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Geophysical Methods Applied to Community Planning

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ABSTRACT

This paper describes geological and geophysical methods which have been used in the initial stages of planning and development for a new community in suburban Buffalo. It will adjoin the campus under construction for the State University of New York. Information drawn by the authors from regional glacial geologic studies plus geophysical traverses over the site have provided architects with rapidly acquired yet reliable data on drift stratigraphy, depth to bedrock, ground water, and drainage conditions preparatory to more expensive, detailed engineering studies. Shallow seismic refraction profiles, which show bedrock 10 to 50 feet below the surface, were supplemented by over 80,000 linear feet of resistivity profiling designed to give qualitative data on the form of the overburden/rock interface. Taken together with scattered shallow borings, these data allow differentiation of areas most suitable for industrial sites, family dwellings, lakes, and green spaces. Furthermore, the data emphasize the poor drainage situation with which engineers will have to deal and the lack of aquifers in the overburden for lake or industrial water supplies. Such inexpensive preliminary studies undertaken in future urban development can greatly aid in management of the land resources.

Introduction

The development of urban areas by means of completely planned new communities is replacing some of the random, relatively unplanned expansion

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of urban areas. In addition, some existing communities are recognizing the need for a better master plan of development to improve the use of their land resources. Finally, the increasing pressures for urban expansion are forcing consideration of marginal lands and low quality sites. In any of these endeavors, it is important to have a knowledge of subsurface conditions in order to effectively locate and properly integrate all functional elements of the community prior to the more expensive, detailed engineering effort. For example, subsurface conditions influence differently the choice of preferred site locations for industrial plants, family dwellings, recreational lakes, and solid waste disposal facilities. Proper site selection depends on such factors as type and thickness of soil strata, depth to bedrock, ground water conditions, and drainage characteristics because development costs can be greatly affected by these factors. If changes in location are required after site work has started because of the discovery of unanticipated subsurface conditions, considerable additional engineering and development costs can be incurred.

The most commonly used method is soil boring which involves drilling a hole by some means and removing samples for inspection. This procedure, which typically costs \$5 to \$10 per foot, is too expensive to use for thoroughly covering a large area during preliminary exploration. It is necessary, therefore, to have some other means of interpolating between the few borings generally provided. The geophysical methods known as seismic and resistivity measurement provide the most economical means of subsurface investigation covering large areas of land. A high degree of reliability is possible when the geophysical measurements are correlated with information on geological conditions and an occasional soil boring. A study of this type, recently completed by the writers, will be described to illustrate how the techniques are applied, and the results which may be expected.

The site location is in the town of Amherst–a suburb of Buffalo. Here the State University of New York (SUNY) is constructing a new campus that is expected to eventually serve about 40,000 students. The growth of the surrounding region which is as yet thinly populated, will accompany occupation of this new campus, and projected population estimates suggest that present open land immediately to the north will develop into a community of about 80,000 people. To help plan and develop this new community, the State of New York has authorized its Urban Development Corporation (UDC) to be responsible for development of rental housing, private housing, recreational areas (including lakes, golf courses, and green spaces), and clean industrial sites.

The objectives in the described study for the UDC were to:

1. determine the thickness and character of the overburden soils;
2. compile preliminary information on the horizontal variations of the surface deposits;

3. indicate the features of the underlying bedrock;
4. determine the location and extent of ground water reservoirs for industrial usage and for recreational lakes.

Geophysical field measurements were accomplished during the late fall of the year, following compilation of general site geology. Detailed boring information from the adjacent SUNY campus site, sparse boring data from previous projects within the area, and supplemental shallow hand borings taken at some of the seismic test locations, provided checks on the reliability of the methods which were used in this study. The entire combined geologic and geophysical field study for an area of about 1,000 acres was completed in 10 days with a typical geophysical crew consisting of 6 persons. Over 80,000 linear feet of resistivity readings were obtained and about 38 shallow seismic determinations were made.

Geology

GENERAL FEATURES

The site of investigation lies on the 35 year flood surface of Ellicott and Tonawanda Creeks within the Salina lowland area of the Lake Ontario basin. The Salina lowland is an east-west belt of low relief developed by Tertiary stream erosion of the weak, gypsum-bearing beds which crop out between resistant questas of the Lockport dolostone (Niagara Escarpment) and the Onondaga limestone.

