications. For example, water table elevations can be determined over an entire site. Some highway departments have used the refraction seismograph for location of caves, limestone potholes and other subsurface openings which would affect the location of a highway route. Highway departments and quarry operators are using the new techniques for rapid and low cost location and evaluation of sand, gravel and stone deposits.

The authors place emphasis on the necessity of having highly qualified personnel operating geophysical equipment. This, of course, is desirable but it is difficult to find men who are so thoroughly qualified. Experience comes with use, and electronic equipment for subsurface exploration has found wide acceptance only recently. Engineers and technicians who have a knowledge of the subsurface soil in the areas in which they operate, can, with a relatively short period of training, do an effective job using the geophysical testing techniques. In some instances, only a few hours of training time has been required to equip personnel with enough information to operate the devices. Routine geologic and soil conditions can be evaluated by operators with a moderate amount of special training. Since most projects involve correlation with sampled borings, the geophysical data can be checked against actual samples. Interpretation of basic data and planning the field techniques, naturally, require additional experience and training.

When unusual geological conditions exist, even sampled boring methods can rarely be expected to give a complete picture of subsoil conditions. At best, a boring will give an indication of the material in the immediately adjacent area. These borings, when correlated with geophysical data will give a much broader picture and confirm the continuation or discontinuation of a stratum or condition. Thus, a boring program supplemented by geophysical exploration (or vice versa) leads to a more detailed soil profile without necessarily increasing the cost of the investigation and, in many cases, actually decreasing the overall cost.

To illustrate the effectiveness of the refraction seismograph subsurface exploration technique, Soiltest, Inc., has conducted demonstrations in 14 different countries. In most cases, the operator conducts the demonstrations without any previous knowledge of the subsurface conditions. It is requested that those arranging for the demonstration site have available data from borings which can be used for correlation and check once the geophysical subsurface exploration information has been developed. The degree of accuracy that can be obtained using the seismograph or the resistivity units, is, of course, dependent on the type of subsurface material encountered, the skill of the operator, operating conditions and the amount of geological information available for the area.

The authors present data on the cost of geophysical investigations. The basis of determination of cost is not defined and could be misleading. Actually, one traverse using geophysical methods can take the place of a number of borings to the complete depth. By using a cross-section grid, a complete area may be evaluated and subsurface data plotted. It would be difficult to assess the cost on the basis of so much per foot of depth investigated. The area covered should be related to the cost. Like sampled borings, the cost is also dependent on the type of materials encountered.

Borings and geophysical work should be correlated and complement each other, and it is unwise to attempt a comparison of cost on a per foot basis.

The very nature of the geophysical method makes it possible to cover a much wider area at less cost in less time. The data should be correlated to borings worked into the same exploration program.