Elevations of the bedrock surface on the site vary between 560 and 525 feet above sea level with the lower elevations to the north and west. This low relief has been reduced even further in Late-Wisconsin glacial time by deposition of till, of glacial lake silts and clays; by silts and sands of early, post-glacial, Lake Tonawanda; and, locally, by flood plain silts. A few beach ridges formed at the southeastern corner of the area stand out quite clearly with only 5 to 15 feet of relief (Figure 1).

The sequence of sediment types on the site is reasonably uniform as suggested by the few scattered borings and by the results of the geophysical studies discussed in the following sections. Listed in their normal order of appearance beginning at the ground surface, the types can be generalized as shown in Table 1:

BEDROCK

The bedrock which underlies the site appears to be composed of dolostone or dolomitic limestone with varying amounts of interbedded gray shale and gypsum. Although there are no exposures on the site, data from boring logs,

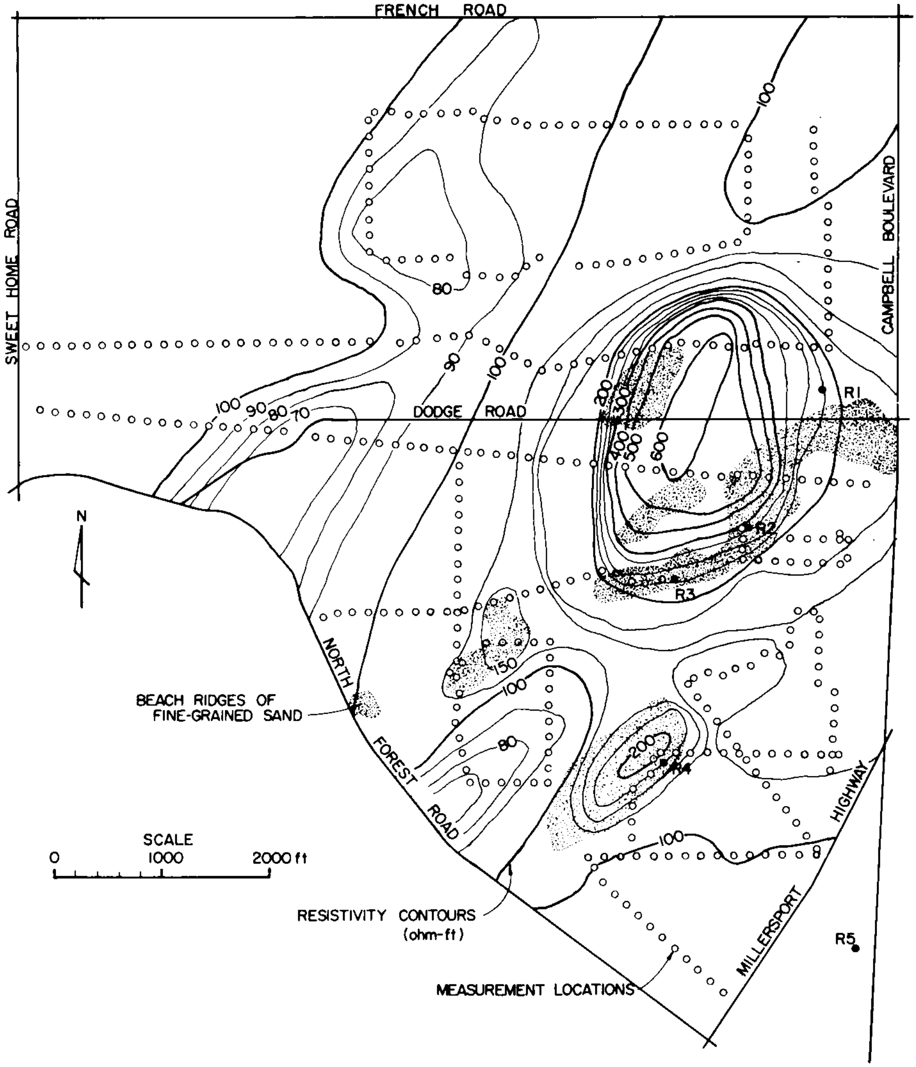

Figure 1. Resistivity contours determined from measurements at points shown using 50-ft electrode spacings.

the seismic velocity values, and information from the excavations on the SUNY campus site suggest that the dolostone belongs to beds of the Camillous Formation of the Upper Silurian, Salina Group. The section expected here includes 30 feet Camillous Formation, 180 feet Syracuse Formation, and 150 feet Vernon Formation Lockport dolostone. Fisher [1]

Table 1

Material	*Thickness, feet*
1. Sand, fine-grained, yellow	3 to 10
2. Silt and clay, red, brown or gray, very thin to massively bedded	9 to 30
3. Till consisting of silt and clay intermixed with gravel and sand, dark red to gray, compact	0 to 30
4. Dolomitic limestone	>5

did not distinguish the Syracuse and Vernon Formations from the Camillous in his correlation chart and the whole section is believed to consist of varying amounts of dolomite, anhydrite, and gray and green shales.

TILL

The presence of a lodgement till overlying the bedrock in at least part of the site is inferred from:

1. examination of available boring logs furnished by the UDC and the Town of Amherst which show "hardpan," or "clay with embedded gravel,"
2. by standard boring blow count* values between 50 and 250,
3. by the seismic information, and
4. by projection from nearby exposures.

The till is red-brown to gray, dense, unsorted deposit laid down at the base of the overriding Wisconsin glacier. It generally has a silty-clay matrix grading to sandy silt in a few areas and contains a significant per cent of gravel. Cobbles and boulders are also present in the till.

LAKE DEPOSITS–SILT AND CLAY

The thickest deposits on the bedrock are the red, brown, or gray, very thin-bedded to massive units of lacustrine silt and clay which are found over the whole site. They consist of greater than 75% silt and clay in varying proportions with a trace of sand and scattered pebbles (gravel). In many

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* Number of blows to drive a standard 2-inch sampling spoon 12 inches with a 14-pound hammer weight falling 30 inches each blow.

exposures the deposits consist of graded units (varves) less than 1-inch thick of gray or brown silts, grading up to fine red silty clay; however, thickly-bedded or apparently massive (non-bedded) units of silty clay up to several feet thick are also present.

Most of these deposits were laid down in glacially dammed Lake Warren III or successively lower glacial Lakes Gradsmere, Lundy, Early Algonquin, or Dana which formed as the ice retreated into the Lake Ontario basin 12,400 years ago [2]. Minor thicknesses of the top-most silty deposits were probably deposited into Lake Tonawanda [3]. This was a very shallow, but long, lake which formed between the Lockport and Onondaga questas by overflow from the Niagara River in early post-glacial times (12,000 to 10,000 years ago).

LAKE DEPOSITS–SAND

Nearly the whole site is also blanketed by a loose, yellow-brown sand containing 50% fine-grained sand with less than a few per cent of small pebbles (fine gravel). The sand, originally deposited as a delta of the adjacent Ellicott Creek into Lake Tonawanda [4], forms a relatively flat sheet between 6- and 8-feet thick in the northwest and slightly lower-lying portion of the site. At the higher elevation, the level of the former Lake Tonawanda border to the south, this delta sand was washed into beach ridges which stand 5 to 10 feet above the surrounding surface. The wave action which formed these ridges also scoured away much of the adjacent sand leaving the lake silts and clays at the surface.

Seismic Measurements

CONCEPT

Field seismic wave velocities of the soils and bedrock at the site were determined using a portable seismograph. A 10-pound hammer and plate were used as the energy source to create a seismic wave in the ground. A switch on the hammer triggered the seismograph at the instant of hammer impact. A geophone pushed into the ground surface some distance from the point of impact detected the wave form which was visually displayed by the seismograph. The wave travel time from hammer to geophone was determined directly from this record. This seismograph had the ability to sum the signals produced by repeated hammer blows. This was an important feature because it permitted the use of a low energy source, and helped eliminate errors from the random ground noise present in an urban area without having to use objectionable, higher energy sources such as explosives.

In operation, the geophone is fixed at a desired location, and the impact point is moved successively away from the geophone in a straight line. A

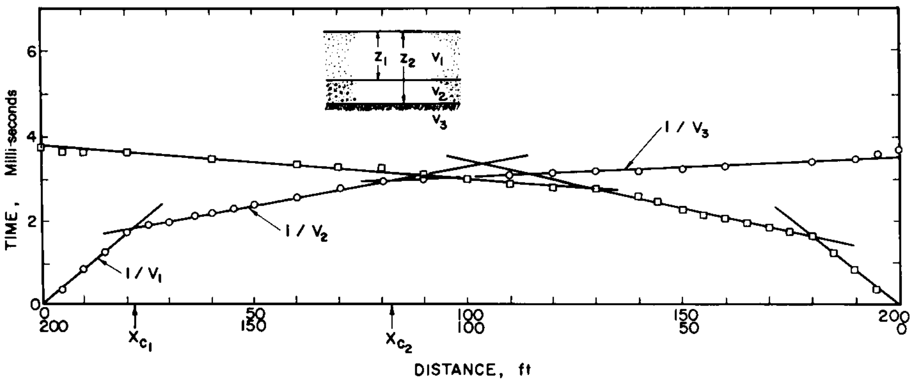

Figure 2. Typical graphs of seismic wave travel time as a function of distance showing forward and reverse traverses.

typical plot of arrival time versus the distance (T-X curve) between geophone and hammer impact point is shown in Figure 2. In general, the subsurface was uniform and the points on the T-X curves were well-represented by straight line segments. Seismic velocities for the individual layers were computed from the slopes of the lines.

The layer thicknesses are calculated from equations based on theory of wave propagation and refraction in layered media. For three-layer, horizontal strata, the thickness of the top layer (Z_1) is calculated from

$$Z_1 = \frac{X_{c1}}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

and depth to the top of the third layer (Z_2) is given by

$$Z_2 = 0.8\,Z_1 + \frac{X_{c2}}{2}\sqrt{\frac{V_3 - V_2}{V_3 + V_2}}$$

where V_1 is the velocity of the top layer, V_2 is the velocity of the intermediate layer, V_3 is the velocity of the third layer, X_{c1} is the distance to the first break, X_{c2} is the distance to the second break in the T-X plot (Figure 2). After the greatest desired distance X is reached, the geophone may be moved to the last impact point and the sounding process repeated in the opposite direction. This reverse profile (Figure 2) indicates whether the layers are uniform in thickness and also gives the dip of the strata.

Seismic refraction soundings were taken with geophone-to-hammer source spacings up to 300 feet. This spread distance was sufficient to locate bedrock depths at all of the seismic sites. Geophone-hammer spacings typically were increased in 5-foot increments up to a horizontal separation of 50 feet, then increased in 10-foot increments up to 100 feet separation and 25-foot increments beyond 100 feet. Reverse profiles were made at a number of sites.

RESULTS

The individual seismic profiles are shown on Figure 3. The soundings were made at the geographical location designated on the map by the position of the bottom of the seismic column except where arrows show the seismic test location. These seismic columns indicate the thickness of the layers, and depth to bedrock at each location. Most of the seismic profiles were composed of three distinct velocity layers; however, in several cases four velocity layers were observed. Data from available soil borings are also shown on Figure 3 for comparison. Figure 4 shows the general agreement between seismic data and boring results, considering the surface profile, for several locations around the site shown in Figure 3.

Universally, throughout the area, the top layer had a distinct velocity of approximately 1,200 feet/sec (fps). This upper 1,200 fps layer represents unconsolidated sediment composed of either unsaturated sand or clay. No significant difference in seismic velocities in this upper layer was encountered between areas underlain principally by the clay versus those underlain by the sand.

In most locations the characteristic seismic velocity of the second layer ranged from 4,500 to 5,000 fps in either sand or clay. Unconsolidated sediment saturated with water typically gives velocities in this range, since the velocity of sound in water ranges between 4,800 and 5,100 fps. Hand auger borings were taken which indicated that in most such cases a thin zone of saturated sand was encountered overlying the sand-clay interface. Thus, the calculated thickness Z_1 corresponds to the depth to the water interface rather than the lithologic contrast. The depth to the saturated zone varies considerably throughout the area, ranging from about 1 to 8 feet below the ground surface.

On the other hand, at several seismic sites, a layer with a velocity of about 3,000 fps was encountered below the top, typical 1,200 fps velocity layer, At these sites a medium clay composed the surface layer and no water was encountered in the hand auger borings. The 3,000 fps layer was underlying stiff clay which in an unsaturated state is known to give velocities of this magnitude.

At one seismic site, seismic velocities were as high as 7,000 fps in the second layer. Velocities of this magnitude may correspond to lodgment till which obviously would have undergone severe loading from glacial overriding. Till is recorded in most borings. However, the seismic determination did not

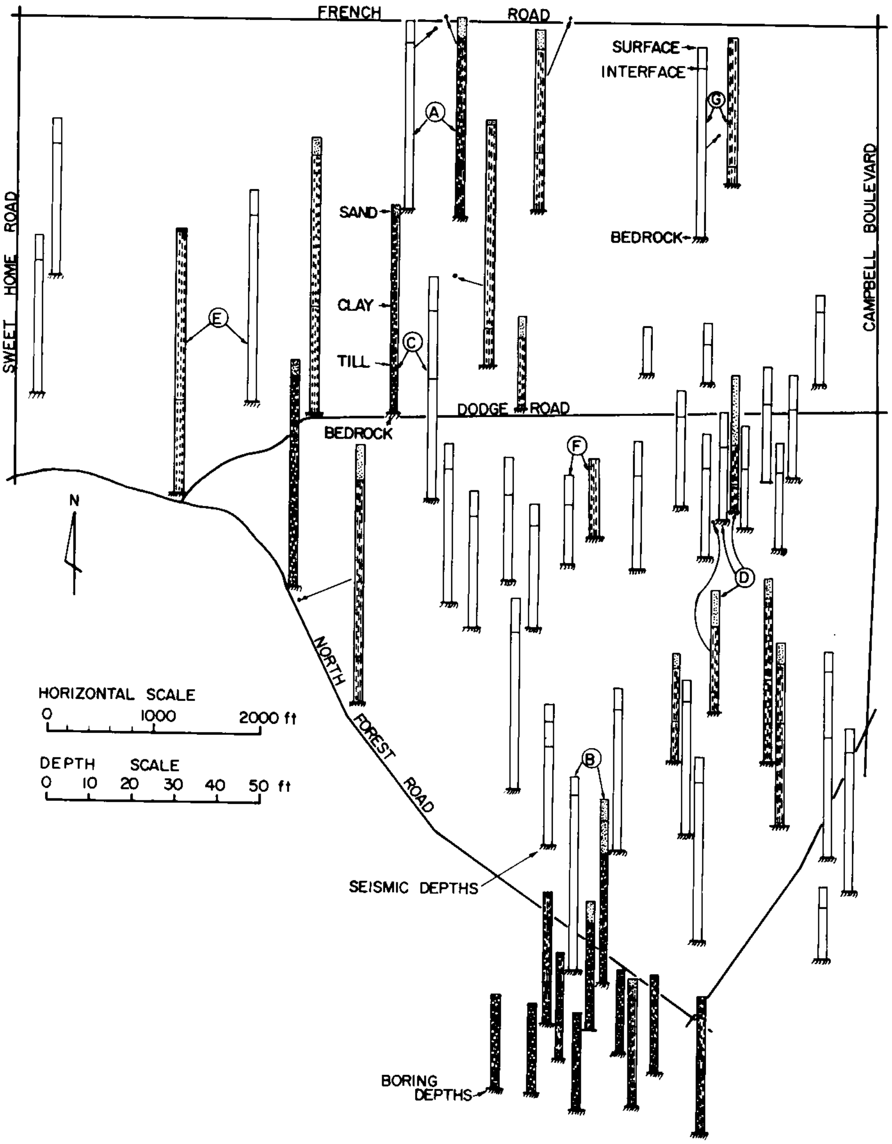

Figure 3. Depths to layer interfaces determined from seismic soundings and soil borings.

generally distinguish the clay-till interface in this area because the geophone-hammer spacing increments were not small enough at the distances which could detect the till.

Bedrock velocities varied from 8,000 to 16,000 fps. At most seismic sites

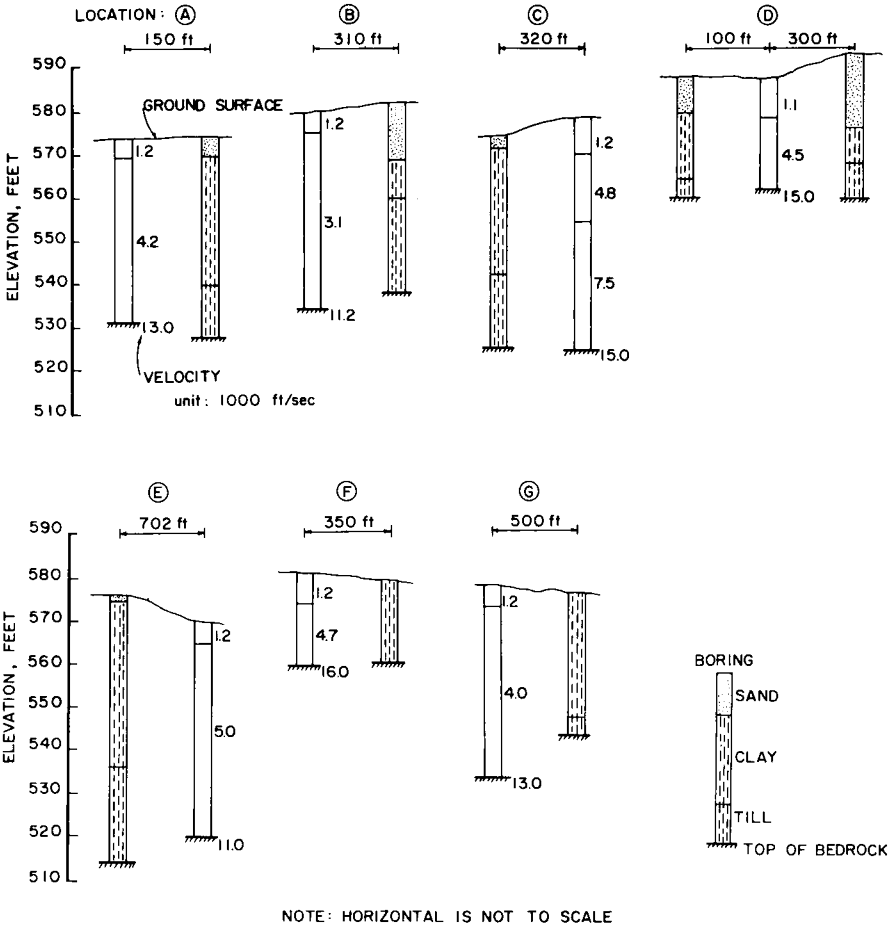

Figure 4. Correlation between seismic data and boring logs at comparable locations shown in Figure 3.

14,000 fps seemed to be typical. The low bedrock velocities (8,000 fps) may be caused by fracturing in the upper surface or by solution cavities. Although there were no test borings to confirm this conclusion, similar reported velocities for bedrock from the SUNY campus site were interpreted to be due to fractures or cavities. The 12,000 to 15,000 fps velocities probably indicated that the bedrock is composed of a dense limestone or dolostone.

Typically, bedrock depths in the west are around 50 to 60 feet from the ground surface, whereas in the eastern part of the area bedrock depths are around 25 to 35 feet. An area of shallow bedrock is located in the northeast portion of the site.

Resistivity Measurements

CONCEPT

The resistance of earth materials to electrical current is related to the water content and chemical composition of the dissolved substances in the water. Both of these factors are directly related to the subsurface soil conditions, thus making it possible to draw conclusions about the underlying conditions from measurements of electrical resistance. When combined with the seismic method, the resistivity method is an important tool in deducing subsurface features and it is a rapid means of mapping horizontal variations.

The resistivity method employed in this study uses four electrodes equally spaced along a line on the soil surface (Figure 5). Current is caused to flow through the soil by applying 90 volts across the outer pair of electrodes. The associated voltage drop across the inner pair of electrodes is measured. The apparent resistivity is computed from the equation

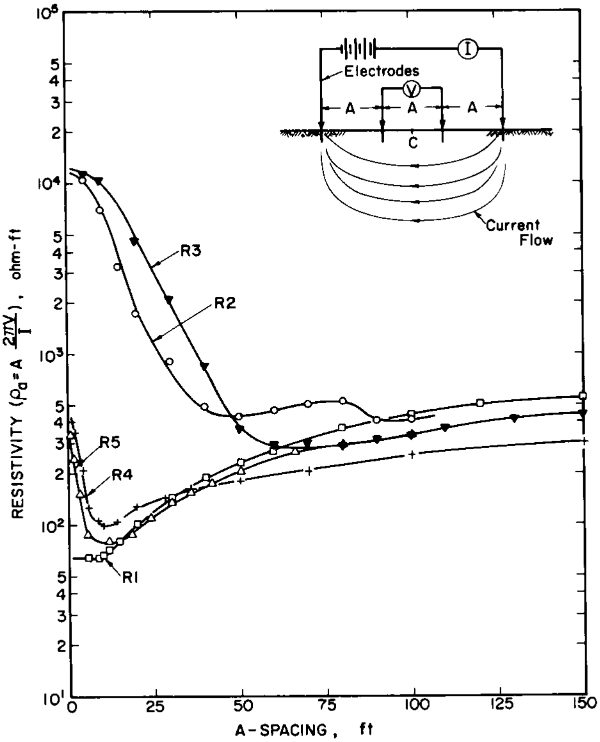

Figure 5. Resistivity depth soundings for locations shown in Figure 1.

$$\rho_a = A\,\frac{2\pi V}{I}$$

where ρ_a = apparent resistivity (ohm-ft.),
A = electrode spacing (ft.),
V = measured voltage drop (volts),
I = applied current (amperes).

The instrument used in these tests provided a direct readout of the quantity $(2\pi V)/I$.

Two different field procedures were followed. The first, depth sounding, involved increasing the A-spacing of all electrodes in selected increments while keeping the center of the configuration (point *c* in Figure 5) at the same point on the soil surface. The second, profiling, involved moving the electrodes as a group to different positions on the soil surface while maintaining constant electrode spacing.

SOUNDING

The sounding method is used to examine variation in resistance with depth. Normally, layers of different resistance are encountered. The calculated apparent resistivity is related to the average resistance over the depth, influencing the reading which increases with A-spacing. Therefore, if resistance increases with depth, the value of ρ_a will increase with A-spacing; conversely if resistance decreases with depth, ρ_a will decrease with A-spacing.

Several examples obtained from soundings made in this study are given in Figure 5. The high values of ρ_a for R2 and R3 at small A-spacing represent the thick layer of sand on top of a beach ridge (Figure 1). For these two cases ρ_a decreased rapidly to a minimum at 50 to 60 foot A-spacing and then increased slightly with further increase in A-spacing. This trend suggests some clay under the sand followed by bedrock. At locations R4 and R5 the surface layer of sand was just a few feet thick, thus ρ_a immediately decreased to low values caused by the clay. The influence of the underlying bedrock became apparent at an A-spacing of 10 to 15 feet. As the A-spacing was increased from this point the values of ρ_a approached those at large spacings from R2 and R3. The surface sand layer was absent from location R1, thus ρ_a increased continuously from the top clay layer down, as the influence of the underlying rock increased.

PROFILING

For the resistivity profiling a constant A-spacing of 50 feet was chosen. Figure 5 indicates that, for this spacing, values of ρ_a from 200 to 400 will represent a thick, surface, sand layer or shallow bedrock, with the seismic measurements distinguishing between the two cases. Values of ρ_a below 200 indicate a thick clay layer and deep bedrock. The four electrodes were tied together with a rope harness and a field crew of four persons carried out a series of traverses across the site. The measured values of ρ_a were spaced at 150-foot intervals because the equipment was advanced each time in a line so that the last electrode was moved to the position of the first electrode in the previous measurement. After all of the points were plotted, contours were fitted by interpolation.

The resulting resistivity contours are shown in Figure 1. For the 50-foot A-spacing in this area the highest ρ_a values correspond to shallow bedrock regions, while the lowest ρ_a values correspond to the deepest bedrock regions. The closed contour lines at the intermediate ρ_a values (150 and 200) represent a surface sand ridge. In general, the contours provide a qualitative estimate of the bedrock surface form and of the depth to the bedrock as a result of the particular A-spacing used in relation to bedrock depth. They indicate that a thin overburden occurs under the highest resistivity readings in the east-central part of the site with a general increase in overburden thickness away from this area. These observations agree with the seismic soundings and available borings.

Ground Water Conditions

WATER TABLE

Part of the task for the UDC study was to provide preliminary data on the ground water table, drainage, and water storage capacity of the site. Much of this was obtained as a byproduct of the seismic sounding and shallow boring tests. The ground water table, as observed in hand auger holes within the upper 10 feet, is perched in the surficial sands on the underlying, nearly impermeable lacustrine silt and clay sheet. This condition, together with the very low relief, allows water to be ponded or to reach the surface for several days during the wet seasons where the surface sand deposits are less than 1 to 3 feet thick. Moist surface areas are clearly apparent in air photographs or inferred from soil maps available from the Soil Conservation Service. They follow shallow NE/SW troughs parallel to the beach ridges (Figure 1). Well observations on the SUNY campus site indicate that sometimes till layers and even the upper few feet of the bedrock below the clay silt sheet are unsaturated. Seismic velocities lower than 4,800 fps in layers below the surface generally indicate that the ground is not saturated. However, most evidence indicates that the equilibrium ground water table is about 568 feet above sea level, which is within 10 feet of the adjacent stream surface. However, the stream is locally sealed off from the adjacent overburden and bedrock by impermeable silt and clay through most of its traverse across the site.

AVAILABILITY OF GROUND WATER

The lacustrine sand strata which act as aquifers at, or below the surface at this site appear to be generally too thin (2 to 8 feet) for important sources of water. However, the underlying bedrock of the Salina Group (Camillus, Syracuse, and Vernon Formations) may offer a high potential. These formations together make up the most productive bedrock aquifer in the Buffalo area although the water is of limited value because of its highly mineralized composition [5].

Conclusions

The combination of the seismic and resistivity methods gives complementary information. The seismic profiles provided depth determinations at many different site locations, but this technique is not the quickest means of examining horizontal variations over the entire site. The resistivity profiling technique is rapid and from a qualitative view an excellent tool to identify these horizontal variations.

The resistivity soundings indicated that with an electrode spacing of 50 feet, the bedrock was the major influence of the readings and not the character of the near-surface material. Thus, for this spacing, the thinner the overburden the higher the resistivity reading, and vice versa. The seismic depth determinations seem to confirm this interpretation, i.e., overburden thicknesses in the west-central section are as great as 60 feet and in this area resistivity values reach a low of 75 ohm-ft. The resistivity high of 600 ohm-ft. in the east-central region is caused by near surface bedrock with an overburden about 10 feet thick. From these extremes, a qualitative view of the bedrock surface form is given by the resistivity contour map.

Several small wavelength resistivity highs (values of 150 and 200 ohm-ft.) in the southeast part of the map are probably not a reflection of thin overburden, but coincide with surface deposits of beach ridges (moderate resistivity material). By choosing a smaller electrode spacing, i.e., 20 foot A-spacing, a sampling of resistivity of a much thinner section of overburden would define these sand beaches. Geologic mapping of the deposits precluded resistivity surveying for these near surface deposits.

The reliability of the seismic depth determinations for bedrock was confirmed by agreement with boring information. At those sites where test borings to bedrock and seismic profiles were in the same vicinity so that they could be compared, the seismic depth determinations for bedrock came within 10% of those from the borings.

Although recommendations for space usage were not a requirement of the study, a few examples will serve to indicate the benefits obtained:

1. Desirable areas for lake development certainly should not be located

over beach sand deposits or areas with thin overburden to bedrock. Leakage problems will ensue in these areas since fractured bedrock can have high permeability.

2. Large areas underlain by relatively thick impermeable clay layers would be best suited for lake development. They could also be used for light housing and recreational areas, but not heavy industrial buildings.
3. Local areas showing the combination of shallow bedrock and thin clay overburden would be much better suited for clean industrial development so that foundation cost can be minimized.
4. Low lying areas with sand to a depth of more than 6 feet will create construction problems and basement dewatering problems because of the perched water conditions.
5. The general lack of important aquifers in the overburden indicates that lakes must be filled from local bedrock or external water supplies. Pumping tests with careful chemical analysis will be needed to fully evaluate the local bedrock water potential.

The same objectives plus detailed engineering analysis can be achieved by extensive borings, but the time and cost factor is much greater and therefore borings do not serve the purpose of providing early-stage information to the planners. Ideally a study of this nature prior to the architectural commitment of space usage serves very useful purposes. The constraints of the usage of sections within the planned development area, set by geologic and hydrologic conditions, can be assessed and priorities determined.

ACKNOWLEDGMENTS

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